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Study of Benefits of Passenger Protective Breathing Equipment From Analysis of Past Accidents

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Final Report

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| 16. Abstract A computer model was developed and utilized for calculating the benefits of passenger protective breathing devices and other fire safety improvements based on an analysis of accidents involving fire occurring from 1966 to 1986. The results of exercising this model on 20 past accidents indicate that the "lives saved" is very sensitive to assumptions. It was determined that seat cushion fire blocking (FB) would have saved almost half the lives. Floor proximity lighting (FPL) is much less effective than FB, saving 3-4 percent of fire deaths. Protective breathing equipment (PBE), assuming no donning delay and 100 percent usage by passengers, is more effective than FPL. However, a 15-second donning delay of PBE may have resulted in a net disbenefit. <i>Keynote</i> | | | |
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TABLE OF CONTENTS

| | Page |
|--|------|
| EXECUTIVE SUMMARY | vi |
| INTRODUCTION | 1 |
| Purpose | 1 |
| Background | 1 |
| DISCUSSION | 2 |
| Description of Model | 2 |
| Sensitivity Analysis of Model | 3 |
| Description of Accidents | 4 |
| ANALYSIS OF DATA AND RESULTS | 8 |
| Major Considerations in Generating Accident Profiles | 8 |
| Accident Profiles | 10 |
| Logic for Accident Profiles | 11 |
| Lives Saved With Improvements | 15 |
| SUMMARY OF RESULTS | 17 |
| CONCLUSIONS | 18 |
| REFERENCES | 18 |
| APPENDICES | |
| A -- Listing of Computer Program | |
| B -- Summary of Accidents | |
| C -- Listing of Data Entry into Computer Program | |
| D -- Distribution List | |



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LIST OF ILLUSTRATIONS

| Figure | | Page |
|--------|---|------|
| 1 | Method of Approach | 20 |
| 2 | Wide-Body PBE Delay | 21 |
| 3 | Wide-Body PBE After Flashover | 22 |
| 4 | Hazards as Function of Time in C-133 Test Article with Postcrash Fire Conditions | 23 |
| 5 | Accident Profiles for 3/5/67 Varig DC-8 | 24 |
| 6 | Accident Profiles for 4/8/68 British Overseas B-707 | 25 |
| 7 | Accident Profiles for 11/27/70 Capitol International DC-8 | 26 |
| 8 | Accident Profiles for 6/7/71 Allegheny CV-580 | 27 |
| 9 | Accident Profiles for 12/8/72 United B-737 | 28 |
| 10 | Accident Profiles for 12/20/72 North Central DC-9 | 29 |
| 11 | Accident Profiles for 7/11/73 Varig B-707 (No Extinguishers) | 30 |
| 12 | Accident Profiles for 7/11/73 Varig B-707 (With Extinguishers) | 31 |
| 13 | Accident Profiles for 1/30/74 Pan Am B-707 | 32 |
| 14 | Accident Profiles for 3/27/77 Pan Am B-747 | 33 |
| 15 | Accident Profiles for 3/1/78 Continental DC-10 | 34 |
| 16 | Accident Profiles for 8/19/80 Saudi Air L-1011 | 35 |
| 17 | Accident Profiles for 11/19/80 Korean Airlines B-747 | 36 |
| 18 | Accident Profiles for 9/13/82 Spantax DC-10 | 37 |
| 19 | Accident Profiles for 6/2/83 Air Canada DC-9 | 38 |
| 20 | Accident Profiles for 3/22/84 Pacific Western B-737 | 39 |
| 21 | Accident Profiles for 8/22/85 British Air Tours B-737 | 40 |
| 22 | Estimated Lives Saved with Safety Improvements | 41 |

LIST OF TABLES

| Table | | Page |
|-------|--|------|
| 1 | Aircraft Accidents with Fire Related Deaths or Destruction of the Aircraft by Fire | 6 |
| 2 | 20 Accidents - Data Base | 9 |
| 3 | Estimated Lives Saved with Safety Improvements | 16 |

EXECUTIVE SUMMARY

This report presents a study of past accidents occurring world-wide in transport aircraft from 1966 to 1986, and the development and utilization of a methodology for assessing the benefits provided if fire safety improvements had been in effect. Fire safety improvements considered were lavatory extinguishers, fire blocking of seats, floor proximity lighting, and protective breathing equipment. The computer program of this model can be utilized to determine benefits for any set of assumptions associated with past accidents or for hypothetical fire scenarios.

The results of exercising this model on 20 past accidents indicate that the "lives saved" is very sensitive to assumptions. It was determined that fire blocking material would have saved almost half of the fire deaths. Protective breathing equipment with no donning delay is more effective than floor proximity lighting, assuming 100 percent usage. However, the effectiveness of protective breathing equipment was shown to be greatly influenced by the assumed time to don the devices, and a delay of 15-seconds in donning time resulted in 82 additional fire deaths.

INTRODUCTION

PURPOSE.

The purpose of this study is to develop and utilize a model for calculating the benefits of passenger protective breathing devices and other fire safety improvements based on an analysis of worldwide transport aircraft accidents involving fire.

BACKGROUND.

During a cabin fire, smoke and toxic gases may inhibit or prevent passenger escape; providing passengers with a supply of breathable air sufficient to accomplish evacuation may enhance chances of survival.

As a result of several accidents involving turbojet airplanes, particularly the accident involving a B-727 at Salt Lake City in November 1965, the attention of the aviation industry focused upon smoke and toxic gases as causal factors of passenger incapacitation, resulting in failure to evacuate the aircraft before fire and heat rendered the environment uninhabitable. The Federal Aviation Administration's (FAA) Civil Aeromedical Institute (CAMI) instituted work on the problem in November 1965 (reference 1).

On January 11, 1969, the NPRM was published in the Federal Register. There was strong opposition to this NPRM by the aircraft industry. British Aircraft Corporation, Air Transport Association, Aerospace Industries of America, and the Airline Stewards and Stewardesses Association were among those opposed to the NPRM. On August 11, 1970, the NPRM was withdrawn by the FAA because of concerns that evacuation might be delayed, that some smoke hoods might be inherently unsafe, and that effectiveness of these devices was questionable. Over the years, however, improvements have been made in smoke hood design leading to the present availability of compact, lightweight units.

Interest was again stimulated by the British Airtours B-737 accident at Manchester on August 22, 1985, when 55 people died. Most deaths were due to inhalation of smoke and toxic gases. Protective breathing equipment (PBE) is being reevaluated in response to the United Kingdom's (UK) Department of Transport's Accident Investigation Branch recommendation and recent improvements in filter technology and stored air-oxygen devices.

A joint effort to study whether PBE offers potential fire safety improvements was initiated by the Civil Aviation Authority (CAA), with participation by regulatory authorities from the FAA, Transport Canada Aviation Group (TCAG), and the Directorate General Civil Aviation (DGAC). As part of this cooperative effort, CAMI undertook a study to evaluate workloads, oxygen consumption, carbon dioxide production, and respiratory exchange rates for passengers during an evacuation. This study was undertaken to define qualification standards for a protective breathing device (reference 2). An evacuation research exercise was carried out at Teesside Airport by Linacre College, UK, in collaboration with the UK CAA. The aim was to observe the effects on delays and "passenger behavior" of donning smoke hoods during a simulated emergency evacuation of an aircraft cabin in both clear air and smoke (reference 3). As part of this effort by the four regulatory authorities, the FAA Technical Center undertook this study to determine the net benefit from PBE had they been utilized in past accidents.

The most important consideration is what is the benefit or how many lives may be saved by PBE. One can do this analysis for two cases: (1) a hypothetical fire scenario, and (2) an actual accident with fire.

The first case is the less complex of the two because one can precisely define cabin fire hazard conditions, effectiveness of the device, evacuation conditions, etc., and thereby predict the PBE benefit. Also, one can vary assumed parameters (donning time, etc.) and determine the sensitivity of these parameters on benefits. The second case is extremely complex because it is virtually impossible to reconstruct the information about the accident that must be known in order to determine what benefits would have occurred from PBE's had they been available. Also, some fire causes for past accidents have been rectified (Varig 707, Saudi L-1011, etc.). In order to relate PBE benefits for past accidents to aircraft in service now, PBE benefits should be assessed in terms of fire hardening and escape provisions representative of today's aircraft. The PBE benefit should not include lives which would have been saved by recent cabin safety improvements, such as lavatory smoke detectors and fire extinguishers, fire blocking of seats, and floor proximity escape path lighting.

DISCUSSION

DESCRIPTION OF MODEL.

A simple model was developed to predict the number of survivors in an aircraft fire scenario, based on mobility and fire hazard profiles. The model is one-dimensional in that time is the only independent variable. Thus, the model requires that the two profiles be described as a function of time ($f(t)$). In the case of an accident, the profiles are a numerical, subjective reconstruction of the relative decrease in occupant mobility and relative increase in fire hazards, both as $f(t)$, from a review of accident reports and information from accident investigators. Inevitably, many assumptions must be made to exercise the model, due to lack of complete information. Figure 1 illustrates these two profiles and how they are utilized to determine evacuation rates. The time of evacuation by the first survivor is t_p . The time the last survivor exits the aircraft is t_L .

Thermal and toxic hazard profile: $P(t)$ versus time after aircraft stopped. As can be seen from figure 1, if $P(t) = 1$, no toxic or thermal hazards exist. If $P(t) = 0$, sufficient hazards exist to result in the incapacitation of all passengers. If all survivors were to successfully evacuate with time to spare, $P(t)$ would exceed 0 at the time the last passenger exited the aircraft. Hazards that cause incapacitation include heat, toxic gases, oxygen depletion, smoke inhalation, and direct exposure to fire.

Mobility rate profile: $ER_M(t)$ versus time after aircraft stopped. $ER_M(t)$ describes the loss in passenger mobility due to physical effects such as poor visibility caused by smoke and inadequate lighting, passengers carrying hand luggage, blockage of aisles by debris, other passengers, and fire. The number of exits, class of exits, and evacuation slide condition influence this profile. The highest mobility rate for an accident (with no improvements) is assigned the value 1.0. When $ER_M(t) = 0$, there is no movement of occupants out of the aircraft.

The evacuation rate $ER_A(t)$ is the product of a constant A, the thermal and toxic hazards $P(t)$, and the mobility rate $ER_M(t)$ (equation 1).

$$ER_A(t) = A \cdot P(t) \cdot ER_M(t) \quad (1)$$

The constant A is calculated from the following relationship (equation 2), given the number of survivors.

$$\text{Number of Survivors} = A \int_0^{t_L} P(t) \cdot ER_M(t) dt \quad (2)$$

At this point, the reasonableness of A should be assessed. This is best done by comparing A with the evacuation demonstration data. Modifying assumptions may be necessary to make A consistent with the evacuation demonstration data.

A fire safety improvement will result in new $P(t)$ or $ER_M(t)$ profiles or both. The profiles for each improvement should be based on the best available information--preferably test data. The model calculates the number of survivors with each improvement from equation number 2.

In this study, benefits in terms of lives saved were calculated for the following fire safety improvements:

1. Lavatory Extinguishers
2. Seat Fire Blocking Layers (FB)
3. Floor Proximity Lighting (FPL)
4. Passenger Protective Breathing Equipment (PBE)

The number of lives saved (benefits) cannot exceed the number of fire deaths.

A listing of the computer program for this model can be found in appendix A. This program was run on a Radio Shack® Tandy 1000SX personal computer in BASIC with a MS-DOS version 3.20 operating system. A Hewlett Packard 7550A continuous feed 8-pen plotter was used to plot the profiles for the accident, with and without fire safety improvements.

SENSITIVITY ANALYSIS OF MODEL.

The most useful application of the model is to examine the sensitivity of the assumed numerical values for certain accident conditions or safety parameters on the calculated survivability. For example, the overriding concern in aircraft fire safety is rapid evacuation of passengers. For most accidents, at some point in time, survival will no longer be possible due to the buildup of non-survivable fire conditions within the cabin, most likely as the result of flashover. For this reason, PBE donning times should be minimal so as not to delay passenger evacuation.

WIDE-BODY SCENARIO. Figure 2 illustrates the profiles for a hypothetical accident fire scenario for a wide-body jet equipped to today's safety standards (lavatory extinguishers, fire blocking, floor proximity lighting). This is a theoretical accident scenario. There is a slow increase in thermal and toxic

hazards from 60 to 180 seconds, followed by a rapid loss in survivability due to flashover at 210 seconds. The evacuation begins at 15 seconds at the maximum rate until 90 seconds; there are incremental step decreases thereafter.

WIDE-BODY RESULTS. Perfect PBE protection for toxic and thermal hazards ($P(t) = 1.0$) was assumed until near flashover, followed by rapid decrease to $P(t) = 0$. It was also assumed that PBE would result in a slightly higher $ER_M(t)$ due to protection against eye irritation. The model was exercised for donning delays of 0, 10, 15, and 20 seconds.

The effect of this PBE delay is dependent on the duration and shape of the fire scenario hazard and mobility curves. For this scenario, PBE (zero delay) saved 49 people. However, delays in donning result in a linear loss of benefits; 10- and 20-second delays, respectively, result in 16 and 33 more fatalities than if masks were donned "instantly." This linear relationship of donning delays and additional fatalities does not hold, however, when the values of $P(t)$ or $ER_M(t)$ change during the donning periods. Donning delays have a great impact on survivability. The disbenefit from lengthy donning delays may be even greater than PBE benefits with no delay. Donning delay disbenefits occur during the beginning of the evacuation when $P(t)$ and $ER_M(t)$ are at their maximum values (highest evacuation rate of passengers). PBE benefits generally occur later in time when these values may be much lower (lowest evacuation rate).

For all the accidents in which the model was exercised, the assumption was made that an aircraft is unsurvivable after flashover. Figure 3 illustrates the effect that a survivable window of time after flashover would have on the number of survivors for the same theoretical accident. This window of time could be due to survivable temperatures after flashover, or it could be due to the additional thermal protection afforded the user of PBE after flashover. Assuming no PBE delay, a 20-second escape window could result in 17 additional lives saved, increasing the number of survivors from 249 to 266.

Inspection of figures 2 and 3 shows a 2:1 ratio in lives saved comparing a 10-second quicker donning time of PBE versus a 10-second additional survival time after flashover. Quick donning saved 16 lives versus 8 lives saved by additional survival time after flashover. For this accident, 10 seconds of protection in the beginning is worth 20 seconds in the end, in terms of lives saved.

DESCRIPTION OF ACCIDENTS.

As part of this cooperative effort, the FAA Technical Center undertook this study to determine the net benefit of PBE for past accidents. Representatives from the regulatory authorities agreed that certain assumptions and ground rules should be followed. It was agreed that the benefit analysis for PBE would be assessed with due consideration given to fire hardening and escape provisions representative of aircraft in service now. The assessment would not include lives which would have been saved by recent cabin safety improvements such as lavatory smoke detectors and fire extinguishers, fire blocking of seats, and floor proximity escape path lighting.

The accidents considered were those known to the four participating authorities which:

1. Occurred over the 20-year period 1966 to 1986.
2. Involved turbine engined passenger aircraft with more than 30 passengers.
3. Occurred during passenger operations, i.e., excluding cargo, positioning, and training flights.
4. Either involved passenger fatalities due to fire, or did not involve passenger fatalities and the aircraft cabin was destroyed or severely damaged by fire.
5. Did not involve extreme impact damage.
6. Did not include Eastern Block aircraft because of difficulties obtaining detailed information.

Conditions for the analysis included the following:

1. The analysis should take account of any delay to evacuation attributed to donning smoke hoods, and any extension of the available evacuation time due to wearing this equipment.
2. Cabin crew should be regarded as passengers. Flight crew should be excluded.
3. Assume perfect PBE protection from toxic hazards.
4. Assume all passengers would don PBE.

Seventy-five accidents were received from the committee of regulatory authorities from the FAA, CAA, DGAC, and Transport Canada (table 1). Based on a review of International Civil Aviation Organization (ICAO), National Transportation Safety Board (NTSB), CAA, and FAA data banks, the group agreed these accidents meet the criteria for the study, with the exception of some accidents on the list with extreme impact damage. The list of accidents gives information on the aircraft, total number of people on board, the number on board that were killed in the accident, and the estimated number on board killed by fire and smoke.

The accident reports do not always indicate the split of fire versus crash trauma fatalities. Of the accident victims tested, the percentage determined to have carboxyhemoglobin (COHb) levels in excess of 10 percent were used to calculate the number of fire victims in the accident. This is the same method used by Hall (reference 4) to estimate the number of fire deaths.

The majority of the accidents on this list lacked detailed information on survivability or did not fully fit the work statement. Twenty accidents contained sufficient information. These were the only accidents in which reference material existed to allow approximations of $P(t)$ and $ER_M(t)$ profiles. These accidents are marked with an asterisk (*) and include the most important accidents accounting for about half the fire fatalities. The accidents analyzed

TABLE 1

AIRCRAFT ACCIDENTS (1966 - 1986) WITH FIRE RELATED DEATHS
OR DESTRUCTION OF THE AIRCRAFT BY FIRE

| | DATE | CARRIER | AIRCRAFT | LOCATION | ON-BOARD | FATALITIES TOTAL | FIRE** |
|-----|----------|---------------------|-----------|--------------|----------|------------------|--------|
| 1 | 02/15/66 | Indian Airlines | Caravelle | Palam | 80 | 2 | 2 |
| 2 | 03/04/66 | Canadian Pacific | DC-8 | Tokyo | 72 | 64 | 0-64 |
| 3 | 04/22/66 | American Flyers | L-188 | Ardmore | 98 | 83 | 15 |
| 4 | 02/16/67 | Garuda | L-188 | Menado | 92 | 22 | 22 |
| 5* | 03/05/67 | VARIG | DC-8 | Monrovia | 90 | 51 | 45 |
| 6 | 11/06/67 | TWA | B-707 | Cincinnati | 36 | 1 | 0 |
| 7 | 01/09/68 | Ethiopian | B-720 | Beirut | 49 | 0 | 0 |
| 8* | 04/08/68 | BOAC | B-707 | Heathrow | 127 | 5 | 5 |
| 9 | 06/12/68 | Pan American | B-707 | India | 63 | 6 | 6 |
| 10 | 07/26/69 | Air Algerie | Caravelle | Biskra | 37 | 33 | 33 |
| 11 | 04/19/70 | SAS | DC-8 | Rome | 65 | 0 | 0 |
| 12 | 05/06/70 | Somali | Viscount | Mogadisco | 30 | 5 | 0-5 |
| 13* | 11/27/70 | Capitol Inter. | DC-8 | Anchorage | 229 | 47 | 47 |
| 14* | 12/28/70 | Trans Caribbean | B-727 | St. Thomas | 55 | 2 | 2 |
| 15* | 06/07/71 | Allegheny | CV-580 | New Haven | 31 | 28 | 27 |
| 16 | 09/06/71 | Pan International | BAC 1-11 | Hasloh | 121 | 21 | 0-21 |
| 17 | 04/18/72 | East African | SVC-10 | Addis Ababa | 107 | 43 | 10-43 |
| 18* | 12/08/72 | United | B-737 | Chicago | 61 | 43 | 29 |
| 19* | 12/20/72 | North Central | DC-9 | Chicago | 45 | 10 | 10 |
| 20 | 01/22/73 | Alia | B-707 | Kano | 202 | 176 | 176 |
| 21 | 05/03/73 | Indian Airlines | B-737 | Palam | 65 | 48 | 0-48 |
| 22* | 07/11/73 | VARIG | B-707 | Orly | 134 | 123 | 122 |
| 23 | 07/23/73 | Ozark | FH-227 | St. Louis | 45 | 39 | 0-39 |
| 24 | 12/20/73 | Lufthansa | B-707 | Delhi | 109 | 0 | 0 |
| 25* | 01/30/74 | Pan American | B-707 | Pago Pago | 101 | 96 | 95 |
| 26 | 03/15/74 | Sterling | Caravelle | Teheran | 96 | 15 | 15 |
| 27 | 06/27/74 | Cambodia Air | B-707 | Battambang | 39 | 19 | 10-19 |
| 28 | 09/11/74 | Eastern | DC-9 | Charlotte | 82 | 72 | 36 |
| 29 | 11/20/74 | Lufthansa | B-747 | Nairobi | 157 | 59 | 35 |
| 30 | 11/23/74 | JAT | DC-9 | Belgrade | 50 | 0 | 0 |
| 31 | 06/11/75 | Air France | B-747 | Bombay | 394 | 0 | 0 |
| 32 | 08/30/75 | Alaska | F-27B | StLawrenceIs | 32 | 10 | 0 |
| 33* | 11/12/75 | Overseas National | DC-10 | JFK | 139 | 0 | 0 |
| 34 | 04/05/76 | Alaska | B-727 | Ketchikan | 50 | 1 | 0 |
| 35 | 04/27/76 | American | B-727 | St. Thomas | 88 | 37 | 36 |
| 36 | 06/04/76 | Air Manila | L-188 | Guam | 45 | 45 | 45 |
| 37 | 11/16/76 | Texas International | DC-9 | Denver | 86 | 0 | 0 |
| 38 | 03/02/77 | Iraqi | B-707 | Baghdad | 60 | 0 | 0 |
| 39* | 03/27/77 | Pan American | B-747 | Tenerife | 396 | 335 | 192 |
| 40 | 03/27/77 | KLM | B-747 | Tenerife | 248 | 248 | 192 |
| 41 | 04/04/77 | Southern | DC-9 | New Hope | 85 | 63 | 20 |
| 42 | 09/27/77 | Japan Airlines | DC-8 | Kuala Lumpur | 79 | 34 | 34 |
| 43 | 10/03/77 | Capitol Inter. | DC-8 | Shannon | 259 | 0 | 0 |
| 44 | 11/19/77 | TAP | B-727 | Funchal | 164 | 125 | 0-125 |

| | | | | | | | |
|--------|----------|------------------|-----------|--------------|------|------|---------------|
| 47* | 03/01/78 | Continental | DC-10 | Los Angeles | 200 | 2 | 2 |
| 48 | 03/03/78 | Iberia | DC-8 | Santiago | 222 | 0 | 0 |
| 49 | 02/04/78 | VASP | B-737 | Sao Paulo | 44 | 0 | 0 |
| 50 | 12/17/78 | Indian Airlines | B-737 | Hyderabad | 132 | 1 | 1 |
| 51 | 03/13/79 | Alia | B-727 | Doha | 64 | 44 | 20 |
| 52 | 04/26/79 | Indian Airlines | B-737 | Madras | 67 | 0 | 0 |
| 53* | 10/07/79 | Swissair | DC-8 | Athens | 154 | 14 | 14 |
| 54 | 02/27/80 | China Airlines | B-707 | Manila | 135 | 2 | 2 |
| 55* | 08/19/80 | Saudi Air | L-1011 | Riyadh | 301 | 301 | 301 |
| 56 | 11/04/80 | TAAG | B-737 | Benguela | 134 | 0 | 0 |
| 57* | 11/19/80 | Korean | B-747 | Seoul | 226 | 15 | 15 |
| 58* | 11/21/80 | Continental | B-727 | Yap Island | 73 | 0 | 0 |
| 59 | 02/17/81 | Air California | B-737 | Santa Ana | 110 | 0 | 0 |
| 60 | 07/27/81 | Aeromexico | DC-9 | Chihuahua | 66 | 30 | 0-30 |
| 61 | 03/17/82 | Air France | A-300 | Sanaa | 124 | 0 | 0 |
| 62 | 08/26/82 | Southwest | B-737 | Ishigaki | 138 | 0 | 0 |
| 63* | 09/13/82 | Spantax | DC-10 | Malaga | 394 | 50 | 50 |
| 64 | 03/11/83 | Avensa | DC-9 | Barquisimeto | 50 | 20 | 0-20 |
| 65* | 06/02/83 | Air Canada | DC-9 | Cincinnati | 46 | 23 | 23 |
| 66 | 07/02/83 | Altair | Caravelle | Milan | 89 | 0 | 0 |
| 67 | 12/07/83 | Aviaco | DC-9 | Madrid | 42 | 42 | 0-42 |
| 68 | 12/07/83 | Iberia | B-727 | Madrid | 93 | 51 | 0-51 |
| 69 | 12/18/83 | Malasian | A-300 | Kuala Lumpur | 233 | 0 | 0 |
| 70 | 03/10/84 | UTA | DC-8 | Ndjamena | 87 | 0 | 0 |
| 71* | 03/22/84 | Pacific Western | B-737 | Calgary | 119 | 0 | 0 |
| 72 | 08/30/84 | Air Cameroon | B-737 | Douala | 122 | 2 | 0-2 |
| 73 | 10/13/84 | Cyprus Airways | B-707 | Zurick | 10 | 0 | 0 |
| 74* | 08/22/85 | British Airtours | B-737 | Manchester | 137 | 55 | 55 |
| 75 | 11/30/85 | Mandala | L-188 | Medan | 45 | 0 | 0 |
| TOTALS | | | | | 8595 | 2705 | 1760- 2262 |

*Accidents with sufficient information to include in study.

**Fire fatalities are estimated.

for PBE benefits are listed separately in table 2. A written summary of each of these 20 accidents can be found in appendix B. The American Airlines 1976 accident in St. Thomas is included in the accident summaries as an example of an accident with a high trauma level. It is not included in the study. These summaries describe (based on available information) the accident evacuation routes and the number of people reported to use each exit, the time the first and last occupants evacuated (critical parameters in the model), the time of flashover, and in some cases, the time people began using each exit. The condition of exits which were not used, the position and condition of bodies recovered, blood chemistry, and the number of fire and impact deaths were also included in the accident summaries.

A detailed analysis of 20 accidents accounts for 1034 fire deaths. This leaves 55 of the 75 accidents in table 1 unaccounted. Of these, 24 had no fire fatalities. The remaining 31 gave rise to about half of the total fire fatalities (726-1228 out of a total of 1760-2262).

ANALYSIS OF DATA AND RESULTS

MAJOR CONSIDERATIONS IN GENERATING PROFILES.

Accident reports invariably are deficient in the detailed information required to define the "shape" of the hazard and mobility profiles used in the benefits model. In order to generate these profiles for each accident studied and for each fire safety concept evaluated, the authors relied heavily on the following past experimental studies (full-scale tests) and/or assumptions/considerations:

1. Flashover - Uncontrolled fires in aircraft cabins produce flashover conditions, a rapid propagation of flames through the fuselage. The onset of flashover is followed by a rapid loss of survivability throughout the cabin (references 5, 6, 7, 8, 9). Figure 4 illustrates a typical plot of the rapid increase in fire hazards associated with flashover. Based on this observed behavior in extensive full-scale tests, it was assumed flashover occurred in most accidents, and resulted in a rapid decrease in the $P(t)$ curve to $P(t) = 0$.
2. Lavatory extinguishers may effectively extinguish a small sink unit fire. The $P(t)$ curve will hold at the ideal value of 1.0 and the evacuation would proceed normally. The assumption of lavatory extinguisher effectiveness applies only to the Varig B-707 accident in Paris.
3. Fire blocking (FB) of seat cushions will delay the occurrence of flashover and the buildup of hazards in the aircraft, delaying the decline of $P(t)$, and will extend the safe time for evacuation. Full-scale test data showed a 43- to 60-second delay in the onset of flashover with Vonar[®] and Norfab[®] type fire blocking layers in a postcrash/ruptured fuselage, zero wind scenario. A 60-second FB benefit was assumed for those accidents that were similar to this scenario. This benefit was increased if the wind conditions were reported to be favorable (wind blowing fire away from fuselage ruptures/openings). Full-scale test data also showed the prevention of inflight fires if the fire blocked seat was the ignition source.

TABLE 2. TWENTY ACCIDENTS - DATA BASE

| DATE | CARRIER | AIRCRAFT | LOCATION | ON-BOARD | FATALITIES | |
|----------|-----------------------|----------|---------------------------|----------|------------|--------|
| | | | | | TOTAL* | FIRE** |
| 3/5/67 | VARIG | DC-8 | MONROVIA, LIBERIA | 90 | 51 | 45 |
| 4/8/68 | BRITISH OVERSEAS | B-707 | LONDON, ENGLAND | 127 | 5 | 5 |
| 11/27/70 | CAPITOL INTERNATIONAL | DC-8 | ANCHORAGE, AL | 229 | 47 | 47 |
| 12/28/70 | TRANS CARIBBEAN | B-727 | ST. THOMAS, VI | 55 | 2 | 2 |
| 6/7/71 | ALLEGHENY | CV-580 | NEW HAVEN, CT | 31 | 28 | 27 |
| 12/8/72 | UNITED | B-737 | CHICAGO, IL | 61 | 43 | 29 |
| 12/20/72 | NORTH CENTRAL | DC-9 | CHICAGO, IL | 45 | 10 | 10 |
| 7/11/73 | VARIG | B-707 | PARIS, FRANCE | 134 | 123 | 122 |
| 1/30/74 | PAN AM | B-707 | PAGO PAGO | 101 | 96 | 95 |
| 11/12/75 | OVERSEAS NATIONAL | DC-10 | JAMAICA, NY | 139 | 0 | 0 |
| 3/27/77 | PAN AM | B-747 | TENERIFF, CANARY IS. | 396 | 335 | 192 |
| 3/1/78 | CONTINENTAL | DC-10 | LOS ANGELES, CA | 200 | 2 | 2 |
| 10/7/79 | SWISS AIR | DC-8 | ATHENS, GREECE | 154 | 14 | 14 |
| 8/19/80 | SAUDI AIR | L-1011 | RIYADH, SAUDI ARABIA | 301 | 301 | 301 |
| 11/19/80 | KOREAN AIRLINES | B-747 | SEOUL, KOREA | 226 | 15 | 15 |
| 11/21/80 | CONTINENTAL | B727 | YAP, WESTERN CAROLINE IS. | 73 | 0 | 0 |
| 9/13/82 | SPANTAX | DC-10 | MALAGA, SPAIN | 394 | 50 | 50 |
| 6/2/83 | AIR CANADA | DC-9 | CINCINNATI, OH | 46 | 23 | 23 |
| 3/22/84 | PACIFIC WESTERN | B-737 | CALGARY, CANADA | 119 | 0 | 0 |
| 8/22/85 | BRITISH TOURS | B-737 | MANCHESTER, UK | 137 | 55 | 55 |
| Totals | | | | 3058 | 1200 | 1034 |

*Ground Fatalities are not included in count.

**Fire Fatalities are estimated.

4. Floor proximity lighting (FPL) can be expected to increase the evacuation rate when dense smoke from a cabin fire has obscured convention ceiling-mounted emergency lighting. Chesterfield demonstrated a 20-percent increase in evacuation rate with FPL (versus ceiling lighting) in an artificial smoke environment with human subjects (reference 10); therefore, in relevant accidents the mobility rate was increased by 20 percent as a result of FPL. FPL will have no effect on $P(t)$.

5. Protective breathing equipment (PBE) should eliminate the hazards in the cabin from smoke inhalation, toxic gases, oxygen depletion (stored gas type), and perhaps should provide some protection against elevated temperatures. Since more passengers will have the ability to escape, the evacuation through each exit will be prolonged. PBE may improve the evacuation rate if irritants and difficulty in breathing were slowing down the evacuation. It was assumed that PBE would provide perfect protection against toxic gases (no leakage through the seals, no malfunction of the masks, perfect filtration for filter type masks). It was also assumed that all passengers would have used PBE. This is probably true for inflight fires, however, the proportion of passengers donning PBE is likely to decrease for postcrash fires. Usage is dependent on many factors such as the extent of cabin damage and the speed of development of the fire threat. Warren, et al., of the CAA assigned a likeliness of use based on the degree of impact damage to the aircraft. They factored likeliness of use into the PBE benefits calculated in this report (assuming no donning delays) (reference 11).

6. A major concern with the use of PBE by passengers is a possible delay in evacuation due to the time it takes to don the device. At this time, reliable information on donning time is not available. Donning delays are a function of the ease of donning a particular type mask, cabin crew instructions, the method of presentation of the mask to passengers, and a unique set of conditions and distractions of each individual accident. This model was exercised for the 20 aircraft accidents for two cases: (1) assuming no donning delay and (2) assuming a 15-second donning delay. Inflight fires were exercised assuming no donning delay since there would have been ample opportunity to don smoke hoods while inflight.

Evacuation tests have been conducted with artificial smoke with naive subjects at Linacre College, Oxford University, in conjunction with the CAA to observe delays caused by donning smoke hoods (reference 3).

ACCIDENT PROFILES.

Hazard and mobility rate profiles as a function of time were developed for each accident based on the authors' best judgment and interpretation of the probable sequence of events extracted from accident reports. The value of A was calculated. The authors then applied the effects of cabin safety improvements to these curves relying on the major considerations discussed in the previous section. Values for the number of survivors were calculated for each improvement from equation 2. Improvements considered were fire blocking (FB), floor proximity lighting (FPL), protective breathing equipment with no donning delay (PBE), and protective breathing equipment with a 15-second donning delay (PBED). Figures 5 through 21 illustrate the profiles for these accidents. A listing of the data entered into the computer program for the aircraft accident profiles can be found in appendix C.

