Department of Transport and Communications

Bureau of Air Safety Investigation

Wire strikes

A technical analysis

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SYNOPSIS

The number of wire strike accidents involving fixed wing agricultural aircraft has increased in the last decade, but the accident rate has remained constant. Of a total of 144 of these accidents, 20 were fatal. Post-impact fire was present in 65% of all fatal accidents.

Most of the accidents occurred during low flying or spraying operations (85%), and the Cessna C-188 series accounted for the majority of the accidents as it is the most widely used aircraft in the industry.

Three broad categories were selected to categorise the point of impact with the wires. These were:

1 landing gear,
2 fin and/or deflector,
3 other parts of the aircraft, such as the wings and propeller.

Each of these categories includes four basic aircraft attitudes at the time of the strike, these being straight and level, climb, descent and turn. These can also be related to specific phases of flight.

In general, turning results in the worst outcome for the pilot, regardless of the wire strike location, whereas a straight and level attitude results in less injury.

The incidence of post-impact fire was mainly associated with aircraft which hit wires with either the landing gear, or parts of the aircraft classified as 'other', whilst in climb. However, fire was associated with a significant number of fatal accidents following a wire strike where the aircraft was in a turn at the time of the strike, when the aircraft struck with parts other than the landing gear, fin or deflector.

The majority of landing gear strikes resulted in uncontrolled ground impact, from which 64% of pilots escaped relatively uninjured. It was found that breaking the wires with present cutters did not necessarily increase the chances of survival. The effectiveness of landing gear wire cutters was not specifically assessed in this report as this aspect could not be generalised across the sample; however, the data suggest that the time and cost involved in the development of an improved landing gear wire cutter may not be justified.

Aircraft struck wires with the fin and/or deflector in 39 cases; 22 pilots were able to maintain controlled flight and land following such strikes. The incidence of fire was consequently minimized.

Striking the wires with one or both wings led to a higher percentage of fatally or seriously injured pilots than when striking with any other part of the aircraft. However, as a general rule, if the wires were broken following a strike with parts of the aircraft other than the landing gear, fin or deflector, the pilots had better chances of escaping relatively uninjured. Such strikes included propeller strikes which resulted in the wires being severed in most cases and provided relatively good protection for the pilot.

The survivability aspects indicated that 50% of fatal accidents were associated with a combination of cockpit failure and fire.

When considering only the Cessna C-188 series and the Piper PA-25 series aircraft, it was found that most fatal accidents were associated with post-impact fires, and Piper aircraft experienced a greater proportion of them. Its cockpit failure rate was also greater, and was associated with more seriously injured pilots. The seat frame failure rate was slightly higher with the Cessna C-188 series aircraft. Most of the Cessna aircraft accidents occurred whilst attempting to fly below the power lines, and in a considerable proportion pilots were able to land following the strike.

The data indicated an increase in awareness of the presence of the wires in the decade 1982-1990, despite the fact that a greater number of accidents was recorded for the period. The percentage of pilots who struck wires due to the factor 'lack of attention' decreased in the last decade, although this factor remains a major cause of accidents. An increase in 'misjudgment', primarily associated with the Cessna C-188 series aircraft, may be related to the high tail profile of the aircraft.

1.0 INTRODUCTION

Wires have long been recognised as one of the greatest hazards facing aerial-work pilots. The outcome of colliding with wires varies from being harmless to unforgiving. Australia averages 7.6 wire strikes each year. Some of these are fatal with aircraft either substantially damaged or completely destroyed.

Most research argues that human factors are largely responsible for wire strikes. Such literature notes the hazards of hitting powerlines whilst engaged in agricultural flying operations, and focuses on how to recognise, locate and avoid wires. A special agricultural issue of the *Aviation Safety Digest* (Bureau of Air Safety Investigation 1985) for example, recommends the following measures: self discipline; attention to briefings; reconnaissance and observation; memory and awareness; appropriate flying technique; and consideration of weather factors. Freeman (1988) explains why a pilot fails to see obvious clues such as poles. In a later work (1990), he identifies the 'extra hazard check' as vital to safe agricultural operations.

The nature of aerial operations makes it unlikely that wire strikes will ever be totally eliminated. But once such an accident has occurred and control of the aircraft is lost, the aircraft's design plays a substantial role in determining how well the pilot is protected.

This report consequently focuses on technical rather than human factors. As an engineering study, its main concern is to describe the technical aspects of a wire strike rather than the usual operational considerations of pilot awareness, weather, powerline markings, etc. Although the pilot's awareness of the wires normally constitutes an aspect of human factors, this study only includes a brief human-factors analysis, as specific problems could be identified and related to aircraft design. The point of interest is 'what happens' not prior to, but throughout the accident sequence. To this end, Australian wire strike accidents from 1972-1990 are analysed to identify patterns associated with the strike itself and the subsequent survival aspects. Knowledge of such patterns may help to reduce the severity of wire strikes in the future and to increase their survivability rate.

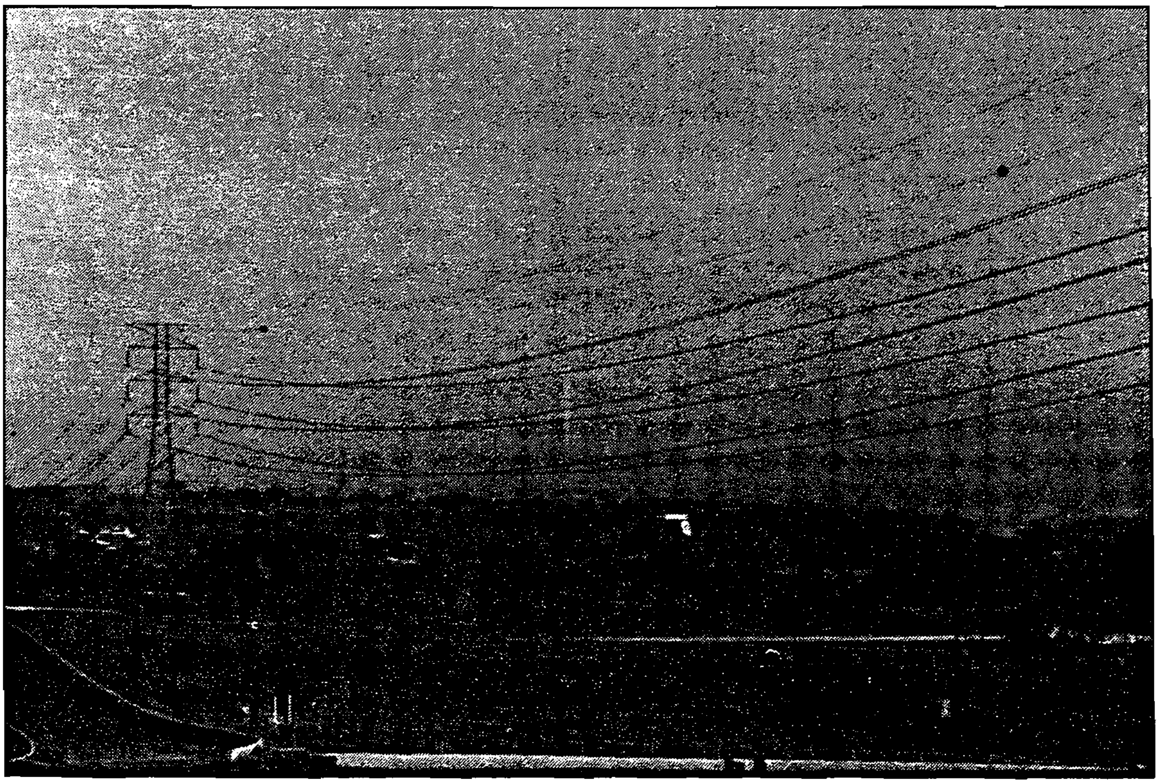

Photo Robyn Beatty Standards Australia

2.0 BACKGROUND

Aircraft specifically designed for agricultural purposes were in operation in the late 1950s, and Piper Aircraft Corporation was the first company to produce such an aircraft on a large scale basis, in the early 1960s. This model was followed in the mid-1960s by an aircraft which had been developed by Cessna. Both companies had identified the requirement for an aircraft which provided enhanced protection for the pilot. In addition, other special purpose aircraft types such as Grumman, Snow etc, were used for agricultural purposes as well as a wide range of aircraft modified and adapted to the agricultural role, such as the DHC-2, C-180, C-185.

The enhanced protection centred on, among other things, structural integrity, landing gear and windshield protection using wire cutters, and fin and rudder protection, achieved with wire deflectors. The companies also reviewed the crashworthiness of the aircraft in considerable detail and by placing the maximum weight forward of the pilot ensured that there was sufficient material to absorb energy in the event of a frontal crash. The crashworthiness of the agricultural aircraft such as the Piper Pawnee PA-25 or Cessna Agwagon rated as 60-70 as compared to a typical general aviation (GA) aircraft rating of between 30-50 (Noland 1986). These ratings are based on a crash survivability checklist which was developed by the Robertson Research Institute (Robertson 1988) which evaluated the restraint system, basic airframe integrity, post-crash fire potential, cabin environment and evacuation.

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What was apparent to those working in the agricultural industry was that although the increased crashworthiness lessened the severity of accidents, several modifications were required to the original designs and the pilot population needed to be constantly reminded about the dangers of hitting powerlines. Specific problems such as the post-impact fire potential, specifically related to the PA-25, were addressed. Extensive studies (Department of Civil Aviation [a]) were undertaken by the Australian Department of Civil Aviation—now the Civil Aviation Authority (CAA)—from 1961 to improve the fuel tank design and crashworthiness. Many proposals were put forward with, among others, the insertion of a flexible rubber cell within the existing fiberglass tank, which was granted approval in 1965. A subsequent analysis of accidents between 1974-1980 revealed that both Piper and Cessna aircraft displayed high post-impact fire rates (17% and 19.6% respectively), more than twice that of the overall rate for GA aircraft. Moreover, both showed increased fire rates following a wire strike accident compared to other types of accidents.

However, it was noted that the fire rate had improved with time for Piper aircraft, reducing from 24% between 1969-1973 to 17% between 1974-1980. A further review of Piper aircraft accidents between 1969-1986 revealed that the post-impact fire rate on aircraft without the fuel cell was 65%, whereas that of aircraft with the fuel cell was 38%. Following this, Piper Aircraft Corporation issued Service Bulletin SB 878 in 1988 making the rubber cell installation mandatory. Also, late in 1988, a concession was granted by the CAA to install a new improved crashworthy fibreglass tank.

Between 1966 and 1971 the Airworthiness Branch of Australia's Department of Civil Aviation (now CAA) undertook a study of wire strike accidents. This was followed by a major development program which aimed to produce a more efficient wire cutter (Department of Civil Aviation [b]). The development of the device was conducted over an eight-year period between 1972 and 1979, with the wire cutter being ready for manufacture in May 1979. However, because of the poor response from the industry, the cutter was never put into production. The reasons associated with the lack of enthusiasm were thought to refer to poor design of the attachment fitting demonstrated on the Piper PA-25 and the high initial cost. Long-term lack of stability of the propellant was also associated with the project being discontinued. The agricultural industry has not been alone in its concerns about the risks associated with wire strikes: the helicopter industry has also concentrated resources on attempts to eliminate them. The most popular protection device was the passive Wire Strike Protection System (WSPS) developed by the Bristol Aerospace Company in Canada (Aeronautical Accessories Limited n.d.). It consists of a double wedge cutter inserted between a saw-toothed cable deflector and a saw-toothed windscreen protector/cutter. The deflector guides the cables into the cutting wedges while inflicting damage to the cables. The windscreen protector/cutter, in addition to performing as the deflector guide, prevents the wires from entering the cockpit area. A recent study by Burrows (1980) concluded that 'the passive WSPS concept tested proved to be highly effective in protecting the OH-58 helicopter against mishaps caused by wire strikes'. Since its original inception, over 35 different kits has been developed for 50 different helicopter models (Bristol Aerospace Limited 1991). Other passive detection systems use lasers, a scanning process similar to radar, and sophisticated optical and infra-red systems. A paper by Potter (1981) specifies three wire-detection techniques comprising a millimetre-wave pulsed radar system, a passive 50Hz system operating on magnetic flux and finally a carbon dioxide laser radar together with a processing algorithm to highlight wire presence.

Active systems, which are capable of detecting cables that do not carry power, included the PRO-AV/British Aerospace Cable Warning System (CWS) which was developed in the early 1980s (Negrette 1990). The program of development was cancelled because the device could not meet its specifications.

Considerable investigation has not identified a suitably adapted detection device for fixed wing aircraft.

3.0 EXAMINATION

This section provides an overview of agricultural flying accidents involving wire strikes from 1972 to 1990. Section 4 reviews the types of powerlines involved in most accidents. Section 5 provides a detailed analysis of various scenarios surrounding wire strike accidents, whilst Section 6 identifies problem areas from the analysis results. Discussion of all issues raised in the study is found in Section 7, which is followed by the conclusions and recommendations.

