THE MEDICAL AND BIODYNAMIC INVESTIGATION OF FATAL AIRCRAFT ACCIDENTS

by

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INTRODUCTION

Powered flight became a practicable proposition in the early part of this century, and as flying increased in amount, so did the accident rate. During the First World War it reached such a peak; with the loss of large numbers of men and machines, that a special organisation was set up to deal with the problem. From this early beginning in the United Kingdom a fully independent investigating authority grew up, which enjoys the backing of parliament, whilst working under the International Civil Aviation Organisation's rules; which it helped to inaugerate (1).

In the 1950's Coroners in the United Kingdom began to take a greater interest in aircraft accidents, following the first full scale forensic study of an air crash (2). Later the loss of two Comets in the mid 1950's gave the necessary impetus, world wide, for the formation of Departments of Aviation Pathology, the first of which was set up at the Institute of Pathology in Royal Air Force Halton. Cooperation between civilian and military experts in the United Kingdom is now so good, that both are regarded as essential for a satisfactory investigation.

This paper presents a description of the way in which aircraft accidents are investigated in the United Kingdom, and by reference to an analysis of a series of accidents, illustrates the rationale behind each step taken.

METHOD

Because accidents are complicated and no one can be an omnibus expert, a team approach is used. The members and disciplines involved vary according to the circumstances, but usually the following people form the nucleus of an investigating team:

1. An Inspector of Accidents Operational: Usually a former senior airline pilot, who is still current on some types of aircraft. He considers the flying aspects of the investigation.
2. An Inspector of Accidents Engineering: An aeronautical engineer with special training in crash analysis.
3. A Forensic Pathologist who will direct the whole of the medical investigation.
4. A Forensic Odontologist: He is responsible for dental identification and may evaluate head injuries.

5. A medical technician to assist the latter two team members and arrange for the collection, packaging and transmission of any specimens.

Thus a wide range of professions is covered. The pilot is the team leader, with the emphasis resting firmly on the word team. Because only a small number of people are involved we tend to know one another very well and acquire some knowledge of each others speciality, thus we can work together with greater ease and confidence.

When a fatal accident occurs to a British registered aircraft, the Accidents Investigation Branch of the Department of Trade are informed. They may then request the assistance of an RAF Pathological team. In the United Kingdom, Coroners and Procurators Fiscal have been advised by the Home Office that we are available, but the final decision as to who should perform the task rests with them.

The actual pattern of working depends upon the individual and the circumstances. I prefer; in ideal circumstances; to see the body in-situ, but this is rarely practicable, for obvious reasons. If not, then I like to see the wreckage and then do the autopsy, others work the other way around. The choice is entirely one of personal preference. Further inspection of the wreckage may be made at any time.

A full autopsy must be done and if practicable specimens taken for histological and toxicological examinations. The medical findings are then considered in the light of:

1. The circumstances of the accident e.g. Where were they going? What were the weather conditions etc.
2. The personal and medical history of the pilot, including his flying experience.
3. An examination of the wreckage and equipment.

When this has been done a report is prepared and submitted to the appropriate authority, paying special attention to:

1. Was there a medical cause for the accident?
2. Were there any features of the aircraft and its equipment which rendered them hazardous?
3. Is there a lesson to be learnt from the accident?

ACCIDENT ANALYSIS

A thorough examination was made of 48 fatal aircraft accidents, involving a wide variety of aircraft types, all of which had been investigated by the Department of Aviation Pathology at RAF Halton (Table 1). The injuries sustained by 51 bodily regions were scored separately, using the scheme shown in Table 2. A special study was then made of those victims who had suffered only mild injuries. Forty-six victims were excluded from the analysis because of inadequate information. This was largely for reasons beyond our control, such as non-recovery of bodies, or extensive post-mortem injury, unrelated to the impact, consequent on prolonged immersion in water, or other agents. The results of this analysis are presented in tabular form.

Total number of accidents	48
Total number of victims	217
Total number of survivors	14
Adequate data for analysis	171

TABLE 1 DETAILS OF THE SERIES

	Bodily part	Overall
No injury	0	0
Mild injury	1	0-50
Moderate injury	2	51-102
Severe injury	3	103-153
Fatal injury	4	154-204

TABLE 2 METHOD OF INJURY SCORING. Injuries to each of 51 different bodily regions or organs were thus scored.