LOGIC FOR ACCIDENT PROFILES (ASSUMPTIONS AND KNOWNS).

1. 3/5/67 Varig DC-8 (Figure 5)

This accident occurred at night and the cabin lights failed at impact. It was assumed that the first door opened at 20 seconds. The aft door opened after a long delay. A 60-second delay was assumed for this door. It was assumed the last person was out of the plane 3 minutes after it came to a stop. A 60-second FB benefit was assumed, since fire entered the fuselage during the evacuation through the window in the vicinity of seat rows 17 and 18. It also entered the fuselage through the open emergency exit, almost completely dividing the cabin at row 15. By delaying the fire involvement of seats, FB would delay the buildup of hazards in the aircraft cabin (thermal and toxic hazard profile) and the evacuation through each exit should proceed longer (mobility rate profile). An early benefit for FPL was assigned due to the combined effect of smoke and darkness. A modest survival benefit was assigned to PBE, recognizing other fire hazards existed in the aircraft. It was assumed PBE protection would have extended the time available to egress.

2. 4/8/68 British Overseas B-707 (Figure 6)

The evacuation was dominated by a spreading external fuel fire. The starboard overwing exits were first utilized (assume at 20 seconds). There were delays at the other exits due to problems preparing the slides for use (assume 30 and 45 seconds). Explosions and spreading fire under the rear of the fuselage resulted in the failure of the escape chute at the rear galley door and rendered the overwing escape route unusable. It was assumed the rear galley exit was unusable at 45 seconds, as only 10 passengers and one steward escaped from this exit. It was assumed the chief steward stopped usage of the starboard overwing exits at 75 seconds, as only 18 passengers escaped by these exits. The main body of the passengers and cabin crew evacuated from the forward galley exit. It was assumed the aircraft was unsurvivable at 180 seconds. No benefit was assigned for FB. A small benefit was assigned for FPL and PBE.

3. 11/27/70 Capitol International DC-8 (Figure 7)

The evacuation was dominated by an external fuel fire and gross amounts of JP-4 fuel entering the aircraft in the center and rear, soaking the majority of the survivors in these areas with fuel. Six survivors were ejected from the plane at impact. It was assumed that the difficulty in opening the aft doors resulted in an additional 15-second delay (30 seconds). It was also assumed that the last person exited the aircraft 180 seconds after stopping. It was concluded from the data that the seats did not begin to get involved until the latter stages of the evacuation. A 30-second FB benefit was assigned. A 20-percent benefit was assigned for FPL. It was assumed that the fuel spilled on the floor would not affect the operation or the benefit derived from FPL. It was also assumed the majority of deaths were due to the ignition of the fuel spilled inside the cabin. A small benefit was assigned to PBE.

4. 12/28/70 Trans Caribbean B-727

No accident profile was drawn for this accident. The two fatalities were father and child. The child was trapped between two seats, and the father was found near him. Both bodies were burned. It was assumed PBE, FPL, and PBE would not have saved them because the father probably would not leave his child.

5. 6/7/71 Allegheny CV-580 (Figure 8)

The aircraft was engulfed in flames. Those that escaped used the left overwing exit and ran through the fire. A 30-second escape window was assumed. The remaining passengers and cabin crew were trapped inside the aircraft. No FB benefit was assigned. An immediate FPL benefit was assumed as it would have highlighted the left overwing escape route. Any delays due to PBE donning would make escape even less likely.

6. 12/8/72 United B-737 (Figure 9)

There was a fairly severe impact, and an intense pool fire formed under the midsection of the fuselage. It was assumed the first people evacuated 20 seconds after stopping. Due to the severity of the impact, it was assumed the full blown evacuation started about 1 minute after stopping, since passengers were probably recovering from the impact. It was assumed that the last passenger escaped (without outside aid) 180 seconds after stopping. There was a continuous buildup of hazards from the ruptures and openings, intense heat and heavy smoke. A 30-second FB benefit was assigned. Although it was daytime, it was very dark inside, so the authors gave an immediate FPL benefit. Due to the high blood COHb levels, a high PBE benefit was assumed.

7. 12/20/72 North Central DC-9 (Figure 10)

There was a minor impact. The DC-9 was engulfed in flames. This accident occurred at night, and the cabin lights went out as the aircraft came to a stop. It was assumed that the first people exited the aircraft at 20 seconds. All survivors were reported to be out of the aircraft and away from the wreckage when the first fire trucks arrived (within 2 minutes). It was assumed the last passenger egressed from the plane at 90 seconds. A 10-second FB benefit was assigned since there was no indication by any of the survivors of fire in the aircraft. An immediate FPL benefit was assigned due to the extreme darkness. It was assumed that PBE would significantly extend survival conditions in the aircraft as the smoke was reported to be very dense. Survivors reported having to get lower and lower toward the floor in order to breathe. It was assumed PBE would have increased the evacuation rate only slightly due to the increasing heat and smoke and difficulty finding the exits. A donning delay of 15 seconds would result in 7 additional deaths utilizing the above assumptions in this model.

8. 7/11/73 Varig B-707 (Figures 11, 12)

It was assumed the thermal and toxic hazard level in the aircraft was 0.1 at the time it came to rest. This value accounts for the fact that the cabin crew who escaped, most wearing protective breathing equipment, were the only unaided survivors. It is difficult to say whether lavatory extinguishers would have put the fire out in the sink unit. The model was exercised with and without the assumption of lavatory fire extinguishment. If the extinguisher would have put out the fire, no hazards would develop, and all lives would have been saved. If the extinguisher would not have put out the fire, FB would have delayed the hazard buildup. An immediate FPL benefit was assumed. It was also assumed that PBE would reduce the hazards to zero for the fire 3 minutes after the plane stopped.

9. 1/30/74 Pan Am B-707 (Figure 13)

The impact was relatively light. The fuel fire was intense, mainly concentrated on the right side of the cabin section. The two left overwing exits were the only usable exits, as the forward and rear entry doors jammed. Nine passengers exited the aircraft through these doors; four later died in the

hospital from severe burns. It was assumed that there was only a 15-second evacuation window, as there was flaming fuel at the trailing edge of the wing, and that fire probably grew, trapping the occupants inside. It was assumed that the plane was unsurvivable at 3 minutes. A 30-second FB benefit was assigned. It is believed that FPL would benefit the evacuation, highlighting the overlooked overwing exits as an escape route. COHb blood levels indicated the PBE would extend the time of consciousness for some of the trapped victims.

10. 11/12/75 ONA DC-10

This model was not exercised. All occupants survived. There would be no PBE disbenefit due to donning delays of PBE since FB and FPL would give a substantial safety benefit.

11. 3/27/77 Pan Am B-747 (Figure 14)

The aircraft was hit from above by a just airborne 747, leaving nearly the whole top open and an accumulation of wreckage in the center and aft. The evacuation time was estimated to be 1 minute in the accident report. Escape routes were L2 and openings on the left side. Explosions were taking place during the short evacuation. It was assumed the evacuation began at 20 seconds. No FB benefit was assigned as the explosions, flash fires, and pool fires dominated survivability. No FPL benefit was assigned as the top of the fuselage was ripped open. No PBE benefit was assigned since other hazards probably predominated. The disbenefit for a 15-second donning delay is high (42 lives) due to the short escape time, however, it is unlikely PBE would be donned under the conditions of this accident.

12. 3/1/78 Continental DC-10 (Figure 15)

This accident was characterized by a spreading external fuel fire on the left side with evacuation through the four right exits. All slides failed before the evacuation was completed. A large group evacuated by jumping to the ground from the exits or wing. The accident report stated the evacuation was complete in about 5 minutes and the fire was out at 6 minutes. The conditions within the plane were very survivable when the fire was put out. Therefore, no benefit was assigned to FB, FPL, and PBE, and PBE donning delays would not result in loss of life.

13. 10/7/79 Swiss Air DC-8

Fourteen bodies were found seated in the same area in the rear. These deaths were labeled as fire deaths. The authors did not know how to treat these victims since the report suggests they had plenty of time to evacuate. The model was not exercised for this accident and no FB, FPL, or PBE benefit was assigned.

14. 8/19/80 Saudi Air L-1011 (Figure 16)

This was an inflight cargo fire. No one evacuated the aircraft. All died from fire. It was assumed the cabin conditions became unsurvivable 20 seconds after stopping. The FAA Technical Center full-scale fire test data indicate that a moderate fire impinging on seats would not propagate with seat fire blocking layers (reference 7). This fire spread into the cabin through floor grills and impinged on the seats. Since FB's have been demonstrated to be very effective in preventing fire spread when the ignition source is moderate, it was assumed that FB would have saved everyone.

15. 11/19/80 Korean Airlines B-747 (Figure 17)

The bottom of the plane was ruptured upon landing, breaking hydraulic lines. There was no external fuel fire. The fire impinged on cabin seats from the floor grills and spread quickly. Since test data from the FAA Technical Center using the C133 full-scale test article indicated that the fire would not propagate with FB, it was assumed that FB would have saved everyone.

16. 11/21/80 Continental B-727

All escaped with not much time to spare. The last passengers were out 55 seconds after the airplane stopped. The model was not exercised for this accident since any disbenefit from PBE donning delay would be outweighed by benefits from FB and FPL.

17. 9/13/82 Spantax DC-10 (Figure 18)

A large external fuel fire developed on the aft right side, with a much smaller fire on the left. There was a positive wind effect blowing the fire away from the plane. The fire department was reported to have arrived within 4 to 5 minutes, and to have taken 1 to 2 minutes to rescue people. Firefighters removed 15 people through 3L from the forward cabin. It was assumed the last egressed at 6 minutes after stopping. It was also assumed the full blown evacuation started at 15 seconds. Three separate evacuations took place, one for each cabin. The third cabin had the most passengers (167) and only one exit available, 3L, which was affected by the fire through most of the evacuation. The second cabin occupants egressed from this exit and 2L and a few from 2R: 3L was the bottleneck for the third cabin. The 50 people that failed to evacuate occupied this cabin. It was assumed all passengers were out of the forward and mid cabins at 110 seconds. A longer than usual 90-second benefit of FB was assigned due to the positive wind effect. It was also assumed FB would increase the evacuation rate, as the visibility would have markedly improved, enabling those bottle-necked at 3L to use the other exits further forward. Even if only a 30-second benefit were assigned for FB, you would have still saved 50 people. Using this model, all fatalities would have been saved with FB.

18. 6/2/83 Air Canada DC-9 (Figure 19)

The inflight fire originated behind the wall of the rear lavatory. The passengers in the rear moved into seats in the forward section while in flight. A thermal and toxic hazard level of 0.75 was assumed as the plane stopped. By this time, the smoke had built up such that people seated could not see their hands in front of their face. It was assumed the first person exited 20 seconds after the aircraft stopped. The NTSB report states the cabin burst into flames as the last person exited R2 at 60 to 90 seconds after the plane stopped. It was assumed the last person egressed at 90 seconds. Five of seven passenger exits were used. The aft rows of seats were probably involved. This hastened the onset of flashover. A 1-minute FB benefit was assigned. The FPL benefit would be immediate. A substantial PBE benefit was assigned because most deaths were from smoke inhalation and toxic gas. The thermal and toxic hazard level was increased with PBE to 1 at time 0 and then gradually decreased due to the buildup of other hazards (heat then fire).

19. 3/22/84 Pacific Western B-737 (Figure 20)

The fire started in the aft engine/wing area. Thick black smoke entered the cabin through melted windows as the aircraft came to a stop. The right overwing exit opened immediately (assume 15 seconds). It was assumed all exits were functioning at 30 seconds. All occupants were out of the plane at 3 minutes

according to passenger and witness statements. Since all occupants successfully egressed, and a flight attendant was able to walk through the aircraft after all were out, it was assumed the plane was unsurvivable at 4 minutes. A 60-second FB benefit was assumed. A substantial PBE benefit was assigned. A 15-second donning delay would pose no disbenefit for this accident.

20. 8/22/85 British Air Tours B-737 (Figure 21)

The port engine and wing caught fire. Upon turning, the fire spread under the fuselage because of wind and totally engulfed the aft fuselage. Smoke initially entered the cabin through the melted aft/port windows just before the aircraft stopped. The first people were out of the left front door 30 seconds from stopping, and out of the right front door at 90 seconds. Passengers stopped using the LF when RF opened. The overwing exit was opened 45 seconds from stopping. Three and one-half to 4 minutes after stopping, all survivors (except one found inside by firemen 5 1/2 minutes after their arrival) were off the aircraft. It was assumed the plane was unsurvivable at 4 minutes. One eventual fatality was taken off the aircraft alive 33 minutes after the aircraft stopped. Sixteen egressed from LF, 35 from RF, and 24 from ROW. A 30-second benefit for FB was assumed, and FPL was assigned a later benefit due to bottlenecks forming at the exits. Passengers were falling down in the aisles. It is believed that PBE would greatly increase survivability, thus extending the evacuation, before the onset of flashover. There is no disbenefit with a 15-second donning delay in this model. The analysts relied on the British accounts of this accident. The profiles for this accident were modified based on discussions with the British due to their more immediate familiarity with this accident.

LIVES SAVED WITH IMPROVEMENTS.

The results of the modeling analysis of the benefits of lavatory extinguishers, FB, FPL and PBE for 20 aircraft accidents is contained in table 3 and figure 22. The findings are discussed below.

EXTINGUISHERS. Lavatory extinguishers may have been effective in only one accident--Varig 1973. If extinguishers were effective in putting the sink unit fire out, 121 lives would have been saved. Otherwise, all lives would have been saved with a combination of FB, FPL, and PBE for Varig 1973.

FIRE BLOCKED SEATS. Fire blocked seats saved the most lives by far. FB are projected to save 45 or 47 percent of fire deaths for these 20 accidents, or 459 or 477 lives saved, depending on the assumed effectiveness of lavatory extinguishers in Varig 1973.

FB would have saved all aboard the 1980 Saudi Air accident. It was assumed FB would have prevented this type of fire because the fire burned into the cabin through the floor. It was demonstrated in the C133 test article that FB would prevent underseat fires from spreading. The analysis also predicts that FB, by delaying seat fire involvement, would have saved all fatalities in the 1983 Air Canada, 1980 Korean Airlines, and 1982 Spantax accidents. In total, 10 of the 20 accidents would have had additional lives saved if FB had been installed.

FLOOR PROXIMITY LIGHTING. FPL provides a much more modest benefit than FB. FPL is projected to save 3 or 4 percent of fire deaths, or 35 or 39 additional lives saved. The largest saving was 9 lives in the 1967 Varig accident. FPL does not directly minimize hazard exposure but increases the evacuation rate. In total, 9

TABLE 3. ESTIMATED LIVES SAVED WITH SAFETY IMPROVEMENTS

| DATE | CARRIER | AIRCRAFT | FIRE DEATHS* | LIVES SAVED* | | | | |
|----------|----------------------------|----------|--------------|--------------|-----|-----|-----|------|
| | | | | EXT | FB | FPL | PBE | PBED |
| 3/5/67 | VARIG | DC-8 | 45 | 0 | 29 | 9 | 7 | 7 |
| 4/8/68 | BRITISH OVERSEAS | B-707 | 5 | 0 | 0 | 4 | 1 | 1 |
| 11/27/70 | CAPITOL INTERNATIONAL | DC-8 | 47 | 0 | 18 | 5 | 24 | 1 |
| 12/28/70 | TRANS CARIBBEAN | B-727 | 2 | 0 | 0 | 0 | 0 | 0 |
| 6/7/71 | ALLEGHENY | CV-580 | 27 | 0 | 0 | 1 | 0 | -2 |
| 12/8/72 | UNITED | B-737 | 27 | 0 | 10 | 5 | 12 | 11 |
| 12/20/72 | NORTH CENTRAL | DC-9 | 10 | 0 | 2 | 7 | 1 | -7 |
| 7/11/73 | VARIG (W/EXT) | B-707 | 121 | 121 | 0 | 0 | 0 | 0 |
| 7/11/73 | VARIG (W/O EXT) | B-707 | 121 | 0 | 18 | 4 | 99 | 99 |
| 1/30/74 | PAN AM | B-707 | 92 | 0 | 0 | 1 | 0 | -6 |
| 11/12/75 | OVERSEAS NATIONAL | DC-10 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/27/77 | PAM AM | B-747 | 190 | 0 | 0 | 0 | 0 | -42 |
| 3/1/78 | CONTINENTAL | DC-10 | 2 | 0 | 0 | 0 | 0 | 0 |
| 10/7/79 | SWISS AIR | DC-8 | 14 | 0 | 0 | 0 | 0 | 0 |
| 8/19/80 | SAUDI AIR | L-1011 | 298 | 0 | 298 | 0 | 0 | 0 |
| 11/19/80 | KOREAN AIRLINES | B-747 | 12 | 0 | 12 | 0 | 0 | 0 |
| 11/21/80 | CONTINENTAL | B-727 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9/13/82 | SPANTAX | DC-10 | 50 | 0 | 50 | 0 | 0 | 0 |
| 6/2/83 | AIR CANADA | DC-9 | 23 | 0 | 23 | 0 | 0 | 0 |
| 3/22/84 | PACIFIC WESTERN | B-737 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8/22/85 | BRITISH TOURS | B-737 | 55 | 0 | 17 | 3 | 35 | 35 |
| TOTAL | (WITH LAV EXTINGUISHER) | | 1020 | 121 | 459 | 35 | 80 | -2 |
| TOTAL | (WITHOUT LAV EXTINGUISHER) | | 1020 | 0 | 477 | 39 | 179 | 97 |

*FLIGHT CREW ARE NOT INCLUDED

of the 20 accidents would have had additional lives saved if FPL had been installed.

PROTECTIVE BREATHING EQUIPMENT (No Donning Delay). PBE would have only prevented 80 fire deaths (8 percent of fire deaths) if extinguishers were effective on Varig. The number of lives saved with PBE increases to 179 (18 percent of fire deaths) if extinguishers were ineffective on Varig B-707. Other than Varig, the British Air Tours B-737 had the greatest PBE benefit: 35 lives saved. Capitol International also had a high PBE benefit: 24 lives saved. In total, 7 of 20 accidents would have additional lives saved if PBE were available with no donning delays.

PROTECTIVE BREATHING EQUIPMENT (15-Second Donning Delay). There is a very significant effect of donning time on PBE benefits. PBE with a 15-second donning delay (PBED) would have caused 2 additional fire deaths if extinguishers were effective on Varig. This decreased the PBE benefit (assuming no donning delay) down by 82 lives into a disbenefit. If extinguishers were ineffective on Varig B-707, PBED would have saved 97 lives. This also shifts the PBE benefit down by 82 lives. The Pan Am B-747 accident had the greatest PBED disbenefit: 42 additional lives lost. This high disbenefit is due to a very short escape time. One can argue that it is unlikely passengers would have donned smoke hoods under the conditions of this accident, and therefore, the high disbenefit for PBED is not realistic. In total, 4 accidents resulted in additional loss of life and 6 accidents in lives saved by using PBED (assuming 100 percent usage).

SUMMARY OF RESULTS

1. The 20 accidents analyzed with the model accounted for 1020 fire deaths of passengers and cabin crew.
2. The net safety benefit projected for passenger protective breathing equipment is very dependent on the assumptions for the Varig 707 inflight fire accident in 1973.
3. If lavatory extinguishers were effective in the Varig inflight fire, extinguishers would have saved 121 people, seat fire blocking layers would have saved 459 people, (almost half of all fire deaths), floor proximity lighting would have saved 35 people and passenger protective breathing equipment would have saved 80 people if there was no donning delay. Passenger protective breathing equipment would have resulted in 2 additional fire deaths if a 15-second donning delay is assumed.
4. If lavatory extinguishers were ineffective in the Varig inflight fire, seat fire blocking layers would have saved 477 people, floor proximity lighting would have saved 39 people, and passenger protective breathing equipment would have saved 179 people if there was no donning delay. However, assuming a 15-second donning delay, passenger protective breathing equipment would have saved 97 lives.
5. The Varig accident in 1973 was the only inflight fire accident with a passenger protective breathing equipment benefit. If lavatory extinguishers were not effective for this fire, passenger protective breathing equipment would have saved 99 lives.

6. The calculated "lives saved" using the model to predict the benefits of fire safety improvements in past accidents is very sensitive to assumptions made for the hazard and mobility profiles in the accident and the impact of the improvements on each profile.

CONCLUSIONS

Based on a modeling analysis of 20 aircraft fire accidents to determine the benefits of recent cabin fire safety improvements, the following conclusions were reached:

1. Seat fire blocking layers is by far the most effective concept.
2. Floor proximity lighting is much less effective than seat fire blocking layers.
3. Passenger protective breathing equipment is more effective than floor proximity lighting assuming no donning delays and assuming 100 percent usage.
4. Passenger protective breathing equipment benefits are very sensitive to donning times and assumptions of whether lavatory extinguishers would have prevented the Varig inflight fire.

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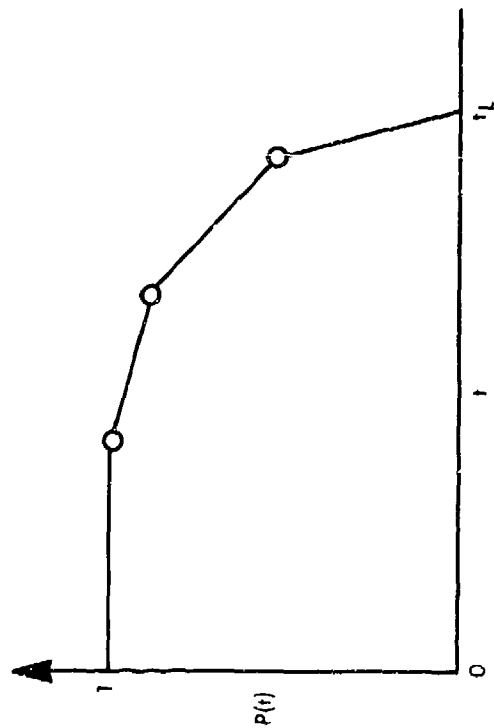
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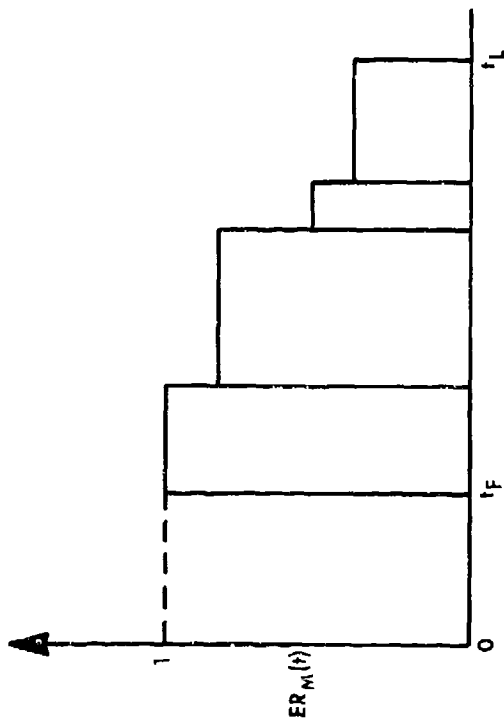
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THERMAL AND TOXIC HAZARD PROFILE



t = TIME AFTER AIRCRAFT STOPPED (SECONDS)
 P(t) = THERMAL AND TOXIC HAZARDS
 t_L = TIME OF EVACUATION BY LAST SURVIVOR

MOBILITY RATE PROFILE



ER_M(t) = MOBILITY RATE
 A = ER_A(t) WHEN P(t) • ER_M(t) = 1
 t_F = TIME OF EVACUATION BY FIRST SURVIVOR

$$\text{EVACUATION RATE} = \text{ER}_A(t) = \int_0^{t_L} P(t) \cdot \text{ER}_M(t) dt$$

$$\text{NUMBER OF SURVIVORS} = A \int_0^{t_L} P(t) \cdot \text{ER}_M(t) dt$$

- SOLVE FOR A FROM NUMBER OF SURVIVORS
- COMPARE A WITH EVACUATION DEMONSTRATION DATA
- MODIFY ASSUMPTIONS, IF NECESSARY, TO MAKE A CONSISTENT WITH EVACUATION DATA
- A FIRE SAFETY IMPROVEMENT WILL CHANGE THE PROFILES, BUT NOT A
- CALCULATE THE NUMBER OF SURVIVORS FOR EACH IMPROVEMENT

FIGURE 1. METHOD OF APPROACH

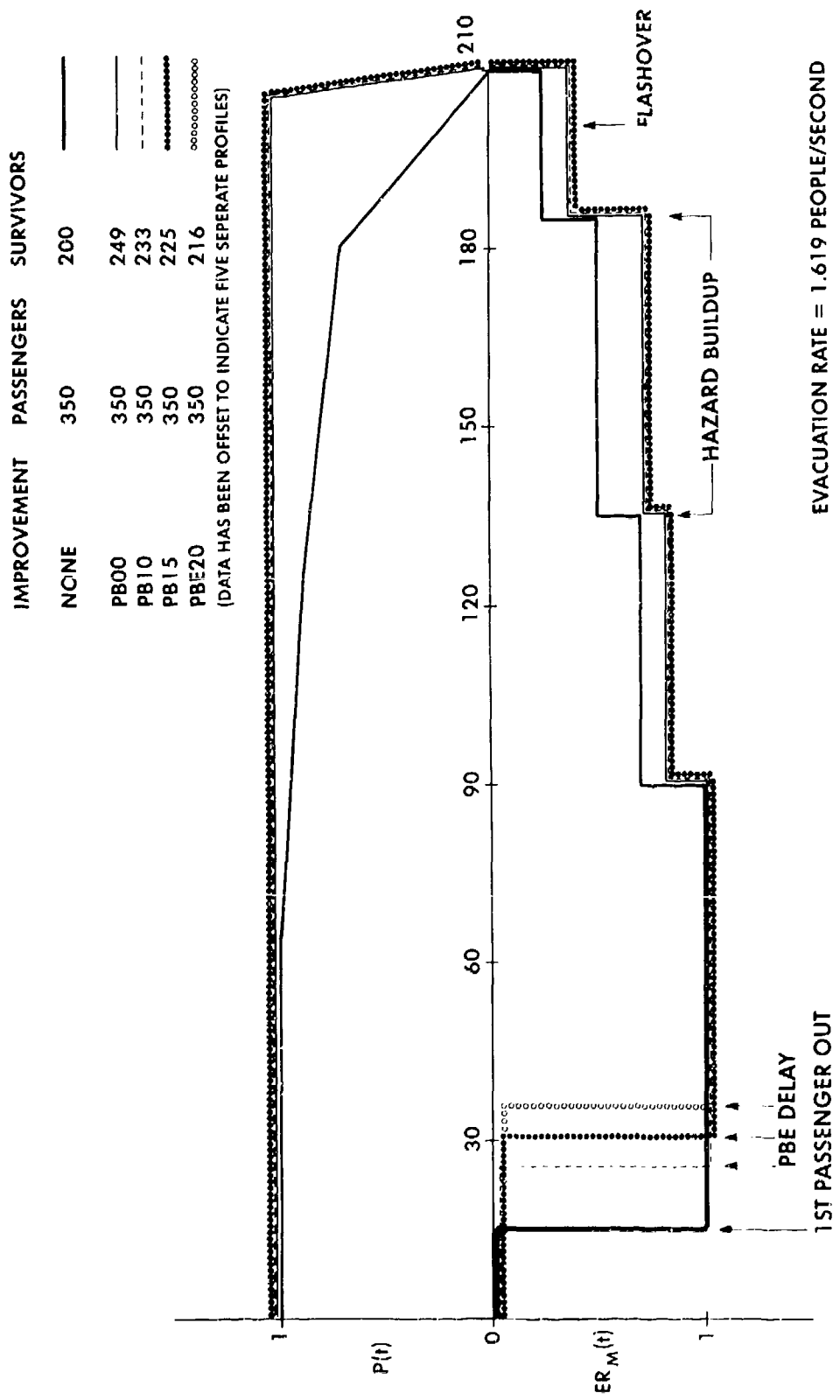


FIGURE 2. WIDE BODY PBE DELAY

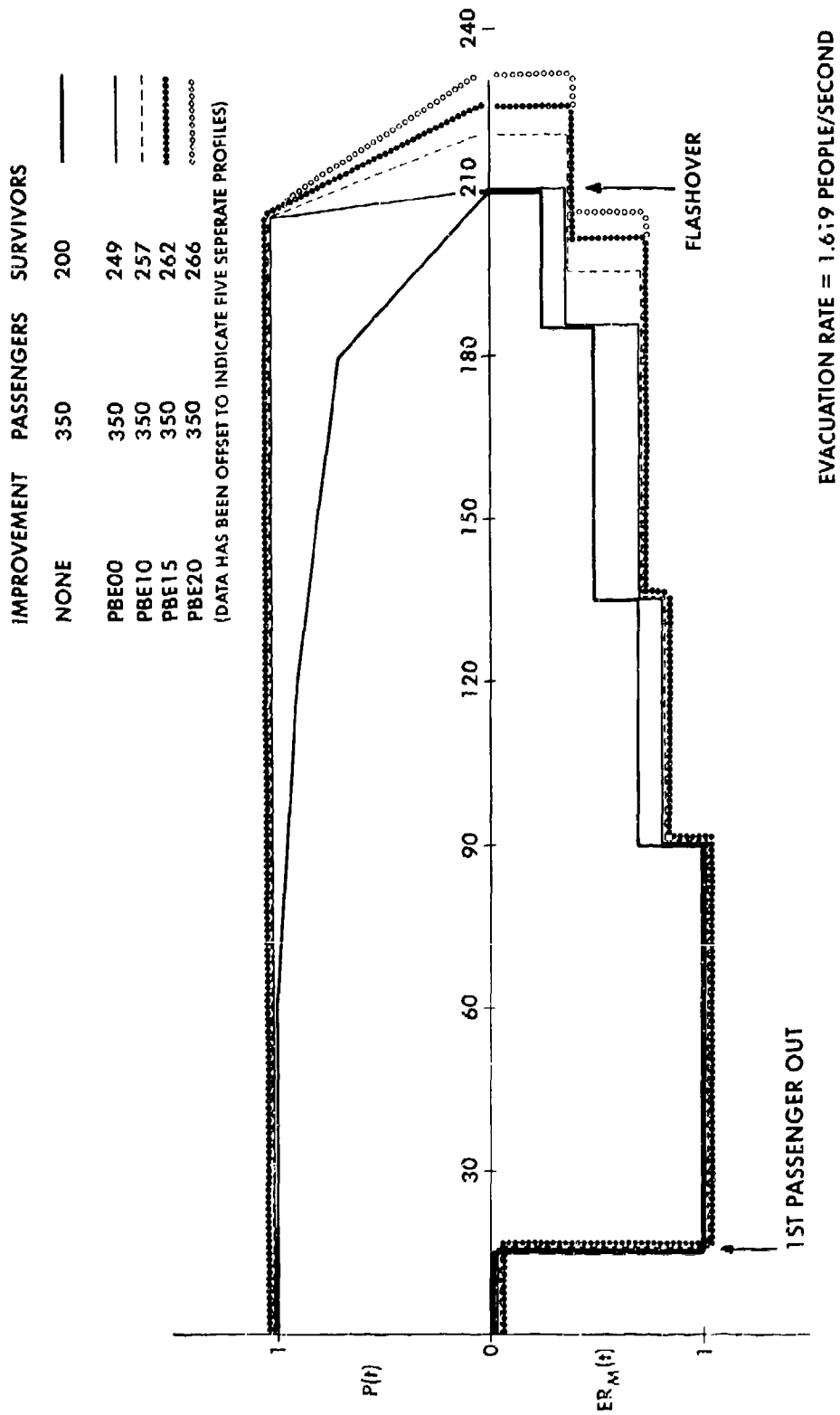


FIGURE 3. WIDE BODY PBE AFTER FLASHOVER

C-133 Test #44 - Phenolic Kevlar
 Station 480
 Height 5.5 Ft.

