LOSS HISTORIES: A UNDERUSED SAFETY RESOURCE

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CONTENTS

ABSTRACT

Establishing emergency response requirements for aircraft mishaps at airports to achieve acceptable risk levels is a continuing challenge to managers, stakeholders, safety professionals and code, standards and regulatory organizations. Traditional approaches involve the use of codes and standards, historical accident data, probabilistic analyses and expert judgments. This paper describes an inquiry to determine whether loss histories might utilized to enhance decision-making about emergency response requirements, and the results of that inquiry.

INTRODUCTION

In air transportation, emergencies involving aircraft mishaps with personal injury or fire occasionally, sometimes on or near airports. Deciding what public or private requirements to establish for airport rescue and fire fighting operations to deal with such occasional emergencies remains a continuing challenge for all with a stake in such activities. Questions persist about what constitutes a needed or adequate level of service for differing airports, the applicability of relevant standards, and objective data and methods for evaluating the performance of responses when they have occurred.

This paper examines the feasibility of analyzing to illuminate the needs and capabilities involved in the airport emergency response requirements decision process. The Time/Loss Analysis method (T/LA) uses the loss history during an emergency and data about intervener actions to the effect each intervener. was initially developed to evaluate the intervention by emergency responders in transportation accidents involving hazardous materials threats or releases.[1] In the 25 years since its initial development, T/LA has been applied to other kinds of occurrences and intervention actions. These applications have resulted in new insights into different kinds of loss histories that occur during emergencies, loss history data that should be gathered, and the interpretation of the loss histories for safety improvement purposes.[2]

Before proceeding, it must be emphasized that nothing contained herein is intended to be or imply criticism of what those involved emergency responses may have done under duress. The intent is to objectively examine the loss history in past who intervened, and how the interveners affected the loss history – in other words, to examine who intervened and what they accomplished, rather than what they did - to see what the findings might suggest for the future.

The issue of what rescue and fire fighting services to provide for aircraft emergencies at airports presents a complex policy problem for officials who by law are responsible for all aviation and airport safety matters in Canada[3] and officials, managers and users elsewhere. Canada, the vexing question is what airport rescue and fire fighting (ARFF) services to require at 28 of the largest and 250 smaller Canadian airports. The answer is complicated by differences in views about what constitutes "adequate protection" and who should pay for it among representatives of the aviation community such as airport owners or operators, aircraft owners and operators, passengers, responders to emergencies, governing organizations and even international organizations .

A second complication is the variety of emergencies that can arise at specific airports. They range from severe crashes of very large passenger carrying aircraft involving fire to small single occupant aircraft crashes, each posing different response challenges. Data to resolve this aspect of the problem have been gathered and analyzed, so some information about this aspect of the decision is available.

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[1] Driver, E.T. and Benner, L., *Evaluating Dangerous Goods Emergency Response With Time/Loss Analyses,* Proceedings of 6th International Symposium-Packaging and Transportation of Radioactive Materials, November 10-14, 1980, Berlin (West), Federal Republic of Germany

[2] Benner, L., *Guide 7 Task Guidance For Preparing Time / Loss Analysis* For Use During MES-Based Investigations, Starline Software Ltd, Oakton VA 2001.

[3] _*An Evaluation Of Emergency Response Capability At Airports In Canada,* CADMUS Corporate Solutions Limited. Nepean, ON Canada 1999 (Cadmus study)

For example, the following figure shows a historical distribution of airport and near-airport crashes through 1997.

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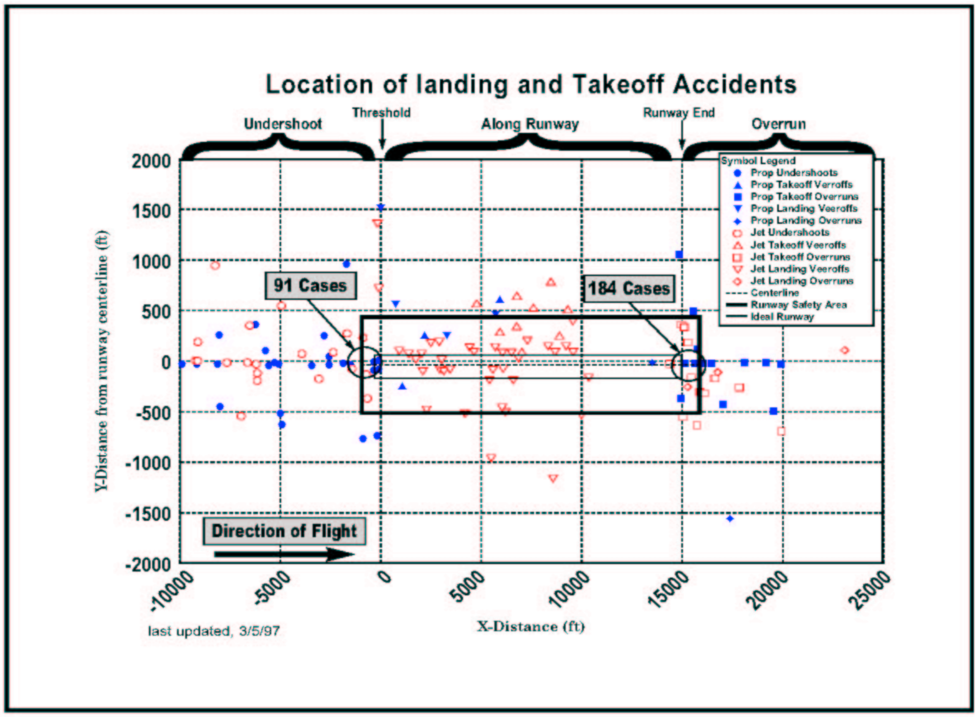

Figure 1, Location of Landing and Takeoff Accidents
Source: Air Line Pilots Association

SURVIVING THE CRASH

Additionally, rare emergencies can arise when large aircraft in distress land at airports not equipped to regularly handle them, as occurred when a United Air Lines DC-10 made an unscheduled landing at the Sioux airport which was geared to handling smaller aircraft

A third complication is the applicability of relevant Standards and Recommended Practices adopted by the International Civil Aviation Organization, an organization formed under an international treaty, and by other organizations. ICAO Annex 14, Section 9.2 Rescue and Fire Fighting (RFF), describes rescue and fire fighting objectives, equipment and services to be provided at various categories of aerodromes. Additional documents produced by other organizations also provide relevant recommended standards.[4] The complication arises because the standards are designed to be generally applicable, but may not be suited to specific airports or national needs, and seem to assume regular airport usage patters for classification purposes.

A fourth complication is the lack of an objective process for capturing and analyzing the results of actions by responders,[5] or put another way, a "scoring" process for judging the need, effectiveness, maturity, cost and value of emergency responses.[6] ICAO's principal Airport RFF objective of its standards and recommended practices (SARPs) is to "save lives," implemented with recommendations in the form of a set of specifications; it does not specify or require any evaluation of intervener performance, or documentation of results achieved (the actual lives

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[4] See CADMUS study, p 49 for description and analysis of International and Professional Bench Marks.

[5] *Report of the Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario* (Moshansky Commission), Volume 1, pp 127-130 and 209-213, especially recommendation MCR 31.

[6] Grose, V.L., *Canadian Airport Emergency Response*, Omega Systems Group Incorporated, Arlington, VA 1998

saved) by its standards and recommendations. ICAO SARPs require the reporting of fatality and serious or minor injury counts among crew, passengers and others, four categories of aircraft damage, and a "brief description of search, evacuation and rescue, location of crew and passengers in relation to injuries sustained, failure of structures such as seats and seat belt attachments."[7] The reporting of "lives saved" or similar results of these search evacuation or rescue actions is not specifically addressed. Reports conforming to these SARPS usually do not address the results achieved by the emergency response capabilities specified in the SARPs.

A fifth complication is the framing of the problem narrowly in terms of aircraft rescue and fire fighting (ARFF) activities, rather than the broader context of all interveners who contribute to "saving lives" after crashes. "Saving lives" is a more complex endeavor involving many interveners whose contributions must be considered contemporaneously with those of ARFF interveners. For example, as indicated by time/loss curves, others contribute to reduced losses by addressing behaviors of aircraft components and furnishings during crashes and post-crash fires, and still others contribute by their actions within occupied aircraft spaces during hostile post-crash environments. They must be recognized as interveners competing for resources devoted to "saving lives" in aircraft crashes, before arriving at conclusions about "adequate ARFF capabilities" at an airport. Framing the intervention contributions this way broadens the range of options to consider to determine the "best" allocation of resources.

Costs of providing rescue and fire fighting services can be quantitatively estimated with sufficient accuracy for supporting such decisions. Unlike costs, benefits of that capability are, at present, uncertain. One study[8] attempted a probabilistic analysis of 287 accidents from 1966-1985, concluding that crash fire and rescue would contribute to a reduction in injury or fatalities in 6 accidents, possibly saving as many as 221 lives but most probably 14-167 lives. This report methodology was roundly criticized in a subsequent study.[9] A 1997 Majority Report of an Aviation Rulemaking Advisory Committee working group concluded that there were no cases where the presence of ARFF equipment on the airport would have made a difference in saving lives, based on historical data about 15 Part 135 accidents from 1983-1994. These judgments were based on examination of narrative data about the evacuation actions or rescue of survivors, rather than an analysis of all the intervener's actions and their influence on the results achieved so the process of saving lives in aircraft crashes could be understood.

Arguments for providing the capability in the past have thus been based primarily on subjective but persuasive evaluations of adverse experiences in publicized incidents,[10][11] or on ICAO and other standards and recommended procedures providing guidance for the capability to be provided.[12] A comprehensive critique of both the data available and past problems trying to use the data is found in the 1999 Cadmus report.[13] A prescribed method and objective data to define, analyze or assert the reasonableness of estimated intervention for this decision, during or after investigations, are presently not mandated or

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[7] *International Standards and Practices, Aircraft Accident and Incident Investigation,* Annex 13, International Civil Aviation Organization, Eighth Edition, July 1994, Appendix 1.15.