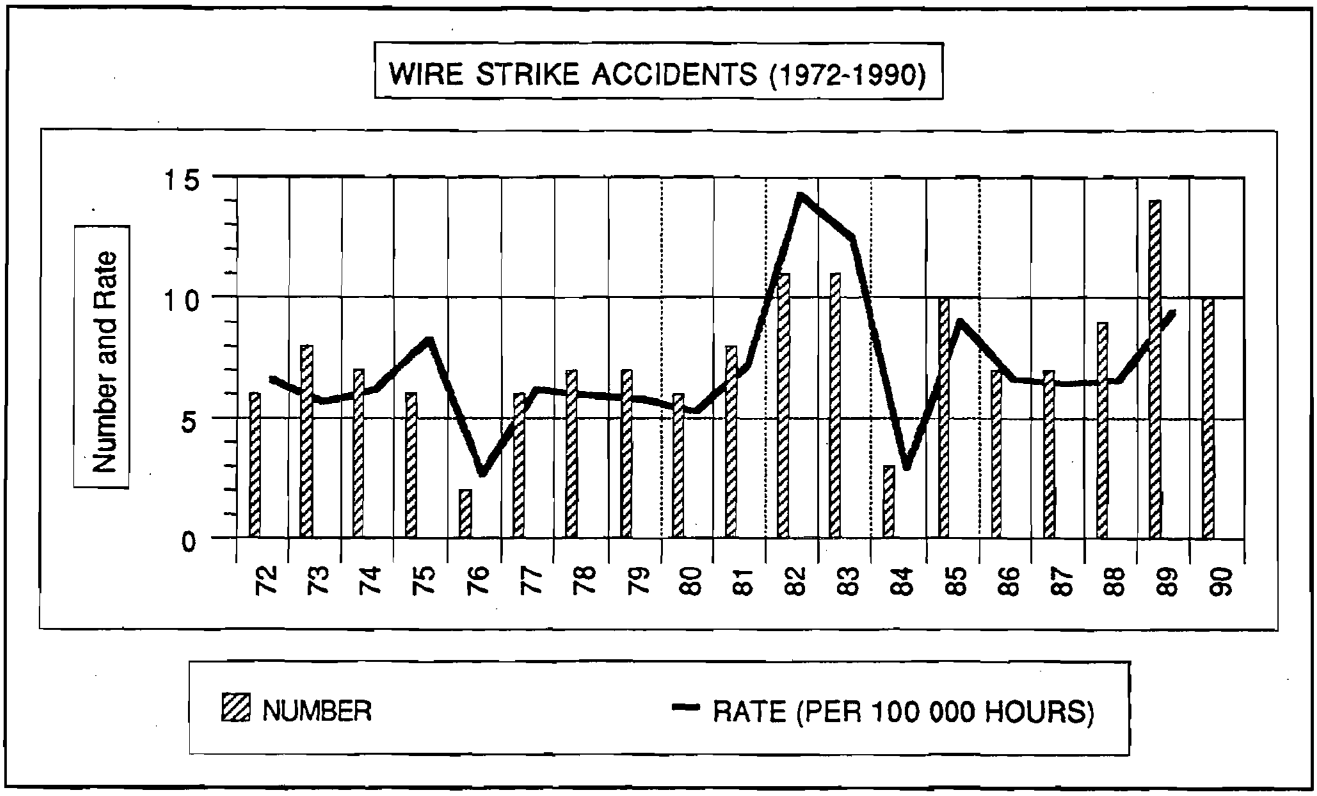
The analysis is based on 144 wire-strike accident investigation reports during that period. To facilitate analysis, a special database was created incorporating relevant parameters which are shown in Appendix A. The database ensured that information could easily be retrieved and manipulated in tabular form.

3.1 Number of Accidents

From 1972 to 1990 a total of 144 wire strike accidents were reported, of which 20 were fatal. The number of accidents per year ranged from two in 1976 to 14 in 1989 with an average of 7.6. The number of fatal accidents per year varied from zero to four with an average of 1.1.

Figure 1 displays the number of accidents per year along with the rate of accidents per 100 000 hours flown. The activity data was obtained from the Domestic Aviation Information Section, Department of Transport and Communications. It is interesting to note that although the number of accidents per year increased to a statistically significant extent over the time period under consideration, the accident rate remained stable, despite the years 1982 and 1983 when the accident rate peaked.

FIGURE 1



3.2 Injuries

The data show that 20 pilots were killed in wire strike accidents in the period under review. The injuries of 28 were classified as serious; 96 escaped either unscathed or with minor injuries.

3.3 Accidents by Aircraft Type

Information retrieved from the files revealed that the Cessna C-188 series and the Piper PA-25 series were involved in the vast majority of wire strike accidents in the period under consideration, accounting for 51% and 25.9% respectively. When the number of accidents for each type of aircraft was considered against the aircraft listed on the Civil Aviation Authority's Register of Aircraft it was estimated that approximately 28% of the Cessna C-188 series had been involved in an accident as compared to approximately 16% of the Piper PA-25 series. These figures were calculated by comparing the number of accidents with the mean number of these aircraft types listed in 1984, 1987 and 1990.

The breakdown of all the aircraft types under review in this report is found in Appendix B.

3.4 Accidents by Category of Operation

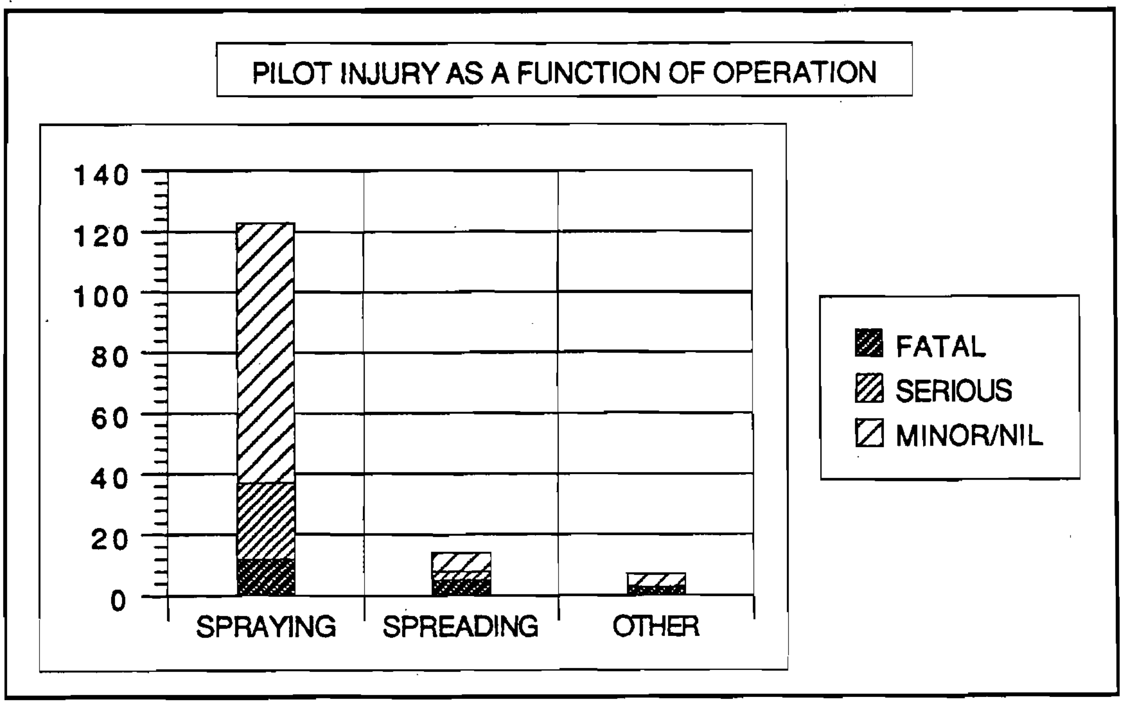
Agricultural operations for the purposes of this study were separated into those flying activities which were performed at or below the height of wires and those undertaken above wire height. These have been categorised as 'spraying' and 'spreading' respectively. Accidents which occurred while en route to or returning from the agricultural operation have been identified as 'other'. Additionally, accidents which occurred whilst the pilot was engaged in unidentified activities were also classified as 'other'.

Although it is recognised that different crop treatments require distinct flying techniques, these have not been addressed in this study.

When accidents were classified according to operation, it was determined that spraying accounted for 123 or 85% of the accidents, indicating that the vast majority of wire strikes occur in low-level flight. Fourteen accidents occurred whilst the pilot was spreading, with the remaining seven accidents being categorised as 'other'.

Figure 2 presents information once accidents are broken down according to operation and level of injury, and indicates that the majority of pilots escaped with minor or no injuries following spraying accidents

FIGURE 2



3.5 Categorising Strike Locations on the Aircraft

For the purposes of this study strike locations have been grouped into three broad categories: landing gear, fin and/or deflector, and 'other' i.e. locations such as wings, propeller, struts, fuselage and cockpit. The windshield wire cutter was not analysed separately as the number of occurrences involving this part of the aircraft was limited.

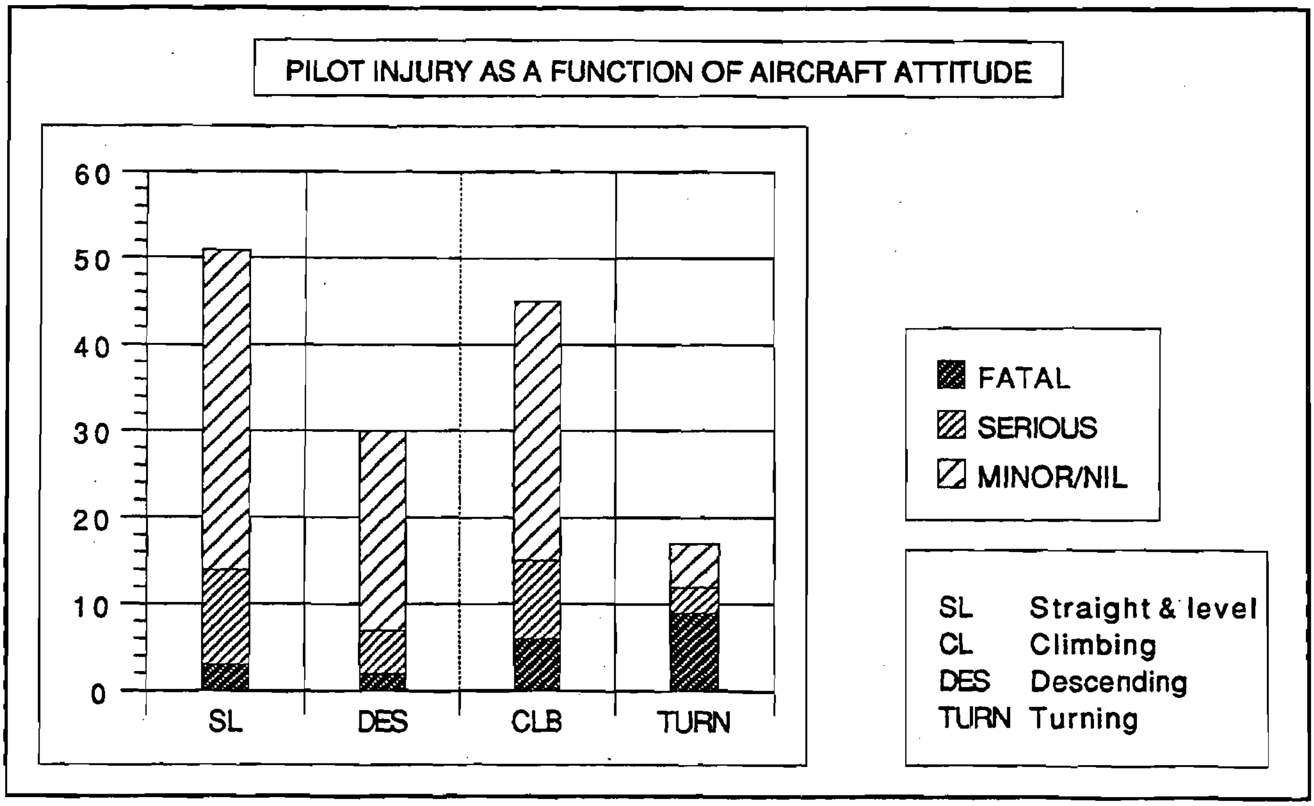
In 45 of the 144 occurrences investigated the aircraft struck the wire with either one or both of its landing gear legs, in 39 with the fin and/or deflector, and in 60 cases another part of the aircraft contacted with the wire. The distribution shows that the largest single category of occurrences involved parts of the aircraft other than the landing gear, fin or deflector.

3.6 Aircraft Attitude

The four main aircraft attitudes which were considered were straight and level, descent, climb and turn. Climbing turns were classified as 'climb'. These categories could also be related to specific phases of flights such as swath run, approach and descent, pull up and climb out, and procedure turn and positioning respectively.

Figure 3 indicates the number of accidents according to aircraft attitude and injury classifications within each attitude category. The results indicated that an approximately equal number of accidents occurred when the aircraft was in climb or straight and level flight, and that approximately two-thirds of all the accidents resulted in minor or no injuries.

FIGURE 3

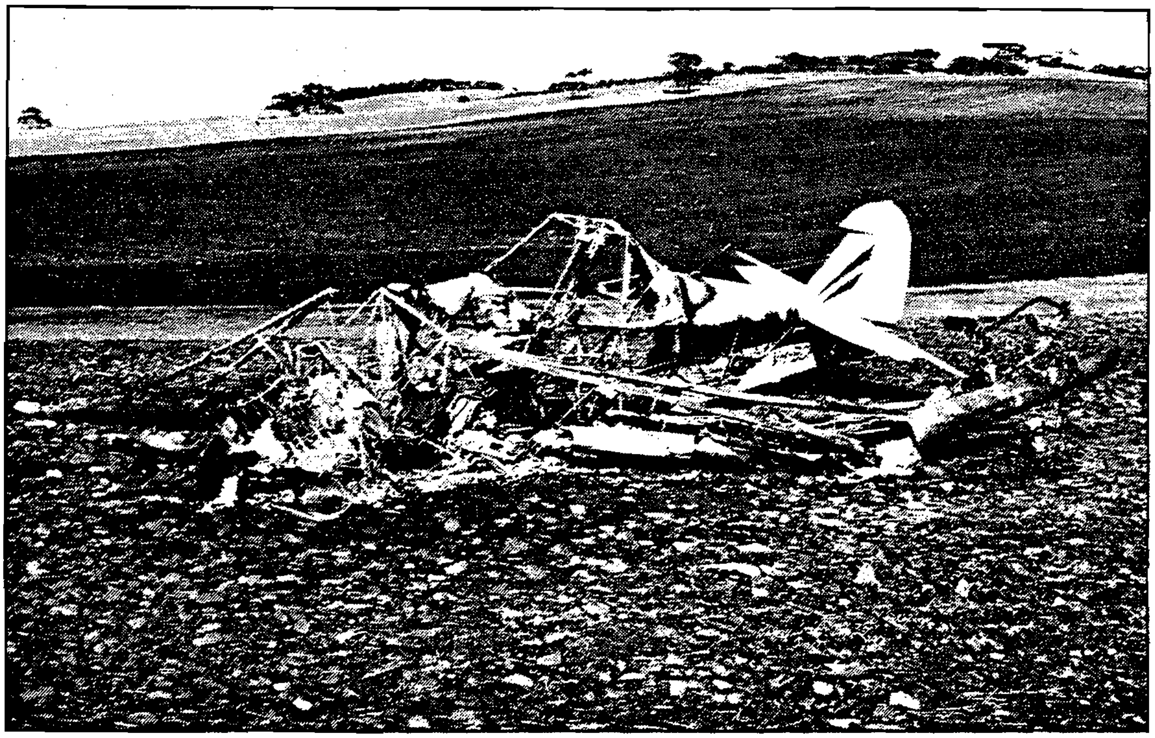


The various aircraft attitudes will be analysed in greater detail in Section 5

3.7 Fires

Post-impact fire is as potentially hazardous as hitting powerlines. A total of 35 occurrences involved a post-crash fire, 13 (37%) of which were fatal. Fire was present in 65% of all fatal accidents.