SCORE	KILLED	SURVIVED	NUMBER
0 - 10	1	13	14
11 - 20	5	-	5
21 - 30	10	-	10
31 - 40	8	-	8
41 - 50	8	-	8
51 - 60	7	-	7
61 - 70	9	-	9
71 - 80	11	-	11
81 - 90	11	-	11
91 - 100	6	-	6
101 - 110	5	-	5
111 - 120	4	-	4
121 - 130	1	-	1
131 - 140	-	-	-
141 - 150	2	-	2
151 - 160	1	-	1
160 +	69	-	69
TOTALS	158	13	171

TABLE 3 INJURY SCORES OF ALL VICTIMS

VICTIM NUMBER	SCORE
3	4
11	2
40	4
48	1
49	0
50	3
74	0
75	5
76	0
72	2
92	3
93	5
TOTAL 12 Victims	29

TABLE 4 INJURY SCORES IN SURVIVORS

Average score for survivors 2.416

VICTIM No.	CAUSE OF DEATH	SCORE	COMMENT
42	Asphyxia/incineration	8	
47	Drowning/concussion	11	
7	Drowning	13	
182	Drowning	14	
14	Asphyxia	15	Bystander
91	Head Injury	16	
71	Drowning/concussion	20	
181	Ruptured Heart	22	
180	Drowning	22	
177	? Judicial hanging/Ruptured heart	23	
73	Drowning	23	
159	Drowning	24	
78	Head and Neck Injury	27	Poor cockpit design
156	C1/2 Dislocation	27	
4	Head Injury	29	
26	Head Injury	29	
55	Asphyxia/Head Injury	31	
72	Drowning/Head Injury	35	
68	Asphyxia	35	
62	Haemorrhage/Ruptured Heart	35	
60	Head Injury	35	Due to Whiplash
87	Head Injury	36	
164	Multiple Injuries	37	
37	Head Injury	38	
16	Haemorrhage	42	
20	Head Injury	42	
155	Head Injury	42	
160	Multiple Injuries	44	
43	Haemorrhage/Ruptured Aorta	44	
23	Asphyxia	48	Lived $2\frac{1}{2}$ hours
39	Multiple Injuries	49	
44	Haemorrhage/Ruptured Aorta	49	

TABLE 5 CAUSE OF DEATH IN 32 VICTIMS SUSTAINING MILD OVERALL INJURY LEVELS

Restraint Failure	12 Victims
Survivable Accidents	10
Possibly survivable	1
Survivors	1
Range of Scores	13 - 96
Average	40.09

TABLE 6 RESTRAINT FAILURE

CAUSATIVE:	Probably one pilot. Very bad psychiatric history and severe coronary artery disease with extensive myocardial fibrosis.	
CONTRIBUTARY:	One middle aged male with extensive coronary artery disease may have collapsed over the co-pilot's controls.	
COINCIDENTAL:	Fatty liver	- 7
	Sarcoidosis	- 3
	Emphysema	- 3
	Extensive coronary Artery disease	- 3
	Pulmonary Fibrosis	- 2
	Myocardial Fibrosis	- 1
	Myocarditis	- 1
	Duodenal Ulcer	- 1
	Healed Tuberculosis	- 1
	Pulmonary Oedema	- 1
	Borderline Vision	- 1
	Pulmonary Fat Embolism	- 14

TABLE 7 ESTABLISHED DISEASE PROCESSES FOUND IN 31 PEOPLE, 15 OF WHOM WERE PILOTS; SOME HAD MORE THAN 1 DIAGNOSIS. Fat embolism included for completion as an illustration of the value of histology.

CAUSATIVE:	1.	Blood alcohol 313 mgm%
	2.	Blood barbiturate level 26 mgm% - probably the cause of accident
COINCIDENTAL:	1.	Two pilots in the same aircraft had slightly raised blood alcohol levels

TABLE 8 RELEVANT TOXICOLOGY RESULTS WITH REGARD TO ACCIDENT CAUSATION

DISCUSSION

Aircraft accident investigation has developed apace with aviation, indeed there is evidence to suggest that the gap between research and development, rests with the manufacturers (3). There are fewer crashes in the air than there are on the roads and despite the high workload in investigating them, a comprehensive enquiry into the causes and effects is a more practicable proposition in every case. This random sample of fatal crashes represents the type of workload regularly seen at RAF Halton.