[8] Sypher-Mueller, *Crash firefighting & Rescue Services in Canada, Volume I Introduction and Study Overview*, p iii (Sypher Mueller Report)

[9] p 106-112 of Cadmus study)

[10] See recommendation MCR 31 in Report of the Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario (Moshansky Commission), Volume 1, pp 127-130 and 209-213

[11] General Information for Working Groups, Safety at Canadian Airports and the Role of the Aircraft Firefighting Regulations, Transport Canada, February 10, 1998.

[12] See Section 4, International and Professional Benchmarks in Cadmus study.

[13] *An Evaluation Of Emergency Response Capability At Airports In Canada,* CADMUS Corporate Solutions Inc. Nepean, ON 1999, Section 6.5

suggested. The degree of detail about what results intervention actions achieved in past accidents varies widely among published reports.

The consequence is a continuing lack of understanding of the relative value of various intervention options, an unresolved predicament for the response capability selection decision makers, and continuing contention.

The predicament continues. The ARFF predicament could be resolved by simply electing to implement existing international and professional standards. However, these standards do not provide for full consideration the tradeoffs between the costs and benefits of providing alternative intervention efforts and levels of such services to accommodate local circumstances and rare events. To resolve this dilemma rationally, an objective analysis of the results actually achieved by interveners such as airport rescue and fire fighting responses and others might be of significant value.

EVALUATING RESPONSES

Why consider Time/Loss Analysis

The latter complication, objective evaluation of intervention actions, is what led to the development of T/LA. United States Public Law 93.633, Title III, Section 304(a)(8), dated January 3, 1975 imposed a requirement on the National Transportation Safety Board to:

> "evaluate the adequacy of safeguards and procedures concerning the transportation of hazardous materials and the performance of other Government agencies charged with the safe assurance of hazardous materials;"

Continuing deaths and injuries among emergency response personnel responding to transportation accidents investigating accidents involving hazardous materials (hazmats) suggested strongly that safeguards or procedures were inadequate. Some way was needed to determine objectively if that was true.

Traditionally, responses were reviewed and evaluated by groups of participants getting together to critique their own performance. These methods were experience based, highly subjective, lacking replicability and not widely disseminated except when a description of the episode was published in a fire service publication. The new legislation challenged the NTSB's technical staff to find analysis methods with results that would withstand public scrutiny for technical consistency and objectivity when alleged inadequacies were reported. The result was the development of the Time/Loss Analysis method (T/LA).

T/LA uses a graphic display of the actual cumulative loss history, an estimated loss history had no intervention been attempted, and intervention attempts over time during an incident. This requires data about the growth of the losses being tracked as the incident progresses, and data about timing and consequences of intervention efforts to change the course of events that would otherwise occur. This structure guides intervention emergency response data acquisition, organization, display and interpretation. Thus it seemed logical to explore the application of T/LA to try to provide an understanding and assessment of airport rescue and fire fighting experiences at airport facilities.

Selection of examples for study.

While the T/LA method has been used elsewhere, it has not been used during investigations of accidents in the aviation community. In the absence of data collected explicitly to evaluate responses, it was necessary to try to develop needed data from existing sources. The search for examples focused on discovering investigation reports of survivable aircraft crashes on or near airports from which losses and intervention actions over time might be developed.

Selection of reports for analysis

Reports of prior inquiries into ARFF requirements, aircraft evacuation and fire loss reduction, cabin safety, and accident and emergency responses were also screened as possible sources for finding candidate emergency experiences from which to develop data to support T/LA analyses.

Sources of candidate reports

The search for examples of emergencies on or near airports that might be candidates for study included prior studies of the issues and reports of survivable accidents, which offered information about intervener actions.

Several prior studies referencing numerous such accidents were identified. The studies reviewed are shown in Table 1.

Table 1 Potentially Relevant Studies Reviewed.

1	Cadmus Corporate Solutions Limited **An Evaluation of Emergency Response Capability at Airports in Canada** 1999
2	Wright, Joseph, **Rescue and Firefighting Research Program**, DOT/FAA/AR-00/67, Federal Aviation Administration, Airport and Aircraft Research and Development Branch, William J. Hughes Technical Center, Atlantic City International Airport, NJ, January 2001
3	National Transportation Safety Board, **Evacuation of Commercial Airplanes**, Safety Study NTSB/SS-00/01 1999
4	National Transportation Safety Board, **Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983 Through 2000**, Washington, D.C. Safety Report NTSB/SR-01/01 2001
5	Aviation Rulemaking Advisory Committee **COMMUTER AIRPORT CERTIFICATION WORKING GROUP FINAL REPORT** February 20, 1997 (Landrum & Brown, Cincinnati OH)
6	Coalition For Airport And Airplane Passenger Safety, **SURVIVING THE CRASH**, *The Need to Improve Lifesaving Measures at Our Nation's Airports*, c/o International Association of Fire Fighters Washington, DC 1999
7	Office of Technology Assessment, Congress of the United States **Aircraft Evacuation Testing: Research and Technology Issues**, OTA-BP-SET-121 September 1993
8	FAA Office of Aviation Research, **Fuselage Burnthrough Protection for Increased Postcrash Occupant Survivability: Safety Benefit Analysis Based on Past Accidents** DOT/FAA/AR-99/57, Washington, D.C. 1999 Final Report.

These studies and an Internet search disclosed accidents that were also reviewed for potential candidates to study[14].

Accessible reports about these accidents were then examined to determine their value for the inquiry. A few reports containing casualty, survival and response information and some times were identified as candidates for further examination. Most, however, had shortcomings, primarily insufficient information to permit development of a loss history, and information from which to determine what responders *accomplished* by their intervention. Another difficulty was lack of information needed to estimate the loss history had the intervention actions not be undertaken.

Table 2 Survivable Aircraft Accidents Selected For Further Review

[14] The internet search disclosed a list of major airline disasters from 1920-2001 (http://dnausers.d-n-a.net/dnetGOjg/Disasters.htm)

Accident location	Date yymmdd	Kind of accident	Occu/ surv.	ARFF avail*	Data Source
Manchester UK	850826	aborted take-off, on airport fire	137/82	Y	AAIB 8/88
Baie Comeau PQ Can	981207	near airport, crash in water	10/3	Y	TSB A98-Q0914
Dryden ON Can	890311	near airport, crash-fire, snow	69/45	Y	Comm of Inquiry Report
Cincinnati US	830602	in-flight fire, on-airport fire	46/23	Y	NTSB AAR 86-02
Cranbrook BC	780211	failed go-around, on airport crash-fire, night blizzard	49/7	Y	personal communication
Dallas/Fort Worth US	880831	take-off on airport crash-fire	108/94	Y	NTSB AAR 89/04
Sioux City US	890719	disabled aircraft crash on airport, fire	296/185	Y	Pilot presentation
Los Angeles US	910201	on airport crash-fire	101/67	Y	NTSB AAR 91-08
LaGuardia	920322	take-off stall, crash in water, fire	51/24	Y	NTSB AAR-93-02
Little Rock US	990601	landing overrun-fire	145/134	Y	NTSB AAR 01-02
Hong Kong PRC	990822	on airport crash-fire, “typhoon”	315/313	Y	AFJ v2-2
Taipei ROC	1031	on airport crash-fire, rainy night	179/96	Y	ASC AAR-02-04-001

A discussion of each case follows.

Manchester UK 1985

The report of an accident investigated by the United Kingdom's Air Accidents Investigation Branch at the Manchester International Airport on 26 August 1985[15] contains extensive information about an aircraft fire on an airport runway, including details about the progression of the accident process, passenger casualties and the intervention actions during that emergency. Because it offers one of the most complete descriptions of what happened and times, it was selected as the first case to study. Additionally the accident occurred on an airport in full view of airport personnel, resulting in optimum response timing. Further, the responses did not involve other complications like crash damage, difficulties in accessing or communicating with the aircraft, or weather impediments.

Preparation of a Time/Loss Analysis for this accident requires the establishment of the time scale, loss scales, loss histories for fatalities, injuries, property damage and intervention times, followed by development of the actual and no-intervention loss history curves, and the intervention points on those curves. This section describes how that is done.

The accident

The accident report contains the following synopsis of the accident.

At 0612 hrs G-BGJL, carrying 131 passengers and 6 crew on a charter flight to Corfu, began its take-off from runway 24 at Manchester with the co-pilot handling. About thirty six seconds later, as the airspeed passed 125 knots, the left engine suffered an uncontained failure, which punctured a wing fuel tank access panel. Fuel leaking from the wing ignited and burnt as a large plume of fire trailing directly behind the engine. The crew heard a 'thud', and believing that they had suffered a tyre-burst or bird-strike, abandoned the take-off immediately, intending to clear the runway to the right. They had no indication of fire until 9 seconds later, when the left engine fire warning occurred. After an exchange with Air Traffic Control, during which the fire was confirmed, the commander warned his crew of an evacuation from the right side of the aircraft, by making a broadcast over the cabin address system, and brought the aircraft to a halt in the entrance to link Delta.

As the aircraft turned off, a wind of 7 knots from 250° carried the fire onto and around the rear fuselage. After the aircraft stopped the hull was penetrated rapidly and smoke, possibly with some flame transients, entered the cabin through the aft right door, which was opened shortly before the aircraft came to a halt. Subsequently fire developed within the cabin. Despite the prompt attendance of the airport fire service, the aircraft was destroyed and 55 persons on board lost their lives.

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[15] Air Accidents Investigation Branch Aircraft Incident Report No: 8/88, Report on the accident to Boeing 737-236, G-BGJL at Manchester International Airport on 22 August 1985. The report is posted on the AIBB web site at http://www.aaib.dft.gov.uk/formal/gbgjl/gbgjl.htm

Figure 1 View of aircraft during fire

Source: AIBB Aircraft Incident Report No: 8/88

Development of loss history curve

First the report was reviewed to extract data required to develop the loss history curves for fatal injuries, non-fatal injuries and property damage.

Establishing the time scale.

To develop and plot the loss curves, the first task is to establish scales for each axis. For the time or x-axis, the first task is to determine the zero intercept (t_0) with the y loss axis for the curve, because it is the anchor point for all time measurements. In this accident the first loss occurred when the engine failure occurred, making the "thud" noise. This will be the t_0 point on the x or time axis, because that is when losses began to grow.