In five cases, it was established that ground impact following a wire strike was survivable but fire engulfed the cockpit area, eliminating the chance for the pilot to evacuate. The data indicate that in six known cases where fire was a factor, the pilots were not wearing protective equipment, e.g. helmet, shoulder harness, and/or protective clothing, resulting in higher degrees of injury, hence decreasing the chances of being able to evacuate the aircraft.



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Within the entire population, when the attitude of the aircraft was considered, the results indicated that fire was most often associated with accidents which followed an aircraft turning into the wires in 41% of the cases. Similarly, fire was present in 29% of all the accidents occurring in climb, in 20% of these in descent and in 17.6% whilst the aircraft was straight and level. However, far more accidents occurred whilst the aircraft was in climb, hence indicating a high incidence of fire within each category of strike locations.

3.8 Summary

In the period between 1972 and 1990 the number of wire strike accidents increased in absolute terms. However, the accident rate showed no such escalation. The majority of accidents involved the Cessna C-188 series and Piper PA-25 series, aircraft which were specifically designed for agricultural operations.

Most of the accidents occurred whilst in low-level spraying activities, with a vast majority of pilots escaping with minor or no injuries. It was found that the largest single category of accidents occurred when wires struck parts of the aircraft other than the landing gear, fin or deflector. When all accidents were considered, the greatest proportion occurred during climb or in straight and level flight.

Post-crash fire was established to be a major problem following wire strikes as fire was found to be associated with the death of the pilot in approximately two-thirds of the fatal accidents. It was also found that, in general, the incidence of fire was high following a wire strike by an aircraft in a climbing attitude and also following a turn.

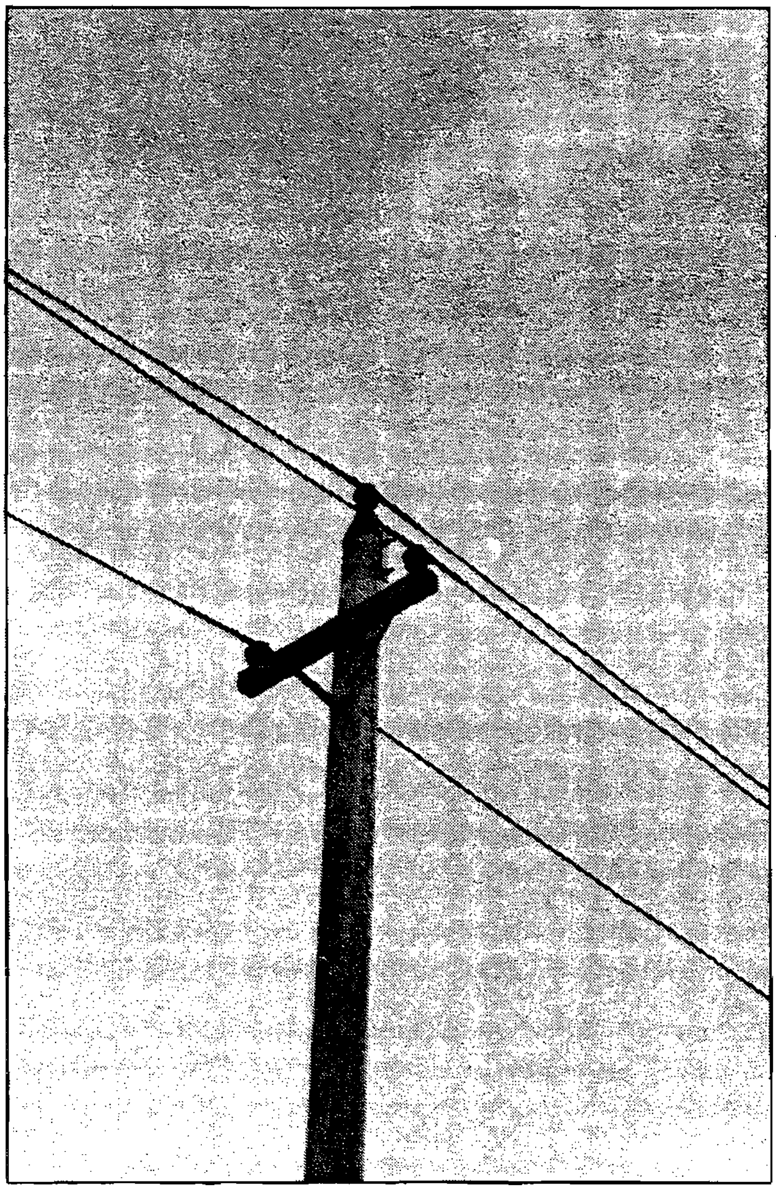
4.0 TYPES OF POWERLINES INVOLVED

The following section reviews the various types of powerlines struck in rural areas. For simplicity, the number of cables specific to each accident were not considered.

The most frequently struck powerline in agricultural areas was found to be a three-strand 2.75 mm diameter galvanized steel wire (3/2.75 GS), formerly a three-strand 12-gauge steel. This type of cable has a minimum breaking load of 2.2 kN (4 991 lbs) and a minimum ultimate tensile strength of 1.31 GPa (190 ksi). The line is normally used to carry 22 000 volts (22 Kv).

The number of known accidents involving this type of power line was 104, of which 17 were fatal. In 45 of the strikes involving this type of power line the wire was broken. However, in 14 cases the wire was severed by the propeller.

A detailed breakdown of powerlines which were struck is shown in Appendix C.



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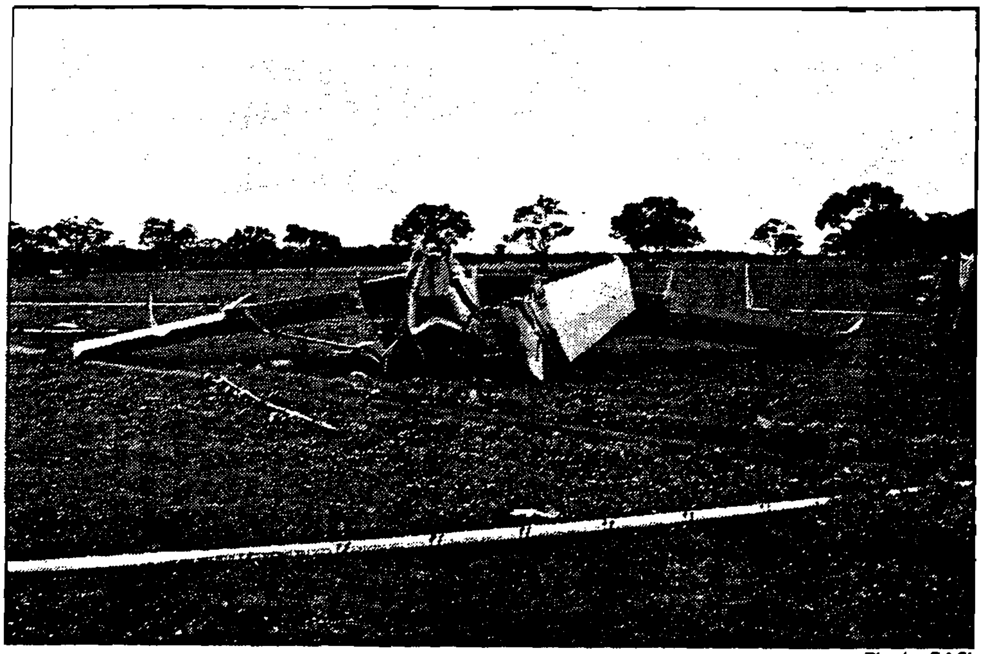
5.0 ANALYSIS

This section provides a detailed analysis of wire strike accidents, assessing various scenarios which have been identified. Parameters under review include: aircraft attitude, incidence of fire, breakage of wire, ability to land following a strike and the influence of the span length. The injury to the pilot was utilised as the factor by which the severity of the scenario was assessed.



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The first part of the section has been sub-divided into those accidents which involved contact with the landing gear, fin and/or deflector and other parts of the aircraft. Following this, patterns for the C-188 series and PA-25 series are discussed, along with the survivability aspects and the pilot's awareness of the wires.

For the purposes of this study, it was assumed that all the aircraft types display similar handling capabilities. It was not possible to consider the angle at which the aircraft hit the powerline as this information was not held on file. Other parameters which were excluded were the terrain, age and condition of powerlines, method of aircraft operation, and pilot experience and recency, as all are unique to each accident.

A comprehensive dynamic model of power cable collision was not undertaken as the information contained within the accident reports failed to provide sufficient data for appropriate modelling, and as such would require significantly more research in the field. Similarly, the effectiveness of landing gear and windshield wire cutters and wire deflectors was not assessed as this aspect could not be generalised.

5.1 Contact with the Landing Gear

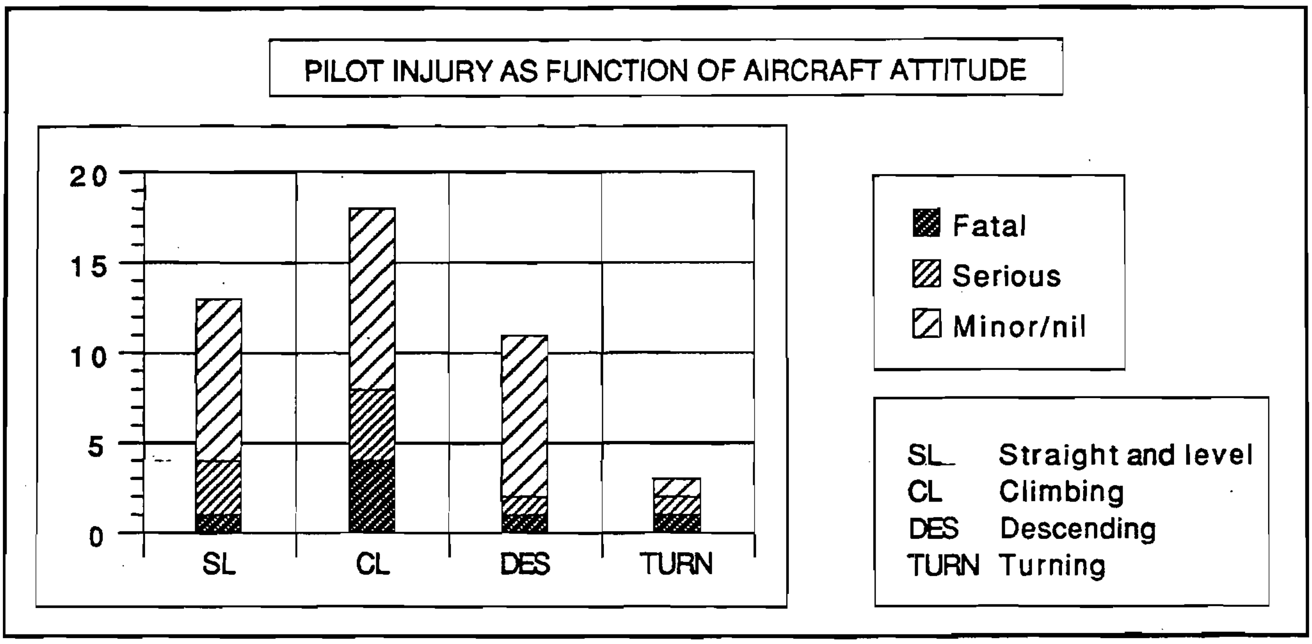
Within the sample, there were 45 accidents in which the aircraft struck the powerline with one or both of the landing gear legs as the primary contact point. Of these, seven were fatal, nine resulted in serious injuries and 29 in minor or no injuries.

5.1.1 Aircraft attitude

The attitude of the aircraft when it made contact with the wire was classified as follows: straight and level (sl), descending (des), climbing (cl), and turning (turn). It can be seen from Figure 4 that accidents which occurred whilst flying straight and level or in descent provided the lowest degree of injury for the pilot (69% and 55% without significant injuries respectively).

Striking powerlines with the landing gear whilst in a climb attitude was responsible for 18 accidents of which four were fatal.

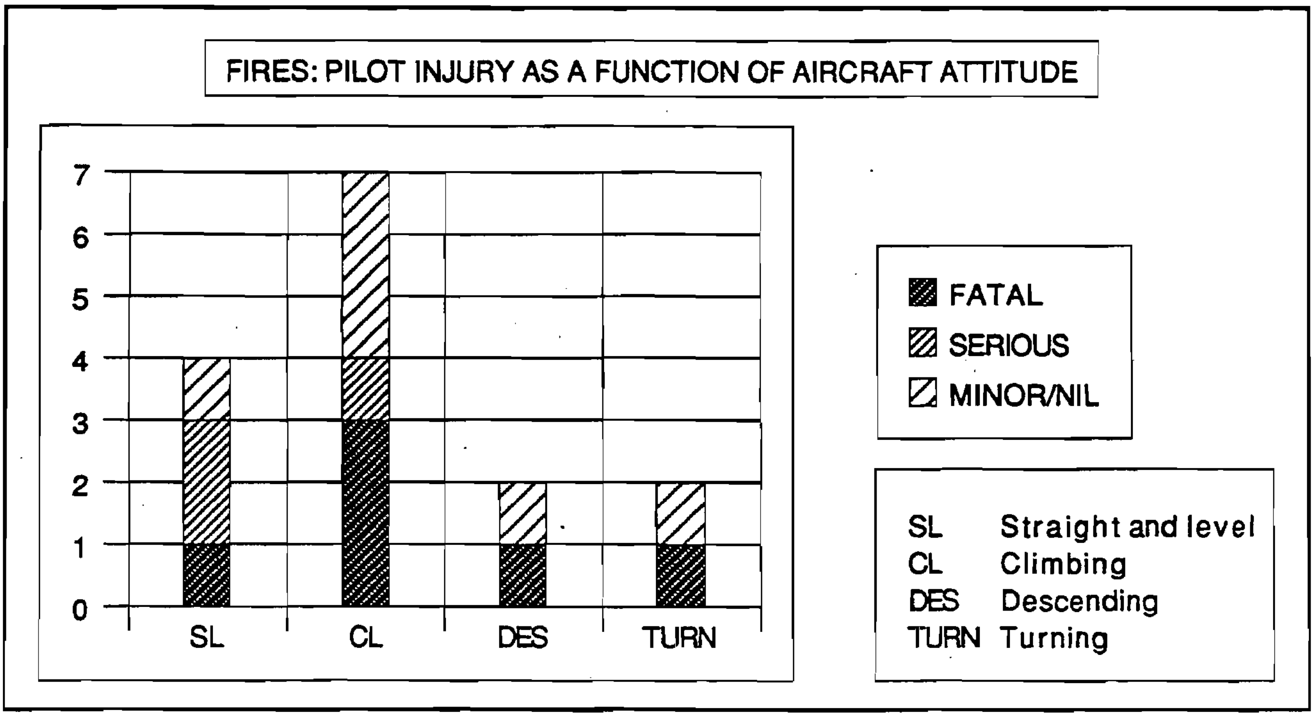
FIGURE 4



5.1.2 Fire

Of the 45 accidents where the primary contact was the landing gear, 15 involved post-impact fire (six of which were fatal), three pilots were seriously injured and six escaped relatively uninjured. It is interesting to note that accidents which occurred following landing-gear wire strikes whilst the aircraft was climbing had a high incidence of post-crash fire (see Figure 5).