The scoring method used is simple and was chosen in preference to more comprehensive systems; such as the AIS; because they do not cater for the often massive injuries seen in this field. It may be necessary to give an answer quickly, and when dealing with large numbers of casualties, a simple system has considerable appeal.

A number of interesting features emerge from a study of the data produced in this analysis. Perhaps the most important from a flight safety point of view, is the fact that there would seem to be greater value in looking more closely at those accidents, or victims, where the injury score is less than 50. Scores above this usually indicate a destructive impact, often at high speed and a higher incidence of severe multiple injuries may be recorded, thus the chances of remedial action by designers is limited.

Those who survived suffered little or no injury, like those in an earlier series (4), even when victims in the same aircraft who died, were severely injured. It is difficult to see why this should be so, especially when they are compared with the injured victims in wholly survivable accidents (5,6).

Eight people in this group of victims, who sustained only mild overall injury were drowned, 5 of whom had an associated head injury, which may have rendered them either unconscious or incapable of reacting quickly and correctly to an emergency situation. Irregularities in the usage of adequate safety equipment were observed in 4 of these cases. One accident was particularly interesting because 3 people died, whilst the remainder were almost totally uninjured, in a low velocity ditching accident, thus highlighting the potential dangers of this situation.

Five people died of asphyxia, one of whom was trapped in her burning house by the wreckage of a crashed aeroplane. Characteristically they all sustained a greater degree of injury, than did the previous group, their average injury score being 27.4 as opposed to 20.25. This suggests a higher impact speed, with greater deformation of the wreckage, producing incapacitating injuries.

Similarly death due to either head injury or bleeding is associated with higher average injury scores (31.55 and 38.5). Again considerable destruction of the airframe and site is seen.

In most accidents the principle accident forces are along the longitudinal plane in the fore - aft direction (4,7,8), their characteristics depending upon:

1. The velocity of the aircraft
2. The angle of strike
3. The nature of the surface struck
4. The structural characteristics of the aircraft
5. The site at which the forces are measured.

High velocity impacts are obviously associated with widespread destruction of the aircraft and its contents, thus at a virtually instantaneous velocity change from 400 kts IAS to 0, only fragments of each may be found. Although it is difficult in many crashes, to get an accurate idea of the velocity change at impact, estimations have been made in some instances, from which it seems that the range of 50-150 kts is the most interesting.

As the angle of strike increases, so does the magnitude of the longitudinal acceleration, until such time as the airframe begins to crush, when energy is absorbed in structural deformation. One consequence of a high angle of strike is cartwheeling; a comparatively unusual occurrence, which is characterised by a considerable loss of forward speed. Indeed, up to 45% of the translational velocity produced is either lost as friction or converted into rotational energy. Thus, in this situation, there is considerable danger of 'ejection' and a high degree of structural deformation.

Airframe configuration and strength; as measured by the ability to absorb energy; are extremely important in the context of crash behaviour. Because of the need to withstand quite large pressure differentials, the hulls of pressurised aircraft need to be much stronger than those of non-pressurised aircraft. Forces capable of tearing the cabin apart, may be produced when engine nacelles are placed on wings which are mounted high up on the fuselage. If the latter are fixed low down, with engines or fuel pods protruding from the lower surfaces, then these may dig into the ground, causing slewing and tearing of the fuselage. Thus as well as the primary accelerations, further peaks may be produced. Where the wings are placed further aft a long nose cone is produced, which can fold over in a crash crushing the occupants.

When an aircraft hits a ground-mounted obstruction, any deceleration so produced is dependent upon the ratio of the strength of the aircraft and the object. If the latter breaks, then the rate of deceleration produced decreases as the mass of the aircraft increases, because the braking force is constant. If it does not break, then the outcome depends upon the strength of the part of the aircraft struck and the mass of the aircraft.

Thus far the discussion has largely been restricted to longitudinal acceleration/decelerations, but vertical forces must not be forgotten, for they may, and indeed do, have a profound effect upon the outcome of a crash. Their magnitude varies considerably, depending upon the aircraft's motion. Thus when an aircraft strikes the ground, such as in an unflared crash landing, the impact pitches the fuselage up, forcing it to rotate about a lateral axis, until its path is parallel to the slope of the ground. Using high speed cinematography, it has been shown that the nose's trajectory changes more rapidly than the remainder. Therefore vertical accelerations are greatest at the impact point, decreasing as the distance from it increases. NACA have shown that up to a distance of 155 inches from the impact a linear relationship exists, thereafter the rate of decrease increases, particularly at the tail. One other effect of the angle of strike can be seen here, for as the angle increases so does the amount of vertical acceleration. This only holds for impacts up to 35° though, after which there is a significant decrease, and at about 75° vertical accelerations are zero. At this point, the resultant of the forces, vertical and parallel to the inclined surface, approximate the aircraft's trajectory. Thus there is no component which is tending to raise the plane.