The next task is to establish the time scale for the x-axis. In this case, the last victim died 6 days after t_0 but most of the losses occurred within 5 minutes of t_0 often a few seconds apart, so seconds were used for the scale along the x coordinate. All times are measured from time t_0. For example, an action that occurs 15 seconds after the thud (t_0) will be shown at 15 on the time scale.[16]

Establishing the Loss scales.

The loss scales are defined by the actual or estimated outcomes, whichever is greater in a specific incident. In this example the actual outcome included 55 fatalities, 15 serious injuries, and 69 minor or no injuries. The property loss was not reported in quantitative terms, but for purposes of this experiment, losses will be assumed to be US $20 million for the damaged aircraft and contents, and US$150,000 for the balance of the costs attributable to the accident. These estimates represent property losses experienced in this accident, and are subject to change (upward) as the no-intervention loss values are estimated later in the procedure.

The aircraft carried 129 passengers and 6 crewmembers, all of whom it is assumed would have been lost had no intervention actions been attempted. It is also assumed that the aircraft would have been a total loss without any intervention actions. The total value of the aircraft and contents (excluding people) is assumed to be US$ 6 million. In this example, intervention reduced the potential losses. Thus the no-intervention loss values of 135 occupants and $US 6 million provide the limits on the y-axis that will be used to plot the T/LA loss curves.

[16] When outliers exist, such as the last death 6 days after the accident in this case, it may be desirable to use an interrupted time scale, switching from seconds to days after cumulative losses approach upper limits.

Fatality loss history

None of the fatal injuries occurred outside the aircraft. To plot the fatality loss history over time, in the absence of such data in the report, the challenge was to identify when each of the fatalities occurred during the course of the incident.

From the report, we learn that 55 persons died. 54 bodies were removed from the cabin after the fire. Firefighters removed one person from the wreckage about 33 minutes (1980 seconds) after the aircraft stopped or t_0+45+1980, but that person died 6 days after the incident.

Timing of fatal injuries

One or more fire fighters rescued the last surviving evacuee from the overwing exit approximately 5 minutes after the aircraft stopped, or t_0 +45+300.

The general T/LA rule for selecting the time assigned to each fatal injury is to use the time at which the lethal exposure or injury occurred to plot the loss history curve. This requires further explanation.

In this accident, all injuries began when the victims who succumbed were first exposed to lethal heat and suffocating combustion products, including cyanide, from the fire inside the aircraft cabin. As the concentrations of the cyanide and hot combustion gases increased, the severity of harm they were doing also increased, at some point in time reaching lethal levels and irreversibly injuring each exposed person who died.

The last survivor was pulled from the overwing exit about 5 minutes after the aircraft had stopped, so it will be assumed that the fatal exposures occurred within that time frame.

The "time of death" -- particularly where multiple casualties are involved -- is rarely if ever established and reported in accident reports. When it is not reported, it must be estimated to permit preparation of the loss history curve.

The report offers the following information.

> Of the 54 occupants who expired on the aircraft, 43 (80%) had cyanide levels in excess of 135 micrograms/100 ml which would have led to incapacitation. Of these, 21 had levels above 270 micrograms/100 ml, the fatal threshold. Forty passengers (74%) had levels of carboxyhaemoglobin in excess of 30% saturation which would also be expected to cause incapacitation. Of these, 13 passengers had levels in excess of 50%, which is generally accepted as the fatal threshold. Only 6 passengers (from seats 21A, 21E, 20E, 17A or B, 17C or D, and 16C) had absorbed less than the incapacitating levels of carbon monoxide and hydrogen cyanide stated above, having died from direct thermal assault. The remaining 48 passengers who died on board did so as a result of smoke/toxic gas inhalation.

For the 54 passengers who expired inside the cabin, the cumulative loss history built quickly, starting at some time after fire penetrated the aircraft hull. The report states that the fire probably penetrated the hull some 20 to 40 seconds after the aircraft stopped (t_0 + 65-85), but no later than 1 minute after it stopped. It also says that thick black smoke was seen pouring out of the overwing exit shortly after it was opened (t_0 +45 + 25 or t_0 +70 seconds) suggesting potentially lethal conditions inside the cabin at that time. This suggests that lethal exposures started no later than t_0 +70, and probably earlier.

To estimate times of death, it is assumed that cyanide induces fatality in seconds following inhalation of lethal doses.[17] Surviving passengers described how quickly they were incapacitated by the gases – after a breath or two – in the cabin. The six passengers who died of burns probably expired about the same time as or slightly after the others due to respiratory injury, since heat exposure levels in the cabin produce death more slowly that the toxic gases. In the absence of reported data, and solely for the purposes of this experiment, it is assumed the first

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[17] Borron, S. W. and Baud, F.J., *Toxicity, Cyanide,* 5 June 2001, posted at http://www.emedicine.com/emerg/topic118.htm

victims began to expire within 60 seconds after inhalation of toxic fumes began (t_0 + 70 seconds) and the last fatal exposure (from heat) in the cabin probably occurred well within 5 minutes of the aircraft stopping, probably within thee minutes or less (t_0 +45+180 or 225 seconds.[18]

The person who was pulled from the cabin 33 hours after t_0 was probably exposed to fatal respiratory system injuries before the last survivor was rescued. After rescue, he was given medical treatment, but he died 6 days later of severe lung damage.

These data offer alternative ending boundaries on the actual fatality loss history. If fatal exposure is used, all 55 fatal exposures occurred before 5 minutes had elapsed after the aircraft stopped (t_0 + 325 seconds). If time of death is used, the maximum cumulative death count of 55 is reached 6 days after t_0.

Fatality timing determination

For "people" loss histories, an intervention perspective helps to identify the preferred time to use for plotting the fatal loss history. The choice is between (a) the initial injury or exposure that was so severe that interveners would not be able to prevent death or (b) the actual time of death attributed by medical examiners. In establishing a time for fatal injury, it can be argued that the death outcomes, which make further intervention moot, rather than some point during the injury process, should define the death for loss history purposes. On the other hand, it can be argued that at the time each of the passengers was exposed to fatal doses of hot combustion gases from the fire, they were no longer candidates for potentially successful intervention.[19] If intervention after injury is successful (the victim survives) the exposures would be sub-lethal, and would not be reported as fatal injury.

For (b) the effects of the rescuers and medical interveners' actions would be shown separately. Had the 55th victim survived, for example, the treatment of this victim would have been successful, and the rescuers and medical interveners would share credit for reducing the fatality losses – the 55th fatality would not have occurred. This and other reports are silent about medical intervention actions and their effects on surviving victims.

For intervention evaluation purposes, the time assigned to fatalities in this example will be the estimated times when the doses of products of combustion reached lethal levels in the exposed victims during the fire. Thus in this case the timing of the 55th fatality would be set during the internal fire exposure.

The report data suggests some points on the cumulative loss history curve. The point for the first fatality is at 1 on the loss axis and at t_0 +45 seconds to stop + 60 seconds to the first lethal exposure, or t= 105 on the x axis. The point for the last fatality is at 55 value on the y axis, and at t_0 + the 45 seconds it took for the aircraft to come to a stop + 5 minutes (300 seconds) or at t = 345 on the x axis.

The remaining points reflecting the increasing number of cabin occupants overcome by the lethal gases are subjective estimates, influenced by reported observations of what happened inside the cabin during the fire. The Purser, for example, reported that by the time he left the cabin (after 34 passengers had evacuated) via the R1 exit, the smoke was so bad the visibility was down to inches, smoke was pouring out the door, and he felt if he inhaled any more smoke, he would not survive. The times are not reported or estimated.

The overwing exit was observed to be open by about 45 seconds after the aircraft stopped. Shortly after it was opened, it was obscured by dense black smoke coming from the rear of the cabin.

> "As observed by the forward cabin passengers the effects of this smoke on the respiratory system was rapid and for some catastrophic. Within one or two breaths of the dense atmosphere survivors recall burning acidic attack on their throats, immediate and severe breathing problems, weakness in their knees, debilitation and in some instances, collapse."

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[18] The timing of the last lethal exposure is unclear, and may have occurred at any time before t_o+33 minutes, when fire fighters searched the cabin interior and found one victim still alive. This affects where the 54th fatality is shown on the loss curve.

[19] This approach is consistent with the reported analysis of the incident, which argues that smoke hoods would have been a desirable intervention measure.

This suggests that the cabin environment became lethal quickly and overexposures were beginning to occur at the rear of the aircraft by the time the smoke reached the overwing exit. This suggests that the first lethal exposure would have occurred around t_0 + 45 seconds to stop+ 45 seconds to open the door + shortly after door opened, say 15 seconds, or t= 105. This was unexpectedly consistent with the prior estimate.

"No intervention" fatality history

Assuming no intervention actions were undertaken, all occupants of the cabin (133 individuals) would have perished rapidly after the aircraft stopped, from overdoses of the lethal and hot gases in the cabin during the fire. Had the cabin exists remained closed after fire breached the cabin, it is likely that the incapacitating gases would have built up even more quickly than they did. Therefore while admittedly speculative in the absence of hard data, the no intervention loss history curve would be placed to the left of (earlier) the actual loss history for the fatalities. Two fatality, both estimated, rates are shown, with one curve plotted about 10 seconds sooner than the other, to show the sensitivity of the estimate to the rate of incapacitation to the lethal gases in the cabin.

Injury losses

The report states that there were a total of 15 serious injuries.[20] It does not provide much data about the timing of these injuries. This inquiry will assume that the minor injuries required no intervention, and that if there was any intervention it made an insignificant difference in the outcome. Therefore, only the serious injuries are shown in the injury loss history.

A no intervention injury estimate is not relevant in this case, because all would have perished in the likely no intervention scenario.

Minor or no injury loss history

The AAIB report describes the evacuation of the fire-affected aircraft with many details, reporting 4 crew, 63 passengers and 1 fireman as "minor or no injuries." The report lacks sufficient detail to develop an good total cumulative time-minor injury history curve. For purposes of this inquiry, only the serious injuries will be used to develop the injury loss history curve.