FIGURE 5

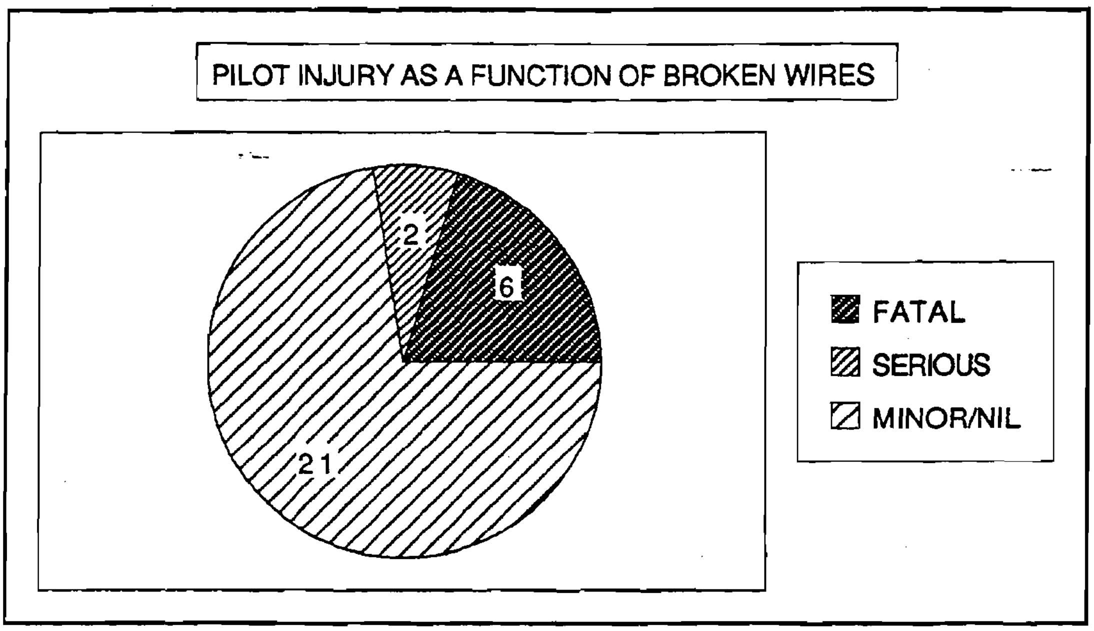


5.1.3 Wires

The same standard definition of 'broken' was applied to each report. To be defined as 'broken' the wire had to be severed rather than just pulled off the insulators. It should be borne in mind that if a conductor breaks following a wire strike, the location of the breakage may not necessarily correspond to that of the point of impact of the aircraft.

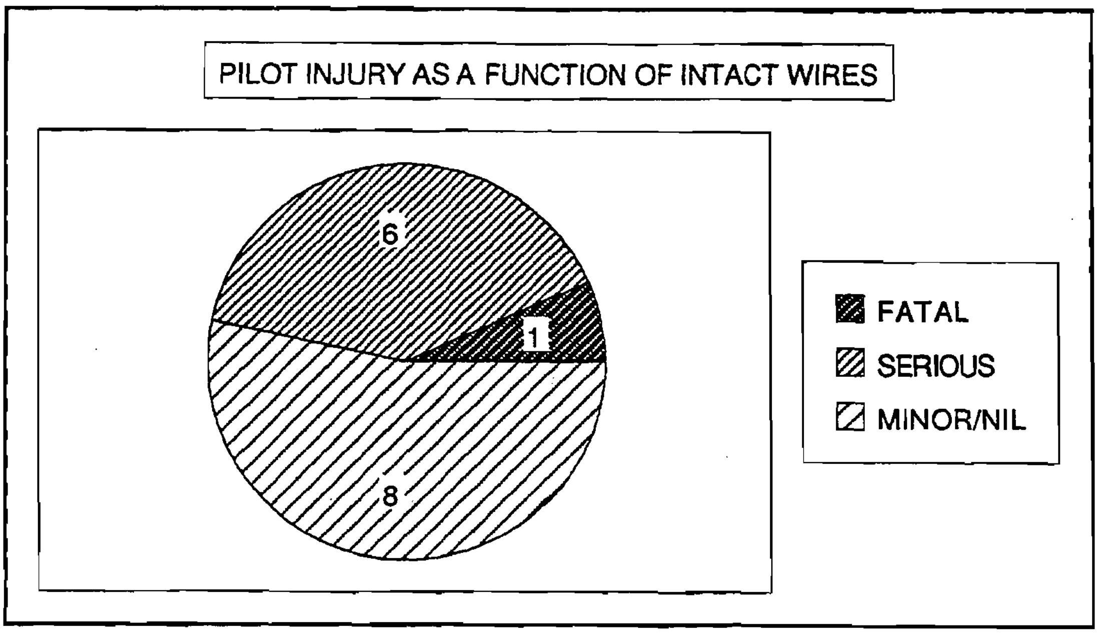
Figure 6 indicates that in 29 landing-gear strikes the wire was severed and in the majority of these cases the pilot escaped relatively uninjured. However, when the wire remained intact the injury io the pilot was on average more severe (see Figure 7).

FIGURE 6



There were 15 landing-gear cases in which the wire remained intact. These resulted in one fatality, six seriously injured pilots, and eight with minor or no injuries.

FIGURE 7



A further breakdown of the injury data was conducted in which the attitude of the aircraft was evaluated. This indicated that injury was avoided or reduced if the wire broke when the aircraft hit the wire whilst in descent or in straight and level flight. Conversely, if the aircraft was climbing at the time of the strike the pilot had a better chance of escaping with minor injuries if the wires remained intact. This breakdown is shown in Appendix D.

Overall it was concluded that breaking of the power cables by the landing gear did not necessarily increase the chances of survival.

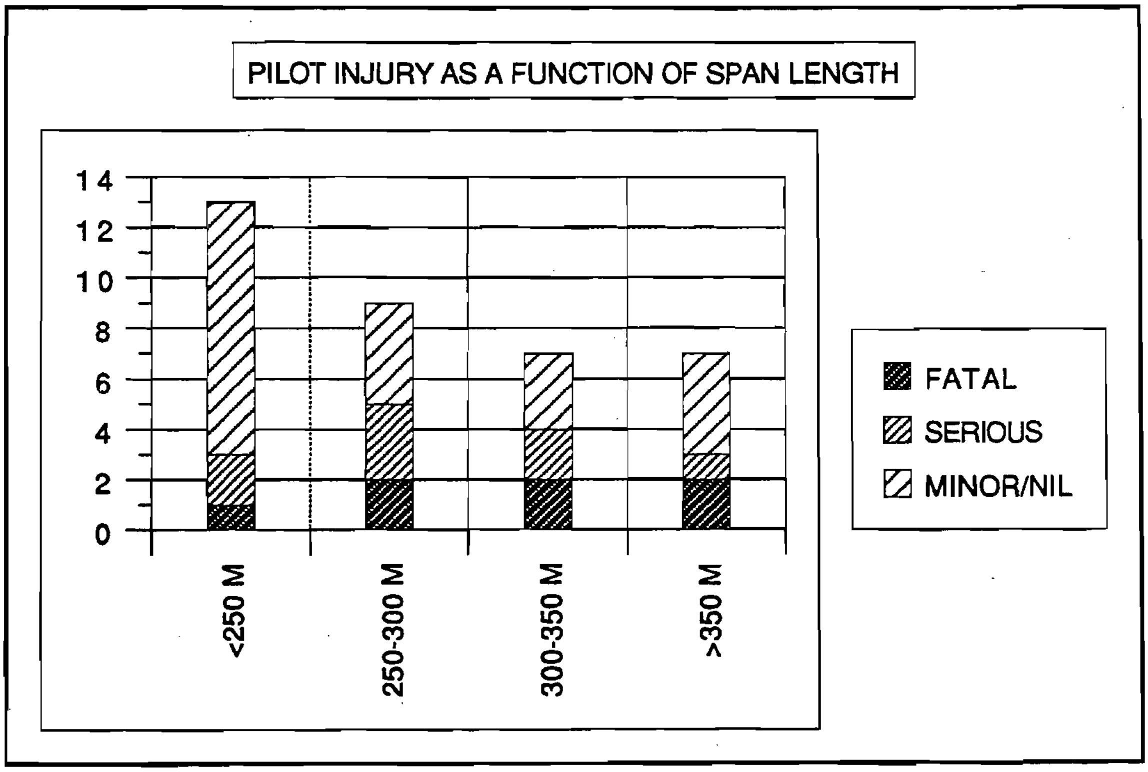
5.1.4 Ability to land following wire strike

Seven aircraft landed following the strike, four of which had been in straight and level flight at the time of the accident.

5.1.5 Span length

Other aspects that should be considered when analysing the dynamics of wire strikes include the type of conductor, span length and striking speed. To obtain a general understanding of the mechanics associated with colliding with wires, it was assumed that the speed of the aircraft during agricultural operations remained fairly constant and within the normal operating range of each aircraft type. A similar approach was made concerning the type of wires, due to a high degree of homogeneity within the database; consequently, span length of the wire was the only variable to be measured against severity of injury (see Figure 8).

FIGURE 8



Note: Cases were eliminated from the analysis if the span length was unknown.

The results indicated that the smaller span lengths tend to be more forgiving when the aircraft contacts the wire with the landing gear.

5.1.6 Summary

The most favourable outcome for the pilot following a strike at the landing gear was achieved when the aircraft was in a straight and level attitude. The majority of accidents involving strikes by the landing gear occurred when the aircraft was in a climbing attitude. This group also accounted for a higher incidence of fire.

In cases in which the wires had been severed, most pilots escaped relatively uninjured. However, paradoxically, the death rate was also higher. It was also found that the short span lengths caused less injuries.

5.2 Contact with Fin and/or Deflector

There were 39 cases in which the aircraft struck the wire with the fin and/or the deflector. Of these, 28 resulted in minor or no injuries, eight resulted in serious injuries and three were fatal.

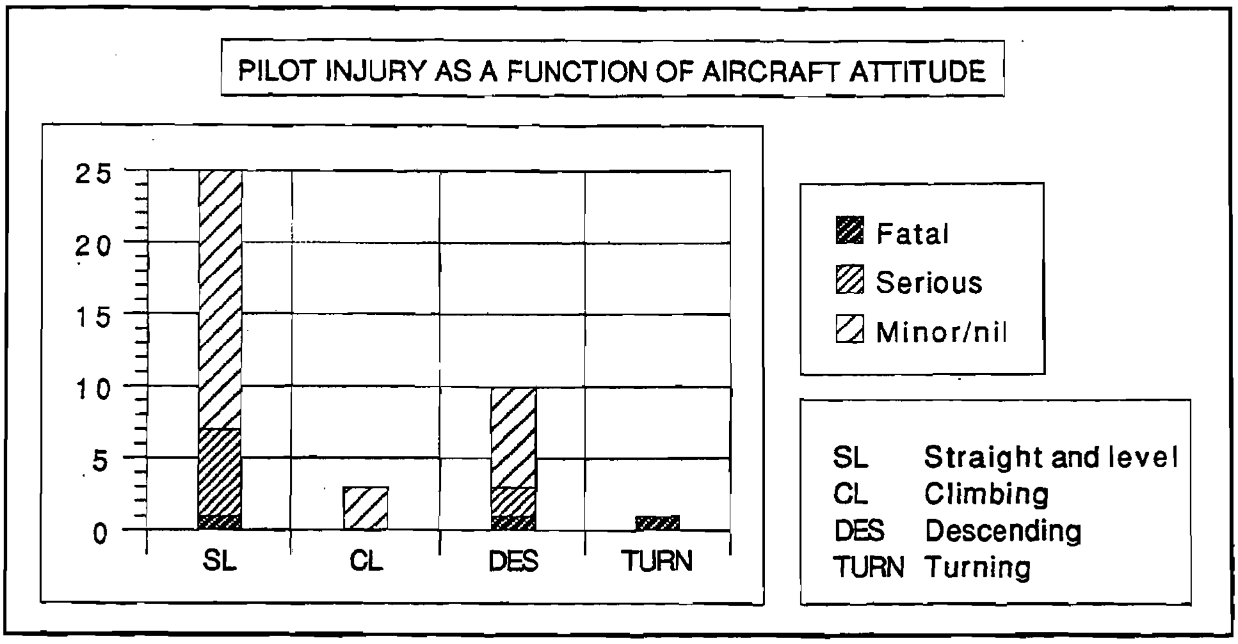
5.2.1 Aircraft attitude

Figure 9 depicts the breakdown of accidents according to aircraft attitude at the time of contact with the fin and/or deflector.

The analysis indicated that the majority of this category of accidents occurred whilst in straight and level flight (64%), with 72% of these pilots being either minimally injured or unscathed.

Of all the accidents involving straight and level flight, in 49% of the cases the contact was with the fin and/or deflector. Nearly half of these pilots escaped relatively uninjured (41%).

FIGURE 9



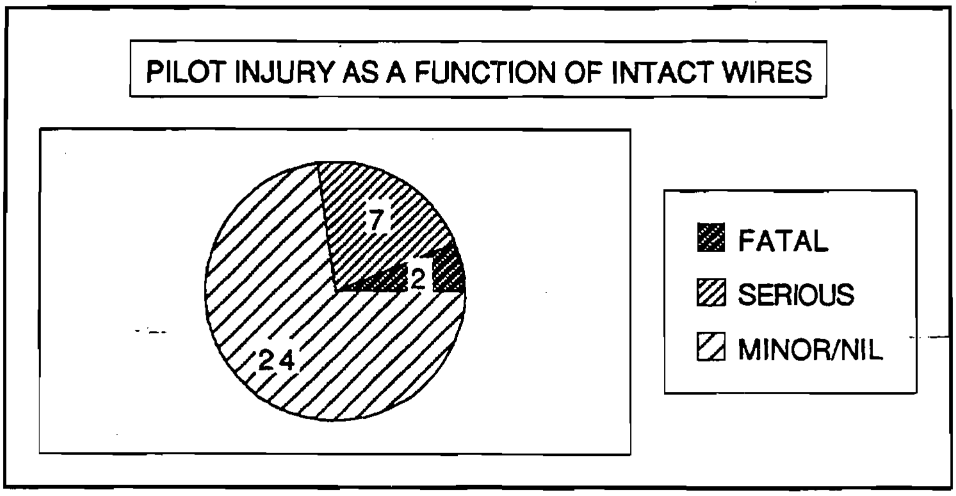
5.2.2 Fire

Four accidents in which the fin and/or deflector struck the wire resulted in post-impact fire, one of which resulted in the death of the pilot and two in serious injuries.