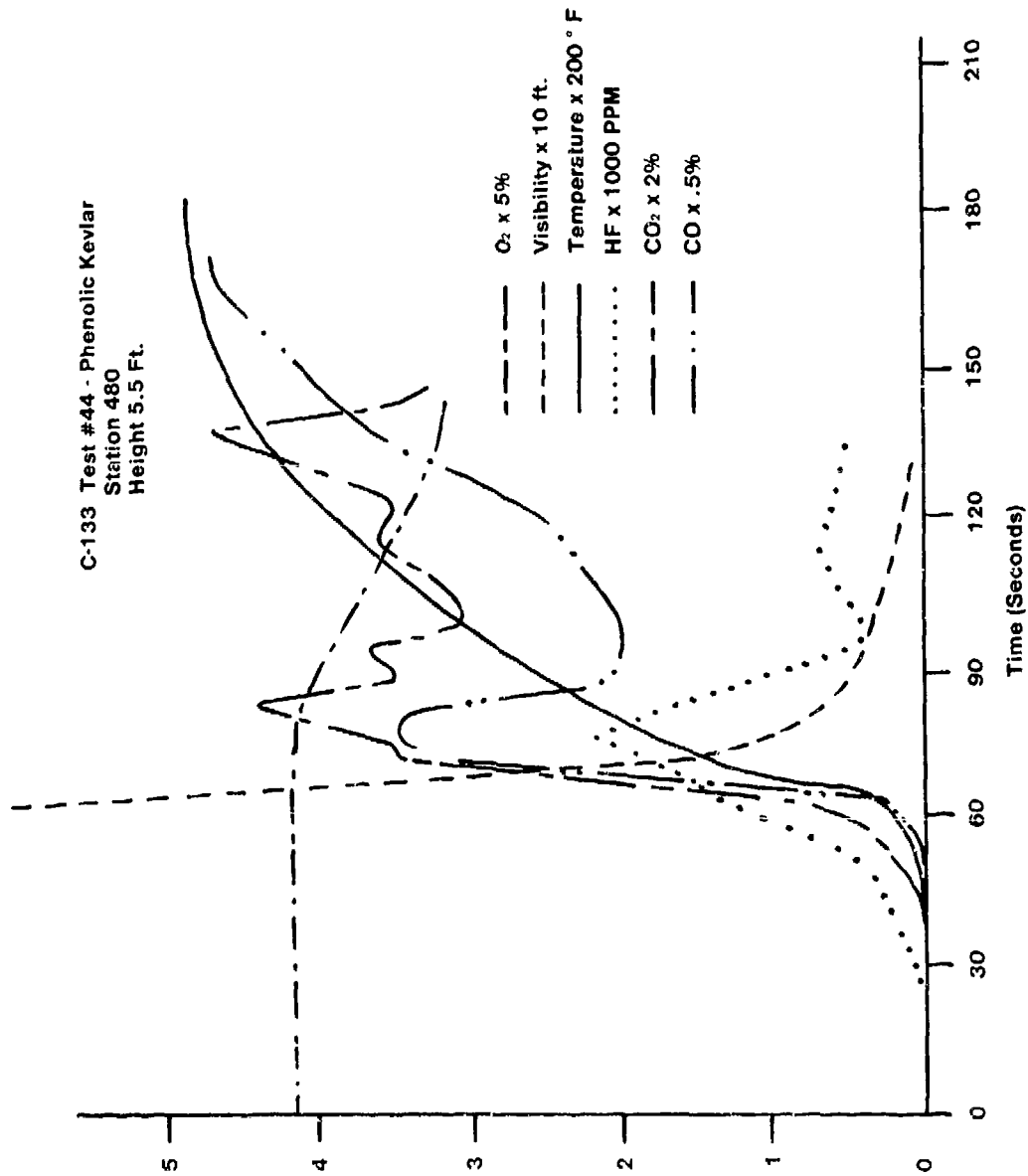
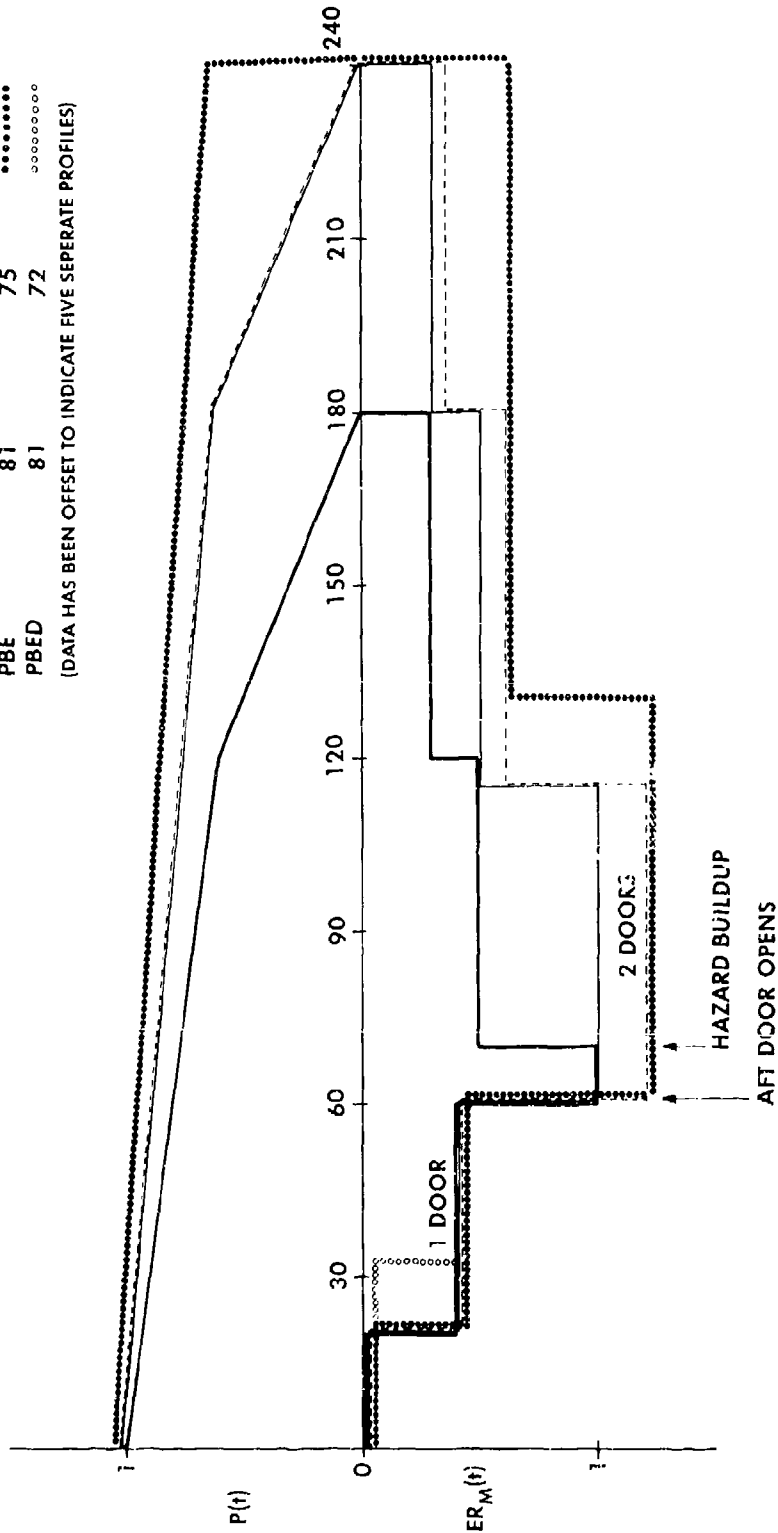


FIGURE 4. HAZARDS AS FUNCTION OF TIME IN C-133 TEST ARTICLE WITH POSTCRASH FIRE CONDITIONS

IMPROVEMENT PASSENGERS SURVIVORS

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 81 | 30 |
| FB | 81 | 59 |
| FPL | 81 | 68 |
| PBE | 81 | 75 |
| PBED | 81 | 72 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)

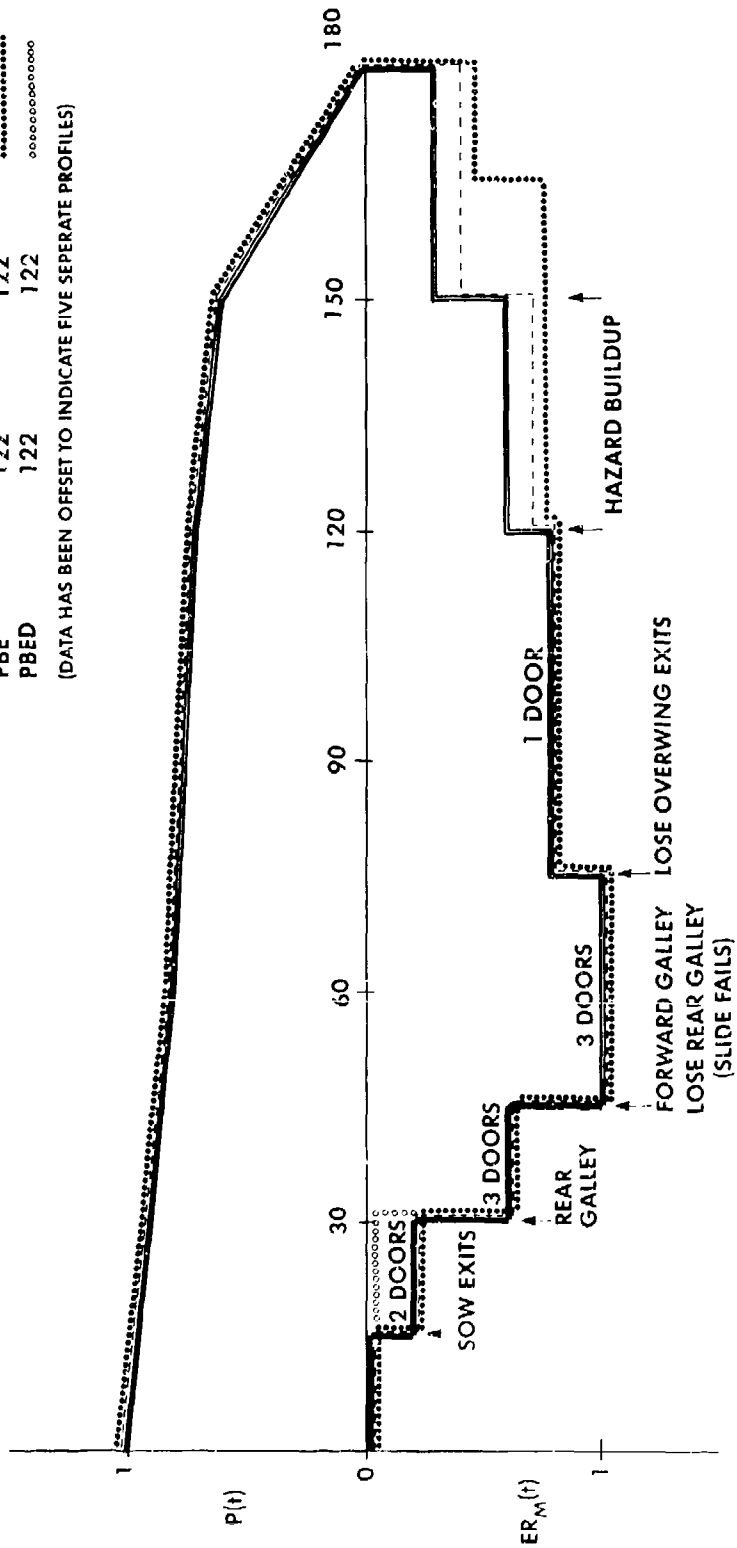


EVACUATION RATE = 0.682 PEOPLE/SECOND

FIGURE 5. ACCIDENTS PROFILES FOR VARIG DC-8 3/5/67

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 122 | 117 |
| FB | 122 | 117 |
| FPL | 122 | 121 |
| PBE | 122 | 122 |
| PBED | 122 | 122 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)



EVACUATION RATE = 1.548 PEOPLE/SECOND

FIGURE 6. ACCIDENTS PROFILES FOR B-707 4/8/68

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 225 | 178 |
| FB | 225 | 196 |
| FPL | 225 | 201 |
| PBE | 225 | 225 |
| PBED | 225 | 202 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)

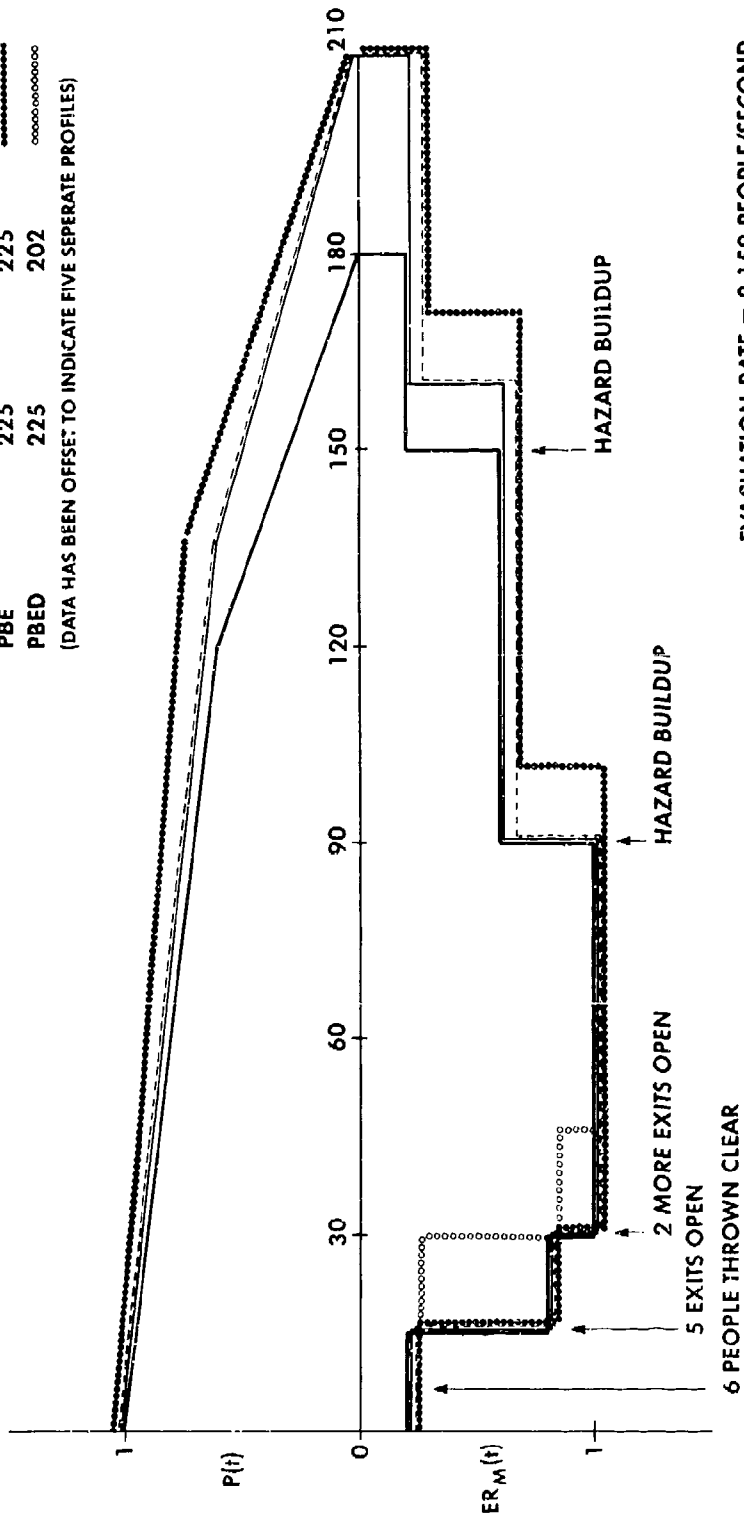
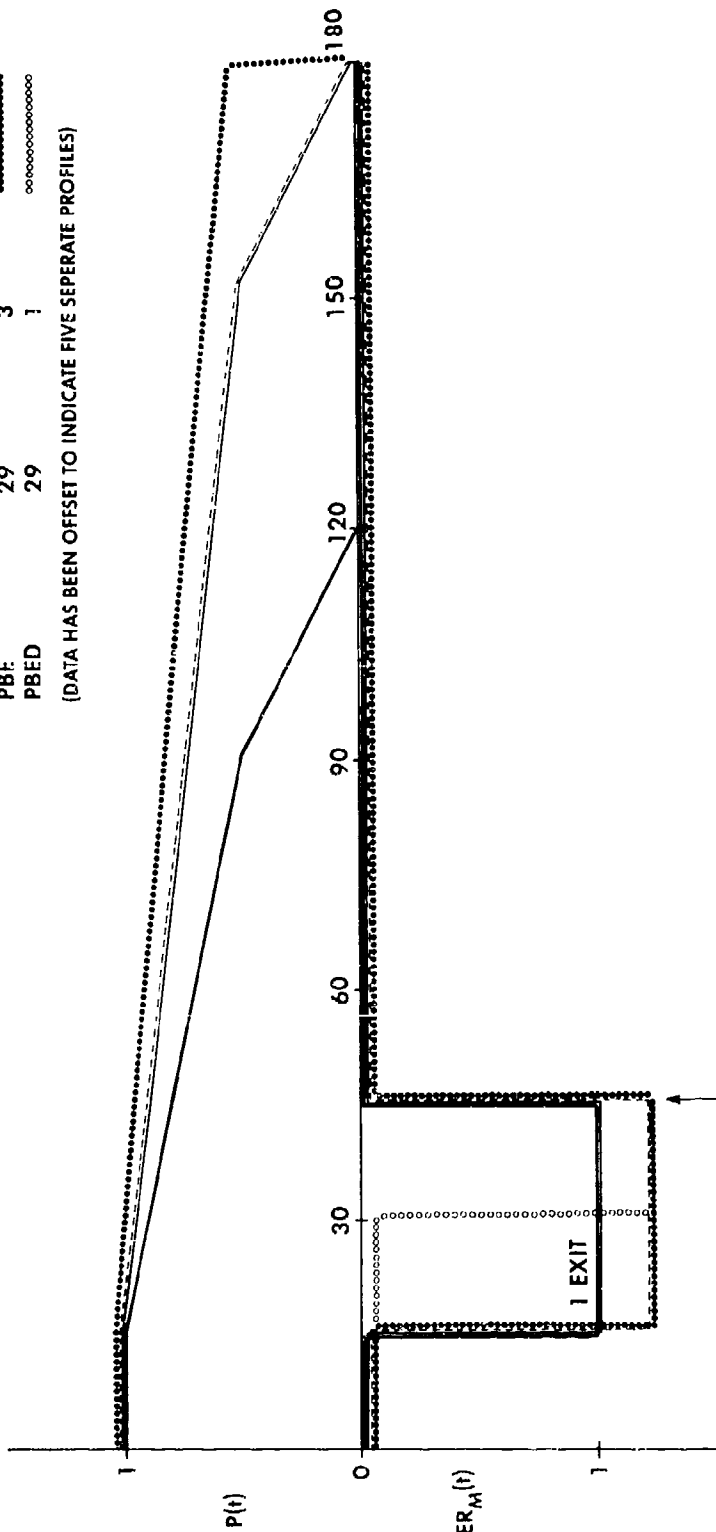


FIGURE 7. ACCIDENT PROFILES FOR CAPITOL AIRWAYS DC-8 11/27/70

IMPROVEMENT PASSENGERS SURVIVORS

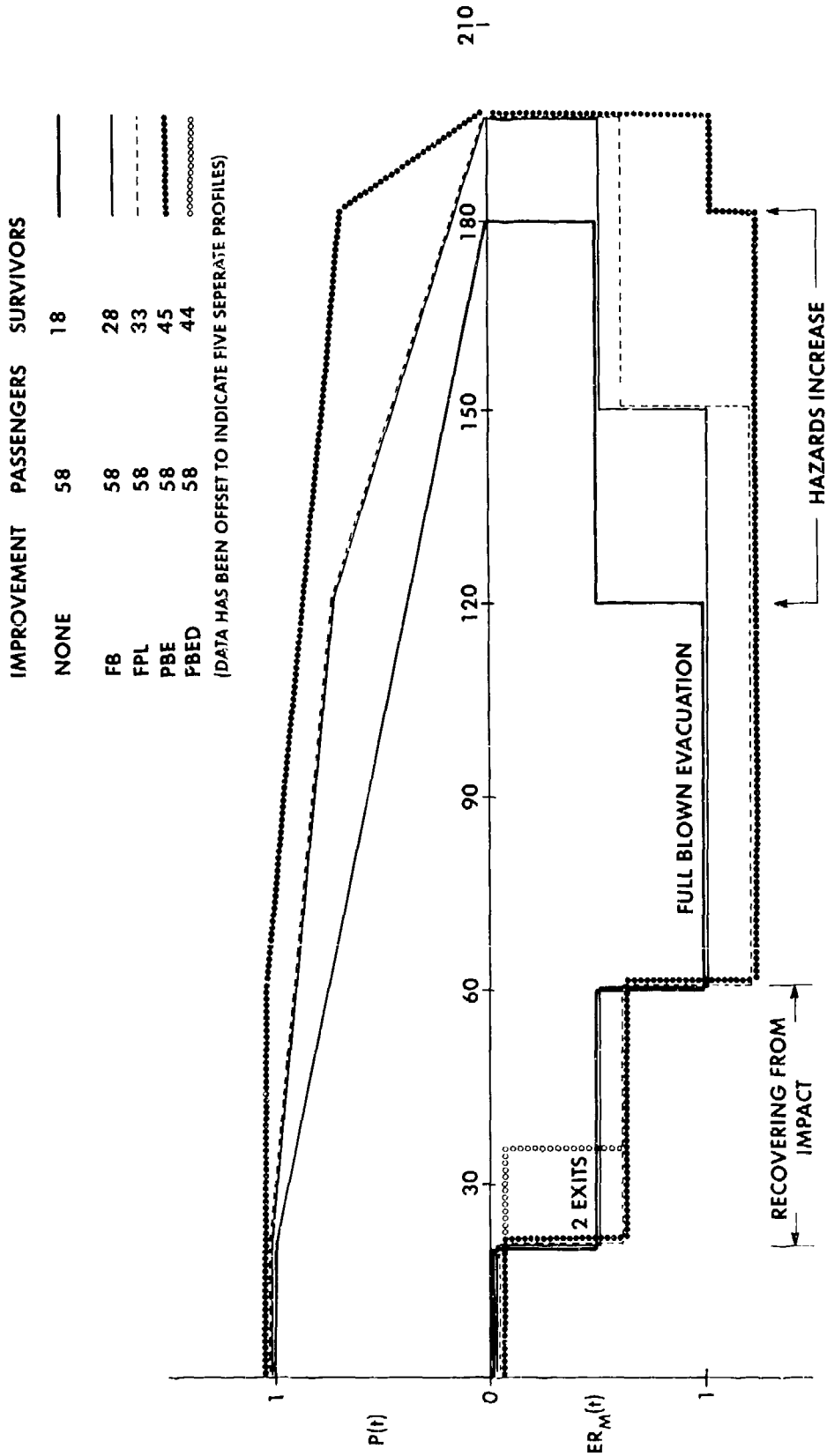
| | | |
|------|----|---|
| NONE | 29 | 2 |
| FB | 29 | 2 |
| FPI | 29 | 3 |
| PBF | 29 | 3 |
| PBED | 29 | 1 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)



EVACUATION RATE = .074 PEOPLE/SECOND

FIGURE 8. ACCIDENT PROFILES FOR ALLEGHENY AIRLINES CV-580 6/7/71

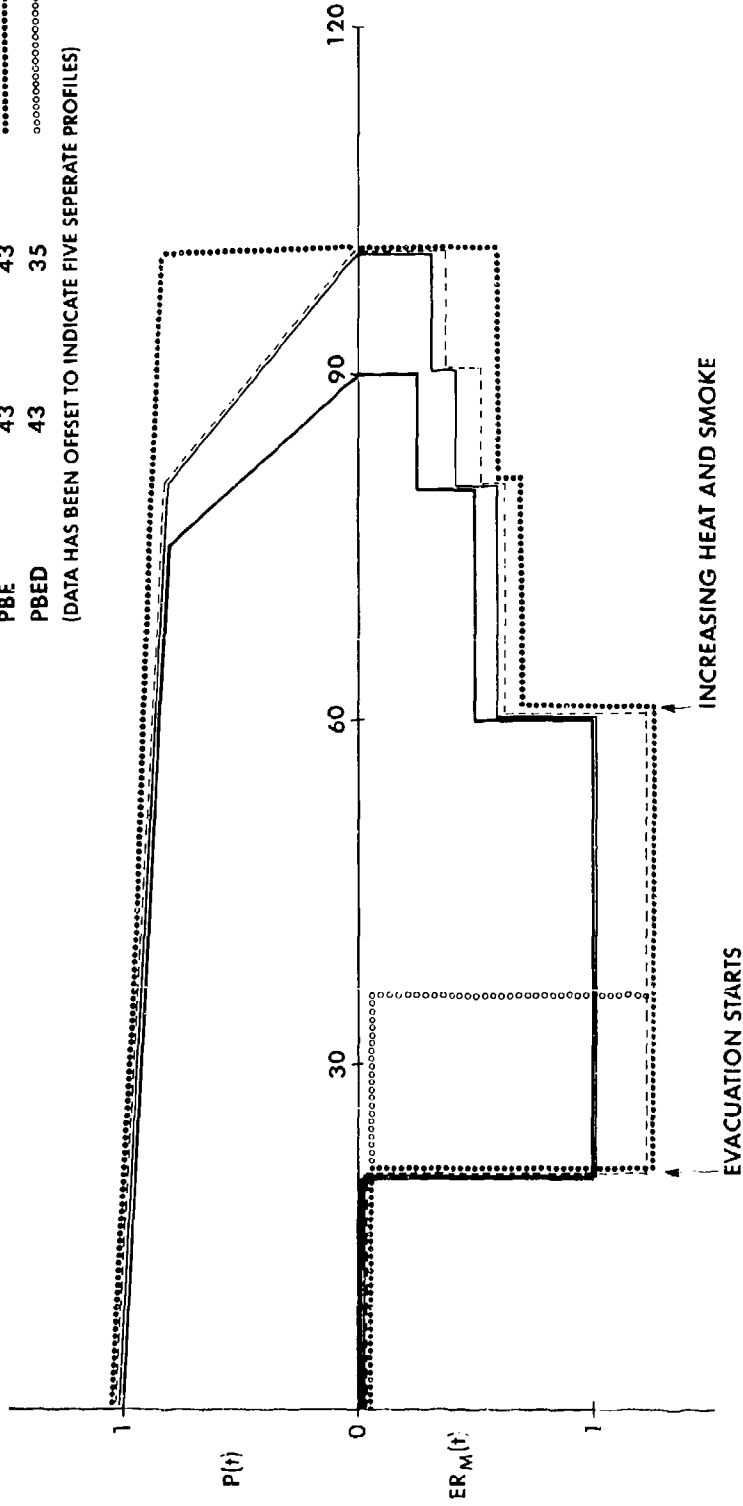


EVACUATION RATE = 0.318 PEOPLE/SECOND

FIGURE 9. ACCIDENT PROFILES FOR UNITED B-737 12/8/72

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 43 | 33 |
| FB | 43 | 35 |
| FPL | 43 | 42 |
| PBE | 43 | 43 |
| PBED | 43 | 35 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)

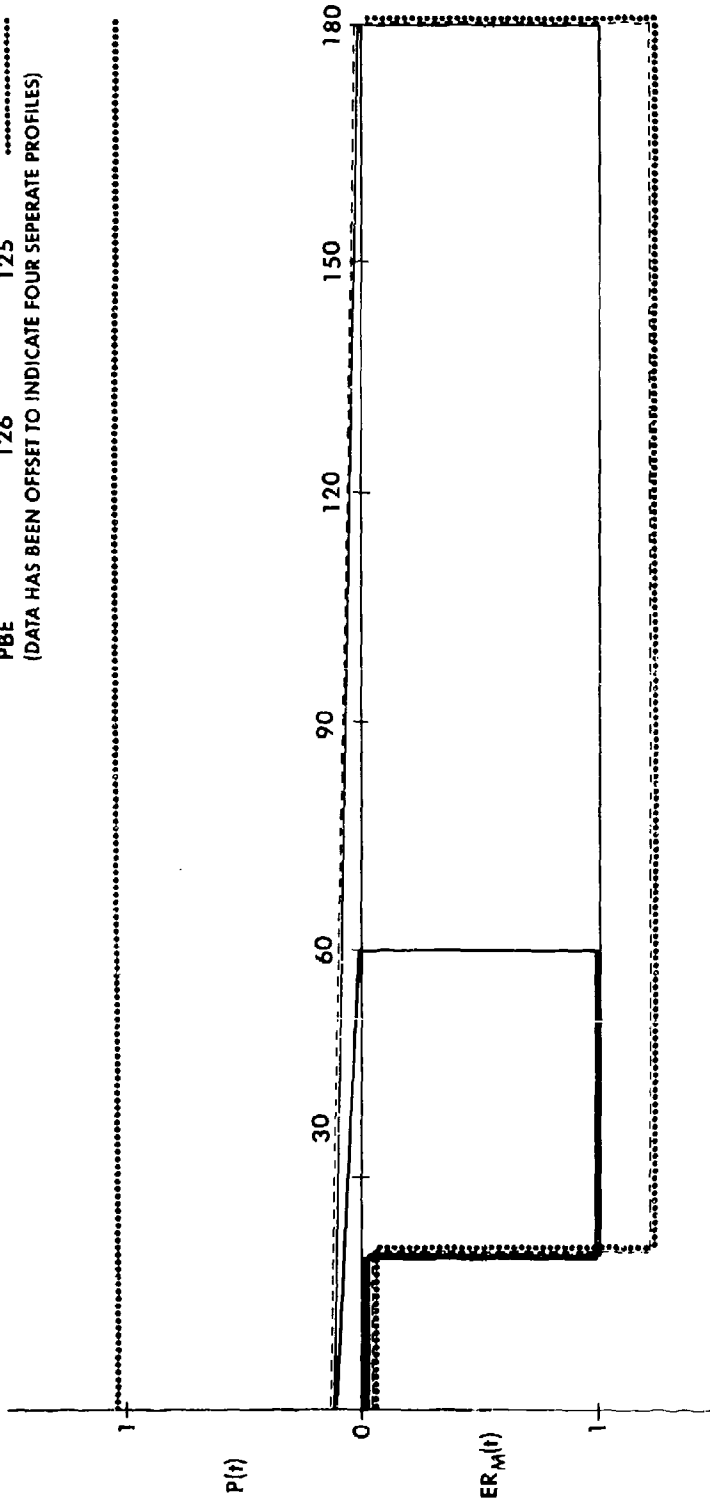


EVACUATION RATE = 0.750 PEOPLE/SECOND

FIGURE 10. ACCIDENT PROFILES FOR NORTH CENTRAL DC-9 12/20/72

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 126 | 4 |
| FB | 126 | 22 |
| FPL | 126 | 26 |
| PBE | 126 | 125 |

(DATA HAS BEEN OFFSET TO INDICATE FOUR SEPERATE PROFILES)

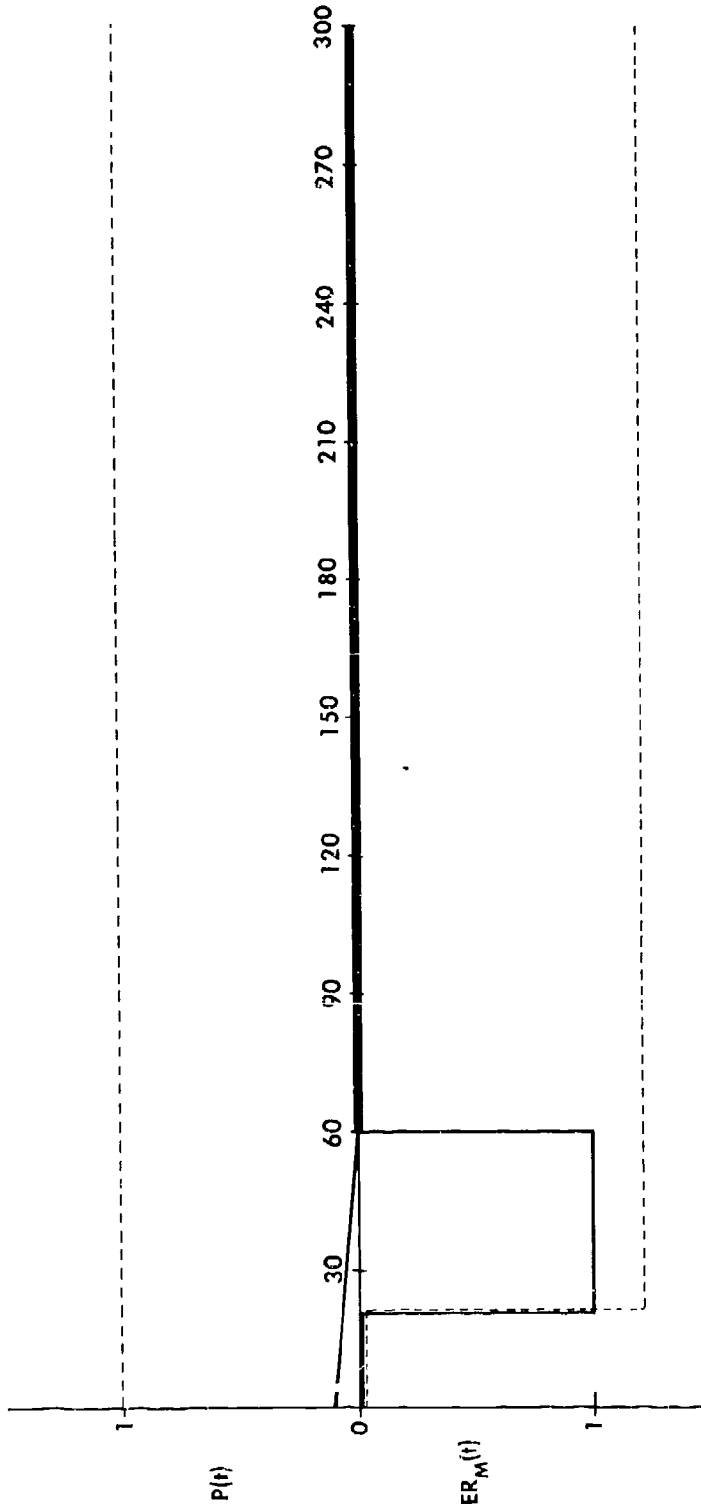


EVACUATION RATE = 3.077 PEOPLE/SECOND

FIGURE 11. ACCIDENT PROFILES FOR VARIG B-707 7/11/73, NO EXTINGUISHERS

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 126 | 4 |
| EXT | 126 | 125 |