All serious injuries were reported as attributable to the fire and combustion products in the aircraft. All injured passengers escaped from the cabin before being exposed to a lethal dose of the combustion products or heat in the cabin. Thus the time bounds from the injury loss history are estimated to start at t_0 +105 seconds when the fire broke through the fuselage into the cabin, and t_0 +325 seconds when the last survivor was rescuedfrom the

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[20] The Aircraft Accident Investigation Board defines severe injury for its reports as

"**Serious injury**" means an injury which is sustained by a person in a reportable accident and which:

(a) requires hospitalization for more than 48 hours commencing within seven days from the date on which the injury was received; or

(b) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); or

(c) involves lacerations which cause nerve, muscle or tendon damage or severe hemorrhage; or

(d) involves injury to any internal organ; or

(e) involves second or third degree burns or any burns affecting more than five percent of the body surface; or

(f) involves verified exposure to infectious substances or injurious radiation; and seriously injured shall be construed accordingly.

Source: http://www.aaib.dft.gov.uk/accidrep/accidrep.htm

This is consistent with ICAO definitions overwing exit by firefighters. It is assumed that most of the injuries occurred early during this time interval and the estimated injury loss history curve is plotted based on that assumption.

Intervener losses

T/LA requires determination of whom or what to consider as interveners, so the effects on the loss history for each intervener can be identified. Members of emergency response organizations like fire fighters and emergency medical personal are easily understood to be interveners, and were present during this incident. They arrived at the scene starting about 70 seconds after t_0 , about 25 seconds after the aircraft stopped. The only known casualty among these responders was one fireman injured when he was blown out of an aircraft doorway about 7 minutes (t_0 +465 seconds) after the aircraft stopped during an attempt to enter the aircraft. His injuries were classified as minor/none.[21]

The incident also illustrates why in some cases interveners must include the aircraft crew, which intervened inside the aircraft to reduce the losses. Their intervention began at t_0 when the commander aborted the takeoff, and continued at 31seconds from the onset of the accident when the commander warned the cabin crew of an evacuation of the aircraft from the right side.

The purser's intervention actions help reduce the losses by his opening the L1 and R1 doors at the front of the aircraft, through which 47 passengers evacuated the cabin.

More escaped through the right overwing door that was opened by two passengers, who must also be considered interveners in that their actions affected the outcome. The delay reduced the number of passengers who could escape through this exit, increasing the cumulative losses. However, after another passenger managed to remove the exit door, 27 survivors managed to get out of the cabin.

A stewardess helped two surviving passengers, who had collapsed, out the L1 door, which must also be considered an intervention action by the crew. Neither forward crew member suffered injuries.

Two crew members at the rear of the aircraft perished, along with most of the passengers in that area. Their specific actions during the emergency are not known. They both died in the fire. One escape door at the rear of the aircraft where these stewardesses would have been stationed was opened, presumably by one or both of the stewardesses. Thus one or both were responding to the aircraft commander's orders and should be viewed as interveners.

The circumstances create uncertainty about whether to categorize both victims as interveners. In constructing the time loss history it makes no difference. However it does influence the selection of interveners to show on the chart, and later the interpretation of the resultant curves.

When investigations are seeking data about such losses to support T/LA during an investigation, these uncertainties should be resolved, if possible, to enhance the accuracy of the loss curve.

Property loss curve

The property loss in this accident, assumed to be $US 5.1 million for the damages to the aircraft and contents after fire suppression efforts, and $US 6 million for total hull loss had no intervention been attempted, and $US 100,000 for the balance of the expenses attributable to the response and cleanup. The loss occurred between the time of the thud at t_0 and some unreported time when the responders withdrew at the conclusion of the fire. The preponderance of the loss occurred during the first several minutes of the fire, so the damage history is arbitrarily shown to rise quickly starting at t_0 .

Where photographic data are available, the property loss history curve can be developed more accurately by investigators. Alternatively, interviews of responders, salvage experts or insurance adjusters might be used to

[21] The incident illustrates the risk to outside interveners when they enter an aircraft cabin to perform rescue tasks while smoke or fire are still present inside the cabin, and suggests that such rescues should not be relied on or predicted to be successful during the active stages of cabin a fire of this kind.

refine the growth of the property losses over time. Where estimates are required, the Delphi or similar estimating techniques might be utilized to develop estimates or ranges of estimates.

Loss History Curves

These estimates result in the estimated loss histories shown in Chart1 below.

Intervener actions

After the loss histories have been developed, the next task is to define and superimpose the interveners and intervention actions on the loss history curve. The report details many of the intervention actions of the crew members, the fire and rescue personnel and many of the passengers during the emergency.

For this analysis, interveners are any persons who had an opportunity to influence the course of events during the entire process that produced the losses, from beginning to end. The emergency process is considered to have begun with the failure in the engine, and ended with the death of the last fatally injured person. Interveners in this example included the cockpit crew, air traffic controller, cabin crew members, some passengers and responding emergency crews. The cockpit crew's actions brought the aircraft to a stop averting a crash with potentially lethal consequences for all aboard had they continued their takeoff. That action, starting within a few seconds after hearing the "thud," and the communications by the air traffic controller made possible the unusually rapid response by rescue and fire fighting personnel on the airport. Their second intervention action was the Commander's evacuation order to the crew, 8 seconds before the aircraft came to a stop. It is unclear whether that action reduced the losses in the cabin, or whether the entire reduction in the fatalities in cabin the should be attributed entirely to the cabin crew. which opened the exit doors and helped passengers out of the aircraft. Their third action was to evacuate the cockpit to save themselves, thus reducing the potential loss by two persons. That apparently ended their intervention, although one could surmise that they may have had a role in the post-evacuation guidance of evacuees, subject to confirmation during the investigation.

Another category of interveners on the scene was the four members of the cabin crew. Their intervention actions began as the aircraft stopped when the purser started to open the R1 door, was unsuccessful, and then opened the L1 door, which he achieved about 25 seconds after the aircraft stopped, coincident with the initiation of the foam discharge from the first fire suppression vehicle. Evacuation through that door began at that time under the supervision of the No. 4 stewardess, with 16 passengers and the No. 4 stewardess exiting through that door. The Purser returned to the R1 door, and succeeded in getting it open, helping 24 passengers escape and escaping himself through that exit. All these evacuees exited away from the fire.

The remaining passengers, including one whom firemen removed alive but mortally injured about 33 minutes after the aircraft stopped, did not survive.

More escaped through the right overwing door that was opened by two passengers, who must also be considered interveners in that their actions affected the outcome. The delay reduced the number of passengers who could escape through this exit, increasing the cumulative losses. However, after another passenger managed to remove the exit door, 27 survivors managed to get out of the cabin.

A stewardess helped two surviving passengers, who had collapsed, out the L1 door, which must also be considered an intervention action by the crew. Neither forward crew member suffered injuries.

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The circumstances create uncertainty about whether to categorize both victims as interveners. In constructing the time loss history it makes no difference. However it does influence the selection of interveners to show on the chart, and later the interpretation of the resultant curves.

When investigations are seeking data about such losses to support T/LA during an investigation, these uncertainties should be resolved, if possible, to enhance the accuracy of the loss curve.

The first responding rescue and fire fighting unit arrived on scene about 25 seconds after the aircraft stopped, and began attacking the fire on the left side of the aircraft. It could not be determined from the report what specific losses their actions reduced, although it can be inferred than they arrested some further fire damage to the aircraft structure by extinguishing the fire.

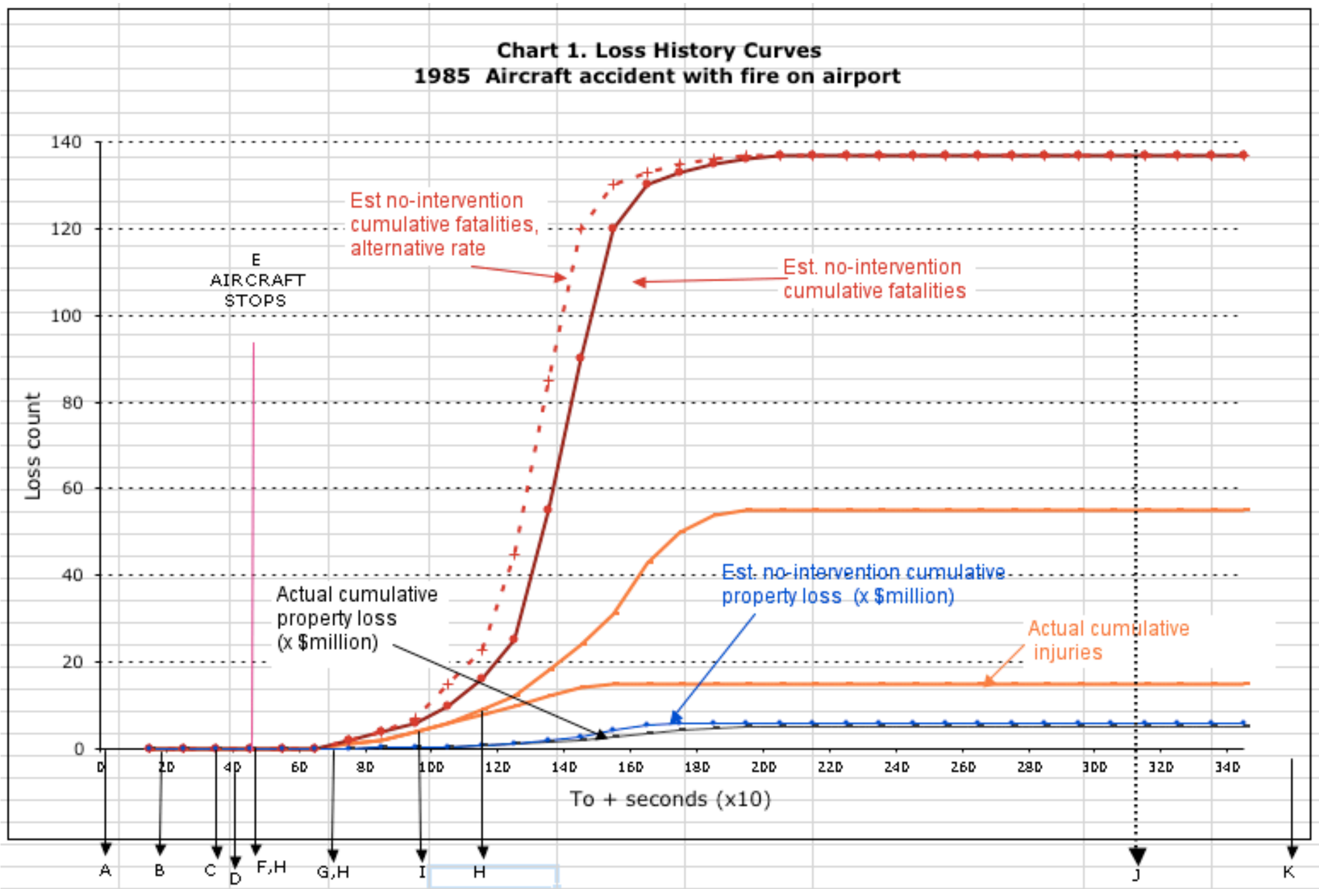
A summary of the interveners, the intervention actions they took, and the timing of the beginning of their intervention is shown in Table 3.