5.2.3 Wires

In the majority of the fin and/or deflector strikes, the wire remained intact (33 out of 39 cases). The majority of these led to minor or no injuries to the aircraft occupant (see Figure 10).

FIGURE 10

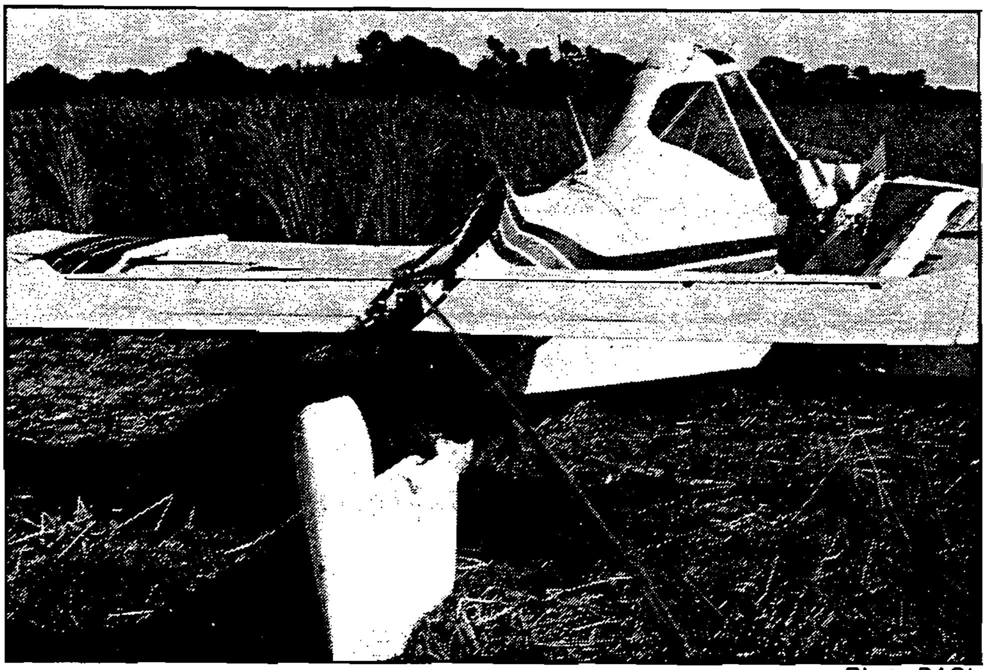


The number of aircraft which broke the wire after hitting it above the propeller arc is so small that the association between the aircraft attitude and the severity of injury to the aircraft occupant could not be meaningfully analysed.

5.2.4 Ability to land following contact

The majority (22) of the aircraft in the fin and/or deflector category were able to land following contact with the wire.

Fourteen of these aircraft had been in straight and level flight at the time of the contact. Fifty percent of aircraft which hit the wire whilst in descent (i.e. five), and all three of the aircraft which were climbing were able to land following contact with the fin and/or deflector.



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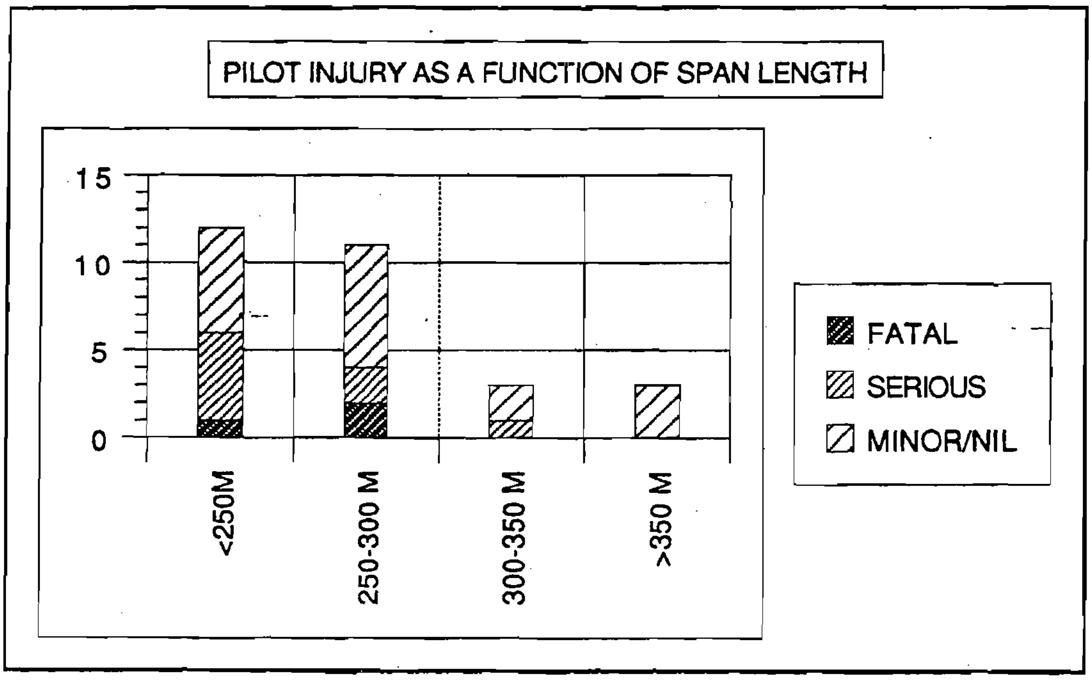
5.2.5 Span length

Figure 11 tends to indicate that a greater number of accidents occurred following strikes with wires of shorter span lengths.

FIGURE 11



Note: Cases were eliminated from the analysis if the span length was unknown.

5.2.6 Summary

The analysis revealed a high probability of the pilot escaping with minor or no injuries if the power line was struck by the fin and/or deflector. This is indicated by the fact that more than half the aircraft in this category were able to land following contact, which also minimized the incidence of fire.

The majority of accidents occurred in a straight and level attitude and this attitude was established to be the most favourable to the outcome for the pilot.

5.3 Contact with Other Parts of the Aircraft

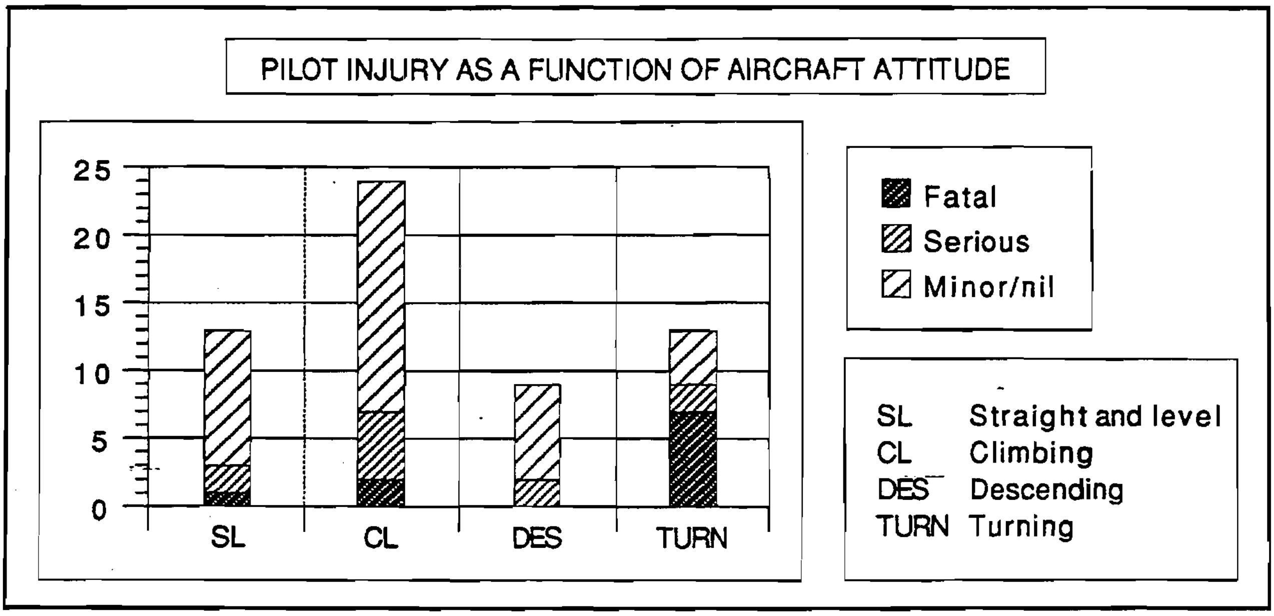
The remaining 60 aircraft struck the wire with parts of the aircraft which, for the purposes of this report, were classified as 'other'. In many cases these happened to be one or both wings. Of the 60 cases, 39 resulted in minor or no injuries, 11 in serious injuries and ten were fatal.

5.3.1 Aircraft attitude

Figure 12 gives the breakdown of accidents according to aircraft attitudes. The results show that the greatest number of accidents involving strikes by parts of the aircraft other than the landing gear, fin or deflector occurred whilst the aircraft was in a climb (40%). Analysis of injury according to the attitude of the aircraft at the time of the accident indicated that similar proportions were killed, seriously injured, minimally injured or uninjured when the aircraft was in climb or in straight and level flight.

Accidents which occurred whilst the aircraft was turning resulted in a higher proportion of deaths and accounted for 35% of all fatal accidents.

FIGURE 12



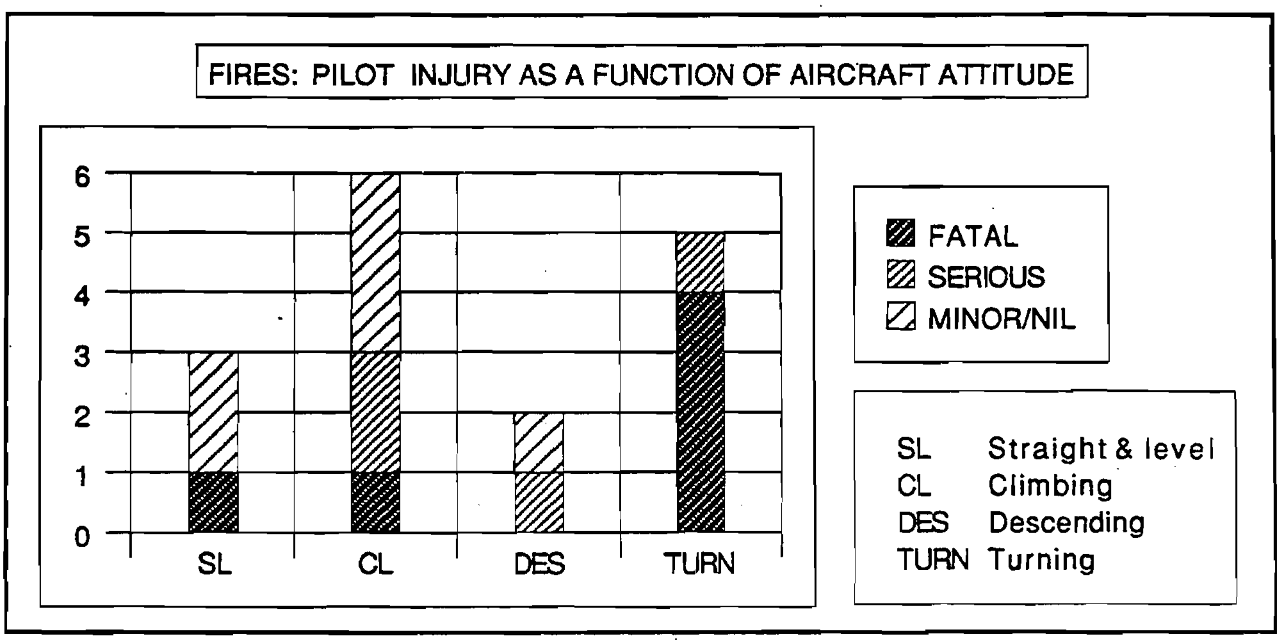
Note: unknown data were not included

5.3.2 Fire

A total of 16 occurrences involving contact with part of the aircraft termed 'other' resulted in fire. Of these, six were fatal accidents, four culminated in serious injuries and six in either minimal or no injuries. When considering each aircraft attitude at the time, results indicated that the greatest incidence of fire was associated with the aircraft striking powerlines in a climb attitude or following a turn (see Figure 13). It is noteworthy that the incidence of fire was similar when accidents occurred during descent or in straight and level flight, with no fatalities in the case of descending aircraft.

Fire was present in 71% of the fatal accidents following wire strikes occurring whilst the aircraft was in a turn and in 46% whilst climbing.

FIGURE 13



5.3.3 Wires

Of the 60 accidents in this category, 19 aircraft hit the wire with the propeller. Seventeen of these pilots were either uninjured or sustained minor injuries. The wires were broken in 16 of these propeller strikes and the remaining three such cases were unknown.

In 29 cases the aircraft contacted the wire with either one or both the wings. Ten of these occurrences resulted in fatal injuries, six in serious injuries and 12 in minor or no injuries. This indicates the serious risk associated with hitting such wires with a wing. Less than half of these cases (12) resulted in the wires being severed.

Overall, in 33 accidents the impact with the wire actually broke it, resulting in three fatalities, four pilots seriously injured, and the remaining 26 without significant injuries (see Figure 14). In the remaining 27 cases in which the wires were not broken, seven were fatal accidents, seven culminated in serious injuries and 13 escaped without significant injuries (see Figure 15).