(DATA HAS BEEN OFFSET TO INDICATE TWO SEPERATE PROFILES)



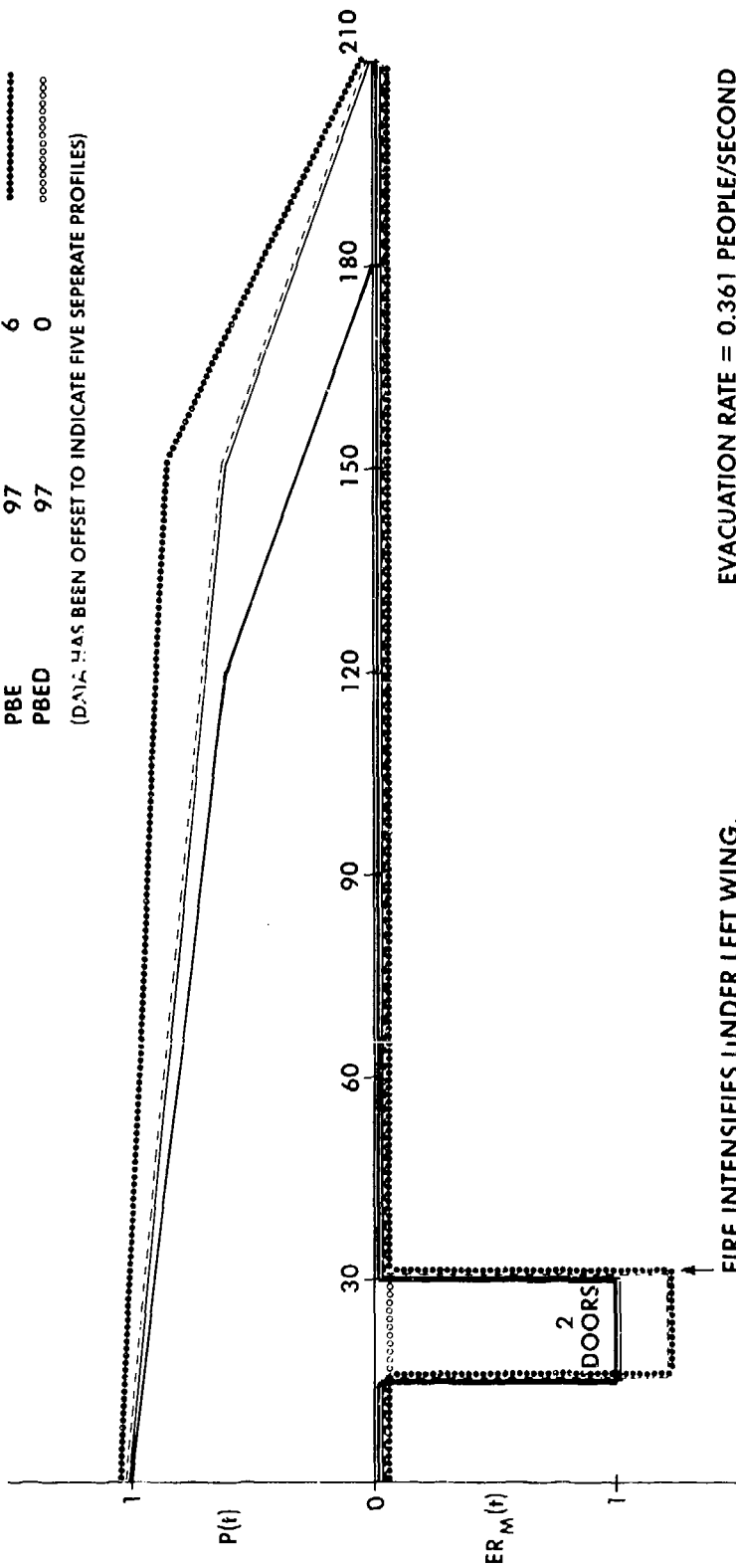
EVACUATION RATE = 3.077 PEOPLE/SECOND

FIGURE 12. ACCIDENT PROFILES FOR VARIG B-707 7/11/73, WITH EXTINGUISHERS

IMPROVEMENT PASSENGERS SURVIVORS

| | | |
|------|----|---|
| NONE | 97 | 5 |
| FB | 97 | 5 |
| FPL | 97 | 6 |
| PBE | 97 | 6 |
| PBED | 97 | 0 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)



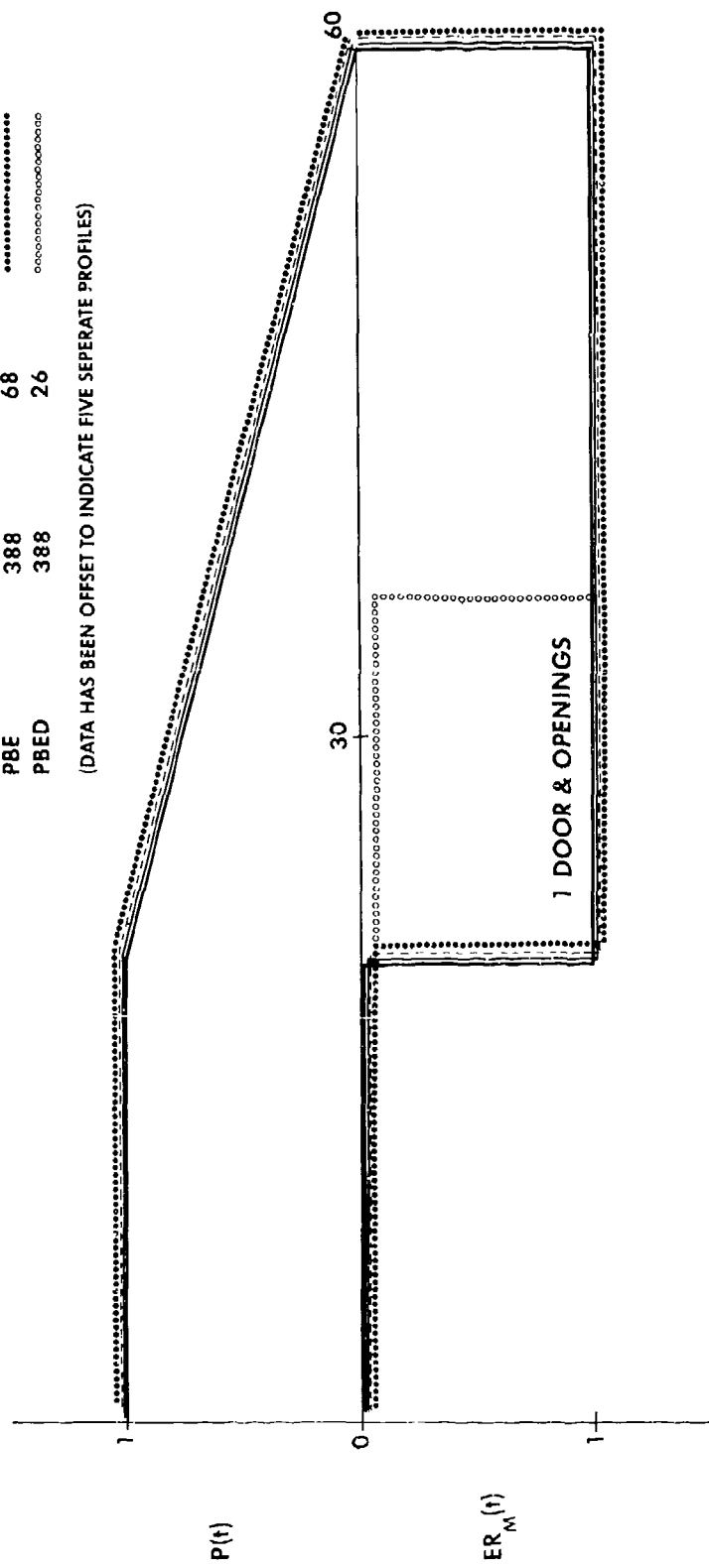
EVACUATION RATE = 0.361 PEOPLE/SECOND

FIRE INTENSIFIES UNDER LEFT WING,
OCCUPANTS TRAPPED INSIDE

FIGURE 13. ACCIDENT PROFILES FOR PAN AM B-707 1/30/74

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 388 | 68 |
| BL | 388 | 68 |
| FPL | 388 | 68 |
| PBE | 388 | 68 |
| PBED | 388 | 26 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)

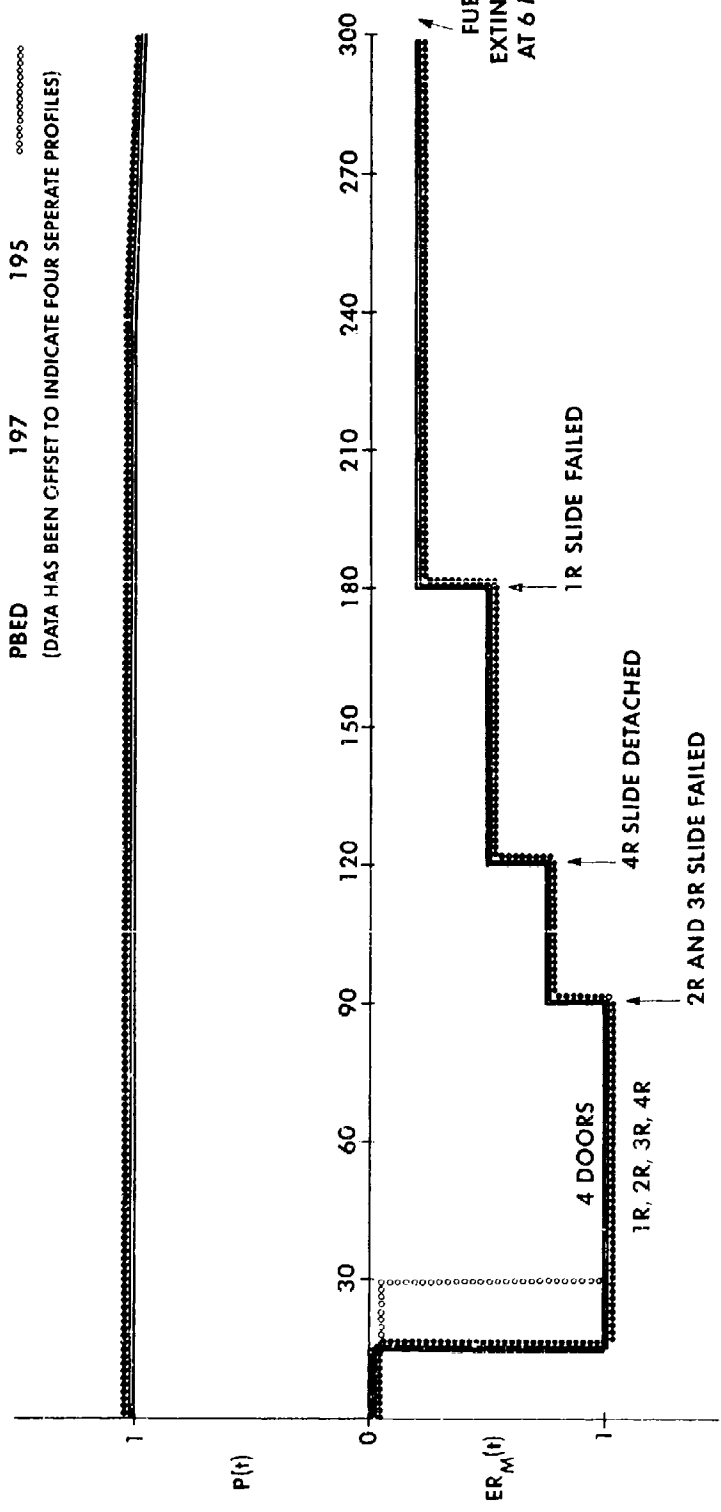


EVACUATION RATE = 3.487 PEOPLE/SECOND

FIGURE 14. ACCIDENT PROFILES FOR PAN AM B-747 3/27/77

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 197 | 195 |
| FB | 197 | 195 |
| FPL,PBE | 197 | 195 |
| PBED | 197 | 195 |

(DATA HAS BEEN OFFSET TO INDICATE FOUR SEPERATE PROFILES)



EVACUATION RATE = 1.290 PEOPLE/SECOND

FIGURE 15. ACCIDENT PROFILES FOR CONTINENTAL DC10 3/1/78

IMPROVEMENT PASSENGERS SURVIVORS

NONE 298 0

FB 298 298

[DATA HAS BEEN OFFSET TO INDICATE TWO SEPERATE PROFILES]

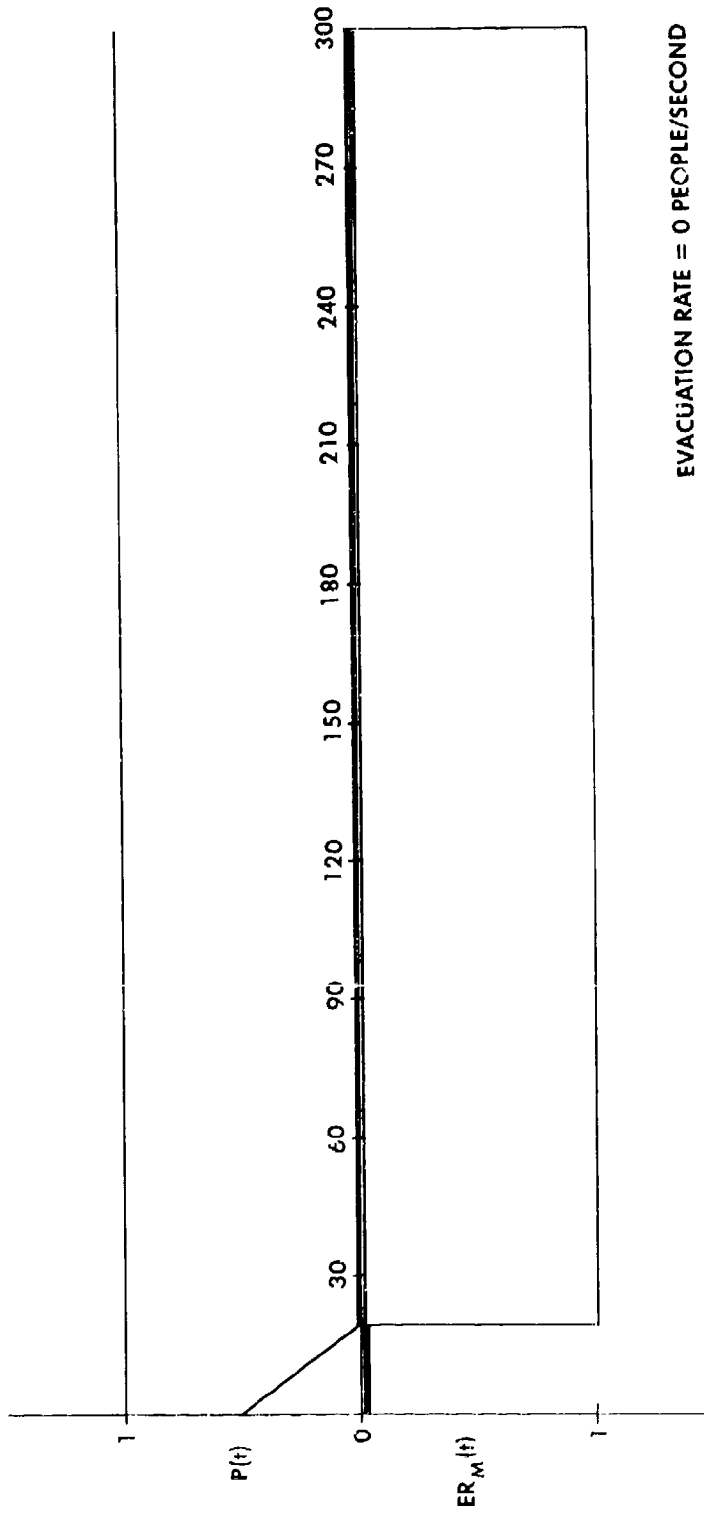
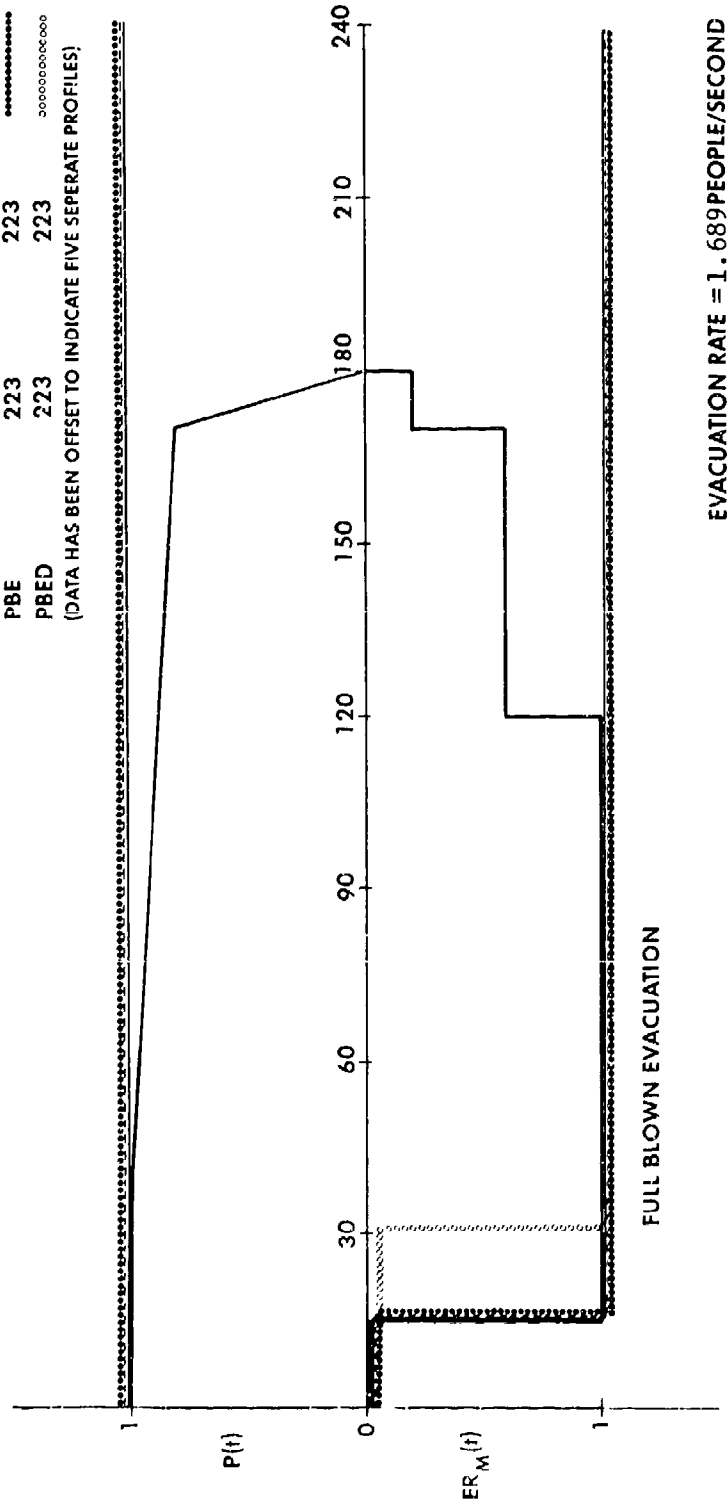


FIGURE 16. ACCIDENT PROFILES FOR SAUDI L1011 8/19/80

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 223 | 211 |
| FB | 223 | 223 |
| FPL | 223 | 223 |
| PBE | 223 | 223 |
| PBED | 223 | 223 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)

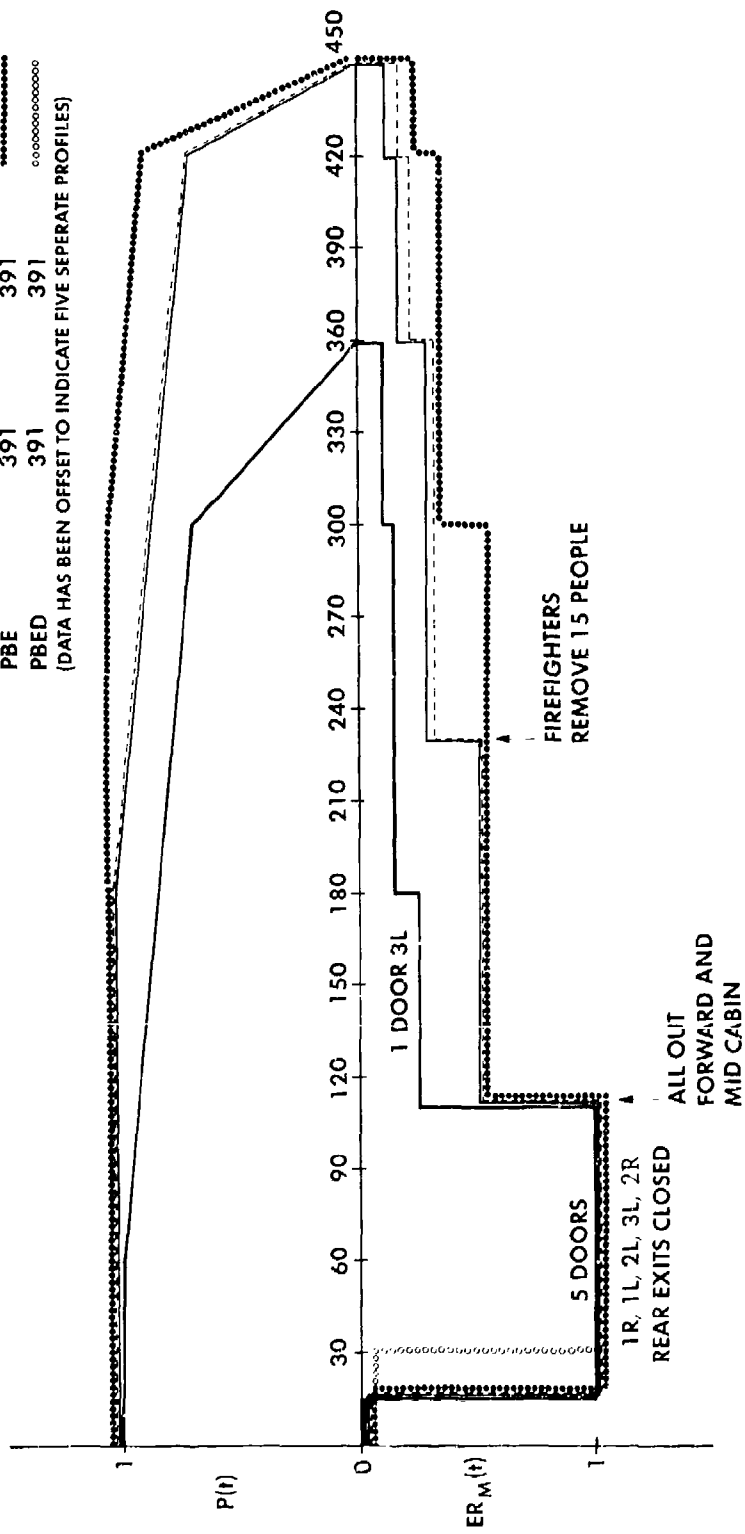


EVACUATION RATE = 1.689 PEOPLE/SECOND

FIGURE 17. ACCIDENT PROFILES FOR KOREAN AIRLINES B-747 11/19/80

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 391 | 341 |
| FB | 391 | 391 |
| FPL | 391 | 391 |
| PBE | 391 | 391 |
| PBED | 391 | 391 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)



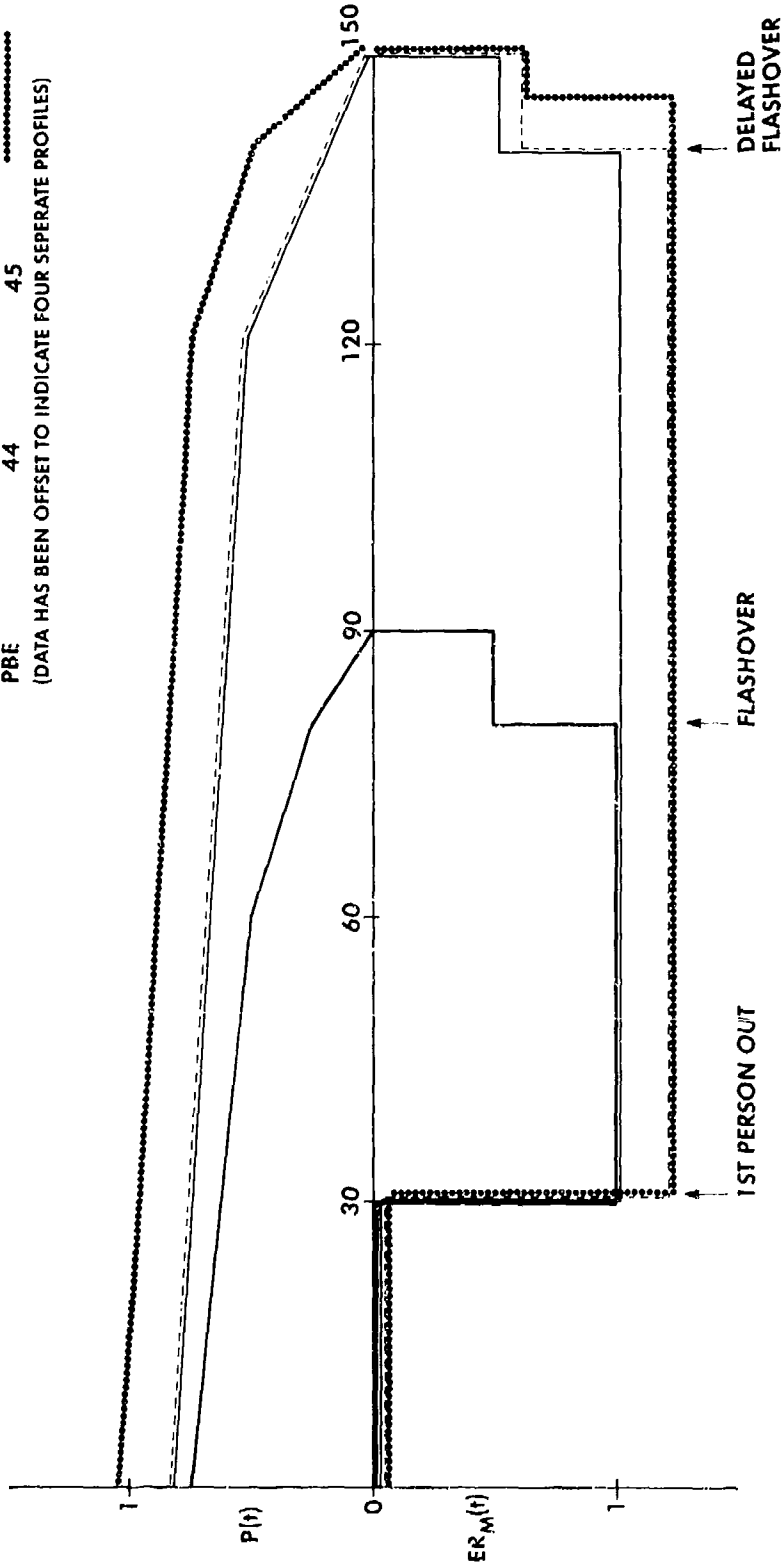
EVACUATION RATE = 2.727 PEOPLE/SECOND

FIGURE 18. ACCIDENT PROFILES FOR SPANTAX DC-10 9/13/82

IMPROVEMENT PASSENGERS SURVIVORS

| IMPROVEMENT | PASSENGERS | SURVIVORS |
|-------------|------------|-----------|
| NONE | 44 | 21 |
| FB | 44 | 44 |
| FPL | 44 | 44 |
| PBE | 44 | 45 |

(DATA HAS BEEN OFFSET TO INDICATE FOUR SEPERATE PROFILES)



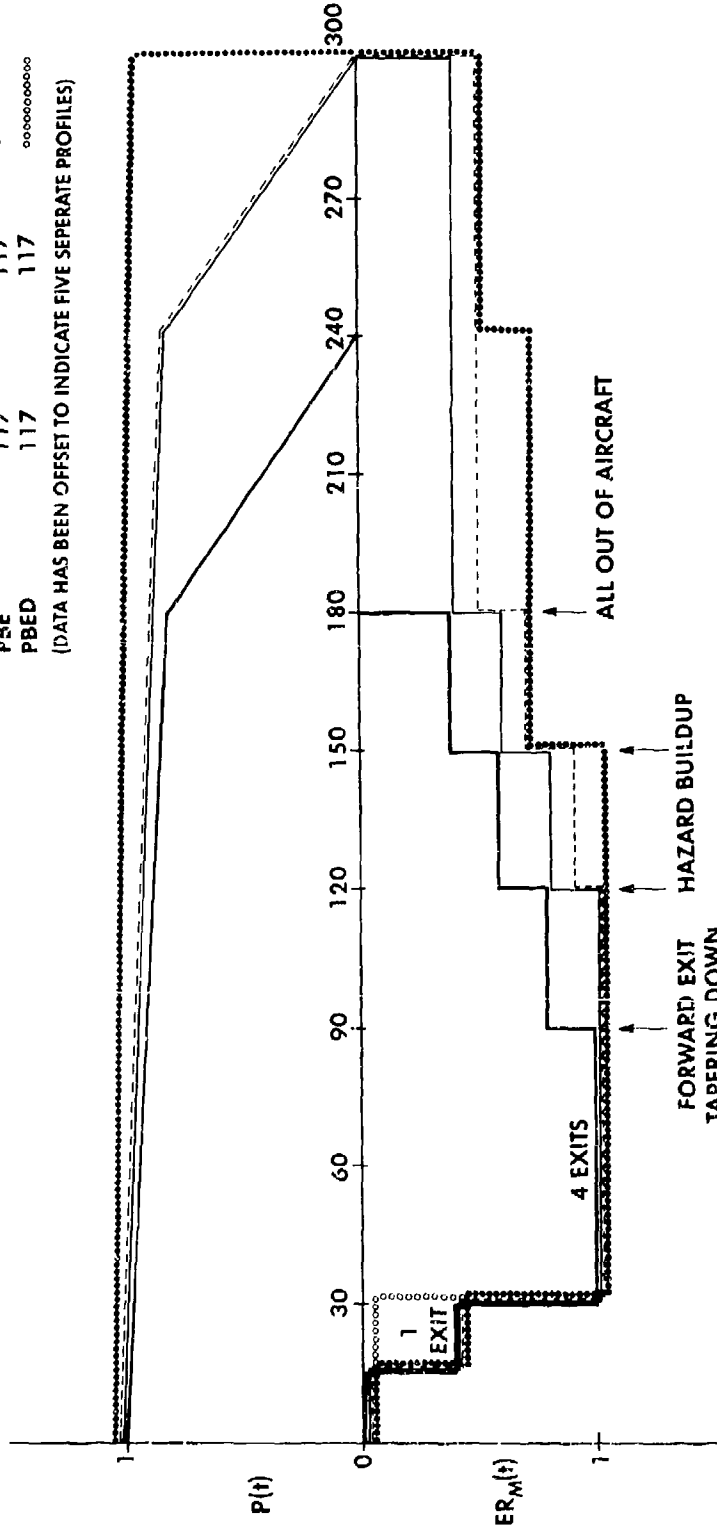
EVACUATION RATE = 0.848 PEOPLE/SECOND

FIGURE 19. ACCIDENT PROFILES FOR AIR CANADA DC-9 6/2/83

IMPROVEMENT PASSENGERS SURVIVORS

| | | |
|------|-----|-----|
| NONE | 117 | 117 |
| FB | 117 | 117 |
| FPL | 117 | 117 |
| PRE | 117 | 117 |
| PBED | 117 | 117 |

(DATA HAS BEEN OFFSET TO INDICATE FIVE SEPERATE PROFILES)