Table 3. Summary of interveners, actions and results
1988 Manchester Accident

	Intervener	t_o+	Intervention actions	Results
A	Commander	1	orders STOP	Avoids subsequent airborne crash, reducing casualties
B	ATC	19	alerted ARFF	Initiated responses by others, effects unclear
C	Commander	37	notified crew to evacuate on starboard side please	gave cabin crew instruction for safest evacuation, contributing to reduced losses by unknown amount
D	Stewardess S4	40	opened R2 door	had unforeseeable adverse effects on fire and toxic gases entering cabin, increasing losses by unknown amount
E	Commander	45	stops a/c in cross-wind position	Resulted in unexpected acceleration of fire in cabin, increasing casualties by ?*
H	Purser	45	attempted to open R1 unsuccessfully	Delayed evacuation, increasing casualties by ? *
F	px10F	45	tried to open door unsuccessful	Delayed evacuation, increasing casualties by ? *
G	R1V1	70	Arrives at a/c	Reduced property loss, other effects indeterminate
H	Purser	70	opened L1	Reduced fatalities by 17 who evacuated successfully
I	px11F	90	opened ROW exit	Reduced fatalities by 27 who evacuated successfully
H	Purser	115	opened R1 door	Reduced fatalities by 34 who evacuated successfully
J	Crew Coach	310	BAC crew coach arrives at a/c	Insufficient data to determine effects on loss curves
K	Firefighter	465	entered a/c thru R1 door	Resulted in minor injury to firefighter, with no offsetting reduction in casualties

* About 38 of the 55 victims in the cabin were recovered from area around rows 8-12. The report is unclear about where the rest were found.

The loss histories and these intervention efforts are plotted on the time loss matrix in Chart 1. The key to Intervener actions and symbols on the chart is shown below the chart.



Key	intervener	t_o+ (min)	Intervention actions
A	C	1	commander orders STOP
B	ATC	19	ATC alerted FD
C	C	37	commander notified crew to evacuate on starboard side
D	S4	40	Stewardess opened R2 door
E		45	a/c stops
F	PX10F	45	PX10F tried to open door unsuccessful
G	R1V1	70	RIV1 arrives
H	P	45	Purser tries to open R1
H	P	70	Purser opened L1
I	PX11F	90	PX11? opened ROW exit
H	P	115	Purser opened R1
J	CC	310	BAC crew coach arrives
K	FF	465	firefighters enter thru R1 door

Baie Comeau PQ

The accident.[22]

The next accident that was analyzed involved a small scheduled commuter aircraft with a pilot, copilot and 8 passengers which crashed into the St. Lawrence River about 2 minutes after a 11:09 AM takeoff, approximately 0.5 nautical mile (nm) from shore and less than 1 nm from the airport in near freezing weather. The pilot, the co-pilot, and four passengers in seats 1A, 1B, 4A, and 4B survived the initial impact. Upon impact, the floor buckled upward and the wing collapsed, destroying the survival space of the passengers in seats 2A, 2B, 3A, and 3B, resulting in asphyxiation due to compression and drowning. The co-pilot sustained a serious facial injury and was unconscious after the crash.

View of BN2A-26 C-FCVK in St. Lawrence River
07 December 1998

Source: TSB of Canada

The pilot and the passengers in 1A and 1B freed the co-pilot from her seat and brought her up on top of the wreckage, where they awaited assistance. The passengers in 4A and 4B, who sustained multiple injuries, were unable to move and remained seated and secured to the rearmost seat. The tide rose, bringing water up to their waists. The water depth at the accident site was estimated as follows:

Table 4. Tide effects on water depth at partially submerged aircraft

Time	To+min	Estimated Water depth (inches)
1111 (accident)	0	20
1200 (aircraft found)	49	41
1236 (first rescue)	85	51
1247 (second rescue)	96	56

Because of their injuries and resulting incapacity, the survivors on top of the cabin were unable to help those passengers out of the wreckage. While the pilot and the passenger from 1A held onto the co-pilot, the passenger

[22] The full report is available from the Transportation Safety Board of Canada, on line at http://www.tsb.gc.ca/en/reports/air/1998/a98q0194/a98q0194.asp#6

from 1B, lying on the roof, held the head of the passenger in 4B out of the water; he did so until water submerged the cabin between 1200 and 1215, 64 minutes after the crash. The passenger in 4A never regained consciousness after the crash and also drowned.

Shortly after the water covered the wreckage, the survivors, who were suffering from hypothermia, could no longer hold onto the co-pilot, who was carried away by the water at about 1230.

Two passengers died while awaiting rescue, which came 96 minutes after the crash. The body of the co-pilot was carried away by the current and was not recovered. The pilot-in-command and two passengers who were rescued sustained serious injuries.

Cumulative Loss history curves

Actual loss history

This is another instance where defining the time of the losses is complicated. The crash dynamics fatally injured 4 passengers, and seriously injured the remaining occupants. Two inured passengers were pinned in the cabin, and could not be rescued by the other three survivors. The copilot's injuries were so severe that it is not clear that timely rescue efforts could have succeeded. All seven of these injuries began at the time of the crash.

The survivors pose a different problem. They survived, though injured, and rescued themselves -temporarily. They would have perished from hypothermia due to the post-crash environment in which they found themselves had they not been rescued. This change in the environment, in effect, creates a second emergency for the survivors. This creates a problem for the T/LA method: how can the second emergency be displayed so the rescue, which indeed prevent further fatalities, can be show to have improved the outcome? This was resolved treating the crash as the first threat to survival for the three surviving occupants that were rescued, and the risking tide as the second threat to those survivors.

No intervention loss history

Had the rescue not succeeded, all occupants would have perished .5 km from shore in water temperatures just above freezing, from injuries during the crash, which disabled them to the degree that they were unable to rescue themselves before succumbing to drowning or hypothermia. Thus the estimated loss history assumes all were fatally injured at the time of the crash, and this is reflected in first step of the no intervention loss curve show in Chart 2. The threat to the crash survivors from the rising tide is depicted by the second step in the no intervention loss curve.

Intervener actions

The pilot and the passengers in 1A and 1B freed the unconscious injured co-pilot from her seat and brought her up on top of the wreckage after the crash, where they awaited assistance. These three individuals aboard the flight were the first interveners to take action to reduce the loss (I-1). Because of the delay in external rescue effort, their intervention, though heroic, did not improve the ultimate outcome. A subsequent intervener who improved the outcome directly was the Bell 206 helicopter pilot who made two trips to the wreckage to rescue the survivors (I-2 and I-3). Other interveners who reached the site were the first boat and a Hercules aircraft, but they had no effect on the outcome.

Indirectly, other interveners attempted to act in this emergency, and should be acknowledged, although their contributions to the outcome varied. For example, the individuals who were involved in the chain of communications that led to the Bell 206 reaching the scene contributed to the improved outcome, and it might be argued that their intervention actions should be shown on the chart, because without them the Bell 206 would not have played the role it did. For the purpose of assessing response performance analysts have a choice of focusing on the results produced by individuals or organizations. The choice is implemented by displaying the intervention time of the individuals or their organization. In this example, the time is displayed for the individuals who acted at the scene. which permits analysis of the effects of their actions, rather than the performance of the organization. If the organization is to be evaluated, the time of the first action by anyone in the organization would be displayed.

In this example, both are shown to illustrate how that can be done. The intervention of the Citizen (**C**) who reported the aircraft location was important in saving the lives of the three survivors, because that led to the dispatch of the helicopter. Similarly, the Sûreté du Québec (SdQ) which received the call and acted on it also played a role in the rescue, as did the helicopter pilot and mechanic (I-2,I-3) who lifted the survivors out of the water.

The TSB of Canada describes the emergency response chronology in Appendix B of its report, reproduced below. Some additional times derived from the text of the report are added in italics to show events related to the outcome. Because the table uses the time of takeoff as the reference time, that is used as t_o for the time scale.