FIGURE 14

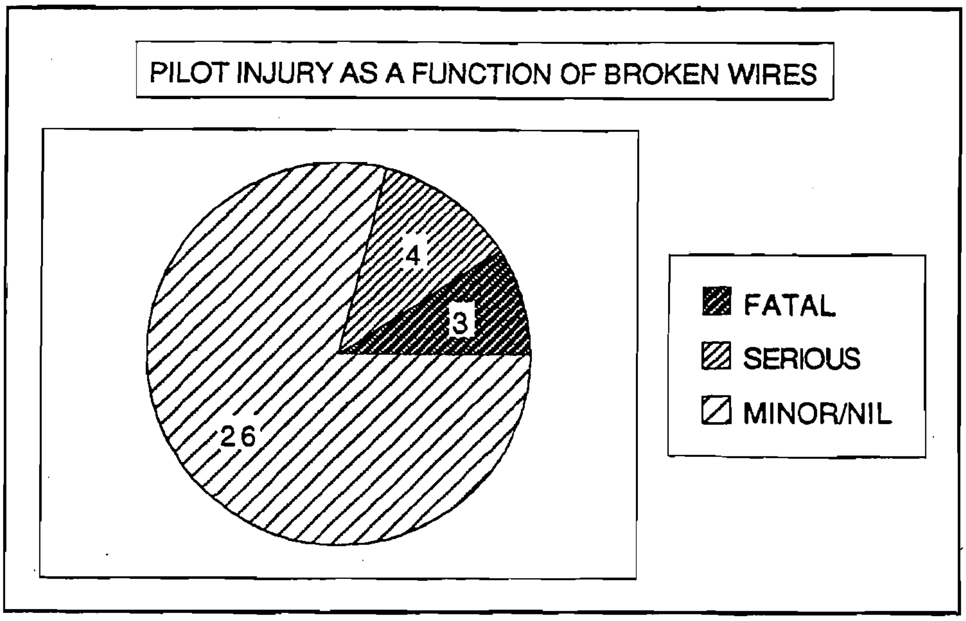
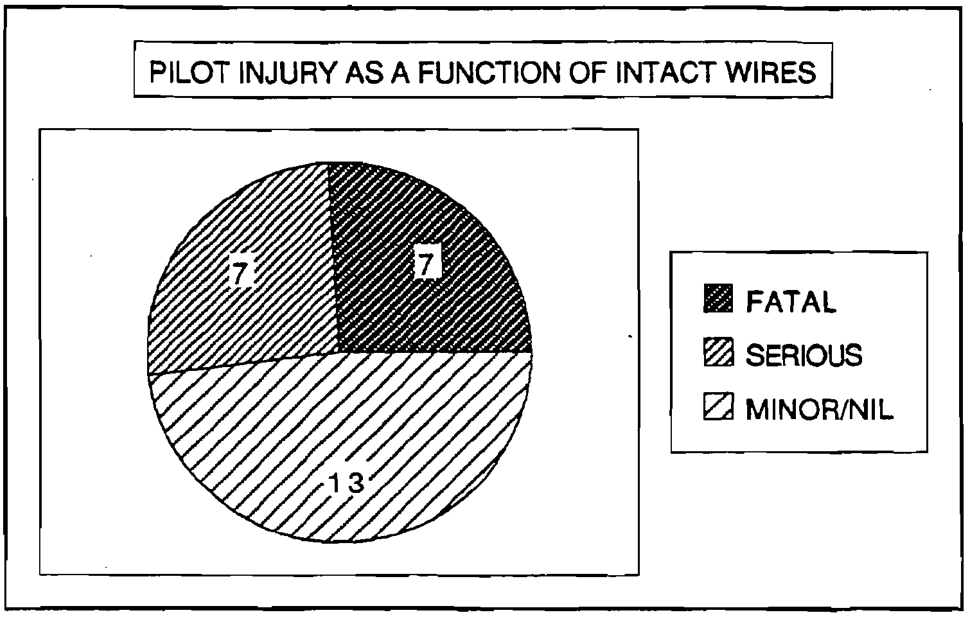


FIGURE 15



The relationship between aircraft attitude and pilot injury is presented in Appendix E. The analysis revealed that in cases where the wire remained intact there was not one predominant attitude that appeared most favourable to the pilot escaping relatively uninjured. Turning resulted in a higher proportion of fatalities.

In the event of strikes breaking the wire, most aircraft attitudes resulted in a low degree of injury.

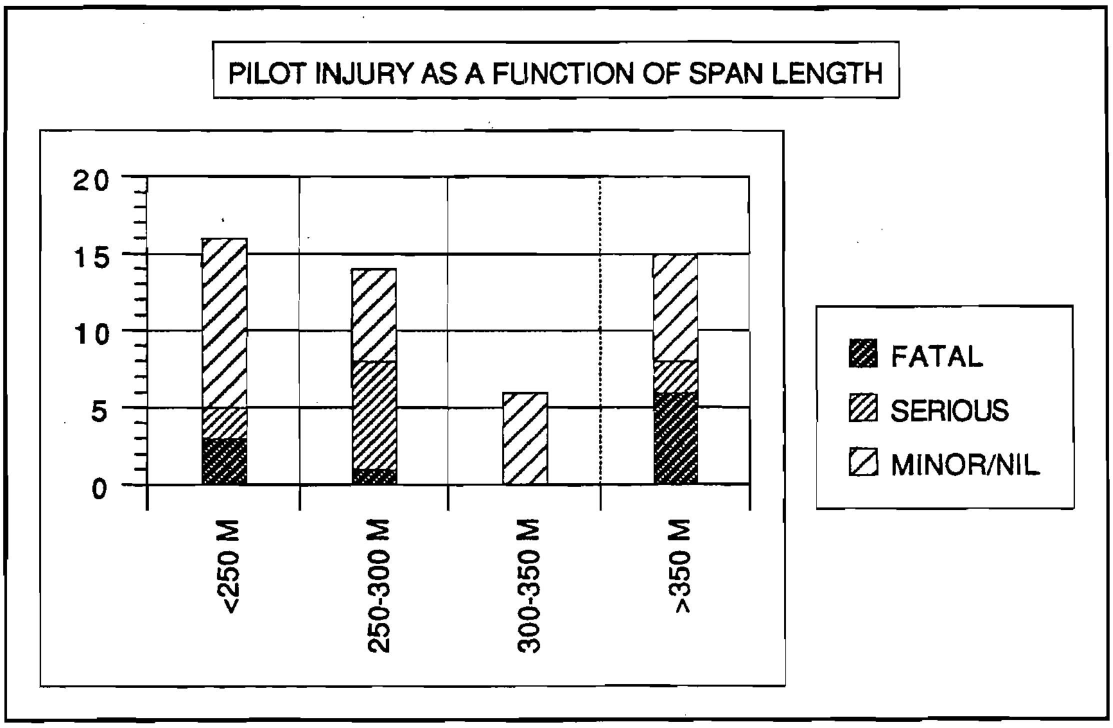
5.3.4 Ability to land following contact

Twenty-three aircraft in this category landed following the wire strike, representing 38% of the accidents. Of these, 13 struck the conductors with the propeller with the majority breaking them. Six of the landing aircraft were in a straight and level flight at the time and nine were in a climb attitude, which account for 46% and 38% respectively, within the subset.

5.3.5 Span length

Figure 16 indicates that the most favourable outcome for the pilot was achieved when the aircraft struck wires whose span varied between 250 and 350 metres.

FIGURE 16



Note: Cases were eliminated from the analysis if the span length was unknown.

5.3.6 Summary

There was no significant difference in the injury rate between the accidents in which the aircraft struck the wire with parts of the aircraft other than the landing gear, fin or deflector, involving aircraft attitudes of straight and level, descent and climb. However, turning into the power line constituted the worst scenario. Post-crash fires were present in 16 cases, and many fatalities were associated with the aircraft performing a turn at the time of the strike.

The lowest degree of injury resulted from cases in which the wires were broken. These included striking conductors with the propeller. Breaking of the wire also increased the probability of being able to land, as slightly more than half of the aircraft that landed had struck the wires with the propeller.

Striking wires with one or both wings resulted in a high fatality rate.

5.4 Implications

In the previous three subsections, the severity of pilot injuries was analysed against various parameters. The aim was to provide an understanding of the elements which affect the seriousness of the accident. It should be recognised that only factors which were common to the sample of accidents were considered, and that other contributing factors which were unique to each accident could not be evaluated.

As a general rule, it was found that the likelihood of escaping with minor or no injuries was greatest if the aircraft was flying straight and level at the time, regardless of the strike location.

It is apparent that attempting to fly below the cables will increase the chances of escaping without significant injuries. This is indicated by the resulting high proportion of minimally injured or unscathed pilots who struck wires at the fin and/or deflector of their aircraft. More than half of these pilots maintained control of the aircraft and were able to land. The incidence of fire was consequently minimized.

Breaking the wires at the landing gear did not necessarily increase the chance of survival. There were more instances in which the wires were broken that resulted in a low level of injuries. However, the death rate was also high, accounting for 30% of all the fatal accidents.

Breaking the wires resulted in less injuries when the aircraft struck with parts of the aircraft classified 'other'. The injury level was low in cases in which the wires were struck by the propeller. Slightly more than half of the instances within this category resulted in the wires being severed.

Cases involving striking powerlines with wings resulted in serious and fatal injuries in a greater proportion than strikes with any other parts of the aircraft.

For accidents other than fin and/or deflector strikes, most occurred during a climb, which was also associated with a high incidence of fire. The distribution of injury levels was similar for the two categories.

5.5 Categorising Types of Aircraft

This subsection provides an overview of the accident trends for the Cessna C-188 series and the Piper PA-25 series.

5.5.1 C-188 series

Of the 72 accidents involving C-188 series, seven were fatal, 15 resulted in serious injury and the remaining 50 pilots escaped with either minor or no injuries. Post-crash fires followed 17 accidents (24%), and six resulted in death (35%). In 43% of the C-188 accidents the aircraft hit at the fin and/or deflector.

Sixty-nine aircraft were involved in spraying operations at the time of the accident. Of these, 30 struck the wire from below with 18 subsequently landing. In 13 cases the propeller actually struck the wires and in all but one unknown case the wire was severed; in one accident the pilot was seriously injured, while in the remaining 12 the pilot received minor or no injuries.

5.5.2 PA-25 series

Thirty-seven Piper PA-25 series aircraft were involved in wire strikes between 1972 and 1990. There were five fatal accidents, and seven in which the pilot sustained serious injuries. In the remaining 25, pilots received minor or no injuries.

In four of the fatal accidents it was established that the aircraft was executing a turn at the time of the strike. Twelve of the total number of accidents to the PA-25 (32%) resulted in post-crash fires, of which four were fatal (33%).

Spraying accounted for 30 of the accidents. Of these, only three pilots flew under the powerlines and were able to carry out a landing following the strike. On nine occasions the propeller struck the cables; one pilot was fatally injured and the remaining eight escaped with minor or no injuries. The wires were severed in seven of the cases.

5.5.3 Summary

Post-crash fires were associated with most fatal accidents for the two aircraft types under review. In proportion, the Piper PA-25 series experienced a greater number of post-crash fires, which were most often associated with the aircraft turning at the time of the wire strike.

The survivability rates and injury patterns were similar in both categories of aircraft.

Cessna aircraft accounted for more occurrences whilst flying beneath the wires.

The propeller actually cut the wires in most instances, and resulted in virtually no injuries in 91% of these cases.

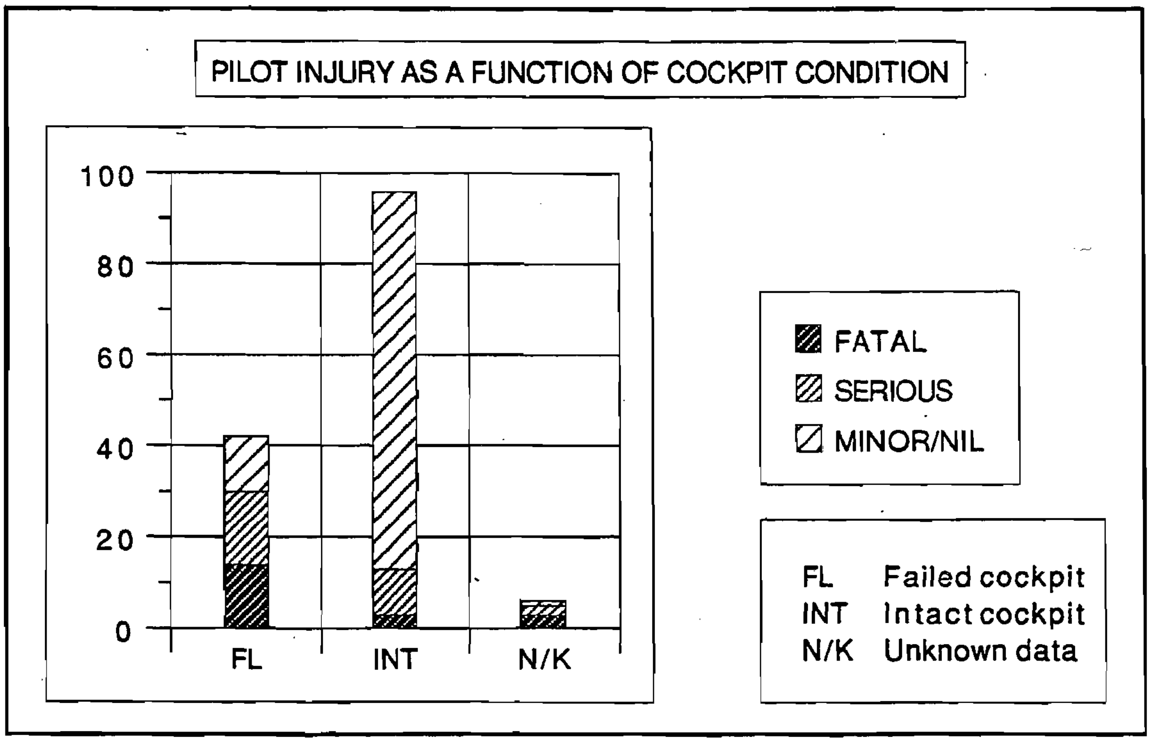
5.6 Survivability Aspects

This subsection reviews three survivability factors: the structural integrity of the cockpit structure, the restraint systems, and the seat frames.

5.6.1 Cockpit structure

Failure of the cockpit structure assumes that the impact forces are sufficient to disrupt the structural integrity of the cockpit area. Forces will act in a different way on individual structures and will result in part or complete distortion, buckling or collapse of the frame. For the purposes of this study any deterioration in the original structure was classified as failure. Figure 17 indicates the status of the cockpit for each category of injury. Appendix F gives a similar breakdown for the two aircraft types under review.

FIGURE 17



The analysis revealed that there was a large proportion of fatal accidents (70%) in which the cockpit environment was known to have failed. The majority of them (71%) were associated with fire. In contrast, a correlation between cockpit failure and fire was present in only 31% of the serious-injury group.

Breakdown by aircraft type revealed that both types suffered structural deformation in 15 cases, causing more fatal accidents with the Piper PA-25 series. Most of the fatal accidents experienced a post-crash fire.

There were 29 C-188 series and 13 PA-25 series accidents in which the aircraft were able to land following the strikes. To reflect a fair assessment, only the remaining accidents were used to determine failure rates. The cockpit failure rate was 35% for the C-188 series and 63% for the PA-25 series.