EVACUATION RATE = 1.082 PEOPLE/SECOND

FIGURE 20. ACCIDENT PROFILES FOR PACIFIC WESTERN B-737 3/22/84

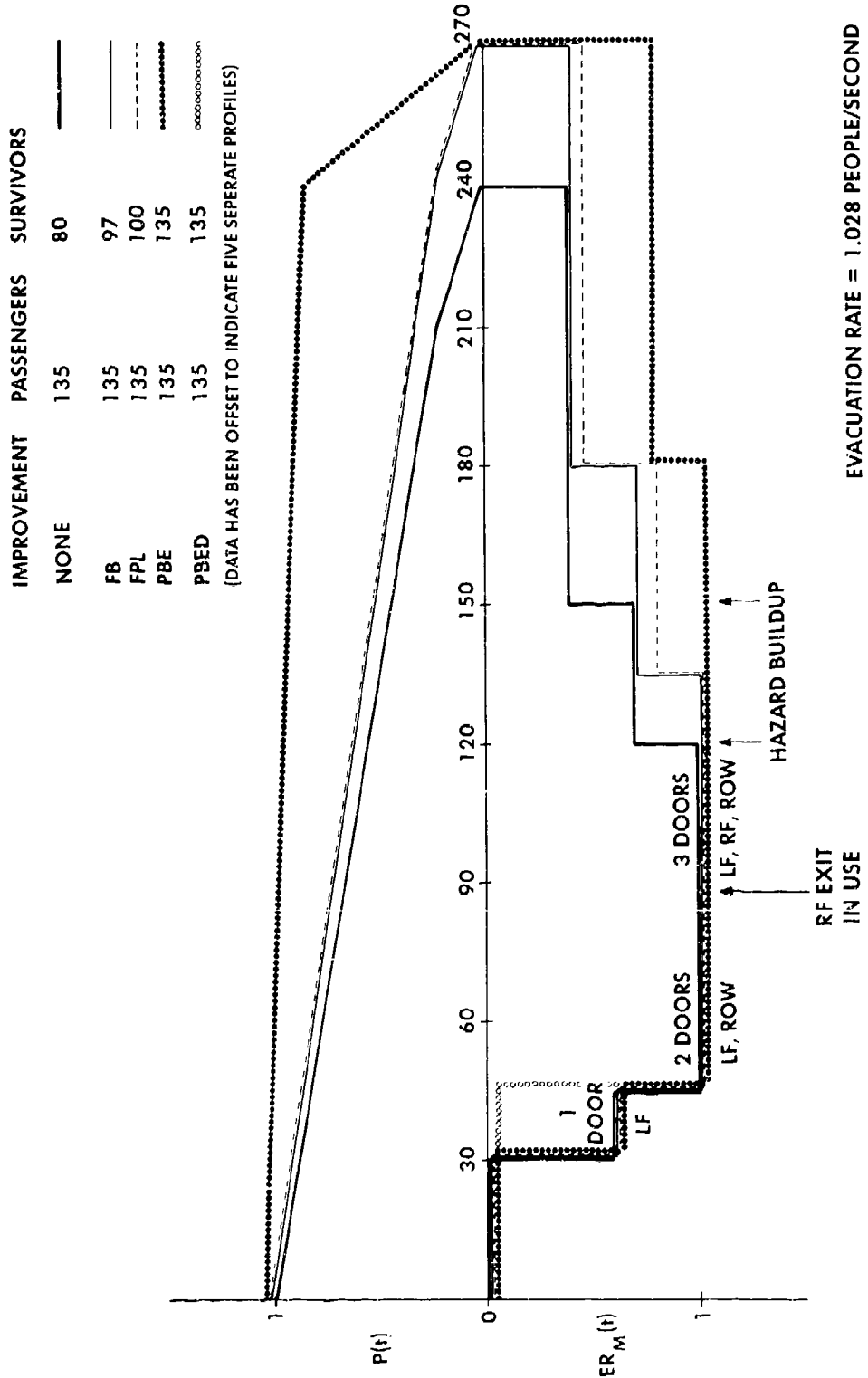


FIGURE 21. ACCIDENT PROFILES FOR BRITISH AIR TOURS B-737 8/22/85

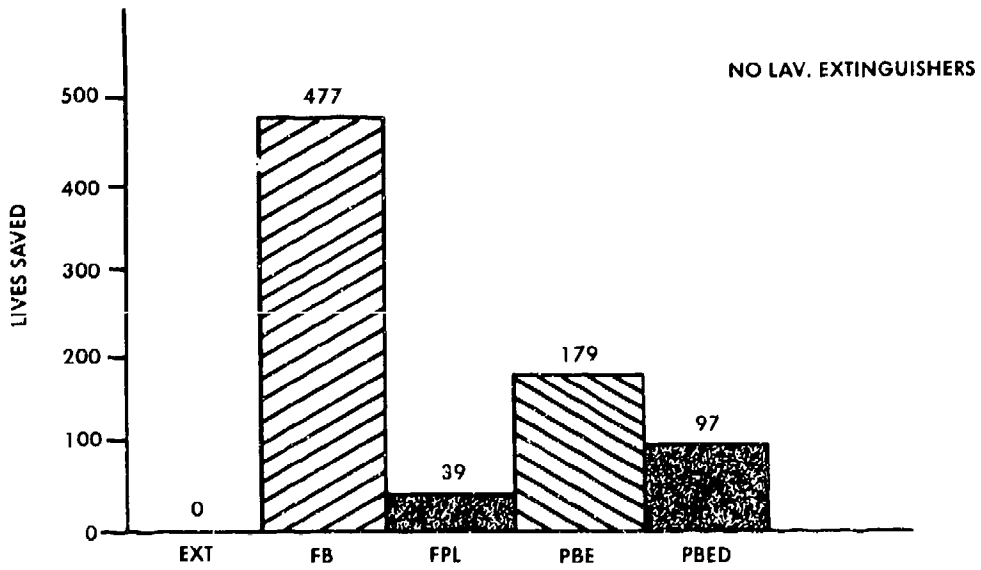
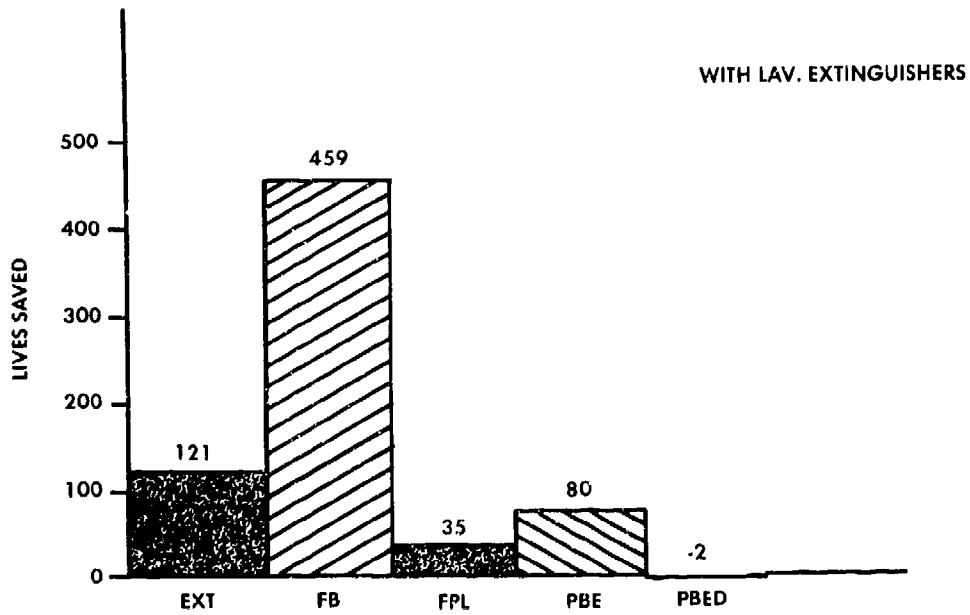


FIGURE 22. ESTIMATED LIVES SAVED WITH SAFETY IMPROVEMENTS

APPENDIX A
LISTING OF COMPUTER PROGRAM

```
10 KEY OFF
20 WIDTH 40
30 SCREEN 0.1
35 LOCATE 1,1,0
40 COLOR 4,2,14
45 CLS
50 LOCATE 15,15,0
90 PRINT "EVAC"
100 C2=TIMER
110 V5=1
120 IF (TIMER-C2) > 5 THEN 110
130 LOCATE 15,15,0
140 PRINT "DEVELOPED BY"
150 LOCATE 16,13,0: PRINT "FIRE SAFETY BRANCH"
160 LOCATE 17,12,0
170 PRINT "FAA TECHNICAL CENTER"
180 C2=TIMER
190 VR=1
200 IF (TIMER-C2) > 5 THEN 190
210 M=1
220 IS=0
```

```

230 I6=0
240 LOCATE 1,1,0
250 SCREEN 0,0
260 WIDTH 80
280 INPUT "IF PLOTTER IS NOT USED TYPE 1, IF USED 0 : ";PLT
290 IF PLT =1 THEN GOTO 340
300 OPEN "COM1:9600,E,7,1" AS # 2
310 PRINT # 2,"IN;IP 1000 1100 3450 6840:"
320 LSP = 2:
330 ELS = -1.5
340 Z7=0
350 Z8=0
360 INPUT "MAXIMUM TIME FOR MODEL : ";:MTIME
370 INPUT "Accident Info ";:A$
380 INPUT "number of passengers ";:NPS
390 INPUT "number of deaths ";:ND
400 INPUT "number of fire deaths ";:NFD
410 LPRINT A$
420 LPRINT "number of passengers = ";:NPS
430 LPRINT "number of deaths = ";:ND
440 LPRINT "number of fire deaths = ";:NFD
450 NS=NPS-ND
460 NS1 = NS
470 NF=NPS-(ND-NFD)
480 INPUT "Time till last passenger out ";:TE
490 PRINT "Set up accident curve "
500 I=1
510 LPRINT "Hazard level curve for accident "
520 INPUT "hazard level then time ";:HL(I),:THL(I)
530 LPRINT "Hazard level "HL(I), "Time ";:THL(I)
540 IF THL(I)=TE THEN GOTO 570
550 I=I+1
560 GOTO 520

```

```

570 J=1
580 INPUT "% evacuation rate then time ";ER(J),TER(J)
590 LPRINT "evacuation level "ER(J),"Time ",TER(J)
600 IF TER(J)≠TE THEN GOTO 630
610 J=J+1
620 GOTO 580
630 THL(0)=0
640 INPUT "INPUT STARTING HAZARD LEVEL : ",HL(0)
650 FOR K=1 TO I
660 SHL(K)=(HL(K-1)-HL(K))/(THL(K)-THL(K-1))
670 NEXT K
680 ICNT = ICNT + 1
690 SCREEN 1
700 THZ(0,M)=THL(0)
710 HZ(0,M)=HL(0)
720 FOR KB = 1 TO I
730 LINE (THL(KB-1),(-50*HL(KB-1)+100))- (THL(KB),(-50*HL(KB)+100))
740 THZ(KB,M)=THL(KB)
750 HZ(KB,M)=HL(KB)
760 NEXT KB
770 FOR KB= 1 TO J
780 LINE (TER(KB-1), (100+(50*ER(KB-1))))-(TER(KB), (100+(50*ER(KB))))
790 TEZ(KB,M)=TER(KB)
800 EZ(KB,M)=ER(KB)
810 NEXT KB
820 C1(M)=I
830 C2(M)=J
840 X1=0
850 LINE (0,100)-(300,100)
860 IF C7 = 1 THEN GOTO 1000
870 IF PLT=1 THEN GOTO 980
880 PRINT #2,"SC 0 " ;TIME;" -1 5 1 STEP:PU:PA " ;TIME;" 0:PG 0 0 :PA 0 -1 5 0
1 5;PU:"

```

```

890 XSCLE = 30
900 PRINT #2,"PA 30 0;XT;LD16;CP -10;LB30";CHR$(3)
910 IF XSCLE >= MTIME THEN 950
920 XSCLE = XSCLE + 30
930 PRINT #2,"PA ";XSCLE;" 0;XT;LD16;LB ";XSCLE;CHR$(3)
940 GOTO 910
950 FOR L = -1 TO 1
960 PRINT #2,"PU:PA 0 ";L;" ";YT;LD18;LB"ABS(L);CHR$(3)
970 NEXT L
980 STOP
990 SCREEN 2
1000 IF PLT =1 THEN GOTO 1300
1010 PRINT #2,"LD2;PU:PA:MTIME/2;" 2.2;LBIMPROVEMENT";TAB(16);"PASSENGERS";TAB(
30);"SURVIVORS";CHR$(3)
1020 PRINT #2,"SI .5 .75;LD4;PU:PA:MTIME/2;" 2.3;LB"A";CHR$(3);"SI:"
1030 INPUT "ENTER LINE COLOR (1-8) : ";CO
1040 CZ(M)=CO
1050 INPUT "ENTER IMPROVEMENT : ";IMPROV$
1060 IF PLT =1 THEN GOTO 1300
1070 IM$(M)=IMPROV$
1080 P=LEN(IMPROV$)
1090 IF Z7 = 0 THEN PRINT #2,"LD2;SP";CO;" ";PU:PA " :MTIME/2.LSP:";LB " : IMPROV$;TA
B(15);NPS.NS);CHR$(3);";PD;PR 15 0;LB";CHR$(3)
1100 LSP=LSP- 125
1110 THX(0)=THL(0)+I5
1120 HX(0)=HL(0)+I6
1130 PRINT # 2,"PU:PA ";THX(0);HX(0);";PD;SP";CO:"
1140 FOR K3 = 1 TO I
1150 THX(K3)=THL(K3)+I5
1160 HX(K3)=HL(K3)+I6
1170 PRINT #2,"PA ";THX(K3);HX(K3);";"
1180 NEXT K3
1190 TEX(0)=TER(0)+I5

```

```

1200 EX(I)=ER(I)+I6
1210 PRINT #2,"PU;PA ";TEX(0),-(EX(1));"FD:"
1220 FOR K3 = 1 TO J
1230 TEX(K3)=TER(I3)+I5
1240 EX(K3)=ER(K3)+I6
1250 EX(K3+1)=ER(I3+1)+I6
1260 PRINT #2,"PO;PA ";TEX(I3),-(EX(I3));"PA ";TEX(I3),-(EX(I3+1));"
1270 NEXT K3
1280 I5=I5+3
1290 I6=I6+91
1300 SCREEN 2
1310 SCREEN 0
1320 IF D7=0 THEN TE1=TE ELSE TE1=TE+TIM
1330 IF D8=1 THEN TE1=TE
1340 X2=0
1350 Y2=0
1360 FOR M=1 TO TE1
1370 FOR L=1 TO I
1380 IF K=THL(L) THEN GOTO 1400
1390 NEXT L
1400 Y1=HL(L-1)-(SHL(L)*K-THL(L-1))
1410 FOR L=1 TO J
1420 IF K=TER(L) THEN GOTO 1440
1430 NEXT L
1440 IF D7=1 THEN X1=ER(L)+EVACRATE
1450 IF D7=1 THEN GOTO 1480
1460 X1=X1+Y1+ER(L)
1470 IF D7=0 THEN GOTO 1550
1480 X0=X0+(Y1+1)-Y1+X1
1490 X1=X1+Y1
1500 X2=Y0+X1
1510 NS1=Y2
1520 NC1=Y3

```

```

1530 NP1=NC1+NS1
1540 IF X2=NP THEN GOTO 2090
1550 NEXT K
1560 IF Z7=1 THEN GOTO 2090
1570 EVACRATE=NS/X1
1580 M=M+1
1590 PRINT
1600 PRINT "the evacuation rate for this accident is "EVACRATE,"people/second"
1610 LPRINT "The evacuation rate for this accident is "EVACRATE,"people/second"
1620 IF PLT=1 THEN GOTO 1650
1630 PRINT #2,"PU:PA":M*TIME/2:ELS:" "LBEVACUATION RATE = "EVACRATE:" PEOPLE/SECO
ND":CHR$(3)
1640 ELS=ELS- 2
1650 PRINT
1660 PRINT
1670 PRINT "Now include Fire safety improvements "
1680 PRINT "These improvements can change time of survivable environment "
1690 PRINT "The rate of buildup of that environment,"
1700 PRINT "for the rate of possible evacuation "
1710 INPUT "FOR NEW CURVE TYPE 0, FOR CHANGE TYPE 1 : "B5
1720 IF B5=0 THEN GOTO 2240
1730 INPUT "Added time till last person out "TIM
1740 TE=TE+TIM
1750 PRINT
1760 IQ=0
1770 LPRINT "New curves with fire improvements are as follows"
1780 FOR K2= 1 TO I
1790 PRINT "input % of time to be added to hazard T(K2)
1800 INPUT :T2(K2)
1810 PRINT
1820 T2(K2)=T2(K2)+TIM
1830 IQ=IQ+T2(K2)
1840 THL(K2)=THL(K2)+IQ

```

```

1850 LPRINT "Hazard level"HL(I2),"Time ",THL(I2)
1860 NEXT I2
1870 TQ=0
1880 FOR I2= 1 TO J
1890 PRINT "Input % of time to be added to evaluation T"K2
1900 INPUT (T2)(I2)
1910 PRINT
1920 TQ=TQ+T2*(I2)
1930 TQ=TQ / J
1940 TER(I2)=TER(I2)+TQ
1950 NEXT I2
1960 PRINT "Do you wish to change evacuation rates?"
1970 INPUT "If yes type 0 "FF1
1980 IF FF1 = 0 THEN GOTO 2040
1990 FOR I2=1 TO J
2000 PRINT "The present exscuation level at T"2,"is "ER(I2)
2010 PRINT
2020 INPUT "Type new evacuation rate" ER(I2)
2030 NEXT I2
2040 FOR I2=1 TO J
2050 LPRINT "Evacuation rate "ER(I2),"at Time " TER(I2)
2060 NEXT I2
2070 I1=1
2080 GOTO 670
2090 I1=INT(N*(1.5))
2100 NG=NE-N(I1)
2110 PRINT
2120 IF NG = 0 THEN N=N(I1)
2130 IF NG > 0
2140 PRINT "for the N"1 "dividers "N(I1) "divided"
2150 LPRINT "for the N"1 "dividers "N(I1) "divided"
2160 IF NG < 0 THEN GOTO 2240

```



```
2180 PRINT #2,"LD2;SP";CO;";PU;PA ";MTIME/2,LSP;";LB ";IMPROV$;TAB(15);NPS,NS1;C
HR$(3);";PD;PR 15 0;LB";CHR$(3)
2190 PRINT
2200 INPUT "To try improvement again type 1";R1
2210 PRINT
2220 IF R1=1 THEN GOTO 1670
2230 GOTO 2390
2240 PRINT "now you can estimate the effect of AN IMPROVEMENT."
2250 Z7=1
2260 PRINT "The present hazard curve is as follows:"
2270 FOR K2= 1 TO I
2280 PRINT "hazard level" HL(K2), "Time " THL(K2)
2290 NEXT K2
2300 Z8=1
2310 PRINT "The present evacuation levels are as follows: "
2320 FOR K2=1 TO J
2330 PRINT "Evacuation level " ER(K2)," time " TER(K2)
2340 NEXT K2
2350 PRINT
2360 PRINT "set up new curve with improvement"
2370 LPRINT "new curves with improvement are as follows:"
2380 GOTO 480
2390 CLS
2400 SCREEN 1
2410 LINE (0,100)-(300,100)
2420 LINE (0,10)-(0,190)
2430 STOP
```

APPENDIX B - SUMMARY OF ACCIDENTS

Carrier - Varig
 Date - March 5, 1967
 Locality - Monrovia, Liberia
 Aircraft - DC 8
 Fire Type - Postcrash
 Event - Landed Short

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|--------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 71 | 10 | 9 | 90 |
| Fatalities | | | | |
| Impact | 6 | 0 | 0 | 6 |
| Fire | 44 | 1 | 0 | 45 |
| Non Fatal Injuries | 14 | | 2 | 16 |

Crash

The aircraft crashed during an attempted landing at Roberts International Airport. The flight was conducting a VOR/locator instrument let down and landing approach when on final approach it touched the ground in the middle of a small village approximately 6000 feet short of the runway threshold. The left wing struck a tree and there were two impacts with the ground. The cabin lights went out after the first impact. The aircraft lost its under-carriage, engines, and other components during a ground slide of approximately 850 feet and burned. This was a survivable accident.

Fire

The passenger seated in seat 18A saw the left wing strike a tree. He looked out the opposite window and saw fire between the engines on the right wing. Passengers reported small fires around the base of the seats and the aft galley (probably as a result of short circuits in the electrical wiring) occurred but quickly went out. One of the overwing emergency doors fell into the cabin. At this point in time, fire was noted outside on both sides of the aircraft. Fire was also reported coming in through the window in the vicinity of seat rows 17 and 18. The fire also entered the fuselage through the open emergency exit, almost completely dividing the cabin at row 15. The fuselage fire appears to have started in the area of the wing center section, progressing faster to the rear than to the front part of the fuselage. This was probably due to the fuel spilled behind the aircraft wing.

Evacuation/Survival Aspects

The accident occurred at night at 0156 zone time. Within the fuselage, reports are that the forward life raft compartment door opened and partially obstructed the forward left hand door. In addition, the contents of the forward galley were all over the floor, indicating that the galley doors opened.

Evacuation/Survival Aspects (cont.)

Survivors stated that passengers from row 13 forward escaped through the forward left hand passenger door. Of 17 passengers and 14 crew members in this section, 11 passengers and 11 crew members escaped through the front passenger door. Two other crew members escaped through the left side cockpit window.

In the aft end of the cabin, the forward life raft compartment door came open. The life raft fell and hit a cabin attendant in seat 28D. This stunned attendant was later pushed out of the aircraft by a passenger. The closet just forward of the right hand coat room broke loose and fell across the aisle. The crew folding seat adjacent to the left aft passenger door broke and dropped the two seated flight attendants to the floor, obstructing the access way to the door. Both cabin attendants suffered traumatic injuries and were rendered ineffective. The left aft passenger door could not be opened on the first attempt. The aft right passenger door could not be opened either. The left aft door was successfully opened on the second attempt and all survivors aft of coach seat, row 15 escaped through this exit. There were 54 passengers and 5 crew members in this section. All 5 crew members and only 10 passengers escaped through this left rear passenger door. The majority of the 44 passengers in the aft section rear of seat 13 who did not survive and did not receive antemortem fracture or traumatic injuries were capable of movement after the crash. The position of the bodies indicated that there was considerable movement toward the rear of the cabin in the direction of the rear door after the 10 passengers and 5 crew members had evacuated through the left rear passenger door.

The forward and aft right doors were never opened. The failure of the cabin lights after first impact rendered evacuation action more difficult.

One crew member who evacuated through the front left hand door ran 50 yards away from the front of the aircraft, returned, after hearing an explosion, and circled around the port wing to see if anyone was getting out the rear door. He stated that on reaching a point midway between the port outer engine and the wing tip he saw that the aircraft, rear of the leading edge of the wing, was circled with flames so he returned to further assist the passengers evacuating at the front left hand door.

Medical and Pathological

Most of the bodies were found severely burned in the aft section of the economy class cabin, lying in the debris with their heads in the direction of the rear of the aircraft, pyramided between the last three rows of seats. Post mortem examination of the bodies revealed a few cases of additional fractures that appeared to be ante-mortem, and the majority of the bodies showed evidence of carbon monoxide poisoning. The cause of death was carbon monoxide poisoning for the majority of the 51 persons who died in the accident.

References

1. ICAO Aircraft Accident Digest No. 17, Vol 11
2. Aircraft Accident Report, Liberia Civil Aviation Administration

AIRCRAFT ACCIDENT SUMMARY

Carrier - British Overseas Airways Corp.

Date- April 8, 1968

Locality - Heathrow, London, England

Aircraft - B 707

Fire Type - Postcrash

Event - Engine Fire

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|---------------|-------------------|-------------------|--------------------|--------------|
| On Board | 116 | 6 | 5 | 127 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 4 | 1 | 0 | 5 |
| Injuries | 38 | 0 | 0 | 38 |

Landing

Approximately one minute after takeoff from runway 28 left, the No. 2 engine failed and a few seconds later caught fire. The crew, having started an Engine Failure Drill had to change directly to an Engine Fire Drill. The fire did not go out. The aircraft was maneuvered for the quickest possible return. During the approach, the No. 2 engine fell away from the aircraft. The aircraft made a successful landing.

Fire

When the aircraft came to a stop, the fire, which had continued to burn near the No. 2 engine position, increased in intensity and the fuel tanks in the port wing exploded. The accident investigation established that the fire continued to burn because of an omission to close the fuel shutoff valve after the engine caught fire. After the aircraft came to rest, the captain ordered a fire drill on the remaining engines. Before this could be carried out, there was an explosion from the port wing which increased the intensity of the fire and blew fragments of the wing to the starboard side of the aircraft. The captain then ordered immediate evacuation of the flight deck. The engine fire shutoff handles were not pulled and the fuel booster pumps and main electrical supply were not switched off. There were more explosions and fuel, which was released from the port tanks, spread underneath the aircraft and greatly enlarged the area of the fire.

Evacuation/Survival Aspects

The cabin crew opened the emergency exits as the aircraft came to a stop and started rigging the escape chutes (this involved positioning a bar behind clips on the cabin floor). The passengers commenced evacuation from the two starboard overwing exits, and shortly afterwards, when the escape chutes had been inflated, from the rear starboard galley door and then the forward starboard galley door.

Evacuation/Survival Aspects (cont.)

However, because of the spread of the fire under the rear of the fuselage, the escape chute at the rear galley door soon burst and following the first explosion, the overwing escape route also became unusable.

The starboard overwing exits were the first utilized; 18 passengers escaped by these exits under the direction of the Chief Steward before he stopped their further use because of the smoke and flames which enveloped the starboard wing area following the main explosion. Nobody left the aircraft by the forward port overwing exit. The starboard rear galley door's chute was rigged, inflated, and found to be misaligned. One of the stewards climbed down to straighten it. Only five passengers and one steward escaped down this chute before the sparks and flames spreading from the port side burst it. Five passengers jumped through this doorway after the chute became unserviceable. The starboard forward galley door's escape chute was delayed in being put into operation, due to difficulty getting the chute retaining bar into its clips. After this initial delay, the main body of passengers evacuated the aircraft rapidly by this route. The evacuation tended to slow down as passengers, both injured and otherwise, began to collect round the bottom of the chute and in front of the starboard wing. The captain left the aircraft by this exit during a gap between the passengers disembarking. When it appeared that all the passengers had left the aircraft, the remaining cabin crew members also used this escape route. The port forward main door was also used. The chute did not inflate at first, after it was deployed, and the flight engineer climbed down and straightened it out at the bottom; it almost immediately caught fire and burst. One passenger escaped jumping from this doorway after the chute collapsed. Three flight crew members egressed through the cockpit windows.

The evacuation took place in an orderly manner, but when the rear galley door and starboard overwing exits became unusable, some momentary confusion resulted among those passengers who had to revise their escape routes. Conditions in the cabin were quite good in the early stages. But they deteriorated rapidly when the explosion occurred. As the evacuation progressed, dense black smoke advanced forward up the cabin from the rear as the fire took deeper and deeper hold. Smoke eventually reduced visibility to zero in the forward galley area. The captain stated it was of a consistency that made you feel that you could pick it up in handfuls and throw it out of the aircraft. He also stated it was completely overpowering. There was some difficulty in helping passengers at the rear of the aircraft, which was the first part of the fuselage to be overwhelmed by the fire. It was in this area that the stewardess was last seen alive attending to the passengers who ultimately succumbed.

The evacuation of passengers had been largely completed by the time the Airport Fire and Rescue Service began to provide assistance. The fire service prevented the fuel in the starboard tanks from catching fire but the rear fuselage and port wing were burned out.

Medical and Pathological

Four of the passengers and one stewardess were overcome by heat and smoke in the rear of the aircraft and did not escape. Thirty-eight passengers sustained injuries during the evacuation.

Comments

- . The escape chutes were very susceptible to heat and flames.
- . More fire-resistant chutes could have resulted in many more lives saved.
- . Rigging the escape chutes resulted in the loss of valuable escape time.

References

1. Civil Aircraft Accident Report, Boeing 707-465
G-ARWE at Heathrow Airport, London on April 8, 1968

AIRCRAFT ACCIDENT SUMMARY

Carrier - Capitol Int. Airways
 Date - November 27, 1970
 Locality - Anchorage, Alaska
 Aircraft DC 8
 Number Passenger Seats - 219 (full load)
 Fire Type - Postcrash
 Event - Aborted Takeoff

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|--------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 219 | 6 | 4 | 229 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 46 | 1 | 0 | 47 |
| Non Fatal Injuries | 43 | | 6 | 49 |

Crash

The aircraft failed to become airborne during the takeoff run and overran the end of the runway. It continued along the ground and struck a low wooden barrier, the instrument landing system structure, and a 12-foot-deep drainage ditch before stopping approximately 3400 feet beyond the end of the runway. One or two jolts were felt, followed by one extremely severe jolt which started the aircraft breakup before it came to rest. The fuselage broke into two major pieces: the tail section aft of the aft jetescape door and the rest of the fuselage with the left wing attached.

Fire

Fire broke out on both sides of the aircraft before it came to a stop. It was followed by several explosions.

Evacuation/Survival Aspects

One man released his seatbelt before the final jolt and was thrown approximately 6 rows forward. Passengers from forward of the galley reported that people were moving down the aisle before the aircraft came to a stop. One man stated that most of them were "thrown around pretty bad." Both overhead luggage racks came down on top of the passengers. Galley equipment came out all over the floor, rendering the forward galley service door unusable as an exit. The aft galley door was only partially opened by a passenger and the No. 1 stewardess because it opened against a small embarkment. Twenty-one people exited through this door or from that vicinity. Five of those people exited through a break in the immediate vicinity of this door. A stewardess opened the main entry door. The forward jetescape floor level exits were located at the ends of seat, row 9. There is no seat 9A or 9F in front of these exits. Military officers seated next to these exits in seats 9B, 9E opened them.

Evacuation/Survival Aspects (cont.)

Nineteen people exited the left exit and 22 exited the right exit. The forward overwing exits are at row 18. The aft overwing exits are at row 20. The men in seats 18A, 20A and 20F opened 3 of the 4 exit window hatches. The 18A exit was opened while the aircraft was still moving, and flames came in for a short while. Some passengers went forward to evacuate rather than attempt this exit. Thirteen people used this exit, six used the 20A exit, one used the 20F exit. Sixteen more passengers reported they used "an overwing exit" but did not specify which one. The overwing exit at seat 18F was reportedly jammed. Eleven passengers reported escaping through the break at the aft of the cabin, six more found themselves outside the aircraft in a clear spot between the two sections of the fuselage. Four of these ejected passengers were still in their respective seats 36E and F and 37C and D.

The aft portion of the aircraft at the break was separated about 30 feet from the rest of the fuselage. Seventeen reportedly went out through that break. Flight attendant No 1, stationed at the aft entry door, was unable to open her door. She crossed the aisle to the galley and, with passenger assistance, opened the exit which was against a small embankment. Only four people reported leaving by this route including the No. 4 flight attendant who was carried out by a passenger.

Gross amounts of raw fuel contaminated the entire area. One man from row 6 stated that when he was departing the aircraft, fuel had already covered the floor. "I recall it was deep enough to cover my shoe" he said. "Fuel was also pouring out at the torn section where I exited close to the ground." A man from row 10 who evacuated through the forward left jetescape door advised that the fuel was like a river at the end of the chute. A man in row 19 reported that when a window exit hatch in front of him was opened, flames shot in followed by some fuel or water, causing him to believe they had landed in water. A man from row 17 reported he was sprayed with fuel during his attempt to escape. All of these people had their clothes discarded because they were fuel soaked.

Many survivors were in the center and rear part of the aircraft at the time of the crash. The majority of these people were soaked with fuel. One survivor commented that it appeared the aircraft had hit water because at the time of impact, the aft section of the aircraft was flooded with what was later found to be JP-4. It is assumed that many of the victims inside the aircraft were also soaked with fuel prior to the explosion/fire.

Approximately 30 to 35 bodies were taken from the wreckage in the area of the wing center section with the majority just aft of the center section. At least two bodies were removed from the areas just aft of the cockpit bulkhead. Approximately three bodies were taken from the area halfway between the wing center section and the cockpit bulkhead. The rest of the victims taken from the crash scene were scattered between the large body concentration aft to the left rear exit. No victims were found connected to their seats. Large concentrations of bodies were found in overlapping positions.