Table 5

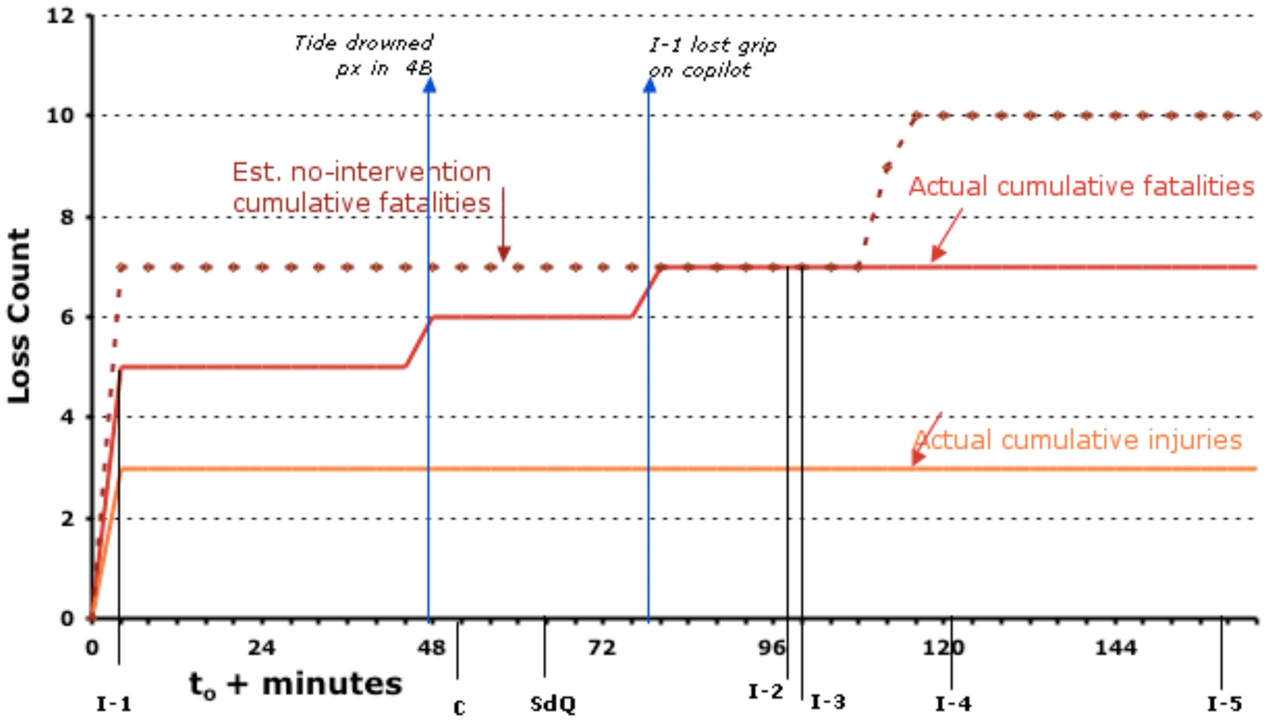
Chronological Outline of Emergency Response
Supplemental entries and results column added by Authors
Interveners are shown in bold face type

Elapsed time after 1109 takeoff	**Action**	***Results***
About 2 minutes	The aircraft crashed into the river. 4 occupants fatally injured during crash, 6 others seriously injured.	
3 minutes	The **Montréal Area Control Centre (ACC)**, the **Mont-Joli Flight Service Station (FSS)**, and **some aircraft** in flight tried to contact Flight ASJ501. A communications search was then undertaken by various agencies.	*No effect on outcome*
Est. 4 minutes	*(I-1)Pilot, px1A extricated co-pilot*	*delayed death of co-pilot*
10 minutes	The Mont-Joli FSS informed the Baie-Comeau airport that Air Traffic Services (ATS) had lost contact with Flight ASJ501 after take-off.	*No effect*
18 minutes	The **Mont-Joli FSS,** which thought that Flight ASJ501 had experienced a communication failure, declared a Code White alert. Code White is used to deploy the personnel of the airports concerned and to put outside agencies on alert. The **Baie-Comeau airport emergency coordination centre** became operational.	*No effect*
22 minutes	One **airport maintenance attendant** at the Baie-Comeau airport went to the apron with a direction finder to see if he could receive an emergency locator transmitter (ELT) signal. A second airport maintenance attendant searched the runway.	*No effect*
24 minutes	Pointe-Lebel firefighters and various police departments were put on standby. **(by ?)**	
26 minutes	The **emergency coordination centre** asked that a search be conducted on Garnier Street, which runs along the river just east of Runway 10.	*No effect*
38 minutes	The **Baie-Comeau airport manager** expanded the ground search southwest of the runway.	*No effect*
41 minutes	The **Baie-Comeau airport manager** tried to locate the aircraft from the control tower.	*No effect*
42 minutes	The **Rescue Coordination Centre (RCC)** in Halifax, Nova Scotia, was notified.	*No effect*
45 minutes	The Canadian Coast Guard (CCG) was notified.*(by ?)* The CCG had a vessel, the Pearks, berthed at the Baie-Comeau harbour.	*No effect*

47 minutes	The **Halifax RCC** dispatched a Hercules from Canadian Forces Base (CFB) Trenton, Ontario, to the area to begin the search.	*No effect*
48 minutes	*Rising tide drowned Injured px in 4B.*	
49 minutes	The **CCG** decided to dispatch the Pearks to search for the aircraft. Also dispatched Griffon helicopter.	*No effect*
50 minutes	The Mont-Joli FSS declared the aircraft missing and moved onto Code Yellow and the alerting phase. All stakeholders were informed.	*No results*
51 minutes	A **citizen** reported seeing C-FCVK in the river *to ?*.	*Led to helicopter dispatch*
61 minutes	*Tide covered aircraft*	
64 minutes	The **Sûreté du Québec** (Quebec police) asked Héli-Manicouagan, a commercial operator based in Baie-Comeau, to dispatch a helicopter to the site of the accident.	*Led directly to rescue*
65 minutes	The **Halifax RCC** dispatched a helicopter from CFB Bagotville to the scene to rescue the victims.	*No effect*
78 minutes	*Tide submerged aircraft, survivors lost grip on copilot*	
88 minutes	A ski-equipped **Bell 206 helicopter** left the Héli-Manicouagan base for the accident scene with a pilot and an aircraft maintenance engineer on board.	*Led to rescue*
98 minutes	The **Bell 206**, which was not equipped with floats or a winch, hovered over the wreckage. The aircraft maintenance engineer helped a survivor aboard. The survivor was then brought to emergency personnel on shore.	*Reduced fatalities by 1*
100 minutes	The **Bell 206** returned to the scene and rescued the other two survivors.	*Reduced fatalities by 2*
121 minutes	The **first boat** arrived at the scene.	*No effect*
159 minutes	The **Hercules arrived** at the scene.	*No effect*
186 minutes	The **Griffon helicopter** arrived at the scene.	*No effect*

The T/LA curve for this incident is shown in Chart 2.

Chart 2. Loss History Curves
1998 Aircraft crash in icy water near airport



Key	**intervener**	**t_o+**	**Intervention actions**
I-1	Pilot+px1A	1	pulled injured copilot from cockpit to atop wing
C	citizen	50	reported location of crash site –triggered rescue of 3
SdQ	Sûreté du Québec	64	initiated helicopter dispatch to site-led to rescue of 3
I-2	Bell 206 crew	98	airlifted 1 survivor from submerged aircraft wing I
I-3	Bell 206 crew	100	airlifted 2 survivors from submerged aircraft wing
I-4	boat	121	arrived at scene after rescue
I-5	Hercules a/c	159	arrived over scene after rescue

Dryden Ontario 1989

A report by a Commission of Inquiry into this crash which occurred about 960 meters off the end of the airport runway into a densely wooded area was also found to be well documented. During the crash, the aircraft fuselage broke into three parts, and fire ensued. The report provided detailed descriptions of the actions of surviving passengers and crew, and emergency responders, and the results of those action. Two victims survived the crash but died later. The other victims all were reportedly dead within minutes of the impact. The information derived from the report, in the manner described above is summarized in Table.6

Fatality loss history

The loss history for the fatally injured occupants involves both crash trauma and fire –related injuries. Exposures occurred "within minutes" of the crash. The report states that firefighting handlines could have reached the wreckage by about 12:50 p.m. or approximately 39 minutes after the crash, and concluded that fire fighting would have had no effect on the fatal injuries, except that two occupants, one of whom died and one of whom survived, may have suffered less had the handlines be used earlier. Thus for TLA purposes, all fatal exposures would be shown to have occurred "within minutes" which arbitrarily will be assumed to mean < 4 minutes.

Because the aircraft broke into three pieces during the crash, estimation of the no-intervention loss curve is challenging. All except 3 survivors self-evacuated. One of the three who was strapped into his seat, was rescued by another passenger. To others were rescued later from among the fatally injured passengers under the supervision of doctors at the scene. It is not clear from the report what their fate might have been had they not been rescued. For the purposes of this study, they will be assumed to have perished without rescue. This means the no-intervention loss curve will show three more fatalities than the actual loss curve.

Information to predict the fate of the other passengers had they not self evacuated could not be derived from the report. From photos of the wreckage after the fires were extinguished, it seems reasonable to assume that had the passengers not evacuated before the fire consumed the aircraft, many but an unknowable number would have perished. Further, the cold weather would have made it more likely that any impaired passengers in the wreckage would have perished. It is not know how many occupants suffered no injuries so predictions of how many would have perished without any intervention effort would have to be developed by further investigation. For this study, it will be assumed all occupants would have perished had nobody taken any intervention actions.

In this case, the large number of self evacuations poses a challenge for displaying those intervention actions, because they would have to be represented by a large number of interveners along the time coordinate on the TLA chart. This problem might be resolved by showing a wide line marked SE representing all the self-evacuees on the chart during the time this was occurring. Because so much happened during the first few minutes after the crash, followed by a period where little happened at the scene, selecting a time scale for the chart posed another challenge. This could be resolved by providing essentially two charts, one for the first few minutes, and the other for subsequent actions on a coarser time scale.

Injury losses

The report provides insufficient data to address possible effects of intervener actions on the injuries reported, so the actual injury loss curve shows all the injuries occurring during the crash and earliest minutes of the fire. A no-intervention injury loss history from the available data was not attempted.

Loss history curves

The two part T/LA curve is shown for fatalities. Chart 3a shows the first few minutes of the crash and fire. Chart 3b shows the loss history over about 60 minutes.

Intervener actions

In this accident all except two of the survivors self-evacuated the damaged, burning aircraft. The intervener actions are described in the Table 6 below. Approximated times are preceded by the symbol ~..