5.6.2 Restraint system and seat frames

The harness and seat frames were considered in a similar manner to that of the cockpit structure. Failures included stretched webbing, shoulder strap failure, buckle failure, toggle failure and attachments failure. The seat frame failures included seats being forced off rails, collapsed, buckled, broken seat legs and fractured frames. Figure 18 and 19 display the status of the restraint system and seat frames for each category of injury respectively. A breakdown of pilot injury as a function of harness condition according to aircraft type is given in Appendix G. Appendix H provides similar data relating pilot injury to seat frame condition.

FIGURE 18

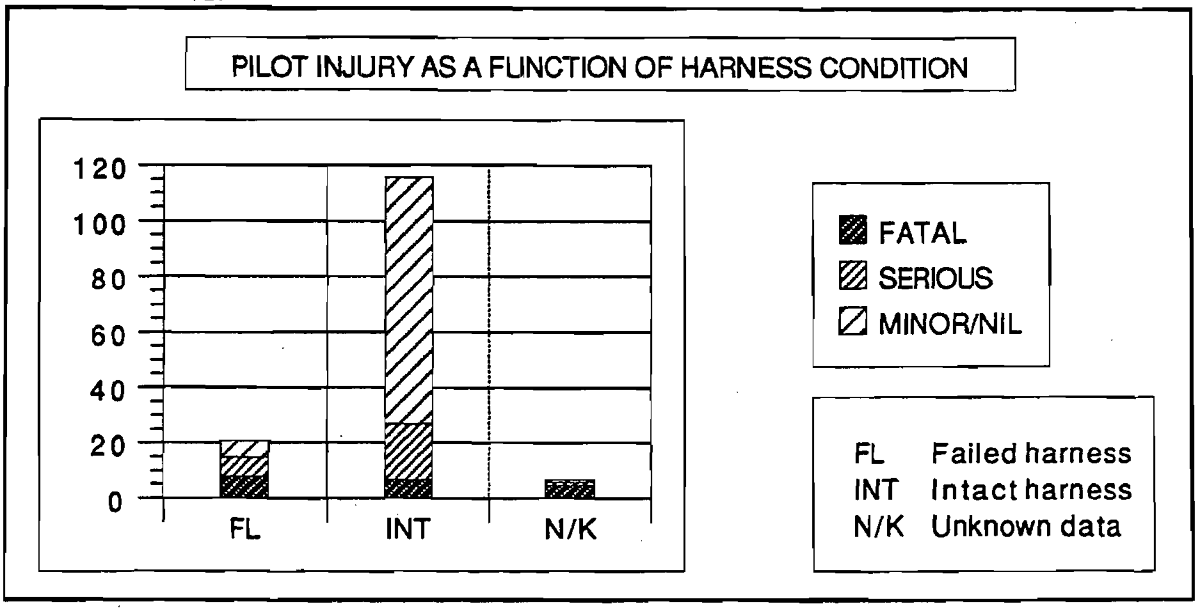
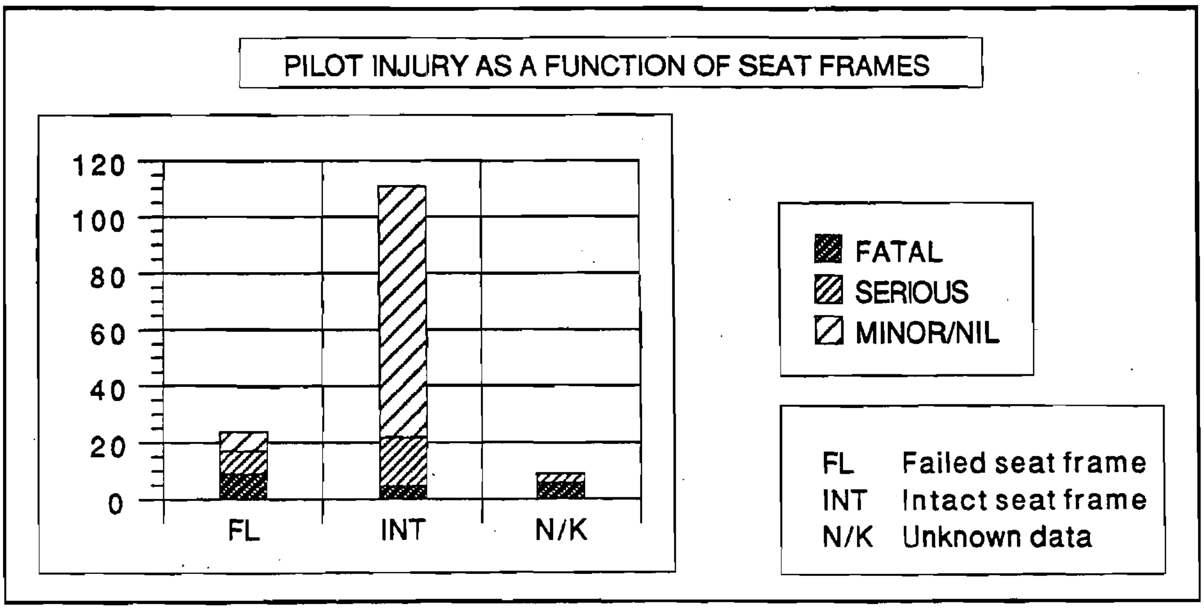


FIGURE 19



The above tables show that in the majority of accidents the harness or seat frame did not fail.

Generally, a slightly smaller failure rate was found with PA-25 series aircraft. Seats failed in 21% of accidents, and harness failure also occurred in 21% of the accidents. The figures for the C-188 series were 31% and 26% respectively. This was excluding the aircraft that were able to land. However, PA-25 series seat failures were associated with more fatal injuries.

5.7 Awareness of Wires

This subsection reviews cases in which the pilots were aware of the presence of the powerlines which they struck. For the purposes of this review the decades 1972-1981 and 1982-1990 were compared. It was determined that the number of accidents increased from 63 to 81 for the two periods.

In 1972-81, 30.6% of the pilots involved in wire strike accidents were unaware of the existence of the wires. In contrast, for the 1982-90 decade only 13.9% of pilots were unaware of the wires they struck, indicating an increase in awareness in the later period.

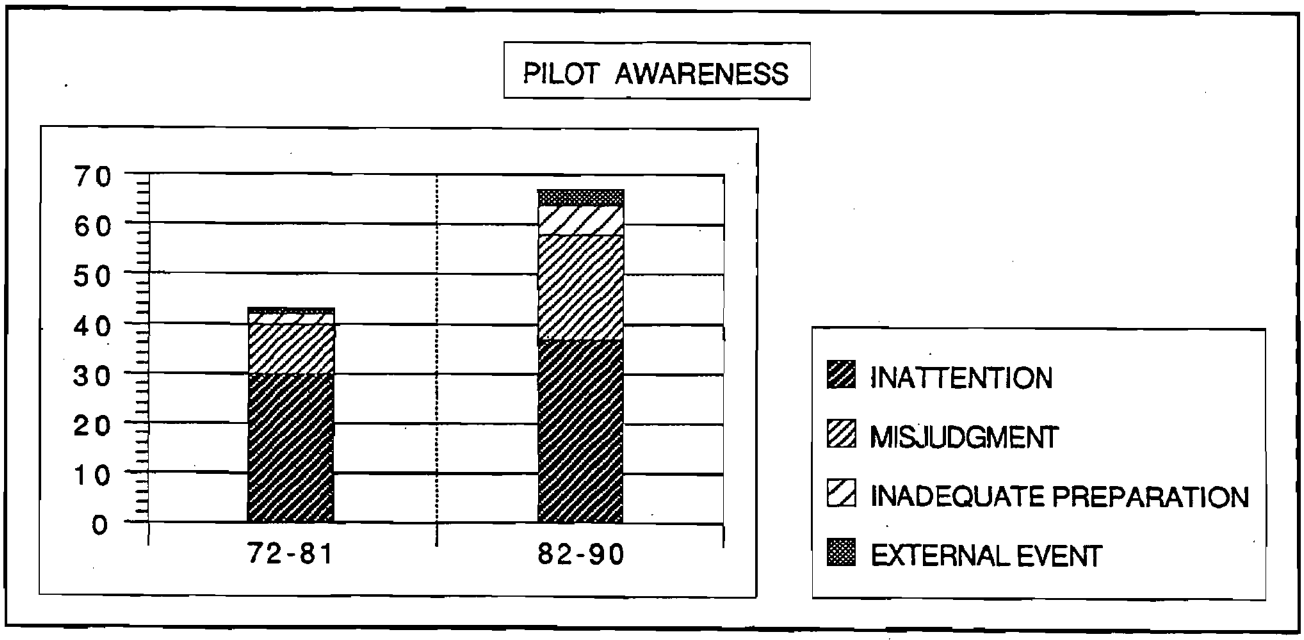
For the purposes of the present study, it was considered impractical to analyse the severity of the accidents in relation to pilot flying hours (total, on type and agricultural) as these may not reflect the relative experience of pilots at operating in the vicinity of powerlines across the sample, nor their recency.

5.7.1 Determining pilot awareness

Pilots in 79% of the total number of accidents under review were aware of the wires. The reasons attributed to the wire strikes were classified in four groups: inattention, misjudgment, inadequate preparation, and external event. Figure 20 displays the proportion per decade for each group.

'Misjudging' includes cases whereby the physical dimensions of the aircraft constitute a problem. A study conducted by the Department of Aviation (now CAA), covering the period 1979-1984 (Torkington 1984), found that certain models of Cessna C-188 were more susceptible to the loss of fin and rudder tips than other aircraft.

FIGURE 20



The results indicate an increase in each group, except for 'inattention' where percentages decreased from 70% to 55%. Misjudging and inadequate preparation appeared to have contributed significantly to the increase of accidents in the last decade. However, inattention represented and remains the majority of the causes, even though a reduction of cases was recorded in the most recent period.

Association with aircraft attitudes revealed that more than half of the total number of accidents that occurred during a turn or in straight and level flight were due to inattention (53% and 51% respectively).

For the entire period the proportions of climb and straight and level accidents resulting from 'misjudgment' were approximately the same (22% and 24%). However, the trend showed an inverse relation per decade, i.e. more misjudgment occurred in straight and level flight during the last decade. During the period 1972-1981, most misjudgment occurred in climb.

5.7.2 Awareness per type of aircraft

The same classification was analysed against aircraft type to identify potential problem areas. A profile diagram of each type is found in Appendix I.

Analysis of the Cessna population revealed that 13 pilots misjudged the clearance compared to five for Piper aircraft in the last decade, giving a relative proportion per type of aircraft of 29.5% and 26% respectively. Inadequate preparation was cited in wire strikes by five Cessna pilots out of six (83.3%), but not one for Piper.

For the entire period, 'inattention' was identified as a causal factor in 40% of the Cessna population, against 57% for Piper. The percentages for 'misjudgment' were 26% and 19% respectively.

5.7.3 Summary

On average, pilots were more aware of the existence of the wires in the last decade. There was a decrease in the percentage of accidents in which 'lack of attention' was identified as a factor, although this category remains the primary causal factor. A high number of these accidents occurred whilst the aircraft was either in a turn or in a straight and level attitude.

The proportion of accidents attributed to misjudgment and inadequate preparation had increased over the past decade. The Cessna C-188 series accounted for the majority of occurrences involving this factor. Most accidents due to 'misjudgment' occurred whilst in a straight and level attitude.

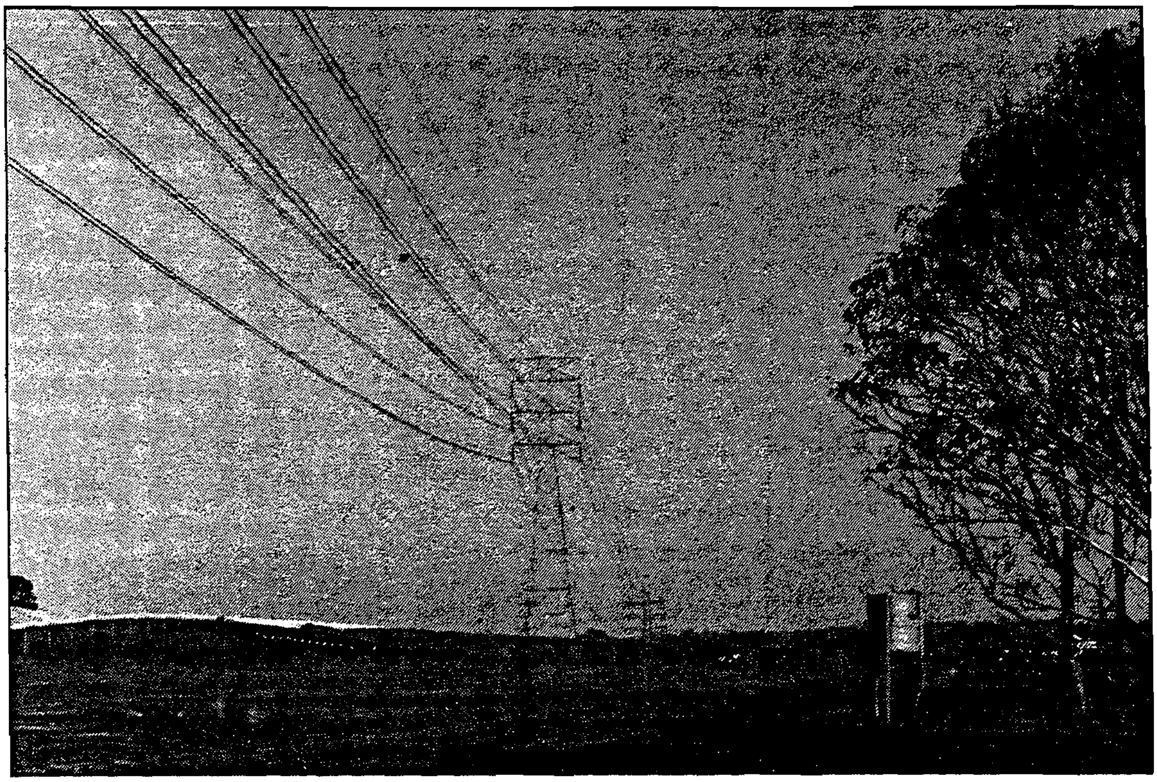


Photo Robyn Beatty Standards Australia

6.0 IDENTIFYING THE PROBLEMS

This section uses the analysis results to establish common factors within the entire wire-strike accident population, coupled with trends found for the two major aircraft types under consideration to identify potential problem areas.