It can be seen from the above, that there are many potential sources of injury in an aircraft crash. These may be summarised thus:

1. Being crushed within a collapsing frame
2. The absence or failure of restraint
3. Entrapment within the wreckage
4. Injuries associated with escape
5. Being struck by loose objects
6. Explosive decompression

The crushing of victims within a collapsing airframe is typically a feature of high velocity impacts. Characteristically the injuries are severe, ranging from total fragmentation to extensive soft tissue and skeletal damage. A high proportion of limb amputations is seen and the whole body looks as though it has been crushed. Perienal splitting, with or without herniation of viscera and wide fracture dislocations of the sacro-iliac joints is synonymous with vertical deceleration.

Entrapment within the wreckage is a rather different problem, with potentially equally serious sequelae being responsible for many deaths in otherwise survivable situations. The victims are trapped either because the exists are jammed due to distortion, or lack of maintenance, or they sustain injuries which render them immobile. In two accidents, not analysed in this study, which were investigated by this department, these features were well documented. Both were accompanied by fire, which was the immediate cause of death of many of those who were killed. In the first case the seats concertined and a bar at the bottom of the seat caused fractures of the tibiae and fibulae in many of the victims, thus they were unable to get to the emergency exits; many of which were unused. In the second incident 5 people died out of a total of 127. They were all trapped by fire near an inoperable exit. Thirty-eight people sustained minor injuries as a result of falls during egress.

Injuries associated with restraint systems have been the subject of considerable debate, some of which has been as ill-informed as it was ill-advised. Antagonists frequently attribute injuries to the safety belt without any acknowledgement of the fact that without them the extent and severity of damage would have been greatly increased. Restraint systems may be adequate or inadequate. Snyder reports an author who suggests that we have 40G people sitting in 20G passenger aircraft riding on 9G seats. Restraint may fail at the following sites:

1. The belt itself
2. Its attachments
3. The seat mounting
4. A combination of the above

Failure occurs either because the forces involved are excessive, the materials and design are defective or the tolerance limits are inadequate. Failure to wear a safety belt cannot rightly be concluded to be an example of failure, but the effects are the same; though at lower impacts. The chances of being thrown clear of the wreckage is greater here and with it goes a six-times increase in the possibility of dying (9). If there is a malfunction of the harness, then a distinct pattern of injuries may be produced (10) in which injuries of the head, thorax and abdominal viscera predominate. This was certainly the case in this series.

Survivors trying to escape from wrecked aircraft may sustain musculo-skeletal injuries due to falls from heights. Many escape chutes and emergency exits are not fireproof and exits become blocked as the fuselage distorts. Ejection seats and capsules pose their own peculiar problems, largely out of the scope of this paper. When unaffected by buffeting fracture of T11-L1 are seen in escapees using seats, whereas those using capsules suffer damage in the upper thoracic region (11). Above 470 kts IAS flailing may be seen with fractures at C4-5 (12), whilst entanglement with parachute lines can produce torsional skin damage and fractures.

Anything which becomes detached during flight may strike occupants or seats, which may be detached, augmenting the forces involved. Skull fractures and penetrating soft tissue damage are frequently seen in this situation.

Sudden changes of pressure are mostly well tolerated, there are very few cases of death resulting from this alone. The principle hazards are hypoxia and turbulence. Perhaps the classical lesion is a ruptured ear drum without skull fracture.

Initially the assessment of injuries in fatal accidents is largely concerned with establishing the cause of death, so that the various legal requirements can be fulfilled. In many instances the phrase 'multiple injuries' is used. Whilst this is scientifically valueless, it does have the advantage of being a convenient device for hiding the true picture from bereaved relatives. A catalogue of horrifying injuries will not help them in any way. It may though, be difficult to decide which of a number of potentially lethal injuries actually killed the individual. It is therefore of considerable advantage to know what force is needed to produce a particular lesion, how quickly it kills and whether or not it is treatable.