Table 6 Summary of interveners, actions and results
1989 Dryden crash

(47* of 69 occupants evacuated or were evacuated)

	Intervener	t_o+ (min)*	Intervention actions	Results (source)
A	FA (8D)	~ -.5	commanded px to assume brace position	At least 20 px complied, perhaps enabling them to evacuate selves after a/c came to rest (282)
B	px 7D	~.25	(opened ROW exit)*	2 px + 1 FA evacuated selves (284)
C	px 8A	~ 1	exited LOW unassisted	1 evacuated self (284)
D	px	~ 2	Exited unassisted through gash forward of right wing	14 evacuated selves but one died later (284)
D	px	~ 2	Exited unassisted through gash aft of right wing	26 evacuated selves unassisted through gash forward of right wing (284)
D	px	~ 2	Exited unassisted through opening forward of left wing	1 survived (284)
E	R C M P constable	` 3	Returned to wreckage to help restrained px evacuate	1 px survived (286)
F	2 Doctors	61	Directed extraction from wreckage(129)	supervised extraction of two injured px, one of whom later died (129)
	UtofO pumper	23	arrived at scene	delayed extinguishing efforts until t_o+109 (123)

* 2 passengers who survived the crash died later of their injuries.

- FA = flight Attendant, px= passenger, RCMP= Royal Canadian Mounted Police, UtofO= Untitled territory of Ontario
- Note: Report states 47 occupants were evacuated, but data from pages 284-286 and 129, shown in the table suggests 48 evacuated or were evacuated; passenger rescued by RCMP may be included in one of the general numbers.
- The time of the crash reported in the Moshansky report is approximately 12:11 pm. The time between the first contact with the trees and when the final debris came to rest is not reported therefore, the reported time of the crash will be used as t_o .

Cincinnati Ohio USA (NTSB AAR 86-02)

This accident was examined because it involved an in-flight fire in the lavatory of an Air Canada passenger aircraft, which landed and burned on an airport. 47 of the 69 occupants survived. Information in the report permitted the construction of the data shown in Table 7, using estimated times suggested by the information in the report.

Table 7 Summary of interveners, actions and results
1978 Cincinnati In-flight Fire and Landing

(23 of 46 occupants evacuated or were evacuated)

	Intervener	t_o± (min)*	Intervention actions	Results (source)
A	FO	~ 13 1904	proposed moving passengers forward in cabin	Contributed to escape of survivors by moving them away from fire location
B	Captain	~17:30 1908:30	declared Mayday	Contributed to escape of survivors by getting aircraft onto ground so survivors could exit a/c
C	Cabin crew	~20	instructed px re OW exits, passed out wet towels, breathing instructions,	reduced inhaled smoke dosage for some survivors, led to rapid opening of OW exits (65)
B	Captain	29	aircraft came to a stop at 1920	enabled evacuation of survivors
B	Captain	~29;30	evacuated self	evacuated safely via cockpit window
A	FO	~29:30	evacuated self	evacuated safely via cockpit window
D	FA1	~29:10	opened L1 door	7 px + 2 FA evacuated through t this door (34)
E	FA3	~29:10	opened R1 door	1 FA evacuated through this door(34)
F	px ?1	~29:15	opened RFOW exit	4 px evacuated through this window (34)
G	px ?2	~29:15	opened RAOW exit	1 px evacuated through this window (34)
H	px ?3	~29:30	opened LFOW exist	6 px evacuated through this window
!	firefighters	~29	arrive at aircraft	no discernible effect on survival
		~30:10 to 30:40	flash fire swept through cabin 60-90 seconds after exits were opened	(23 unevacuated passengers perished)
I	firefighters	~30	initiate external attack	no discernible effect on survival
I	firefighters	~31	initiate interior attack	no discernible effect on survival

* t_o = time flush motors in lavatory circuit breakers tripped, or 18:51, which is first signal of fire that was discernible by any interveners.

Cranbrook BC

Of 49 persons on board when the aircraft crashed, 7 survived. The official report states the airport crash truck arrived near the site within 5 minutes, but offers no data or conclusions about emergency response achievements. In that accident, an individual operating a snow plow on the runway was also the Crash Fire Rescue person on duty, and had to return to the airport fire hall to get the fire truck, arriving at the site with the Airport Fire Chief about 5 minutes after the crash. They found some individuals wandering in the snow outside the aircraft, with burn injuries or still on fire, and during rescue efforts, one of the rescuers clothing caught fire. Some individuals were led away from the wreckage, injured, but it could not be determined whether any of the rescued survived, or whether they survived by their own actions. Others reached the site shortly after the fire fighters, but there is no record of their actions.

The official report of this accident did not provide sufficient data to develop the loss history curves, but the accident was noteworthy for our study from another perspective. A personal communication described the response actions of one of the first on-scene rescuers at the crash site, The difficulties in locating and accessing the crash site, the scope and severity of the crash and fire, and the complexity of passenger rescue activities in the snowy crash/fire environment resulted in the "one-on-one" rescue of self-evacuated individuals in distress by those able to get to this remote scene, and made fire fighting efforts impossible.

Photo of Cranbrook crash site

In any deliberations about rescue activities these kinds of impediments must be recognized, as for example, when considering rescue equipment and staffing requirements for larger aircraft in distress, which might land at or near any airport, as demonstrated by the Sioux City example and others.

Dallas/Fort Worth NTSB/AAR-89/04

This accident involved an aborted takeoff of a Boeing 737, and came to rest about 3,200 feet beyond the departure end of the runway. The flight was airborne approximately 22 seconds from liftoff to the first ground impact near the ILS localizer antenna. The airplane was destroyed by impact forces and the post-crash fire. Of the persons on board flight 1141 12 passengers and 2 crewmembers were killed, 21 passengers and 5 crewmembers were seriously injured, and 68 passengers sustained minor or no injuries.

The report contains an attempt to estimate the number of lives saved by fire blocking materials on the seat cushions in this aircraft, and concluded that the fire blocking materials added about 90 seconds to the time the forward cabin remained survivable, and that "a number of lives were saved because the seat cushions were covered with fire blocking material." This is reported as an intervener D in the summary of interveners, actions and results in this accident.

The report has little detail about the evacuation of the passengers following the crash. The information available is summarized in the Table 8.

Table 8 Summary of interveners, actions and results
1988 Dallas-Fort Worth Aborted Take-off Fire

(94 of 108 occupants survived)

	Intervener	t_o+ (min)*	Intervention actions	Results
A	DFW Control tower	~.5	notified DPS of crash	began notifications that may have helped some injured survivors live
B	px	>~1	used fuselage breaks for up to 4.3 minutes	at least 45 evacuated selves and survived (Figure 8)
C	px	>~1	opened or used various exits	as many as 46 evacuated selves and survived
D	fire blocking seat covers	>~1	forward cabin remained survivable "longer"	helped unknown number of px to survive
E	FF	~4.3	arrived at crash site	knocked down fire within 5 minutes, after px self evacuated
F	Physicians	~46.5	arrived at scene	? began treatment of injured victims, one of whom later died
E	FF	?	rescued flight crew from cockpit	3 injured survivors rescued

- t_o = 0900:35.3, at sound of first impact.
- px = passenger, FF= firefighters
- last exiting px was hit by foam @4:20 after accident

Sioux City NTSB/AAR-90/06

This accident was of interest because of the survival of so many occupants in an apparently devastating crash. It involved the high speed crash landing, breakup and fire of a severely impaired DC-10 aircraft carrying 285 passengers and 11 crew members, not normally scheduled to land at this airport. 164 occupants survived this very severe crash and fire. One passenger reportedly reentered the wreckage and rescued an infant. Other survivors apparently self-evacuated the wreckage. The Safety Board was unable to determine whether attempts by firefighters to rescue potential survivors would have been successful after the crash because of the rapidly deteriorating survival conditions. The report provides some information about the injuries and evacuation, but details about the survival actions of the passengers were insufficient to develop a summary of intervener actions or a T/LA chart. The Safety Board "believes that the initial mass application of foam to the cabin section of the inverted fuselage facilitated evacuation of the ambulatory survivors. The Safety Board was unable to determine whether attempts by firefighters to rescue potential survivors would have been successful after the crash because of the rapidly deteriorating survival conditions." In the absence of information to the contrary, it is assumed all the passengers self-evacuated the damaged aircraft.

While survival and intervention actions were not fully described, it was noted the accident illustrated an unusual situation that must be considered in selecting emergency response protection levels for airports. In this case, the Sioux Gateway Airport is an "Index B" airport under 14 CFR 139. The airport "Index" is based on the size of scheduled air carrier aircraft that normally use that facility and the average daily departures of airplanes--in this case--DC-9, B-737, and B-727-100 series airplanes., and is used to determine ARFF capabilities at the airport. DC-10 airplanes are not normally scheduled to land at Sioux Gateway Airport and require the use of an "Index D" airport, which recommends more than twice the quantity of firefighting extinguishing agents required of an "Index B" airport.

Further complicating the response in this accident was the last minute change in the runway selected under diress by the aircraft crew for the landing, and the location of a large section of the aircraft cabin in a cornfield with high corn stalks.

Los Angeles NTSB AAR 91-08

While landing, a B 737 collided with a Metroliner with 12 occupants on the runway, and slid to a stop against an abandoned airport fire station. Fire erupted during the crash dynamics. When the B-737 care to rest, ambulatory passengers and crew members attempted to self evacuate .

The report states that "the emergency response for this accident was timely and effective. The close proximity of Fire Station 80 to the accident site, coupled with the rapid response of the ARFF units, facilitated personnel efforts to apply extinguishing agent to the external fires, and to assist some of the passengers in egressing from the B-737. The Safety Board believes that these factors reduced injuries and saved lives." It then mentions that sufficient personnel also allowed the extrication of the first officer, while protecting him from fire. Additional life-saving actins by emergency responders not identified.

The report describes a delay in opening the right overwing exit prompted by the passenger who "froze" and the subsequent altercation involving two other passengers significantly hampered the evacuation to the extent that additional passengers who may have been able to escape did not.

While the report contains incomplete data to permit development of the T/LA chart, the table summarizing reported intervention actions and their results for 57 of the 66 survivors was prepared as part of the analysis effort, and is shown below.

Table 9 Summary of interveners, actions and results
1991 On-airport Collision and Post-crash Fire
(66 of 101 occupants in two a/c survived)

	Intervener	t_o+ (sec)*	Intervention actions	Results
	none	~20	none	all occupants of Metroliner perished during collision dynamics
	FAR1	~30	opened R1 exit door	2 px and FAF1 self evacuated
	px?`	~30	opened L	2 px self-evacuated
	px11D	~40	opened ROW exit	37 px self evacuated
	FAL2	~45	opened L2, R2 exit doors	15 px + FAL2 self-evacuated
	firefighter	~120	extricated First Officer from cockpit	Injured First Officer was unable to self evacuate
	unknown		unknown	9 of 66 survivors not reported; probably self evacuated

t_o= 18:006:59, the time of the first impact.; all subsequent times are estimated.