Medical and Pathological

Autopsies were performed on 22 of the 46 fatalities. All but four bodies were viewed by a pathologist. The primary cause of death was fire, with evidence of inhalation of combustion product and/or searing of the larynx and trachea, in all cases examined. While the bodies were quite burned, he felt there was no real evidence of extremity fractures that would have prevented escape. Nineteen blood samples were sent to the FAA, Pharmacology - Biochemistry Laboratory in Oklahoma City:

| <u># Samples</u> | <u>% CO Saturation</u> |
|------------------|------------------------|
| 4 | Less than 20% |
| 4 | 20-30% |
| 4 | 30-40% |
| 3 | 40-50% |
| 2 | 50-60% |
| 2 | 60-70% |

Comment

- . Military Personnel and their dependents - Military Contract Flight
- . Fuselage broke into 2 pieces
- . 7 of 11 exits used
- . 41 escaped through breaks in aft end of cabin; 6 thrown outside aircraft
- . Fully loaded
- . Bodies soaked in fuel prior to explosion/fire
- . No time information

References

1. Aircraft Accident Report No. NTSB-AAR-72-12
2. LeRoy, C.H., NTSB Human Factors Group Chairman's Factual Report. No. 7012, Docket No. SA-423, Exhibit No. 6-A

AIRCRAFT ACCIDENT SUMMARY

Carrier - Trans Carribbean
Date - December 28, 1970
Locality - St. Thomas VI.
Aircraft - B 727
Number Passenger Seats - 134
Fire Type - Postcrash
Event - Landing, Runway Overrun

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|--------------------------|-------------------|--------------------|--------------|
| On Board | 48 (including 2 infants) | 7 | | 55 |
| Fatalities | | | | |
| Impact | 0 | 0 | | 0 |
| Fire | 2 | 0 | | 2 |
| Serious Injuries | 9 | 2 | | 11 |

Crash

Upon landing, the aircraft bounced three times, ran off the runway and came to rest about 300 feet past the runway.

Fire

A fire started in the left wing root area but did not intensify until 53 occupants had evacuated the aircraft. The aircraft was consumed by fire.

Evacuation/Survival Aspects

In the process of coming to a stop, the aircraft fuselage broke into three major sections: forward, center and aft. The aft section is the only section reported to have a major fire hazard (appreciable smoke or heat). The aft section contained 41 seats, and was occupied by 22 passengers and 2 flight attendants. Two of the three exits in this section were used in addition to the break in the fuselage.

The stewardess in 26D was delayed because a triple seat unit in front of her fell with its occupants backwards on her lap. She pushed them away and proceeded to the left galley exit door. She was unable to open it and then tried the right aft exit. She was unable to open this exit door because of the canted fuselage. However with the aid of several passengers, she opened the door and inflated the evacuation slide.

The other flight attendant got out of her seat and started forward down the aisle. There were many obstructions. People coming aft knocked her down and climbed over her. She shouted to the passengers to pull the door out, not inward. She started forward again crawling over seats, wiring and other obstructions. She then directed passengers in the aft break area to jump to the ground.

Evacuation/Survival Aspects (cont.)

The cabin started to fill with smoke and her eyes were burning. She recalled considerable smoke and heat in that area as the last passengers made their exit (4 or 5 children).

Twelve evacuees of the aft section escaped through the fuselage break, and ten used the slide out the main door. The two passenger fatalities were located in the aft section. They were father and child. The child was trapped between two seats in row 22.

Medical and Pathological

Both deaths were from severe burns and bone fractures, not gases. One fatality was trapped by debris between 2 seats.

Comment

- . 2 of 3 exits used and fuselage break in aft section
- . 41 seats in aft section occupied by 22 passengers and 2 flight attendants
- . Last passenger escaped within one minute
- . 2 deaths - neither due to gases

References

1. Aircraft Accident Report No. NTSB-AAR-72-8,
2. Walhout, Gerrit, J., NTSB Human Factors Group
Chairman's Factual Report of Investigation, Report No. 7013

AIRCRAFT ACCIDENT SUMMARY

Carrier - Allegheny Airlines
Date - June 7, 1971
Locality - New Haven, CT.
Aircraft - CV 580
Number Passenger Seats - 50
Fire Type - Postcrash
Event - Landed Short

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|------------------------|-------------------|--------------------|--------------|
| On Board | 28 Including 2 infants | 1 | 2 | 31 |
| Fatalities | | | | |
| Impact | 0 | 0 | 1 | 1 |
| Fire | 26 | 1 | 0 | 27 |
| Serious Injuries | 2 | 0 | 1 | 3 |

Crash

The CV 580 crashed while attempting an instrument approach to runway 2 at the Tweed-New Haven Airport. The aircraft struck three beach cottages and came to a rest approximately 270 feet beyond the cottages. The fuselage fractured circumferentially near fuselage station (FS) 790. The cockpit section of the fuselage was broken open and small parts of the cockpit interior were scattered around the immediate area of the cockpit.

Fire

An intense fire ensued immediately upon initial impact and continued to burn to the point of near total destruction of the upper portion of the fuselage and cabin area. The remaining interior was gutted and much of the floor was burned away. Witnesses reported that the entire fuselage began to burn when the aircraft impacted the ground.

Evacuation/Survival Aspects

One of the two surviving passengers sat on the right side with a window exit directly behind him. He quickly turned around, leaned over his seat back, removed the right forward overwing exit. A "wall of fire" immediately came into the cabin. It burned his hands and face. He jumped back and saw that the exit directly across the cabin was open. He went through it onto the left wing. He ran through the fire and jumped into some nearby "swamp" water. He stated that at one point during the crash sequence, he was thrown forward and his head impacted the seatback in front of him. He saw heavy smoke at both ends of the cabin but reported that his area was only slightly smoky. He heard a voice in the rear of the cabin yell "Everybody come to the rear."

Evacuation/Survival Aspect (cont.)

The female survivor was seated in row 4 left window seat by the exit during the crash sequence. The next thing she remembered was finding herself standing in the aisle. She recalled it was dark and that she could see only to the rear of the cabin to a distance of 3 or 4 rows of seats. She noted smoke and fire both to the rear and forward of her position in the aisle. She was very "conscious" of heat and flame. She recalls seeing 7 or 8 persons up and moving about in her field of view toward the rear. She also heard a voice call "try to get to the back." After moving a step or two to the rear, then forward, she saw a man go out a "door" and she quickly followed him. She moved across a burning area into a water-filled ditch where she sat and later moved away.

Several witnesses stated that when they first arrived at the burning aircraft, they heard voices of people within the aircraft.

Emergency exits were located as follows: four overwing exits located adjacent to rows 4 and 7 on each side of the cabin; two exits located adjacent to row 10, and an exit aft of row 13 on the left, equipped with a door mounted evacuation chute. The extent of fire damage precluded a determination if emergency exits were opened by the non-surviving passengers or stewardess, except in the case of the aft service door. The remains of that door were in place with the bottom latch hooks engaged.

The first officer was recovered by rescuers from a position on the ground about 20 feet in front of the nose section of the burning fuselage. The captain was observed in his seat in the nose section of the burning aircraft and was not reached by rescuers. Most bodies were found in the aft section of the fuselage: 11 passengers in the aft cabin, the stewardess in the aft lavatory, and 3 passengers in the aft cargo area. The other 12 bodies were scattered in the forward section of the cabin. A few of them were near the open left overwing exit.

Medical and Pathological

The three survivors sustained serious injuries. The first officer was in critical condition with severe burns, lung injury from smoke inhalation, and severe fractures of both legs. Both legs were subsequently amputated. Two passengers sustained burn injuries to their hands and face.

All fatalities were found within the confines of the burned aircraft. Carbon deposits were found in the pulmonary tree of all fatalities, except the captain. All victims demonstrated severe thermal injury. The captain's injuries also included a skull fracture and rib and collarbone fractures. The flight attendant suffered rib fractures and fracture of the left clavicle and vertebra. Toxicological studies were completed on 24 passengers. These passengers were found to have COHb saturations of 30 percent to 70 percent with an average 52 percent saturation. Sixteen passengers had measurable amounts of sodium cyanide with values ranging from 0.02 mg percent to 1.0 mg percent. The stewardess had COHb saturation of 70 percent and 0.3 milligram sodium cyanide/100 ml blood.

An autopsy was performed on all passengers. The immediate cause of death for each passenger was pulmonary edema and congestion, associated with smoke inhalation and extensive burn injuries.

Comment

. 1 of 7 passenger exits used

References

1. Aircraft Accident Report, Report No. NTSB-AAR-72-20
2. Fahrni, John H., NTSB Human Factors Group
Chairman's Factual Report No. 7105, Docket No. SA-427, Exhibit 6-A

AIRCRAFT ACCIDENT SUMMARY

Carrier - United Airlines

Date - December 8, 1972

Locality - Midway Airport, Chicago, Illinois

Aircraft - B 737

Number Passenger Seats - 20 seats first class and 67 seats coach class = 87

Fire Type - Postcrash

Event - Landing

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|--------------------------|-------------------|--------------------|--------------|
| On Board | 55 (including 2 infants) | 3 | 3 | 61 |
| Fatalities | | | | |
| Impact | 13 | 0 | 1 | 14 |
| Fire | 27 | 0 | 2 | 29 |
| Serious Injuries | 11 | 1 | 0 | 12 |

Crash

The aircraft was executing an ILS approach to runway 31L at Midway Airport when it crashed about 1.5 nautical miles southeast of the runway into a residential area. The tail section came into contact with electrical wires just before the crash. Several houses were destroyed. The fuselage stopped in the debris almost centered over a 3-foot-deep basement. The foundation extended about as high above ground. The aircraft nose and centerwing stub damaged about one-half of the near sides of each of the adjacent houses, leaving half of one to the left as high as the peak. The aircraft was destroyed by impact and subsequent fire.

Fire

Dense smoke was observed 5 seconds after contact with the wires; flames appeared 15 to 20 seconds after contact. One survivor sitting over the wing stated that within 5 to 10 seconds after impact, there was fire below or/and around the left wing, then some on the right side. Two survivors from row 8 reported seeing fire coming back from the nose outside the aircraft. One of them did not notice it until he reached the exit, which he thought could have been a break in the right side of the fuselage. A man in row 11 and lady in row 12 saw fire inside the aircraft a few feet ahead of their seats. With the preponderance of ignition sources and fuels available in the basement of the center house, and the chimney effect of the half-house remains on both sides, the fire was intensely hot and very concentrated. This is illustrated by the statement of a United Airlines employee who worked the fire hose near the No 2 engine that he did not feel the heat. Radiant heat from a fire of this magnitude in an open area would have been intense.

Five minutes after the accident, a witness just came on the scene. He stated the aircraft midsection was completely engulfed in fire at that time. Flames were about 10 feet high. Passenger estimates of fire fighters arrival at the accident range from within 3 minutes to within 5 minutes.

Evacuation/Survival Aspects

The final ground impact was described as an extremely hard jolt. Most describe the decelerative force as one which threw them forward against their seatbelts sufficiently hard to badly bruise and/or cut their lower abdomen and hips. Numerous loose objects were tossed about the cabin, e.g., ceiling panels, overhead hatracks, and hatrack contents. The stewardess in the jump seat in the forward cabin blacked out at impact. She found herself trapped in her seat, pinned at her right arm and both legs. Debris around her was at least waist deep. She felt fire around her on the back and right arm before being rescued by firemen. It took almost half an hour for the firemen to extract her. The liquor compartment and oven units came out of the aft buffet, which had been secured in preparation for landing.

When the aircraft came to rest, the normal cabin lighting had failed and it was very dark inside. No one saw emergency lights and the breaks in the right side of the fuselage did not get noticed until they were illuminated by the fire from outside the aircraft.

Only seconds after the aircraft came to rest, one stewardess from the coach section opened the aft entry door and closed it because smoke and flames were coming in. She had difficulty closing it due to blockage by the partially deployed door slide. The galley service door was opened soon thereafter into a scene of much burning debris and wood, a 3-4 foot drop was bridged with the inflated evacuation slide. Evacuation was started. Several survivors scrambled or crawled over the bent forward seatbacks to the aft galley service door exit. The majority of evacuations were initiated rapidly and were self-accomplished.

The plane was filling rapidly with thick, grey smoke, with visibility reduced to about 4 to 5 feet, as the stewardess assisted passengers who were trapped, or blocked by debris in the cabin, and directed them to the exit. She had to go back to the door for air before returning to the cabin. Passengers were still coming out, and when she returned again to the cabin, the smoke was so black and thick that she could see no one else. It billowed from the forward part of the aircraft to the galley. It was thick and very black and in her eyes, nose, etc. She described it as "thick and heavy---It seemed to have weight to it--If you inhaled it. it just wouldn't go down your throat."

Two men reportedly tried unsuccessfully to open the right overwing exit. The left overwing exit was opened and one man walked into an area surrounded by fire. Firefighters found the forward entry door partially open.

Survivors reported two sizeable breaks in the right side of the fuselage at the cabin partition (forward of row 6) and between seat rows 9 and 10. Each of these openings was used for egress by three survivors. Six survivors exited via the break in the fuselage, eleven exited via the rear exit door, and one survivor was removed from the wreckage. All passenger survivors were seated in rows 8-12 and 16-17. The only survivor in the fuselage section forward of the wing was the stewardess, rescued by firemen. Male survivors on the right side at rows 8, 10, and 11 had difficulty releasing their respective seatbelts because their seats, though intact, had come partially loose and were leaning forward, semisuspending the occupants by their seatbelts.

Medical and Pathological

The cause of death of first class passengers was attributed more to violent trauma than those of the coach passengers. No first class seats were removed intact. Twenty five had blood CO saturation levels exceeding 80 percent.

Comment

- . Stewardess extricated by fireman - Extraction took at least 30 minutes.
- . 1 passenger escaped through the left window exit into the fire. The body was recovered later.

References

1. Aircraft Accident Report No. NTSB-AAR-73-16
2. LeRoy, C. Hayden, Human Factors Group Chairman's Factual Report, Docket No. SA-435, Exhibit No. 6A and Attachment III (Medical) Of Human Factors Report

AIRCRAFT ACCIDENT SUMMARY

Carrier - North Central
Date - December 20, 1972
Locality - O'Hare Airport, Chicago, Ill.
Aircraft - DC 9
Number Passenger Seats - 100
Fire Type - Postcrash
Event - Collision with Convair CV-880 during takeoff

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 41 | 2 | 2 | 45 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 10 | 0 | 0 | 10 |
| Serious Injuries | 9 | 1 | 0 | 10 |

Crash

The North Central Airlines DC-9 was taking off on the runway under poor visibility (visibility 1/4 mile in fog) when he saw the Delta Airlines Convair CV-880 taxiing across the runway. Neither flight crew saw the other in time to avoid the collision. After colliding with the tail of the Delta Convair 880, the North Central DC-9 continued along the runway and came to a rest approximately 300 yards northwest of the intersection of runway 32L and 27L. Passengers described the collision as being a slight bump. The subsequent touch down of the aircraft and the crash slide were described as being comparable to normal landing. Deceleration forces were described as being very slight with some side-to-side motion. None of the passengers reported being propelled into the seat in front of them.

Fire

Shortly after impact, the DC-9 was engulfed in flames and was gutted by fire.

Evacuation/Survival Aspects

The accident occurred at night. The cabin lights went out as the aircraft came to a stop. The extreme darkness reportedly made the location of emergency exits very difficult.

After the aircraft came to a stop smoke began to enter the cabin almost immediately. Some passengers stated that initially there was some pushing and shoving, but generally there was very little panic. Passengers reported having to get lower and lower toward the floor in order to breathe. The smoke was very dense, according to survivor accounts.

Evacuation/Survival Aspects (cont.)

The forward stewardess jump seat failed to retreat against the bulkhead and hampered movement to the exit. Several passengers stated that they attempted to push the seat up but were unsuccessful. Most of the passengers indicated that their biggest obstacles in evacuating the aircraft were smoke and the lack of emergency lighting. Also the supervision of the evacuation by the flight and cabin crew members from a position outside the aircraft delayed egress of some of the passengers.

One stewardess was seated in the forward jump seat and the other stewardess was seated in seat 15B. After impact and during the slide, the rear stewardess opened the left overwing exit at row 12. After the aircraft had stopped, she then deplaned through the exit. The forward stewardess opened the entry door and did not deploy the slide. She stated she was then pushed out of the aircraft and she assisted passengers in deplaning through the door. She stated there were no obstructions in the aisle leading to the exit.

The DC-9 was evacuated through the forward entry door as well as both forward window exits. The forward entry door slide did not deploy, and the rear tail cone emergency exit was not used. Three of seven passenger emergency exits were used in the evacuation.

The first officer egressed through his cockpit window and assisted passengers off the aircraft through the forward entry door. The captain went back into the cabin and assisted passengers off the aircraft. Once he had deplaned, he again reentered the aircraft and helped more passengers off the aircraft.

Thirty two passengers and four crew members successfully evacuated the DC-9. One passenger succumbed 5 days later. Nine passengers did not evacuate. Four passengers followed the stewardess out through the left forward overwing exit, one passenger exited through the right forward overwing exit, and the rest of the survivors deplaned through the main entry door.

The nine passengers remaining were found in the following locations by firemen.

- . One male passenger in the tail cone aft of the pressure bulkhead.
- . One male passenger in the rear rest room
- . One female passenger in the cockpit
- . One male passenger halfway in the cockpit
- . Five female passengers (including one invalid) along the left side of the cabin area (seated).

The four passengers who left their seats apparently attempted to find an exit but were unable to do so under the conditions that existed.

The first fire trucks were reported at the DC-9 accident scene within 2 minutes. At the time of arrival of the first fire vehicle, all survivors were out of the aircraft and had moved away from the wreckage.

Medical and Pathological

All of the fatally injured died of smoke inhalation and burns. None of the fatally injured passengers received any traumatic injury. COHb levels for the nine deceased passengers (recovered from the plane) ranged from 26.4% saturation to 63.7% saturation. Cyanide levels ranged from 1.1 g/ml to 2.7 g/ml.

Comment

3 of 7 passenger exits used
Nighttime accident with "poor" emergency lighting
4 passengers "lost" in the darkness

References

1. Aircraft Accident Report No. NTSB-AAR-73-15
2. Burgin, Robert E., NTSB Human Factors Group Chairman's Factual Report of Investigation, Report No. 7211
3. Laceyfield, Delbert J, P.H.D., Aviation Toxicology Laboratory, AAC-114, Toxicology Report on Chicago, Ill, 20 Dec 1972 Aircraft Accident, Case No. 946

AIRCRAFT ACCIDENT SUMMARY

Carrier - Varig Co.
 Date - July 11, 1973
 Locality - Orly Airport, France
 Aircraft - Boeing 707
 Number Passenger Seats - 132
 Fire Type - Inflight

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|--------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 117 | 9 | 8 | 134 |
| Fatalities | | | | |
| Impact | 0 | 1 | 0 | 1 |
| Fire | 116 | 5 | 1 | 122 |
| Non Fatal Injuries | 1 | | 10 | 11 |

Fire

The probable cause is a fire which appears to have broken out in sink unit of the rear starboard lavatory. The fire was detected when the smoke penetrated into the lavatory area.

A few minutes after the plane stopped, there were flames under the fuselage, fully behind the port side, enveloping the skin on the outside. There were no flames on the top. The plane was destroyed by fire on the ground.

Evacuation/Survival Aspects

About 7 minutes passed from the discovery of the fire to landing. The smoke was first white, then black. Black smoke appeared on the cabin ceiling almost simultaneously in the tourist and first class cabins. It advanced horizontally and towards the floor. A crew member with a mask entered the tourist cabin (zero visibility). He saw 3 flashes occurring in the back of the plane. The blast threw him to the floor. He returned to the front. When he entered the cockpit, smoke could be seen in the cockpit for the first time.

An emergency descent was made. The crew put on masks and goggles. Smoke rapidly became thicker in the cockpit. About 3 minutes after the first report of fire, smoke filled the cockpit. The pilots opened the side windows when it became difficult to see the instrument panels. The pilots landed the plane using VFR with their heads out the window. The forced landing was fully successful. Only the second mechanic was fatally injured when the plane crashed, since he was standing unsupported and unharnessed (high COHb levels).

While the aircraft was descending, a stewardess reported the passenger cabin was half filled with smoke and passengers were collapsing. The captain ordered an overwing emergency exit removed. A stewardess with a full oxygen face mask tried unsuccessfully to comply with the order.

Evacuation/Survival Aspects (cont.)

The front doors opened immediately after the airplane came to a stop. Even though the doors and exits were not blocked, only the occupants of the cockpit and two members of the cabin personnel were able to escape from the plane by their own means. All exits remained completely utilizable. One of the surviving cabin personnel was wearing a full face mask with a portable oxygen bottle. The others used a wet towel over the nose and mouth. In the cabin, no exit had been opened. Two crew members familiar with the layout of the plane, who were near the doors used by the other crew members, were unable to escape. The Board of Inquiry's report states that it is quite probable that the occupants of the cabin were unconscious at the time of the crash. The report continues to say that it is likely that most victims died only after the plane came to a halt. Three unconscious passengers were rescued by firemen about 10 minutes after the aircraft came to a stop. Two of them were revived. Only one survived. No passenger escaped unaided.

Of the nine persons in the cockpit, 5 had oxygen masks. Opening the side cockpit windows caused turbulence, beneficial to those who had no mask.

Medical and Pathological

Out of 120 bodies examined, 78 percent showed a carbon monoxide poisoning coefficient equal to or over 66 percent; Death was reported by the Board of Inquiry to be a result of carbon monoxide poisoning. Nine percent had a coefficient ranging between 0.50 and 0.60; The probable but not definite cause of death was CO poisoning. For the 13 percent whose coefficient of poisoning was lower than 0.50, carbon monoxide cannot be attributed as the cause of death.

There was one death due to impact. The second mechanic was not wearing his seatbelt. The COHb analysis performed on the mechanic (37% coefficient of poisoning) killed by the shock of impact, makes it possible to affirm that at that time, carbon monoxide poisoning of the occupants was sufficient to prevent them from acting. The passengers were found in their seats. They died while seated.

Comment

- . No passengers and 10 crewmen escaped unaided
- . 2 of 3 passengers carried off by firemen were revived. Only one of them survived
- . Death primarily due to CO
- . Exits used-

| | |
|---------------------------|---|
| Right cockpit window | 4 |
| Left cockpit window | 4 |
| Left front passenger door | 1 |
| Right front galley door | 1 |

References

1. Board of Inquiry Final Report, December 1975
2. ICAO Aircraft Accident Digest No. 21, Accident #7
3. CAA World Airline Accident Summary

AIRCRAFT ACCIDENT SUMMARY

Carrier - Pan American World Airways
Date - January 30, 1974
Locality - Pago Pago, American Samoa
Aircraft - Boeing 707
Number Passenger Seats - 146
Fire Type - Postcrash
Event - Landed Short

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|--------------------------|-------------------|--------------------|--------------|
| On Board | 91 Including 12 children | 6 | 4 | 101 |
| Fatalities | | | | |
| Impact | 0 | 0 | 1 | 1 |
| Fire | 86 | 6 | 3 | 95 |
| Serious Injuries | 5* | 0 | 0 | 5 |

*Includes 1 passenger who died 9 days after the accident.

Crash

The aircraft crashed 3865 feet short of runway 5 at Pago Pago International Airport. The National Transportation Safety Board determined that the cause of the accident was the flight crew's late recognition and failure to correct an excessive descent rate due to destabilizing wind changes. The fuselage was totally intact except for the right forward section of the cockpit. There was evidence of extensive damage to the cargo section of the aircraft during the crash sequence. The survivors described the impact as relatively light with no interior damage observed after the aircraft came to a stop.

Fire

Witnesses at the crash site indicated the fire was intense, and was mainly concentrated on the right side of the cabin section of the aircraft. The tail section was relatively free of external fire damage. The fire consumed the right side of the fuselage completely as well as the top and interior of the cabin and cargo areas. The wings were severely damaged by fire.

Evacuation/Survival Aspects

After the aircraft came to a complete stop, the situation inside the cabin was described as being one of panic with most people rushing to either the forward or aft sections of the cabin, leaving the center wing area of the cabin relatively free of people. Large fires were seen outside the right side of the aircraft. There was no fire seen in the cabin. One person opened an overwing exit on the right side of the aircraft: Flames came in through the exit and he closed it. Other survivors opened the left overwing exits. All the survivors except the third officer escaped through the left overwing exits. The wing was described as very hot. Several survivors fell into flaming fuel at the trailing edge of the wing. The third officer was assisted in his escape by two other crew members and left the aircraft through a hole in the cockpit wall.

Evacuation/Survival Aspects (cont.)

The surviving passengers were all seated near the middle of the aircraft and did not hear instructions given by the flight attendants after the crash. It is possible that the flight attendants were overcome by smoke or that they tried to open the exits and did not redirect passengers to alternate exits. It is also possible that the passengers crowded around doors and for that reason the flight attendants were unable to open the exits.

It is unlikely that all the passengers could have escaped from the aircraft through the left overwing exits. However it is possible that there would have been more survivors had the passengers acted according to preflight direction and proceeded to the nearest exit, instead of moving toward the main exits through which they had originally entered.

An examination of the passenger seat frames revealed no failures. Both the forward and rear entry doors were found in jammed positions. The forward entry door was found partially opened and the rear entry door was found still closed. The forward galley service door was not found in the wreckage, and the rear galley service door was found in the locked position.

Initially nine passengers and one flight crew member successfully evacuated the aircraft after impact. Four of the passengers died in the hospital before they could be interviewed. The interviewed survivors indicated that a heavy rain was falling on the crash site after they extracted themselves from the aircraft.

Only one fatally injured passenger was found outside the aircraft. Many bodies were found grouped near the front and rear exits of the passenger cabin. Several of the fatally injured passengers were found still belted in their seats throughout the cabin. Two cabin attendants bodies were found in the aisle area forward of the aft main entry door in a forward facing position. Only one body was found in the cockpit area. Ninety one bodies were recovered from inside the fuselage. One was recovered from outside.

Medical and Pathological

Only one occupant, the third officer, received any traumatic injuries in the crash. Autopsies were performed on all of the fatally injured occupants and all were determined to have succumbed to smoke inhalation and massive third degree burns. Out of 49 blood samples, 14 had COHb levels less than 20 percent, 16 had COHb levels from 20 to 29 percent, ten had COHb levels from 30 to 39 percent, six had COHb 40 to 49 percent and two had COHb levels from 50 to 69 percent. The surviving passengers received first, second, and third degree burns to the face, arms, legs, back, and chest. Two of the survivors had only face and hand burns.

Toxicological examinations of the casualties revealed in each case, significant levels of carbon monoxide and hydrogen cyanide.

Comment

. 2 of 8 passenger exits used - Two left overwing exits.

References

1. Aircraft Accident Report No. NTSB-AAR-77-7
2. Burgin, Robert E., Human Factors & Witness Group Chairmans Factual Report No. 7403, Docket No. SA-444, Exhibit No. 6A

AIRCRAFT ACCIDENT SUMMARY

Carrier - Overseas National Airways
Date - November 12, 1975
Locality - Jamaica, New York
Aircraft - DC-10-30
Number Passenger Seats - 380
Fire Type - Engine Fire
Event - Impact Seagulls, aborted takeoff

| <u>Number</u> | <u>Passenger</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|------------------|-------------------|--------------------|--------------|
| On Board | 128 | 8 | 3 | 139 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 0 | 0 | 0 | 0 |
| Serious Injuries | 0 | 0 | 2 | 2 |

Crash

While attempting a takeoff from runway 13R at the John F. Kennedy International Airport, Jamaica, NY, ONA flight 1032 collided with a flock of birds, experienced a fire in the number three engine and executed a high speed abort. During the aborted takeoff, the number three engine came apart and the ensuing fire engulfed the right wing of the aircraft. The aircraft came to rest at the departure end of runway 13R.

Fire

The passengers reported they heard a loud pop or bang during the takeoff roll. Most passengers thought the aircraft had blown a tire. Passengers saw fire and an orange glow around the right wing. Windows in the right overwing and right aft cabin areas began melting and cracking during the aircraft deceleration. Several passengers seated near these windows moved to the center of the passenger cabin while the aircraft was still moving.

The first fire vehicles were reportedly on the accident scene within 1 minute after the aircraft came to a stop. As the fire vehicles arrived, they observed that fire covered the right wing surface and all ground area on the right side of the fuselage front and rear of wing plus fire on ground near left rear. These fires were extinguished almost immediately (30 seconds) after the units arrived. Fire in the interior of the fuselage was noticed but could not be extinguished at that time. Approximately 5 minutes after outside fires were put out, the fire inside the aircraft broke through the top of the fuselage causing it to collapse and the front section of the aircraft rolled to the right. Venting caused by the rupture of the fuselage intensified that fire area; however, it did provide access for the firemen to apply extinguishing agent. At this point the fire was considered to be under control and practically extinguished.

Evacuation/Survival Aspects

The passenger compartment was a single class arrangement divided into three cabin sections. The forward section contained 92 passenger seats; 2 lavatories located in the front of the cabin; and 2 type 1 passenger entry doors, one on

each side of the cabin. The second section contained 123 passenger seats; a galley buffet serving section located in the forward part of the section; and 2 type A passenger entry doors, one on each side of the galley buffet. The third cabin contained 165 passenger seats; two type A overwing emergency exits, located in the front of this section; and 2 type A passenger entry doors, located in the rear of this section.

Smoke entered the cabin before the aircraft came to a complete stop. Once the aircraft came to a stop, the center cabin became dark because the fire sooted the windows; however, the cabin was not dark enough to hamper evacuation from the aircraft. Once the aircraft stopped, exits 1L and 4L were opened by the assigned flight attendants. Exits 1R, 2L, 3L and 4R were opened by passengers. When exits 1L, 2L and 3L were opened, smoke and fire entered the cabin. None of the passengers exited through the 2L and 3L exits; however, all were redirected from these exits to other usable exits. The only usable passenger exits were 1R, 4R and 4L. However, one passenger climbed down the slide at exit 1L. Passengers agreed that the emergency evacuation slides at exits 1R, 4R and 4L were not fully inflated. Doors 2R and 3R were never opened.

The passenger cabin atmosphere during the evacuation was described as hurried but calm. Everyone knew what had to be done and they did it.

One of the fiberglass ceiling access panels, in the rear of the passenger cabin, partially blocked the aisle on the left side of the cabin and also partially blocked access to the 4L exit. Evacuation commands were not made; no one indicated a need for them. Fuel was pooled around the 4R slide; one passenger fell face down in the fuel. The last passenger out of the aircraft indicated he made a quick check of the cabin before deplaning. When he deplaned, he indicated that fire and smoke were entering the cabin in great amounts.

All 128 passengers and 11 crew members evacuated the aircraft within approximately 1 minute. All passengers were employees of Overseas National Airways. All passengers had received varying degrees of emergency training or familiarization on the aircraft except for one of the scheduling personnel.

Most passengers interviewed indicated that evacuating 380 passengers in this situation would have been impossible. The last usable exit was 1R, one passenger indicated that the fire equipment arrived as the last person was exiting the aircraft.

Many police and firemen and some passengers had suffered extreme smoke inhalation.

References

1. Aircraft Accident Report No. NTSB-AAR-76-19
2. Burgin, Robert E., NTSB Human Factors Group Chairman's Factual Report of Investigation, Report No. 7512

AIRCRAFT ACCIDENT SUMMARY

Carrier - American Airlines
Date - April 27, 1976
Locality - St Thomas, Virgin Islands
Aircraft - B 727
Number Passenger Seats - 91
Fire Type - Postcrash
Event - Landing, Overran Runway

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 81 | 4 | 3 | 88 |
| Fatalities | 35 | 2 | 0 | 37 |
| Impact | | | | |
| Fire | HIGH TRAUMA LEVEL | | | |
| Serious Injuries | 17 | 2 | 0 | 19 |

Crash

The aircraft overran the runway after landing. It struck an ILS antenna, crashed through a chain link fence and came to rest against a building. The final impact was felt on the right side of the center section. One unbelted passenger was projected five rows forward from her seat, over the heads of other passengers, one other unbelted passenger was thrown forward.

Fire

Fire erupted immediately after the right wing struck the embankment. The fire spread rapidly through the center section and right wing areas of the aircraft, isolating the separated tail section from the remainder of the cabin area. The cabin area, the inboard sections of both wings, and the interior of the cockpit were eventually destroyed by fire.

Evacuation/Survival Aspects

This accident was partially survivable. The cabin broke into three parts during the impact. Black acrid smoke and intense fire penetrated the forward and center sections of the broken fuselage as the aircraft slid to a stop. The passengers and flight attendants who survived the accident escaped through breaks in the fuselage or through the overwing emergency exits on the left side of the fuselage within an estimated 1 to 1 1/2 minutes after the aircraft came to a stop. The three flight crew members escaped through the first officer's sliding window. The mass attempt to exit from the aircraft was hampered by the funnel effect on approach to the emergency exit windows.

Several passenger seats broke loose from their mounts. Some were found outside of the immediate fuselage area.

Evacuation/Survival Aspects (cont.)

The forward entry door was unopened. The aft door was damaged and could in no way be opened. The cockpit cabin door was jammed.

The majority of the deceased were recovered from the aft portion of the wreckage (21 of 37 bodies). Nine passengers and one flight attendant seated in the first class cabin, and 26 passengers and 1 flight attendant seated in the coach cabin, died in the aircraft crash. One of the deceased, a 34 year old male seated in 7A, was ejected from the aircraft still affixed to his seat. He died of skull fractures and internal hemorrhaging. Four deceased persons had less than 20 percent of the body surface involved with third-degree burns. The rest had more severe burn injuries.