Attempts to answer questions such as these may be facilitated by considering patterns of injury thus:

SIMILARITIES	DISSIMILARITIES
a) Same accident	a) The same accident, (i.e. the odd man out)
b) Different accidents	b) Different accidents

The value of injury patterns in the interpretation of a sequence of events can be seen if two dissimilar accidents are considered; both investigated by the Department (Table 9). In the first instance this was a manifestly survivable accident, yet many people died. The other was obviously not survivable, and only a few bodies were found as the accident occurred over the sea.

INJURED REGION	NUMBERS INJURED A	B
Lower Limb	45/64	12/12
Face	18/64	12/12
Spinal	22/64	12/12
Lap Belt Injury	8/64	10/12
Survivable	YES	NO

TABLE 9 COMPARISON OF TWO DISSIMILAR ACCIDENTS

Thus in B it would seem that everyone knew that there was an emergency, because the lap belts were fastened during a phase of flight, which would not at that time have warranted it. In the second accident, failure to survive occurred because the seats collapsed, breaking the tibiae and fibulae of the victims. That is there was a tie-down failure; pure seat failure being associated with femoral injuries, rather than damage to the lower leg.

From a study of injuries sustained by all the victims in this series, it would seem that the high incidence of injuries to the head, thorax and abdomen has a simple basic mechanism. Most light aircraft and all passenger seats are only equipped with a lap belt; though pilots in the UK must now wear a lap and diagonal belt. Therefore in the predominant fore-aft impact, because belts are loosely fastened, the victim moves forward, taking up any slack in the belt, they then rotate over it, hitting their heads and possibly the thorax against the seat in front (or instrument panel), with hyperextension of the spinal column.

The value of a medical examination of the victims of aircraft accidents goes beyond the problem of the injuries and their causation, providing a unique opportunity to study the pathology of trauma, arrested disease and youth. It also enables us to monitor the processes of medical selection and surveillance of aircrew. This has been reviewed elsewhere (12), here only a brief summary of the principles will be given. If we consider only aircrew and the part which a disease process, found at autopsy, may have had in the causation of accidents it can be seen that it may be either causative, contributary or coincidental. To cause an accident the disorder must be either immediately fatal or incapacitating. For it to contribute to the cause, it should impair the pilots ability to fly the aircraft at all times. To fulfil all the requirements stated above a full autopsy and histological study must be undertaken, since disease may be macroscopically or microscopically detectable. Table 7 summarises the findings in this series. From this and other surveys it can be seen that the private flyer is the greatest health risk, since he is not selected and his medical surveillance is less stringent. The problem with commercial pilots is that they are getting older, but they are selected, so their problems tend to be centred around asymptomatic diseases. Military flyers are usually young, fit, highly selected and very carefully monitored individuals.

Studying the histology of trauma has been a little disappointing (13). Nevertheless it can be extremely valuable indicating the time of death and sequence of events, particularly when fat, liver and bone marrow emboli are sought for and found.

Toxicological studies can be of incalculable value. The finding of carbon monoxide may indicate an in-flight fire or heater failure, or suggest post-crash survival. Alcohol tends to be a greater problem in countries other than the UK (14). Nevertheless in one case (Table 8) alcohol was clearly indicated as an accident cause. Drugs may be in the body for a variety of reasons. Though pilots should not fly whilst receiving medication, there may be circumstances in which this is permissible. In one accident; not reviewed here; a back calculation on prescriptions, drugs held and the toxicology results, indicated that a man, who had undisclosed epilepsy, could have had an attack which caused the accident. The evidence suggested that he had not taken his tablets, consequently he suffered an epileptic attack and there was no other logical cause for the accident.

CONCLUSION

The investigation of fatal aircraft accidents is an exacting science, which demands assiduous attention to minute detail, by every member of the team. From the results given in this series it can be seen that there is still greater need for improved passenger and aircrew protection. Seats and harnesses are in many cases inadequate. Because of the higher impact speeds a lap and diagonal belt may be inadequate. The lap belt provided for passengers is inadequate and the narrow spaces between seats means that most adults cannot adopt the prescribed safety position. Only by carrying out a full investigation; as outlined; can all the questions be answered, and more importantly can sensible, reasoned recommendations for the improvement of flight safety be made.

ACKNOWLEDGEMENTS

I would like to thank the Director General of Royal Air Force Medical Services for permission to publish this paper.

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