FA = cabin flight attendant and station

LaGuardia NTSBIAAR-93/02

This accident involved a stall on takeoff, crash and fire of USAir flight 405, a Fokker 38-4000, after an attempted takeoff at night from runway 13 at LaGuardia Airport, Flushing, New York. 24 of 51 occupants survived. The airplane came to rest partially inverted at the edge of Flushing Bay and parts of the fuselage and cockpit were submerged in water. After the airplane came to rest, passengers stated that several small residual fires broke OUI on the water and on the wreckage debris. The report does not provide sufficient detailed information about the survivors' actions and times involved to permit development of a summary of intervention actions or a T/LA chart.. Passengers stated that they escaped through large holes in the cabin, indicating they self evacuated themselves from the damaged aircraft. The lead fight attendant and first officer escaped through a hole in the cabin floor near the flight attendant's position. Several passengers reported assisting others out of the cabin and into the knee-deep water. Many of then walked in the water to the dike, climbed up the wall and over an embankment. and slid down a steep hill to the runway. Others were assisted out of tile water by ground personnel. The report does not describe specific instances where ARFF personnel's rescue efforts resulted in saving any survivor's lives,.

Interveners included ARFF personnel who arrived in the area about 4 minutes after the notification to initiate fire fighting efforts. Port Authority rescue boat divers entered the water about 2220 and did not find any passengers alive in the water or in the airplane. The Safety Board concluded that the emergency response was effective and contributed to the survivability of the airplane's occupants.

Little Rock NTSB AAR 01-02

At 2350:44, in a severe storm, a DC-9-82 (MD-82) with 2 flight crewmembers, 4 flight attendants, and 139 passengers, crashed after it overran the end of runway 4R during landing at Little Rock National Airport in Little Rock, Arkansas. 134 occupants survived the crash and post-crash fire.

The report identifies 70 of the occupants, four of whom died, who either self evacuated the wreckage, were thrown out of the broken fuselage during the crash dynamics, or were removed from the wreckage by responders. These actions are summarized in Table 10 below. The report is silent about intervener actions and their results with respect to the other occupants. Thus the data are insufficient to prepare a full loss and intervention history.

Source: NTSB Report AAR 01-02

This accident introduced a different kind of "evacuation" and intervention to the study, in that passengers were physically ejected in their seats from the broken fuselage during the crash dynamics. Seven passengers were ejected from the forward opening (four of whom survived) and 5 were thrown through a midsection gap between fuselage sections (four of whom survived.)

Table 10 Summary of interveners, actions and results
1999 Landing Overrun and Post-crash Fire
(134 of 145 occupants survived)

	Intervener	t_o+ (sec)*	Intervention actions	Results
	structure for 21L approach lighting system	5	induced fuselage openings during crash dynamics	ejected 7 px in seats, 4 surviveds ejected 6 px in seats, 5 survived 3 px self evacuated through openings FA1 rescued by px through opening FA2 self evacuated through opening FA3+ 4 px self evacuated through opening near aft galley door
	px 1	~40	opened L fwd OW exit	not used to evacuate because of fire
	px 2	~40	opened R fwd OW exit	4 px self evacuated through exit
	px 3	~30	opened L rear OW exit	4 px self evacuated through exit
	px 4	~30	opened R rear OW exit	26 px self-evacuated through exit
	FA4	~60	opened tail cone exit	12 "people" escaped through opening
	rescue workers	540+	extricated First Officer from cockpit	Injured First Officer was unable to self evacuate
	rescue workers	540+	roved "xome" px from from first class section	indeterminate number of px removed from wreckage,

Hong Kong PRC AFJ v2-2

An MD-11 with 315 occupants crashed while landing during typhoon weather conditions about 18:45, flipping on its back and coming to rest inverted, with a ground fire breaking out during the crash. 3 passengers died, and 211 others were reportedly taken to hospitals, "many" with burn injuries. An official report of the accident was not available for this study, so the accident could not be analyzed for this study. Information about the accident was published in other media, which were reviewed for data.

While articles in fire service-oriented publications and proceedings described the rescue efforts in terms of what the responders did, and mentioned a search of the cabin interior after the fire was extinguished, the data to evaluate the results of the response effort are not presented in the format needed for this study. Reported times are inconsistent, but suggest that the fire was extinguished in about 15 minutes after the crash. [23]One article mentions that rescuers removed one fatally injured passenger from the wreckage and assisted 20 others from the fuselage over a 40 minute period.[24] No mention is made of the crew or their role in the evacuation. The rest of the passengers apparently self-evacuated. No further detail is offered to objectively assess the self evacuation or the assistance provided by the crew or responders.

Thought the number of survivors was very high in this crash, it is not analyzed in this study.

Taipei ROC Taiwan ASC AAR-02-04-002

A 747 –400 with 179 occupants crashed into construction equipment and runway construction pits at night during an attempted takeoff on a partially closed runway during heavy rain and winds, broke up and was totally consumed by post crash fire. 4 cabin crew members and 79 passengers died, and 71 other occupants were injured. The report discusses the survival and emergency response actions in extensive detail, without describing the timing of their actions, but also reports some inconsistencies and gaps in the information about survivor actions and rescue efforts. Information about the survival of 57 passengers was not available. Since the survival record is incomplete for our purposes, no attempt was made to generate an Summary of Intervention Actions or T/LA chart for this accident. .

Fire Fighters reportedly rescued three severely burned passengers (who had self evacuated) at the IL door area, and also rescued several passengers who jumped out the forward cabin to the left side of the aircraft. It appears the cabin crew helped evacuate the rest of the survivors, or they self-evacuated from the broken tail section. While the report addresses medical services, no data about the results of their intervention needed for this analysis were reported.

Discussion Of Results

The work confirms well recognized views about the importance of timely crew and passenger intervention when aircraft accidents occur. On the other hand, the work may challenge other generally held views about ARFF intervention in accidents. Almost all the survivors in the survivable accidents self-evacuated from damaged or burning aircraft. Whether this small set of examples is representative was not considered or determined, because the intent was to determine if responses could be evaluated in specific incidents.

This study used the goal of saving lives as the primary measure of performance in the accidents studied. One of the difficulties this exposed was the determination of the effectiveness in injury reductions efforts after evacuation from the aircraft was accomplished. This needs further work.

The lack of data needed to evaluate the degrees of success of ARFF actions in specific cases, and the difficulties developing loss histories on which to base such evaluations, was apparent from the examples in this study and referenced standards. In those few examples where judgments about ARFF performance were offered in a report,

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[23] *Aviation Fire Journal*, Vol 1:4, September/October 1999, page 7

[24] Critchdon, G., *Aviation Fire Journal*, Vol 2:2, May/June 2000, page 4

this lack of data raised questions about the criteria or rationale used to make the evaluations, since the criteria were not reported.

The many types of aircraft emergencies on or near airports are well recognized, and further reinforced by the examples examined here. Response demands also vary widely, adding to the challenges in trying to determine optimum or adequate or minimum rescue and firefighting response capabilities to provide at airports. Presently, the principal criterion for determining the response capabilities provided is the length and width of the aircraft normally using the airport, with other demands like facility fire protection considerations providing supplementary criteria.

The range of emergency types is readily discernible by what happened in these few examples. Vagaries of the weather, severity of a crash, location of the accident site and the environment in which interveners must act, nature of the aircraft and its passenger load, and time of day all affect response results. In aviation accidents with fire penetrating an intact the cabin interior, the risk of potential loss of life is high because of the rapid lethality of the combustion products accumulating inside cabin and the heat generated by the fire, severely diminishing opportunities for timely rescue from cabin interiors by arriving responders. Contributing to this risk is the near total reliance on cabin crew and individual passengers to achieve rapid self evacuation from the passenger areas of the cabin, as shown by each of these examples. The aircraft crews and passengers constituted the first on-scene interveners in every case studied.

The Summary of Interveners, Actions and Results Tables, developed during this study from a few existing reports, offer one way to document actions by interveners, and their results, and the loss history curves graphically illustrate the results. One of the questions that arose during the study was who might be tasked to collect the data needed to assess response performance. While some questions about the specific data, to collect, such as the injury exposure and treatment effects, require further study, the data do permit identification of the interveners and their actions which made a difference in the outcomes of the accident processes. But, who should capture and report such data?

Another question about performance assessment also was noted in one of the reports. That is the question of how to assess the performance of intervention initiative such as improving seat materials or floor emergency lights, for example. Both were addressed in one of the reports studied but the objective assessment question was not resolved. While that question was beyond the scope of this study, the time/loss matrix framework may help to identify, from the shape and position of the loss history curves, what effect a particular safety change may have had on the loss history. Alternatively a time history of the change in survivability might be helpful in trying to assess the value of these aircraft accident survivability improvements.

In summary, the study indicates it would be useful for all stakeholders in the ARFF capabilities decision to

- recognize the lack of historical data to support objective intervener performance evaluations in future accidents;
- change ICAO and national accident survival reporting requirements to report at least Summary Tables of intervention actions and the results they achieved, in the form reportedl;
- change passenger training approach to improve reliability of overwing exit opening by passengers when cabin environment becomes contaminated during accidents; and
- work out who should be tracking response results routinely, and how to report those results.

Addendum

During the curse of the study, the range of locations where accidents occur, from on airports to remote areas away from airports, and the differing levels of capabilities available to respond, suggested a public policy question about passenger equity in crash response capabilities. From the perspective or passenger risk bearing equity, do occupants of aircraft which happen to crash away from airports or at small remote airports deserve the same level of protection as passengers in accidents on larger airports with facility ARFF capabilities? No attempt was made to address this issue in this study, but the results observed suggest a need to initiate a dialogue about what constitutes interveners and their relative roles in reducing passenger risks in aircraft incidents.

End.