Medical and Pathological

- . Post mortem examination of the 35 passengers and 2 crew members revealed that they died of a combination of impact trauma, smoke inhalation, and third-degree burns.
- . Six of the fatalities had carbon monoxide saturation of less than 20 percent. Nine had levels ranging from 20 to 29 percent. Seven had levels from 30 to 39 percent. Some levels ranging from 40 to a high of 56 percent.

References

1. Aircraft Accident Report No. NTSB-AAR-77-1
2. Rumsch, B.J., M.D., " Medical Examiner Report of a Boeing 727-95 Aircraft Accident," Journal of Forensic Sciences, Vol 22, No. 4, Oct 1977

This accident is an example of an accident with a high trauma level. It is not included in this study and cannot be found in table 2.

AIRCRAFT ACCIDENT SUMMARY

Carrier - Pan Am
Date - March 27, 1977
Locality - Tenerife, Spain
Aircraft - B 747
Number Passenger Seats - 390
Fire Type - Postcrash
Event - Takeoff, Collision with Other Aircraft

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Others</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|---------------|--------------|
| On Board | 378 | | 16 | 2** | 396 |
| Fatalities | 326* | | 9 | 0 | 335 |
| Impact | | | | | 143 |
| Fire | | Est. 190 | 2 | | 192 |
| Serious Injuries | 30 | | | | 30+ |

* 9 passengers who subsequently died are listed as fatalities.

** Company employees, sitting on the cockpit jumpseats, who had boarded the plane in Tenerife

Crash

A KLM 747 just airborne skidded over the PAN AM 747 aft fuselage while it was taxiing. The first-class lounge disappeared as a result of the impact as well as nearly the whole top of the fuselage. The lounge floor gave way. At the center and aft of the plane the accumulation of wreckage and twisting of metal sheets of the fuselage formed a trap, preventing forward exit of the passengers.

Fire

After the aircraft came to a stop, the left engines were still running and there was fire under the left wing.

Evacuation/Survival Aspects

None of those in the first-class lounge survived. According to the survivors, the shock of impact was not excessively violent, leading them to believe that the cause was an explosion.

Escape routes used were door L2 and openings in the left side. The left engines were still turning and there was a fire under the wing at this side. A large number of passengers escaped off the left wing, jumping from it to the grass. Explosions were already taking place.

Total evacuation time is estimated to be about 1 minute.

References

1. Joint Report K.L.M. - P.A.A. 12.7.1978 Collision Aeronaves, Boeing 747 PH -BUF DE K.L.M. Y BOEING 747 N 737 PA de PANAM en Los Rodeos (Tenerife) El 27 De Marzo De 1977
2. ICAO Aircraft Accident Digest No. 23, No. 2

AIRCRAFT ACCIDENT SUMMARY

Carrier - Continental Airways
Date - March 1, 1978
Locality - Los Angeles, California
Aircraft - DC-10
Number Passenger Seats - 258
Fire Type - Postcrash
Event - Aborted Takeoff, Ruptured Fuel Tanks

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 186 | 11 | 3 | 200 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 2 | 0 | 0 | 2 |
| Serious Injuries | 28 | 1 | 0 | 29 |

Crash

An aborted takeoff was initiated when multiple tire failure occurred on the left main gear at an airspeed of about 152 KIAS. The aircraft overran the departure end of the runway and came to rest about 650 feet past the end of the runway. When the aircraft departed the runway, the left main gear failed, causing the left wing fuel tank to rupture.

Fire

Fire was observed immediately as the aircraft came to rest. The CFR crew men saw the aircraft overrun the runway and catch on fire. As they approached the aircraft, fire was observed engulfing the left wing root and they could see passengers evacuating from the right side of the DC-10. The estimated response time for the first CFR vehicle was 1 - 1 1/2 minutes. They directed the turret at those passengers who were on fire, immediately extinguishing the fire. Approximately 4 minutes elapsed between the initial alarm and the arrival of CB-2 and CB-3. Once the complete fire fighting effort began, the fire was extinguished within 2 minutes. The safety board believes that the quick response of the Los Angeles Fire Department prevented greater loss of life and lessened injuries to evacuees.

Evacuation/Survival Aspects

All cabin doors and both cockpit windows were opened during the evacuation. The 1L slide was found on the ground still packed. All other left side slides had deployed and had been burned. No one exited on the left side of the aircraft because the left wing area was engulfed in fire. All the right cabin door slides were deployed and used. All these slides failed or burned before the evacuation was completed. About 110 passengers and crew members evacuated before the usable slide/rafts on the right side failed. The remainder evacuated mostly by jumping to the ground from the exits or trailing edge of the wing. The last group of people to exit the aircraft used the escape rope at the first officer's position. The evacuation was complete in about 5 minutes. The fire was extinguished at 6 minutes.

The inflight supervisor was directing passengers toward the 4R exit. When the passenger flow slowed, he observed that the 4R slide had failed (it detached and lay on the ground). From his vantage point, he could see that there was no one at 3R or 2R but that there was a crowd of passengers at 1R. He went forward across the top of the seats to a point in the cabin that was forward of the passengers who were lined up to use 4R.

At this point he yelled "Turn around, hold hands, and come this way." As he led the passengers forward, a cloud of thick heavy smoke entered the cabin through 3K, he said he could not see anything but he told the people "Don't let go, don't stop, follow me, I know where I am going." He led the passengers to 1R and turned them over to the first flight attendant. He then went through the cabin searching for passengers. After determining that the mid and aft cabins were clear of passengers, he went to the 4R exit, grabbed the door sill, hung down and let go. He said he fell into a foot or more of kerosene. The slide/raft at 1R was one of the first to be deployed and remained in use longer than the other three.

Passenger statements and testimony given at the public hearing indicated that there was some smoke but no fire inside the cabin during the evacuation.

A woman and her husband were fatally injured. The aircraft's captain, while assisting with the evacuation at the top of the 1R slide, observed the husband on the ground attempting to get up while the fire was quickly approaching and surrounded the area. No information on how his wife joined her husband in this area was developed.

All injuries were received during the evacuation sequence and not during aircraft deceleration.

The only seats sustaining thermal damage were 18A, 18B, 24A, and 24B, and the flight attendant's seat at 3L. This damage was probably caused by radiant heat entering the cabin through the 3L exit and through the cabin windows when they melted. Most of the windows between 3L and 4L were melted and burned. Little or no evidence of fire penetration was noted at these open windows. There was no smoke damage inside the cabin. The fire did not penetrate the insulation or side wall panels. The only exception was in the area near rows 24 and 25 where flight fire damage was noted at the floor and side wall junction.

Comment

- Average age of passengers was 60.
- Average age was 50 years for those sustaining minor injuries and 69 years for those sustaining serious injuries.
- 2 passengers who expired outside plane were surrounded by spreading fire.

References

1. Aircraft Accident Report No. NTSB-AAR-79-1
2. Braden, Cale, Human Factors Group Chairman's Factual Report of Investigation, NTSB No. 7804, Docket No. SA-461 Exhibit No. 6-A

AIRCRAFT ACCIDENT SUMMARY

Carrier - Swissair
 Date - October 7, 1979
 Locality - Athens, Greece
 Aircraft - DC-8-62
 Fire Type - Postcrash
 Event - Landing, Overran Runway

| <u>Number</u> | <u>Passenger</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|------------------|-------------------|--------------------|--------------|
| On Board | 144 | 7 | 3 | 154 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 14 | 0 | 0 | 14 |
| Serious Injuries | 0 | 0 | 0 | 0 |

Crash

After a late and fast touch down, and after improper use of braking systems, the DC-8 overshot the runway and the overrun area at about 20-25 knots, fell down a slope of 4 meters and caught fire. The first impact occurred most likely with the nose wheel within reach of the bitumen road. The second impact must have occurred with the afterbody/tail on the end of the overrun area approximately the same time the nose wheel was bent backwards due to the terrain which rises by about 0.5 m. The left wing was broken in front of the No.1 engine. The fuselage was broken in front of the vertical stabilizer. The main landing gear was torn off the wing structure. The aircraft was destroyed by impact and fire.

Fire

As soon as the aircraft overshot the runway and immobilized outside the airport's boundary, fire broke out at the right main part of the fuselage. The impact forced the right main landing gear to bend backwards by approximately 180° and tore open the fuel tanks of the right wing. Fuel from these tanks started to flow and the fire was extended not only to the aircraft, but to the road at the right side of the aircraft. The fire fighting service was in action in approximately 3 minutes, before the last person had left the aircraft through the left front exit.

As soon as the aircraft came to rest, the crew opened the left front and rear doors. The front door opened normally, and the slide worked quickly. The left door had some difficulty in opening, probably because of deformation, and it was opened with some delay. The slide did not deploy.

According to crew and passenger statements, approximately 120-130 passengers left the aircraft through the left front exit. The exit doors and emergency exits at the right side of the aircraft weren't used at all. Overwing exits at the left side weren't used as well because according to the flight attendants' statements fire was on the left side too. The delay in opening the rear door resulted in passengers moving back and forth. The rear of the cabin had more smoke than the front part due to the lack of draft.

The passengers were finally directed to the front door. The front slide failed after it had been used by 40-50 passengers and the passengers were then jumping from a height of 1.70 meter. Eleven passengers sustained minor injuries due not only to the height but also to the fact that they were jumping on each other. The evacuation lasted approximately 3 1/2 to 4 1/2 minutes. The co-pilot reentered the aircraft after the last passenger was out to search for passengers. He couldn't see anything because of smoke.

According to witness statement as well as the Swissair boarding cards, the 14 dead persons were seated at the rear part of the aircraft between the 21st and 26th row. It seems that these passengers hadn't tried to leave the aircraft, considering the evacuation had been completed from the rear door, as stated by the flight attendant. Five of the dead were seated in row 25. Many passengers walked through that area and no one had reported any difficulties in passing through.

Medical and Pathological

Fourteen fatalities were found sitting in rear rows 21-26. The forensic medical post-mortem reports testify that the death of 14 passengers was caused by burns of third degree on the whole body.

References

1. Swiss Aircraft Accident Report. Nr. 1979/A1 (English copy on CAA Occurrence File 79/04116C) 922

AIRCRAFT ACCIDENT SUMMARY

Carrier - Saudi Air
Date - August 19, 1980
Locality - Riyadh, Saudi Arabia
Aircraft - Lockheed L-1011
Number Passenger Seats - Fully Loaded
Fire Type - (Inflight) Cargo Compartment Fire

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|---------------------------|-------------------|--------------------|--------------|
| On Board | 287 (including 2 infants) | 11 | 3 | 301 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 287 | 11 | 3 | 301 |
| Serious Injuries | 0 | 0 | 0 | 0 |

Fire

A fire developed in the C3 cargo compartment inflight. Nineteen minutes after the flight engineer notified the captain of fire on board, the aircraft came to a stop on the runway. After it stopped on the taxiway, a witness observed a fire through the windows on the left side of the taxiway between the L3 and L4 doors. This witness said there was no fire outside the aircraft at this time. Three minutes 15 seconds after the aircraft stopped the engines were shut down. Smoke rose from the top of the fuselage, followed almost immediately by flames. The burn through the cabin floor structure was localized beneath the 2nd through 6th row of dual seat units forward of L4.

Evacuation/Survival Aspects

Seventeen minutes before the aircraft came to a stop, the flight engineer stated that everyone was panicking in back; 13 minutes before stopping, a cabin attendant reported he could not go to the back aft of L2 and R2 because people were fighting in the aisles. Eleven minutes before stopping the CVR recorded an announcement by the cabin crew to stay calm and to stay seated. Ten minutes before stopping a cabin attendant came forward and advised the crew that "there is too much smoke in the back." The cabin attendant repeated instructions to the passengers to stay in their seats to prepare for landing. Two minutes after landing, the aircraft came to a stop on the taxiway. After the aircraft stopped on the taxiway, a witness parked his car just behind and to the right of the aircraft. He observed a fire through the windows on the left side of the cabin between the L3 and L4 doors. He said there was no fire outside the aircraft at this time. He could not see any fire in the cockpit or cabin.

Immediately after stopping, an announcement was made to the tower "We are shutting down the engines and are now evacuating."

Evacuation/Survival Aspects (cont.)

One and a half minutes after stopping the tower told FLT SV 163 they have a fire in the tail. FLT 163 responded "Affirmative, we are trying to evacuate now." This was the last transmission received from the aircraft. Three minutes fifteen seconds after the aircraft came to a stop, the engines were shut down.

The witness that parked his car behind the aircraft said that just as the engines were shut down, there was a big puff of white and black smoke emitted from the aircraft belly, just forward of the wings. Firefighting personnel observed within a minute of engine shut down, smoke rising from the top of the fuselage just forward of the No. 2 engine intake. The smoke was followed almost immediately by flames.

The crash fire rescue personnel did not succeed in opening a door until 26 minutes after the plane came to a stop (R2 door). Three minutes after R2 was opened, flames were seen progressing forward from the rear section of the cabin. The bodies were found bunched up around unopened exits. The flight crew were found still at their duty stations (seated). The evacuation procedure was not started. The captain, by allowing the engines to continue to operate after he stopped the aircraft, effectively prevented the cabin crew from initiating the evacuation on their own.

The environmental control system packs were shut down before the engines were shut down, resulting in loss of any ventilation air introduced within the fuselage.

Medical and Pathological

Post mortem examinations and toxicological findings revealed that the deaths in this accident were due to the inhalation of toxic gases and/or exposure to the effect of the fire, heat, and lack of oxygen. Heavy soot deposits were found in the trachea in the majority of cases examined. Blood COHb was in the range of 42 to 58 percent in all cases examined. The bodies were found bunched up around unopened exits. Some bodies had no burns, while others were severely charred. The captain and first officer were found in their seats and had sustained charring burns.

Comments

Full load
All died-toxic gases or hypoxia

References

1. Aircraft Accident Report- President of Civil Aviation, Jeddah, Saudi Arabia

AIRCRAFT ACCIDENT SUMMARY

Carrier - Korean Airlines
Date - November 19, 1980
Locality - Kempo Airport, Seoul Korea
Aircraft - 747
Number Passenger Seats - 380-400
Fire Type - Postcrash
Event - Landed Short

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 208 | 15 | 3 | 226 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 9 | 3 | 3 | 15 |
| Serious Injuries | 4 | 0 | 0 | 4 |

Crash

The 747 landed short of the runway. The main landing gear was pushed backward and up causing a rupture in the bottom of the plane into the cargo compartment where struts were ruptured. The plane slid down the runway on its nose gear belly. The wings were intact. No fuel tanks were ruptured.

Fire

Fire erupted in the cargo compartment area from sparks and hydrolic fluid from the ruptured struts. There was no external fuel fire. The fire erupted in the cargo compartment area just after stopping. There was no fire from jet fuel. The plane quickly filled with smoke. The fire entered and impinged on the seats from floor grills. Fire gutted the fuselage quickly.

Evacuation/Survival Aspects

Evacuation was fairly orderly. There were some injuries getting off the plane. The smoke got heavy fairly rapidly. Some survivors suffered smoke inhalation.

Three fatalities found in the cockpit were members of the flight crew. The flight crew may possibly have committed suicide. Three of the other fatalities were flight attendants. The indications were that flight attendants were attempting to help passengers egress. The bodies of two flight attendants were found with the body of a very large man, reportedly drunk, alongside the collapsed circular stairway. Other bodies were scattered throughout the fuselage. The upper lounge fell during the fire sequence.

An observer with a camera reported that within 5 minutes the total cabin was ablaze. He took sequential pictures of the evacuation.

At least 8 of the 10 evacuation doors were opened.

Medical and Pathological

All died from fire. The impact was minor, there were no trauma deaths.

References

1. Conversations with Richard Hill of the Federal Aviation Administration.
2. Associated Press newspaper clipping.
3. ICAO Accident Summaries.

AIRCRAFT ACCIDENT SUMMARY

Carrier - Continental Airlines
Date - November 21, 1980
Locality - Yap, Western Caroline Islands
Aircraft - B 727
Number Passenger Seats - 82
Fire Type - Postcrash
Event - Landing, Runway Overrun

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 67 | 2 | 4 | 73 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 0 | 0 | 0 | 0 |
| Serious Injuries | 2 | 0 | 1 | 3 |

Crash

The aircraft touched down 13 feet short of the runway and the right landing gear immediately separated from the aircraft. The aircraft gradually veered off the runway and came to rest 1700 feet beyond the initial touch down. The crash forces were not sufficient to cause serious impact injuries to the occupants. The aircraft experienced considerable under carriage and right wing damage. The fuselage was intact and resting with wings level with a slight nose down pitch on stopping.

Fire

A severe ground fire erupted immediately along the right side of the aircraft as it came to rest.

Evacuation/Survival Aspects

Passengers opened the left overwing exits and began exiting immediately. The right forward overwing emergency exit was also opened. Smoke and flames entered the cabin.

The first flight attendant, seated on the left aft entry door jumpseat said pillows, blankets, and hats fell from the overhead racks. The first attendant was blocked by passengers from getting access to the aft door. The smoke was getting thick and suffocating. After she got the door open, she was unable to actuate the stairs as the cabin began to fill with smoke, she got some empty pillow case covers to put over her mouth and nose as the smoke was thick and suffocating. She then noticed a light forward and screamed for the passengers to go forward. She detached the restraining strap and groped her way to the light in a crouched position and went out the aft left overwing exit.

Evacuation/Survival Aspects (cont)

The other flight attendant was positioned in seat 16C opposite the galley service door. He said it was a normal flight but the landing was very severe. He observed the emergency exit light over the galley service door (flashlite type) fell to the floor along with the PA microphone and service phone. Also the coffee pot fell out of coffee makers. When the aircraft stopped, he unfastened his seatbelt and yelled for the passengers to unfasten their belts. He moved to the galley service door and observed raging flames outside through the porthole. He noticed the left overwing exits already open and passengers exiting. The right forward overwing emergency exit had been opened and flames and smoke were entering the cabin. He went to the cargo compartment to secure the dry chemical extinguisher and to see if the forward cabin door was usable. The forward door was not usable because of the shifted cargo. He returned to the cabin with the dry chemical extinguisher and fought the fire around the forward right overwing emergency exit until the passengers in that area had evacuated.

He escaped through the forward left emergency exit window. He reported that it was his custom "to time" the landing roll and was prepared to do so on this landing, but the hard landing caused him to forget to start his stopwatch. He stated that he remembered his watch when the aircraft came to a sudden stop and then he started the timer. After he had evacuated the aircraft he looked back and observed 2 passengers exiting the aft left emergency exit followed by the first flight attendant. The sight of her reminded him to stop his watch. The timer showed 54:48 seconds. He then observed the second officer exit through the forward left overwing exit. He stated that the rear of the aircraft was not visible due to smoke (grey-black). He also stated that during landing roll he had yelled "grab your ankles" once. Additionally he stated that after the aircraft came to rest he yelled "get out of the aircraft" in both English and Japanese. Persons seated forward of the overwing exits remember seeing smoke, but it did not effect their vision or breathing.

Two crew members opened and escaped through the F/O sliding window. All other occupants used either the forward or aft left overwing exits. The second flight attendant stated that within 30 seconds after the last person had been evacuated from the aircraft, he heard popping noises and a loud "swish." He turned around to see a thick, black pillar of smoke towering from the aircraft site.

The aircraft was equipped with eight exits. Attempts were made to open 7 of them. Four were successfully opened (F/O sliding window, right forward overwing exit, and both left overwing exits).

Comment

- . Last passenger and flight attendant evacuated at 55 seconds
- . No fatalities

References

1. Aircraft Accident Report NTSB-AAR-81-7
2. Braden, Gale E., Human Factors Group Factual Report 8014
(with attachment 1: Passenger Statements & attachment 2: Flight Attendant Statements)
3. Photographs of accident scene

AIRCRAFT ACCIDENT SUMMARY

Carrier - Spantax
Date - September 13, 1982
Locality - Malaga, Spain
Aircraft - DC 10
Number Passenger Seats - Plane Fully Loaded
Fire Type - Postcrash
Event - Aborted Takeoff

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 381 | 10 | 3 | 394 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 47 | 3 | 0 | 50 |
| Serious Injuries | 40 | 0 | 0 | 40 |

Crash

The pilot aborted the takeoff because of "vibrations" of unknown origin. The aircraft proceeded off the end of the runway and struck a number of objects, creating sufficient damage to cause fuel spillage, but no fire, as it decelerated. Approximately 700 feet from the end of the runway, the aircraft crossed a road and struck a house. This impact was quite severe, ripping off the right wing and creating a fireball. The fireball "followed" the aircraft until it came to rest approximately 1000-1200 feet beyond the runway. The fuselage was believed to be entirely intact at this point, resting on its belly.

Fire

A large external fuel fire developed on the right hand side of the aircraft aft of the wing area. The fire size was estimated 25 feet long (fuselage direction) and 50 feet wide. Flames extended 2-2 1/2 times the height of the fuselage. A much smaller fuel fire formed on the left hand side. The wind speed was 14 knots. The wind vector was forward to aft and at a slight angle with the fuselage center line, tending to bend the flames away from the fuselage. The aircraft was gutted from the inside-out by fire (the external fuel fire was extinguished by the fire department).

Evacuation/Survival Aspects

There are witness accounts that fire broke in through the tail and dense smoke seeped in probably through a tear in the upper part of the passenger cabin at the height of door 4R.

Evacuation/Survival Aspects (cont.)

Slides were deployed for the front emergency exits immediately: 1L, 2L, and 1R. Door 2R was opened later by a passenger (intense fire on that side). After 3 or 4 passengers exited, the slide that served 2R was disabled by fire. Because that landing gear was sheared off, the slides formed a shallow angle and occupants were able to "walk down the slides."

Door 3R was not opened due to the intense fire on that side. The stewardess in charge of opening door 3L saw fire on the left side of the plane but decided to open it anyway because she noted the fire was more intense on the right side. The three stewardesses located toward the plane's tail tried to open doors 4L and 4R without success according to witness accounts.

The evacuation took place slowly because the passengers picked up their carried luggage before evacuating. In the third cabin, besides the problems brought about by hand-carried luggage, a bottleneck resulted due to the number of passengers, most of them on the left aisle, that were trying to reach door 3L. On top of that, evacuation was carried on with difficulty due to the fire having destroyed the 3L slide.

The lack of visibility, due to the fire and smoke, and the cabin dividers made it impossible to have a view of the plane as a whole, and consequently, three different evacuations were carried out. One from each cabin.

The 91 passengers in the first cabin left the plane through doors 1L, 1R and 2L. The 122 in the second cabin left through doors 2L, 3L and some through 2R. The third cabin was occupied by 167 passengers. Of these, the 117 that evacuated the plane did so by using door 3L which was affected by the fire through most of the process. The 3L slide was rendered useless. The 47 passengers and 3 crew members that died occupied the third cabin.

The fire department arrived at the scene approximately 5 minutes after the crash. Firemen removed 15-20 people from the forward cabin using door 3L (all but one lived). Some were unconscious.

Medical and Pathological

All fatalities are attributed to fire or its effects. Trauma was not a factor. Eight victims died of the direct consequence of the fire that penetrated the plane, probably through a crack in the upper part of the passenger cabin at the height of door 4R. This crack was produced by one of the collision impacts. About 8-9 autopsies were conducted indicating 30-32 percent COHb in the blood and heavy sooting of the trachea and mucus. No scorching was observed in the trachea.

Comment

- . No scorching was observed in the trachea.
- . The COHb levels were not high enough to be fatal. However incapacitation occurs at lower levels than death, perhaps at half the fatal concentration (ref. Stanley Mohler Paper). The 30 percent blood COHb range produces severe headache, weakness, dizziness, dimness of vision, nausea, and collapse.

References

1. INFORME Techico 2/85, commission DE INVESTIGACION DE ACCIDENTS
2. Telcon with Richard Hill 9/15/82
3. Sequential Photographs of Accident Scene
4. Mohler, S. "Air Crash Survival Injuries and Evacuation Toxic Hazards," Aviation Space and Environmental Medicine 46(1): 86-88, 1975

AIRCRAFT ACCIDENT SUMMARY

Carrier - Air Canada

Date - June 2, 1983

Locality - Greater Cincinnati Airport, Ohio

Aircraft - DC-9

Number Passenger Seats - 100 (from plane seating diagram)

Fire Type - Inflight-Fire in aft lavatory behind wall & ceiling

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 41 | 3 | 2 | 46 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 23 | 0 | 0 | 23 |
| Serious Injuries | 0 | 0 | 0 | 0 |

Fire

A flight attendant, noting a strange smell, opened the left lavatory door and saw a light grey smoke from floor to ceiling. The in-charge flight attendant then inspected the situation. He saw smoke coming out of the seams where the aft lavatory wall and ceiling meet. He then closed the doors and notified the flight officer. The grey smoke quickly progressed forward in the cabin. Several passengers reported a short interval (estimated by one passenger to be 5 minutes) during which the smoke subsided. When the airplane began a steep descent, the smoke got heavier, intensified, increased in density and moved forward. Dense smoke filled the cabin. No open flames were witnessed inside the cabin inflight.

Seventeen minutes elapsed after discovery of the fire to the aircraft landing on the runway. The cabin burst into flames as the last person exited R2. This occurred 60-90 seconds after the plane stopped. The fire spread rapidly forward.

Evacuation/Survival Aspects

The flight officer came aft to inspect the fire, returned to the cockpit to get his goggles. When he reached the lavatory, the door was hot to the touch. He informed the captain and shortly after, a rapid descent was initiated. Both the pilot and flight officer used smoke goggles and an oxygen mask. Passengers in the rear were instructed and helped to move into seats in the forward section of the aircraft. During the descent, some passengers received evacuation instructions from the flight attendants. Several passengers said that when the flight attendants were walking down the aisles checking seat belts, it would have been impossible to have read the briefing cards at that time due to smoke. Most passengers reported the smoke hurt their chest and lungs and caused respiratory irritation. Several passengers kept their heads down while the airplane was inflight, saying it relieved some of the symptoms.

One man in seat 10E knelt between the seats, keeping his face as close to the floor as possible, and breathing through a wad of tissues he had brought on the airplane. He didn't have any difficulty breathing; other passengers reported breathing through the paper napkins from their dinner tray, headrest covers, clothing, or wet hand towels which were handed out by a flight attendant to passengers in the first several rows. There were no reports of panic on the airplane. As soon as the airplane stopped, the man seated in 2B undid his seat belt and walked across the passageway to the front of the plane. He was engulfed by a thick cloud of smoke. He could not see anything nor could he feel anyone pushing against him. He heard coughing inside the cabin and sounds of people. Other passengers stated that by the time the plane landed, they could not see their hands in front of their faces while seated or standing.

Five of the seven passenger exits were used in the evacuation. The left front door was used by seven passengers and two flight attendants. The right front door was used by one flight attendant. Six passengers used the left front window exit, and four passengers used the right front window exit. One passenger exited through the right aft window exit. The captain and flight officer exited through the cockpit window.

The first passenger exited the left forward door 30 seconds to 1 minute after the aircraft stopped. The right front window (R2) was the first overwing exit opened. The cabin burst into flames as the last person exited R2 (60-90 seconds after the plane stopped).

The survivors who had moved aft to reach the overwing exits found them because they had memorized the number of rows between their seats and the exits, and therefore counted the rows by feeling the seat backs as they moved aft. Some were able to see a dim glow of light as they reached the exit. In one case, the survivor felt a slight breeze across the back of her legs when she reached the area of an open exit. Two bodies were found further aft. They apparently failed to see the exit.

The Safety Board concluded the air conditioning packs were turned off at least 4 minutes before the airplane landed (almost two complete changes of cabin and cockpit air otherwise would have occurred). There was subsequently virtually no fresh air supply to the cockpit and cabin.

Medical and Pathological

There were no significant impact forces. Some fractures occurred post-mortem. The majority of the fatalities were found either in the aisle or seated in rows 2 through 9. The survivors had no significant levels of CO in their blood. The fatalities had COHB levels ranging from 20 to 63 percent saturation. Three fatalities had alcohol levels greater than 0.1 percent concentration. All bodies showed some degree of burning, ranging from widespread second-degree burns of exposed areas to fourth-degree burning with charring of exposed skin.

Comment

Plane 84 percent loaded
Twenty-one surviving passengers and Flight Attendants
Five of seven passenger exits used
Most deaths-smoke inhalation/toxic gas

Note Very high CN blood levels! ABS sidewall panels

References

1. Aircraft Accident Report No. NTSB/AAR - 86-02
2. Petrakis, John, J., Human Factors Group Chairman's Factual Report, DCA - 83-AA-027, Docket No. SA-480

AIRCRAFT ACCIDENT SUMMARY

Carrier - Pacific Western Airlines
Date - March 22, 1984
Locality - Calgary, Alberta, Canada
Aircraft - B 737
Number Passenger Seats - 114
Fire Type - Engine fire, wing fire, left wing
Event - Aborted takeoff

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|------------------|-------------------|-------------------|--------------------|--------------|
| On Board | 114 | 3 | 2 | 119 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 0 | 0 | 0 | 0 |
| Serious Injuries | 1 | 0 | 0 | 1 |

Fire

During the take-off run, at about 70 KIAS, the captain rejected the take-off in response to a loud bang and slight veer to the left. As the aircraft was taxiing clear of the runway onto a taxiway, the captain was made aware of fire in the left engine/wing area. The aircraft came to a stop and an emergency evacuation was carried out. A cross wind of about 4 knots blew the fire down and under the fuselage (conv. Jim Stewart, Past Chief Investigator).

Fire consumed substantial portions of the aircraft before being extinguished by airport Crash Fire Rescue Services.

Evacuation/Survival Aspects

The accident occurred during daylight in the early morning. Passengers in the left overwing area were the first to be aware of the existence of fire. Passengers who had an unobstructed view of the engine reported the fire began at the time the noise accompanying the failure was heard. As the aircraft continued to taxi, the fire gradually increased in size. The windows closest to the fire source began to discolor, deform and melt through. By this time passengers were getting out of their seats. These windows melted through about the same time the aircraft came to a stop, about 1 minute 30 seconds after the bang. When the windows melted through, there was a bursting effect. It was accompanied by a "whoosh" sound and thick black smoke immediately entered the cabin. Fire was also reported entering the cabin.

The passenger seated next to the right overwing exit opened it when advised to do so by other anxious passengers. This was the first exit opened. The first few passengers through this exit reported the slide from the right galley service door had not yet been deployed when they exited the aircraft. The evacuation through this exit was without panic; however, a sense of urgency prevailed. Smoke presented a problem to the last few people out this exit.

Evacuation/Survival Aspects (cont.)

The last one out this exit had to drop to his knees to breathe fresh air before he was able to reach the exit. He used his briefcase to shield the left side of his face from heat and he followed the person in front of him.

The rear door was opened by flight attendant No. 2 immediately after the plane stopped. Smoke and flames were immediately visible out the door so he hesitated before opening the door fully. The slide was inflated and he then directed passengers out the door. The cabin quickly filled with smoke after the door was opened and visibility quickly dropped to nil. The No. 2 attendant had to repeatedly stick his head out the door to get breaths of fresh air. When all passengers seemed to have gone he returned to the galley area and attempted to search for other passengers with his arms. Visibility was nil. Upon feeling no one, he then proceeded down the slide. Almost immediately after reaching the ground the slide deflated due to fire damage.

There was almost a total lack of visibility in the rear during the later stages of the evacuation. Heat was felt and some reported scorched hair and clothing. The passengers had to follow the person ahead to locate the right rear exit. By the time most had reached the exit the smoke had lowered to about knee height. The bottom portion of the door and the slide were all that was visible. Some passengers reported that only because of the light were they able to tell they had reached the door. Because of the smoke and flames seen outside by some passengers, many hesitated at the door before going down the slide. Some recalled being pushed out the door by someone.

Passengers in the forward part of the cabin were not aware of the existence of fire until much later. Some passengers in the front of the cabin were not aware of the serious nature of the event until they evacuated. There was no announcement of the evacuation. As the fire progressed, passengers began to leave their seats to retrieve hand baggage. However, passengers were standing in the aisles ready to exit as the doors were opened.

There were no reported slide malfunctions. Four the five passenger exits were used. Of the passengers interviewed 19 exited from the forward left door, 11 exited from the forward right door, 19 exited from the aft right door, and 23 exited from the right wing exit. Most passengers exited from the closest exits. The left rear door was never opened due to the fire outside the door.

Almost all passengers were regular business travelers on the Boeing 737. Passengers ranged in age from 23 to 62. There was one 14-year-old boy. With the exception of one woman who required crutches, none were physically handicapped.

Passenger and other witness statements suggest the evacuation took about 3 minutes.

Medical and Pathological

Twenty-nine passengers reported to the hospital. Blood samples were taken from these passengers. Carbon monoxide levels were minimal when measured.

Comment

3-minute evacuation
All survived

References

1. Pacific Western Airlines, B737, Registration C - GQPW, Operations Group - Final Report, Volume 1 of 4, File #40003.
2. Conversation with Jim Stewart, Past Chief Investigator for this accident

AIRCRAFT ACCIDENT SUMMARY

Carrier - British Air Tours
Date - August 22, 1985
Locality - Manchester, United Kingdom
Aircraft - B 737
Number Passenger Seats - 130
Fire Type - Postcrash
Event - Engine Fire, Aborted Takeoff

| <u>Number</u> | <u>Passengers</u> | <u>Cabin Crew</u> | <u>Flight Crew</u> | <u>Total</u> |
|---------------|---------------------------|-------------------|--------------------|--------------|
| On Board | 131 (including 2 infants) | 4 | 2 | 137 |
| Fatalities | | | | |
| Impact | 0 | 0 | 0 | 0 |
| Fire | 53 | 2 | 0 | 55 |

Crash

Takeoff was abandoned when the engine burst at 126 knots.

Fire

Fire was first spotted 10 seconds after the bang. The port engine and wing caught fire. Upon turning, the fire spread under the fuselage because of wind and totally engulfed the aft fuselage.

Evacuation/Survival Aspects

The survivors statement indicated that the smoke suddenly emanated from the rear of the cabin just before the aircraft stopped and initially entered the cabin through the melted aft/port windows. The smoke quickly moved forward and passengers from seats 6A and 6B, waiting to get into the aisle, said they couldn't see and it became very hot as they entered the aisle to get to the forward exits. Passengers behind them either climbed over seats to get forward, or felt their way down the aisle by way of the seat. People seated in seats 7A and B could not see the exit when they reached it, but had to feel the walls to find a gap. A female passenger from seat 15A who climbed over seats to move towards the front exit was pushed passed the exit by a mass of bodies. People all around her were collapsing on the floor. She fell to the ground unconscious just outside the doorway. She revived and pulled herself out.

At least 15 passengers reported going over seats or climbing over other collapsing passengers in the aisles. Of these 15 passenger survivors, at least 11 used the starboard overwing exit for escape, which represents some 44 percent of those who used the congested aisle. Many passengers who ultimately got out the starboard overwing exit, collapsed temporarily within or adjacent to this exit due to incapacitation; e.g., passengers from seats 12D, 14F, 15A, and 8B.

Evacuation/Survival Aspects (cont.)

Many passengers reported holding their breath as smoke hit them and that one breath of the thick black smoke caused breathing problems and lung pain.

With regard to the exits used during the evacuation, some 15-17 used the left forward exit, 34-36 used the right forward exit. Some 27 passengers (including 2 infants) used the right overwing exit. Survivors indicated hesitation by some to exit the left front on the side of the fire, which slowed evacuation out of the doors.

The first people were out the left front door at 30 seconds from stopping and, out the right front door at 90 seconds from stopping. The overwing exit was opened 45 seconds from stopping. Passengers stopped using the left front door when the right front door was opened due to the presence of fire on the left side. In 3 1/2 to 4 minutes after stopping, all survivors (except one 14-year-old boy from seat 12D found by the firemen 5 1/2 minutes after their arrival) were off the aircraft. One eventual fatality, a 31-year-old man from seat 8B had superficial burns over 24 percent of his body, was taken off the aircraft alive 33 minutes after the aircraft stopped.

Medical and Pathological

The 14-year-old boy rescued by firemen had pulmonary burns and burns to his hands. He was released from the hospital 7 days later. The 31-year-old man (rescued by firemen some 33 minutes after the aircraft stopped) had extensive pulmonary burns and surface burns to 24 percent of his body. He died 6 days later.

Forty-eight of the fifty-five deaths were due to inhalation of toxic gas/smoke with no direct fire impingement and most were found bunched near the overwing exit. Only minor injuries were noted.

Comment

Plane fully loaded
3-4 passenger doors used
48 deaths from gas/smoke inhalation
Aircraft thermally survivable long after last passenger exited.

References

1. Letter from E.J. Trimble and D.F. King of AIB to R. Ashford of CAA
December 23, 1985
2. McSweeney, Thomas E., Trip Report, Joint FAA, CAA, DGAC and CATA Meeting
in England to discuss Passenger Protective Breathing Equipment
September 29 - October 2, 1986

APPENDIX C
LISTING OF DATA ENTRY INTO COMPUTER PROGRAM

VARIG DC-8 3/5/67

number of passengers = 81
 number of deaths = 51
 number of fire deaths = 45

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .6 | Time | 120 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 20 |
| evacuation level .4 | Time | 60 |
| evacuation level 1 | Time | 70 |
| evacuation level .5 | Time | 120 |
| evacuation level .3 | Time | 180 |

The evacuation rate for this accident is .681689 people/second

new curves with improvement are as follows:

Hazard level curve for accident FB

| | | |
|---------------------|------|-----|
| Hazard level .6 | Time | 180 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 20 |
| evacuation level .4 | Time | 60 |
| evacuation level 1 | Time | 115 |
| evacuation level .5 | Time | 180 |
| evacuation level .3 | Time | 240 |

Of the 81 passengers, 59 survived

new curves with improvement are as follows:

Hazard level curve for accident **FPL**

| | | |
|----------------------|------|-----|
| Hazard level .6 | Time | 180 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 20 |
| evacuation level .4 | Time | 60 |
| evacuation level 1.2 | Time | 115 |
| evacuation level .6 | Time | 180 |
| evacuation level .35 | Time | 240 |

Of the 81 passengers, 68 survived

new curves with improvement are as follows:

Hazard level curve for accident **PBE**

| | | |
|----------------------|------|-----|
| Hazard level .6 | Time | 239 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 20 |
| evacuation level .4 | Time | 60 |
| evacuation level 1.2 | Time | 130 |
| evacuation level .6 | Time | 240 |

Of the 81 passengers, 75 survived

new curves with improvement are as follows:

Hazard level curve for accident **PBED**

| | | |
|----------------------|------|-----|
| Hazard level .6 | Time | 239 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 35 |
| evacuation level .4 | Time | 60 |
| evacuation level 1.2 | Time | 130 |
| evacuation level .6 | Time | 240 |

Of the 81 passengers, 75 survived

BRITISH OVERSEAS B-707 4/8/68

number of passengers = 122

number of deaths = 5

number of fire deaths = 5

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .8 | Time | 60 |
| Hazard level .7 | Time | 120 |
| Hazard level .6 | Time | 150 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 15 |
| evacuation level .2 | Time | 30 |
| evacuation level .6 | Time | 45 |
| evacuation level 1 | Time | 75 |
| evacuation level .8 | Time | 120 |
| evacuation level .6 | Time | 150 |
| evacuation level .3 | Time | 180 |

The evacuation rate for this accident is 1.548029 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .8 | Time | 60 |
| Hazard level .7 | Time | 120 |
| Hazard level .6 | Time | 150 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 15 |
| evacuation level .2 | Time | 30 |
| evacuation level .6 | Time | 45 |
| evacuation level 1 | Time | 75 |

| | | | |
|------------------|----|------|-----|
| evacuation level | .8 | Time | 120 |
| evacuation level | .6 | Time | 150 |
| evacuation level | .3 | Time | 180 |

Of the 122 passengers, 117 survived

new curves with improvement are as follows: **FPL**

Hazard level curve for accident

| | | | |
|------------------|----|------|-----|
| Hazard level | .8 | Time | 60 |
| Hazard level | .7 | Time | 120 |
| Hazard level | .6 | Time | 150 |
| Hazard level | 0 | Time | 180 |
| evacuation level | 0 | Time | 15 |
| evacuation level | .2 | Time | 30 |
| evacuation level | .6 | Time | 45 |
| evacuation level | 1 | Time | 75 |
| evacuation level | .8 | Time | 120 |
| evacuation level | .7 | Time | 150 |
| evacuation level | .4 | Time | 180 |

Of the 122 passengers, 121 survived

new curves with improvement are as follows: **PBE**

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .8 | Time | 60 |
| Hazard level | .7 | Time | 120 |
| Hazard level | .65 | Time | 150 |
| Hazard level | 0 | Time | 180 |
| evacuation level | 0 | Time | 15 |
| evacuation level | .2 | Time | 30 |
| evacuation level | .6 | Time | 45 |

| | | | |
|------------------|----|------|-----|
| evacuation level | 1 | Time | 75 |
| evacuation level | .8 | Time | 120 |
| evacuation level | .7 | Time | 150 |
| evacuation level | .4 | Time | 180 |

Of the 122 passengers, 121 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .8 | Time | 60 |
| Hazard level | .7 | Time | 120 |
| Hazard level | .65 | Time | 150 |
| Hazard level | 0 | Time | 180 |
| evacuation level | 0 | Time | 15 |
| evacuation level | .2 | Time | 30 |
| evacuation level | .6 | Time | 45 |
| evacuation level | 1 | Time | 75 |
| evacuation level | .8 | Time | 120 |
| evacuation level | .75 | Time | 155 |
| evacuation level | .45 | Time | 180 |

Of the 122 passengers, 122 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | | |
|--------------|-----|------|-----|
| Hazard level | .8 | Time | 60 |
| Hazard level | .7 | Time | 120 |
| Hazard level | .65 | Time | 150 |
| Hazard level | 0 | Time | 180 |

| | | | |
|------------------|-----------------|------|----------|
| evacuation level | 0 | Time | 30 |
| evacuation level | .6 | Time | 45 |
| evacuation level | 1 | Time | 75 |
| evacuation level | .8 | Time | 120 |
| evacuation level | .75 | Time | 165 |
| evacuation level | .45 | Time | 180 |
| Of the 122 | passengers, 122 | | survived |

CAPITOL AIRWAYS. DC-8. 11/27/70.

number of passengers = 225

number of deaths = 47

number of fire deaths = 47

Hazard level curve for accident

Hazard level .6 Time 120

Hazard level 0 Time 180

evacuation level .2 Time 15

evacuation level .8 Time 30

evacuation level 1 Time 90

evacuation level .6 Time 150

evacuation level .2 Time 180

The evacuation rate for this accident is 2.158884 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

Hazard level .6 Time 135

Hazard level 0 Time 210

evacuation level .2 Time 15

evacuation level .8 Time 30

evacuation level 1 Time 90

evacuation level .6 Time 160

evacuation level .2 Time 210

Of the 225 passengers, 196 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

Hazard level .6 Time 135

Hazard level 0 Time 210

| | | | |
|------------------|-----|------|-----|
| evacuation level | .2 | Time | 15 |
| evacuation level | .8 | Time | 30 |
| evacuation level | 1 | Time | 90 |
| evacuation level | .65 | Time | 160 |
| evacuation level | .25 | Time | 210 |

Of the 225 passengers, 201 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .7 | Time | 135 |
| Hazard level | 0 | Time | 210 |
| evacuation level | .2 | Time | 15 |
| evacuation level | .8 | Time | 30 |
| evacuation level | 1 | Time | 100 |
| evacuation level | .65 | Time | 170 |
| evacuation level | .25 | Time | 210 |

Of the 225 passengers, 225 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .7 | Time | 135 |
| Hazard level | 0 | Time | 210 |
| evacuation level | .2 | Time | 30 |
| evacuation level | .8 | Time | 45 |
| evacuation level | 1 | Time | 100 |
| evacuation level | .65 | Time | 170 |
| evacuation level | .25 | Time | 210 |

Of the 225 passengers, 202 survived

ALLEGHENY AIRLINES CV-580 6/7/71

number of passengers = 29
number of deaths = 27
number of fire deaths = 27

Hazard level curve for accident

| | | |
|--------------------|------|-----|
| Hazard level 1 | Time | 15 |
| Hazard level .5 | Time | 90 |
| Hazard level 0 | Time | 120 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 45 |
| evacuation level 0 | Time | 180 |

The evacuation rate for this accident is $7.434945E-02$ people/second
new curves with improvement are as follows: **FB**

Hazard level curve for accident

| | | |
|--------------------|------|-----|
| Hazard level 1 | Time | 15 |
| Hazard level .5 | Time | 150 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 45 |
| evacuation level 0 | Time | 180 |

Of the 29 passengers, 2 survived

new curves with improvement are as follows: **FPL**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 15 |
| Hazard level .5 | Time | 150 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 15 |
| evacuation level 1.2 | Time | 45 |
| evacuation level 0 | Time | 180 |

Of the 29 passengers, 3 survived

new curves with improvement are as follows: **PBE**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 15 |
| Hazard level .5 | Time | 179 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 15 |
| evacuation level 1.2 | Time | 45 |
| evacuation level 0 | Time | 180 |

Of the 29 passengers, 3 survived

new curves with improvement are as follows: **PBED**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 15 |
| Hazard level .5 | Time | 179 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 30 |
| evacuation level 1.2 | Time | 45 |
| evacuation level 0 | Time | 180 |

Of the 29 passengers, 1 survived

UNITED B-737 12/8/72

number of passengers = 58

number of deaths = 40

number of fire deaths = 27

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level 1 | Time | 20 |
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 20 |
| evacuation level .5 | Time | 60 |
| evacuation level 1 | Time | 120 |
| evacuation level .5 | Time | 180 |

The evacuation rate for this accident is .318408 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level 1 | Time | 20 |
| Hazard level .7 | Time | 120 |
| Hazard level 0 | Time | 195 |
| evacuation level 0 | Time | 20 |
| evacuation level .5 | Time | 60 |
| evacuation level 1 | Time | 150 |
| evacuation level .5 | Time | 180 |
| evacuation level .5 | Time | 195 |

Of the 58 passengers, 28 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

| | | |
|-----------------|------|-----|
| Hazard level 1 | Time | 20 |
| Hazard level .7 | Time | 120 |

| | | | |
|------------------|-----|------|-----|
| Hazard level | 0 | Time | 195 |
| evacuation level | 0 | Time | 20 |
| evacuation level | .6 | Time | 60 |
| evacuation level | 1.2 | Time | 150 |
| evacuation level | .6 | Time | 195 |

Of the 58 passengers, 33 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | 1 | Time | 60 |
| Hazard level | .65 | Time | 180 |
| Hazard level | 0 | Time | 195 |
| evacuation level | 0 | Time | 20 |
| evacuation level | .6 | Time | 60 |
| evacuation level | 1.2 | Time | 180 |
| evacuation level | 1 | Time | 195 |

Of the 58 passengers, 45 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | 1 | Time | 60 |
| Hazard level | .65 | Time | 180 |
| Hazard level | 0 | Time | 195 |
| evacuation level | 0 | Time | 35 |
| evacuation level | .6 | Time | 60 |
| evacuation level | 1.2 | Time | 180 |
| evacuation level | 1 | Time | 195 |

Of the 58 passengers, 44 survived

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NORTH CENTRAL DC-9 12/20/72

number of passengers = 43

number of deaths = 10

number of fire deaths = 10

Hazard level curve for accident

| | | |
|----------------------|------|----|
| Hazard level .8 | Time | 75 |
| Hazard level 0 | Time | 90 |
| evacuation level 0 | Time | 20 |
| evacuation level 1 | Time | 60 |
| evacuation level .5 | Time | 80 |
| evacuation level .25 | Time | 90 |

The evacuation rate for this accident is .7496592 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .8 | Time | 80 |
| Hazard level 0 | Time | 100 |
| evacuation level 0 | Time | 20 |
| evacuation level 1 | Time | 60 |
| evacuation level .5 | Time | 80 |
| evacuation level .4 | Time | 90 |
| evacuation level .3 | Time | 100 |

Of the 43 passengers, 35 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

| | | |
|-----------------|------|-----|
| Hazard level .8 | Time | 80 |
| Hazard level 0 | Time | 100 |

| | | | |
|------------------|-----|------|-----|
| evacuation level | 0 | Time | 20 |
| evacuation level | 1.2 | Time | 60 |
| evacuation level | .6 | Time | 80 |
| evacuation level | .5 | Time | 90 |
| evacuation level | .35 | Time | 100 |

Of the 43 passengers, 42 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .8 | Time | 99 |
| Hazard level | 0 | Time | 100 |
| evacuation level | 0 | Time | 20 |
| evacuation level | 1.2 | Time | 60 |
| evacuation level | .65 | Time | 80 |
| evacuation level | .55 | Time | 100 |

Of the 43 passengers, 43 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .8 | Time | 99 |
| Hazard level | 0 | Time | 100 |
| evacuation level | 0 | Time | 35 |
| evacuation level | 1.2 | Time | 60 |
| evacuation level | .65 | Time | 80 |
| evacuation level | .55 | Time | 100 |

Of the 43 passengers, 35 survived

VARIG B-707 7/11/73 EXTING. DID NOT PUT OUT FIRE

number of passengers = 126

number of deaths = 122

number of fire deaths = 121

Hazard level curve for accident

Hazard level 0 Time 60

evacuation level 0 Time 20

evacuation level 1 Time 60

The evacuation rate for this accident is 3.076923 people/second

new curves with improvement are as follows: **FB**

Hazard level curve for accident

Hazard level 0 Time 180

evacuation level 0 Time 20

evacuation level 1 Time 180

Of the 126 passengers, 22 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 0 | Time | 180 |
| evacuation level 0 | Time | 20 |
| evacuation level 1.2 | Time | 180 |

Of the 126 passengers, 26 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 180 |
| evacuation level 0 | Time | 20 |
| evacuation level 1.2 | Time | 180 |

Of the 126 passengers, 125 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 180 |
| evacuation level 0 | Time | 35 |
| evacuation level 1.2 | Time | 180 |

Of the 126 passengers, 125 survived

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LAVATORY EXTING. PUT OUT FIRE

VARIG B-707 7/11/73

number of passengers = 126

number of deaths = 122

number of fire deaths = 121

Hazard level curve for accident

Hazard level 0 Time 60

evacuation level 0 Time 20

evacuation level 1 Time 60

The evacuation rate for this accident is 3.076923 people/second

new curves with improvement are as follows: **EXTING.**

Hazard level curve for accident

Hazard level 1 Time 300

evacuation level 0 Time 20

evacuation level 1.2 Time 300

Of the 126 passengers, 125 survived

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PANAM B-707 1/30/74

number of passengers = 97

number of deaths = 92

number of fire deaths = 92

Hazard level curve for accident

Hazard level .6 Time 120

Hazard level 0 Time 180

Hazard level 0 Time 210

evacuation level 0 Time 15

evacuation level 1 Time 30

evacuation level 0 Time 30

evacuation level 0 Time 210

The evacuation rate for this accident is .3610109 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

Hazard level .6 Time 150

Hazard level 0 Time 210

evacuation level 0 Time 15

evacuation level 1 Time 30

evacuation level 0 Time 30

evacuation level 0 Time 210

Of the 97 passengers, 5 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

Hazard level .6 Time 150

Hazard level 0 Time 210

evacuation level 0 Time 15

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| | | | |
|------------------|-----|------|-----|
| evacuation level | 1.2 | Time | 30 |
| evacuation level | 0 | Time | 30 |
| evacuation level | 0 | Time | 210 |

Of the 97 passengers, 6 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | | |
|------------------|-----|------|-----|
| Hazard level | .8 | Time | 150 |
| Hazard level | 0 | Time | 210 |
| evacuation level | 0 | Time | 15 |
| evacuation level | 1.2 | Time | 30 |
| evacuation level | 0 | Time | 30 |
| evacuation level | 0 | Time | 210 |

Of the 97 passengers, 6 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | | |
|------------------|----|------|-----|
| Hazard level | .8 | Time | 150 |
| Hazard level | 0 | Time | 210 |
| evacuation level | 0 | Time | 0 |
| evacuation level | 0 | Time | 210 |

Of the 97 passengers, 0 survived

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PANAM B-747 3/27/77

number of passengers = 388

number of deaths = 320

number of fire deaths = 190

Hazard level curve for accident

Hazard level 1 Time 20

Hazard level 0 Time 60

evacuation level 0 Time 20

evacuation level 1 Time 60

The evacuation rate for this accident is 3.48718 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

Hazard level 1 Time 20

Hazard level 0 Time 60

evacuation level 0 Time 20

evacuation level 1 Time 60

Of the 388 passengers, 68 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

Hazard level 1 Time 20

Hazard level 0 Time 60

evacuation level 0 Time 20

evacuation level 1 Time 60

Of the 388 passengers, 68 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | |
|----------------|------|----|
| Hazard level 1 | Time | 20 |
|----------------|------|----|

| | | |
|----------------|------|----|
| Hazard level 0 | Time | 60 |
|----------------|------|----|

| | | |
|--------------------|------|----|
| evacuation level 0 | Time | 20 |
|--------------------|------|----|

| | | |
|--------------------|------|----|
| evacuation level 1 | Time | 60 |
|--------------------|------|----|

Of the 388 passengers, 68 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | |
|----------------|------|----|
| Hazard level 1 | Time | 20 |
|----------------|------|----|

| | | |
|----------------|------|----|
| Hazard level 0 | Time | 60 |
|----------------|------|----|

| | | |
|--------------------|------|----|
| evacuation level 0 | Time | 35 |
|--------------------|------|----|

| | | |
|--------------------|------|----|
| evacuation level 1 | Time | 60 |
|--------------------|------|----|

Of the 388 passengers, 26 survived

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CONTINENTAL DC10 3/1/78

number of passengers = 197

number of deaths = 2

number of fire deaths = 0

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 240 |
| Hazard level .9 | Time | 360 |
| Hazard level 1 | Time | 480 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 90 |
| evacuation level .75 | Time | 120 |
| evacuation level .5 | Time | 180 |
| evacuation level .2 | Time | 300 |
| evacuation level 0 | Time | 480 |

The evacuation rate for this accident is 1.289727 people/second

new curves with improvement are as follows: **FB**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 240 |
| Hazard level .9 | Time | 360 |
| Hazard level 1 | Time | 480 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 90 |
| evacuation level .75 | Time | 120 |
| evacuation level .5 | Time | 180 |
| evacuation level .2 | Time | 480 |

Of the 197 passengers, 195 survived

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new curves with improvement are as follows: **FPL**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 240 |
| Hazard level .9 | Time | 360 |
| Hazard level 1 | Time | 480 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 90 |
| evacuation level .75 | Time | 120 |
| evacuation level .5 | Time | 180 |
| evacuation level .2 | Time | 480 |

Of the 197 passengers, 195 survived

new curves with improvement are as follows: **PBE**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 240 |
| Hazard level .9 | Time | 360 |
| Hazard level 1 | Time | 480 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 90 |
| evacuation level .75 | Time | 120 |
| evacuation level .5 | Time | 180 |
| evacuation level .2 | Time | 480 |

Of the 197 passengers, 195 survived

new curves with improvement are as follows: **PBED**

Hazard level curve for accident

| | | |
|-----------------|------|-----|
| Hazard level 1 | Time | 240 |
| Hazard level .9 | Time | 360 |

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 480 |
| evacuation level 0 | Time | 30 |
| evacuation level 1 | Time | 90 |
| evacuation level .75 | Time | 120 |
| evacuation level .5 | Time | 180 |
| evacuation level .2 | Time | 480 |

Of the 197 passengers, 195 survived

KOREAN AIRLINES 11/19/80

number of passengers = 223

number of deaths = 12

number of fire deaths = 12

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level 1 | Time | 30 |
| Hazard level .8 | Time | 170 |
| Hazard level 0 | Time | 180 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 120 |
| evacuation level .6 | Time | 170 |
| evacuation level .2 | Time | 180 |
| evacuation level 0 | Time | 240 |

The evacuation rate for this accident is 1.689081 people/second

new curves with improvement are as follows: **FB**

Hazard level curve for accident

| | | |
|--------------------|------|-----|
| Hazard level 1 | Time | 240 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 240 |

Of the 223 passengers, 223 survived

new curves with improvement are as follows: **FPL**

Hazard level curve for accident

| | | |
|--------------------|------|-----|
| Hazard level 1 | Time | 240 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 240 |

Of the 223 passengers, 223 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | |
|----------------|------|-----|
| Hazard level 1 | Time | 240 |
|----------------|------|-----|

| | | |
|--------------------|------|----|
| evacuation level 0 | Time | 15 |
|--------------------|------|----|

| | | |
|--------------------|------|-----|
| evacuation level 1 | Time | 240 |
|--------------------|------|-----|

Of the 223 passengers, 223 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

| | | |
|----------------|------|-----|
| Hazard level 1 | Time | 240 |
|----------------|------|-----|

| | | |
|--------------------|------|----|
| evacuation level 0 | Time | 30 |
|--------------------|------|----|

| | | |
|--------------------|------|-----|
| evacuation level 1 | Time | 240 |
|--------------------|------|-----|

Of the 223 passengers, 223 survived

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SPANTAX DC-10 9/13/82
number of passengers = 391
number of deaths = 50
number of fire deaths = 50

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 60 |
| Hazard level .7 | Time | 300 |
| Hazard level 0 | Time | 360 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 110 |
| evacuation level .25 | Time | 180 |
| evacuation level .15 | Time | 300 |
| evacuation level .1 | Time | 359 |
| evacuation level 0 | Time | 360 |

The evacuation rate for this accident is 2.727134 people/second
new curves with improvement are as follows: FB

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 180 |
| Hazard level .7 | Time | 420 |
| Hazard level 0 | Time | 450 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 110 |
| evacuation level .5 | Time | 230 |
| evacuation level .25 | Time | 360 |
| evacuation level .15 | Time | 420 |
| evacuation level .1 | Time | 450 |

Of the 391 passengers, 391 survived

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new curves with improvement are as follows: FPL

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 180 |
| Hazard level .7 | Time | 420 |
| Hazard level 0 | Time | 450 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 110 |
| evacuation level .5 | Time | 230 |
| evacuation level .3 | Time | 360 |
| evacuation level .2 | Time | 420 |
| evacuation level .15 | Time | 450 |

Of the 391 passengers, 391 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level 1 | Time | 300 |
| Hazard level .85 | Time | 420 |
| Hazard level 0 | Time | 450 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 110 |
| evacuation level .5 | Time | 230 |
| evacuation level .5 | Time | 300 |
| evacuation level .3 | Time | 420 |
| evacuation level .2 | Time | 450 |

Of the 391 passengers, 391 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

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new curves with improvement are as follows: FPL

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level 1 | Time | 180 |
| Hazard level .7 | Time | 420 |
| Hazard level 0 | Time | 450 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 110 |
| evacuation level .5 | Time | 230 |
| evacuation level .3 | Time | 360 |
| evacuation level .2 | Time | 420 |
| evacuation level .15 | Time | 450 |

Of the 391 passengers, 391 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level 1 | Time | 300 |
| Hazard level .85 | Time | 420 |
| Hazard level 0 | Time | 450 |
| evacuation level 0 | Time | 15 |
| evacuation level 1 | Time | 110 |
| evacuation level .5 | Time | 230 |
| evacuation level .5 | Time | 300 |
| evacuation level .3 | Time | 420 |
| evacuation level .2 | Time | 450 |

Of the 391 passengers, 391 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

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| | | |
|---------------------|------|-----|
| Hazard level 1 | Time | 300 |
| Hazard level .85 | Time | 420 |
| Hazard level .0 | Time | 450 |
| evacuation level 0 | Time | 30 |
| evacuation level 1 | Time | 110 |
| evacuation level .5 | Time | 230 |
| evacuation level .5 | Time | 300 |
| evacuation level .3 | Time | 420 |
| evacuation level .2 | Time | 450 |

Of the 391 passengers, 391 survived

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AIR CANADA DC-9 6/2/83

number of passengers = 44

number of deaths = 23

number of fire deaths = 23

Hazard level curve for accident

Hazard level .5 Time 60

Hazard level .25 Time 80

Hazard level 0 Time 90

evacuation level 0 Time 30

evacuation level 1 Time 80

evacuation level .5 Time 90

The evacuation rate for this accident is .8484849 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

Hazard level .5 Time 120

Hazard level 0 Time 150

evacuation level 0 Time 30

evacuation level 1 Time 140

evacuation level .5 Time 150

Of the 44 passengers, 44 survived

new curves with improvement are as follows: FPL

Hazard level curve for accident

Hazard level .5 Time 120

Hazard level 0 Time 150

evacuation level 0 Time 30

evacuation level 1.2 Time 140

evacuation level .5 Time 150

Of the 44 passengers, 44 survived

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new curves with improvement are as follows: PBE

Hazard level curve for accident

Hazard level .7 Time 120

Hazard level .45 Time 140

Hazard level 0 Time 150

evacuation level 0 Time 30

evacuation level 1.2 Time 145

evacuation level .6 Time 150

Of the 44 passengers, 45 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident

Hazard level .7 Time 120

Hazard level .45 Time 140

Hazard level 0 Time 150

evacuation level 0 Time 45

evacuation level 1.2 Time 145

evacuation level .6 Time 150

Of the 44 passengers, 44 survived

PACIFIC WESTERN B-737 3/22/84

number of passengers = 117

number of deaths = 0

number of fire deaths = 0

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .8 | Time | 180 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 15 |
| evacuation level .4 | Time | 30 |
| evacuation level 1 | Time | 90 |
| evacuation level .8 | Time | 120 |
| evacuation level .6 | Time | 150 |
| evacuation level .4 | Time | 180 |
| evacuation level 0 | Time | 240 |

The evacuation rate for this accident is 1.082498 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .8 | Time | 240 |
| Hazard level 0 | Time | 300 |
| evacuation level 0 | Time | 15 |
| evacuation level .4 | Time | 30 |
| evacuation level 1 | Time | 120 |
| evacuation level .8 | Time | 150 |
| evacuation level .6 | Time | 180 |
| evacuation level .4 | Time | 300 |

Of the 117 passengers, 117 survived

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new curves with improvement are as follows: FPL

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .8 | Time | 240 |
| Hazard level 0 | Time | 300 |
| evacuation level 0 | Time | 15 |
| evacuation level .4 | Time | 30 |
| evacuation level 1 | Time | 120 |
| evacuation level .9 | Time | 150 |
| evacuation level .7 | Time | 180 |
| evacuation level .5 | Time | 300 |

Of the 117 passengers, 117 survived

new curves with improvement are as follows: PBE

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .9 | Time | 299 |
| Hazard level 0 | Time | 300 |
| evacuation level 0 | Time | 15 |
| evacuation level .4 | Time | 30 |
| evacuation level 1 | Time | 150 |
| evacuation level .7 | Time | 240 |
| evacuation level .5 | Time | 300 |

Of the 117 passengers, 117 survived

new curves with improvement are as follows: PBED

Hazard level curve for accident .

| | | |
|-----------------|------|-----|
| Hazard level .9 | Time | 299 |
| Hazard level 0 | Time | 300 |

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| | | | |
|------------------|----|------|-----|
| evacuation level | 0 | Time | 30 |
| evacuation level | 1 | Time | 150 |
| evacuation level | .7 | Time | 240 |
| evacuation level | .5 | Time | 300 |

Of the 117 passengers, 117 survived

BRITISH AIR TOURS B-737 8/22/85

number of passengers = 135

number of deaths = 55

number of fire deaths = 55

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .2 | Time | 210 |
| Hazard level 0 | Time | 240 |
| evacuation level 0 | Time | 30 |
| evacuation level .6 | Time | 45 |
| evacuation level 1 | Time | 120 |
| evacuation level .7 | Time | 150 |
| evacuation level .4 | Time | 240 |

The evacuation rate for this accident is 1.028278 people/second

new curves with improvement are as follows: FB

Hazard level curve for accident

| | | |
|---------------------|------|-----|
| Hazard level .2 | Time | 240 |
| Hazard level 0 | Time | 270 |
| evacuation level 0 | Time | 30 |
| evacuation level .6 | Time | 45 |
| evacuation level 1 | Time | 135 |
| evacuation level .7 | Time | 180 |
| evacuation level .4 | Time | 270 |

Of the 135 passengers, 97 survived

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new curves with improvement are as follows: **FPL**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level .2 | Time | 240 |
| Hazard level 0 | Time | 270 |
| evacuation level 0 | Time | 30 |
| evacuation level .6 | Time | 45 |
| evacuation level 1 | Time | 135 |
| evacuation level .8 | Time | 180 |
| evacuation level .45 | Time | 270 |

Of the 135 passengers, 100 survived

new curves with improvement are as follows: **PBE**

Hazard level curve for accident

| | | |
|----------------------|------|-----|
| Hazard level .8 | Time | 240 |
| Hazard level 0 | Time | 270 |
| evacuation level 0 | Time | 30 |
| evacuation level .6 | Time | 45 |
| evacuation level 1 | Time | 135 |
| evacuation level 1 | Time | 180 |
| evacuation level .75 | Time | 270 |

Of the 135 passengers, 135 survived

new curves with improvement are as follows: **PBED**

Hazard level curve for accident

| | | |
|--------------------|------|-----|
| Hazard level .8 | Time | 240 |
| Hazard level 0 | Time | 270 |
| evacuation level 0 | Time | 45 |

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| | | |
|----------------------------|------|----------|
| evacuation level 1 | Time | 135 |
| evacuation level 1 | Time | 180 |
| evacuation level .75 | Time | 270 |
| Of the 135 passengers, 135 | | survived |

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APPENDIX D

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