Most of the accidents reviewed occurred in straight and level flight or during climb. The incidence of post-impact fire was mainly associated with aircraft which hit wires with either the landing gear or parts of the aircraft which were classified as 'other', whilst in climb. However, fire was associated with a significant number of fatal accidents following an aircraft turning, when the aircraft struck with parts other than the landing gear, fin or deflector.

In general, turning into the wires invariably resulted in more fatal accidents, regardless of the parts of the aircraft with which contact was made with the wires.

Striking the wires with the wings accounted for a higher number of seriously injured and fatally injured pilots than strikes involving any other parts of the aircraft.

Striking wires at the landing gear occurred in 31% of the accidents, with 64% resulting in the wires being severed. Of the accidents resulting in broken wires, 72% of the pilots escaped relatively uninjured.

The Cessna C-188 series accounted for the greatest number of accidents. Most of the accidents occurred during attempts to fly below the powerlines, and in a considerable proportion of cases, the pilots were able to land following the strike. A high percentage of the Cessna pilots misjudged the height of the wires, particularly in the last decade, whilst in a straight and level attitude. There was also a higher percentage of Cessna pilots who did not conduct a proper preparation prior to executing the work.

In proportion, Piper PA-25 series aircraft showed a greater incidence of fire than that of Cessna C-188 series. Its cockpit structure failure rate was greater, and was associated with more serious injuries. The reliability of restraint system and seat frames on both aircraft types was similar, although the seat frames on the Cessna C-188 series displayed a slightly higher failure rate.

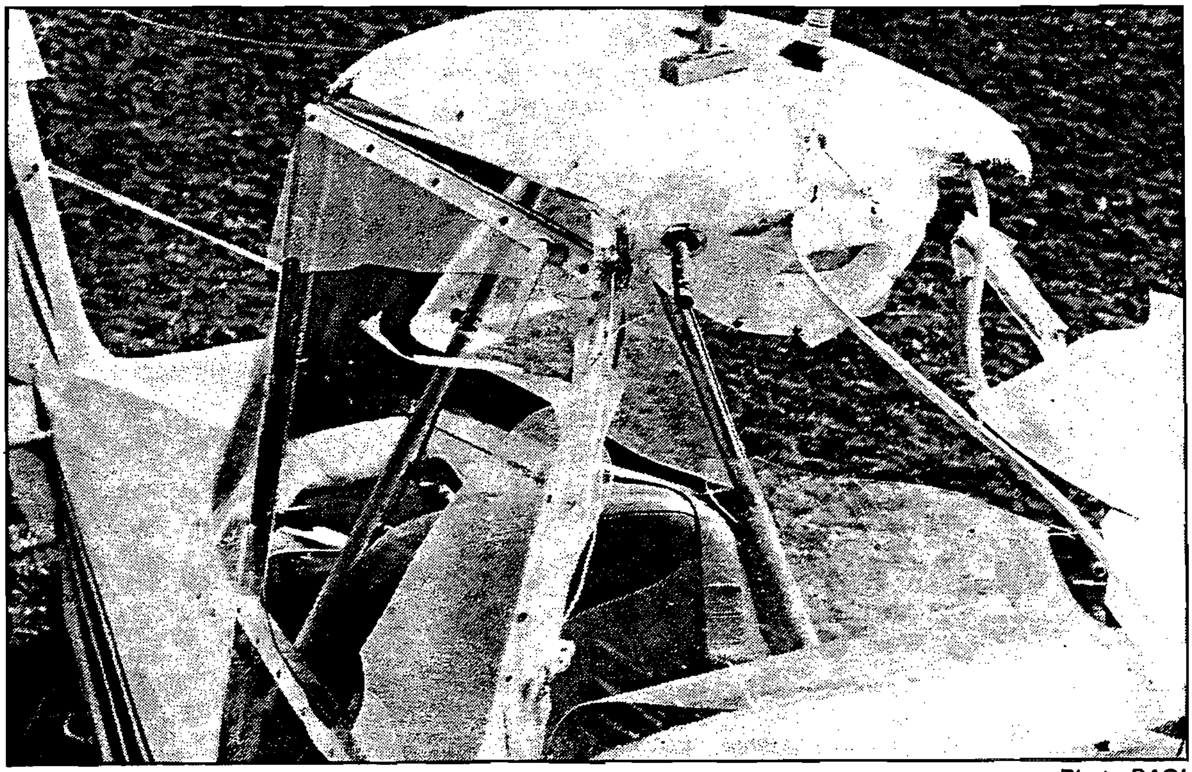


Photo BASI

7.0 DISCUSSION

While the period 1972-1990 saw a growing number of wire strike accidents, the actual accident rate was relatively constant given the increase in aerial agriculture during the same period. Peaks in the rate in 1982 and 1983 may be indicative of changes which occurred during the economic recession. During that period, fewer hours were flown and the accident rate sharply increased.

The statistical interpretation of data in this study assumes that agricultural activities remained unchanged throughout the period. However, it is important to remember that, due to economic pressures, land usage intensified, resulting in growing urbanisation and a greater density in powerlines. Furthermore, the development of more cost-efficient spraying equipment required new flying strategies. Factors such as these may well have contributed to the increase in the number of wire strike accidents during the last decade.

Despite research to improve survivability rates for post-impact fires, the incidence of fire following a strike remains a major problem. In six known cases where fire was a factor, the pilot would have suffered less injury had he been wearing a helmet, a shoulder harness and/or protective clothing. Strikes involving the landing gear or what are termed 'other' parts of the aircraft were more likely to experience a post-impact fire. These tended to occur during a climb or a turn, suggesting a stall and subsequent loss of control before the aircraft impacted the ground. Such strikes increase the chance of rupturing components within the fuel system and spilling fuel. (Robertson (1981) identified fuel spillage as a major problem when dealing with fire). Piper PA-25 series aircraft appear to have experienced proportionately more post-impact fires than Cessna C-188 aircraft during the period 1972-1990; however, the Department of Civil Aviation analysis for the years 1969-1986 (Department of Civil Aviation [a]) shows that insertion of a rubber fuel cell in this aircraft type greatly reduced the incidence of fire. The present study found the Piper PA-25 series' overall fatality rate to be similar to that of the Cessna C-188 series, suggesting that while the incidence of post-impact fire for the PA-25 series aircraft is higher, the modifications were effective in reducing the fatality rate.

Each strike location provides a specific outcome. A cable cutter study (Department of Civil Aviation [b]) concluded in 1974 that 83% of strikes below the propeller resulted in a ground impact. The present study determined that when strikes involve the landing gear, there is a tendency for the aircraft to pitch nose-down as a direct result of striking below the centre of gravity (CG).

It was also found that wire strikes involving landing gear caused fewer injuries when the cable span was relatively short. This may be explained as follows. During a collision there is a transfer of kinetic energy into work done per unit time (Shames 1970). Work done is defined as the amount of force required to displace the cable over a given distance. To successfully break the wire, the impacting aircraft must overcome the inertia of the cable to reach the point of maximum tension in the direction of motion. This requires a certain amount of force. Assuming rigid anchor points, a relatively short span will involve relatively less cable weight and require a correspondingly smaller force from the impacting aircraft to break the cable.

A landing gear device that could cut the cable would improve survivability by preserving the inertia of the aircraft, thus reducing the likelihood of ground impact. However, the time and cost involved in developing an improved cable cutter may not be justified from the data. Improvement to the existing landing gear cutter would include a modified blade with a saw-toothed edge, similar to that of the WSPS currently installed on many helicopter types.

It has long been recognised that wire strikes involving the fin and/or deflector offer the best chances of survival. Since the striking point is above the CG of the aircraft, the aircraft tends to pitch nose-up, which can be an advantage when flying close to the ground. Most aircraft involved in wire strikes of this sort failed to sever the wire, mainly because the deflector and empennage section of the aircraft are not strong enough to oppose the inertia of the cable. (The rigidity of the deflector system is limited by the strength of the structure to which it is attached.) While the deflector often apparently failed to deflect the cable, the number of successful deflections could not be determined. Since these findings are based on reported accidents only, it is probable that unreported accidents—especially those involving strikes at the fin and/or the deflector—would have modified the outcome.

In the case of wire strikes involving what have been termed 'other' parts of the aircraft, the relative strike vector passes through or near the CG, with no sudden pitch change expected. In almost a third of such accidents, the propeller struck the wire and typically succeeded in cutting it. In most of these cases there were few injuries, and more than half of the aircraft successfully landed following the strike. When the propeller cut the wire, the pilot normally escaped relatively unscathed. While the pitch, diameter and power available to the propeller were not considered in this study, it is clear that propeller-cutting efficiency also depends on the following factors: the transfer of high stored rotational energy from the propeller; high RPM, an extremely short time interval (msec) between the travel of two blades; and the effectiveness of the leading edge profile as a cutting tool. Factors such as these provide the airspeed necessary to control the aircraft and minimise airframe damage. Proposed safety improvements to the propeller include the insertion of high strength steel to the leading edge, or the use of small quantities of explosive embedded in the leading edge, which would be activated on contact with the wire (Bruken et al. 1979). Both improvements would require a completely redesigned propeller.

The present study identified cockpit structure and fire protection as items affecting survivability. A number of cockpit structures failed on impact. In those occurrences which resulted in fatalities, a large proportion were associated with fire. Serious injuries, however, were mostly associated with impact damage. Although Cessna aircraft appear to be slightly stronger than Piper aircraft, there is still room for structural improvement. (A crash-survivability checklist developed by the Robertson Research Institute (Robertson 1988) gave a better rating for a typical agricultural aircraft than for a GA aircraft. Rather than attributing a specific value to each item, they were rated together against optimum values. Optimum values are based on the relative hazard potential of the items considered, the two most important being the restraint system and the post-impact fire).

A large number of Cessna aircraft lost fin and rudder tips while attempting to fly under the powerline. While such accidents are relatively survivable, their incidence lends weight to the Civil Aviation Authority's concerns about vertical protrusion of the tail section (Torkington 1984). The Cessna's high tail profile suggests that extra care should be exercised when judging clearances, the more so considering that the last decade saw an increase in accidents due to 'misjudgment'. While constituting only a small sample, a majority of the Cessna pilots studied were not properly prepared before executing the task. This underscores the need for human-factors solutions such as improved training and in-flight memory prompts.

Despite existing regulations relating to the endorsement of pilots to carry out aerial agricultural operations, the statistics suggest that enforcement of the industry to follow proper training and supervisory procedures may be lacking. This is indicated by the increase of accidents, particularly involving the Cessna C-188 series, due to misjudgment, in straight and level flight.

8.0 CONCLUSIONS

1. The accident rate for the period under review remained stable.
2. The number of accidents per year showed a significant increase in the last decade.
3. Post-impact fire remains a major problem and was associated with approximately two-thirds of the fatalities.
4. The incidence of post-impact fire was generally high following a wire strike by an aircraft in climb, and striking it with parts other than the fin and/or deflector.
5. The greatest number of fatal accidents was associated with an aircraft turning and contributed to the high incidence of post-impact fire when striking with parts of the aircraft other than the landing gear, fin or deflector.
6. A straight and level attitude at wire contact provides the lowest injury rate for the pilots and increases the chances of being able to land.
7. Striking at the fin and/or deflector constitutes the safest strike location and favours the ability to land following contact with powerlines.
8. Incidence of fire is low when striking at the fin and/or deflector.
9. Cutting wires with the propeller provides relatively good protection.
10. A combination of cockpit deformation and fire was associated with a large proportion of fatal accidents.
11. Piper aircraft suffered structural damage in a greater proportion than did Cessna.
12. Inattention remained a major factor in wire strike accidents, particularly as in the majority of accidents pilots had prior knowledge of the wires they struck.
13. 'Misjudgment' and 'inadequate preparation' were found to be associated with the increase of the number of wire strike accidents during the last decade.
14. Cessna pilots experienced relatively more accidents due to 'misjudgment' which were possibly associated with the height of the tail when the aircraft was in straight and level flight.

9.0 RECOMMENDATION

It is recommended that the Civil Aviation Authority, the Aerial Agricultural Association and the Bureau of Air Safety Investigation meet to discuss the safety issues raised in this report with a view to jointly developing safety education measures. In particular, the meeting should address:

1. pilot fire protective clothing;
2. aircraft fire extinguisher equipment;
3. aircraft crashworthiness;
4. pilot responsibilities and preparation; and
5. pilot rating requirements contained in CAO 40.6.

APPENDIX A

Parameters under review include:

1. Aircraft type
2. Aircraft registration
3. Date of occurrence
4. Location
5. Aircraft damage
6. Injury
7. Phase of flight
8. Impact attitude
9. Wire span
10. Wire height
11. Wire type
12. Wire array
13. Wire break
14. Strike attitude
15. Strike speed
16. Strike location
17. Impact speed
18. Occurrence of fire
19. Cockpit condition
20. Harness condition
21. Seat condition
22. Operation type
23. Pilot's awareness

APPENDIX B

Breakdown of all the aircraft types under review, between 1972 and 1990, associated with their respective number of accidents and fatal injuries.

TYPE	NO. OF ACCIDENTS	FATAL ACCIDENTS
Cessna C-188 series	72	7
Piper PA-25 series	37	5
Grumman G-164	8	0
DHC-2 Beaver	5	3
Fletcher FU-24	4	3
Rockwell S-2R	4	0
Transavia PL-12	3	0
Piper PA-36 series	2	1
Airtractor AT-301	2	0
Cessna C-180 series	1	0
Cessna C-185 series	1	0
Ceres CA28	1	0
Yeoman YA 1-25	1	0
IMCO A9-A	1	0
DH-82A Tiger Moth	1	0
Snow Commander 600	1	1

APPENDIX C

Other types of powerlines include:

Three-strand 2.00 mm diameter galvanized steel (3/2.00), formerly 3-strand 14- gauge. Minimum breaking load of 12.36 kN (2 779 lb) and an ultimate tensile strength of 1.31 GPa (190 ksi).

Steel conductor aluminium clad 6/1/3.00. Minimum breaking load of 14.5 kN (3 260 lb) and an ultimate tensile strength of 1.34 GPa (194 ksi).

Aluminium conductor steel reinforced (ACSR) typically 3 aluminium and 4 steel strands with diameters varying from 1.7 mm, 2.3 mm to 2.5 mm. Minimum breaking load of 24.4 kN (5 486 lb).

6/1/2.5 ACSR , minimum breaking load of 10.3 kN (2 316 lb).

Nineteen-strand 3.25 mm diameter all aluminium conductors (19/3.25). Minimum breaking load of 24.7 kN (5553 lb) and an ultimate tensile strength of 0.165 GPa (24 ksi).

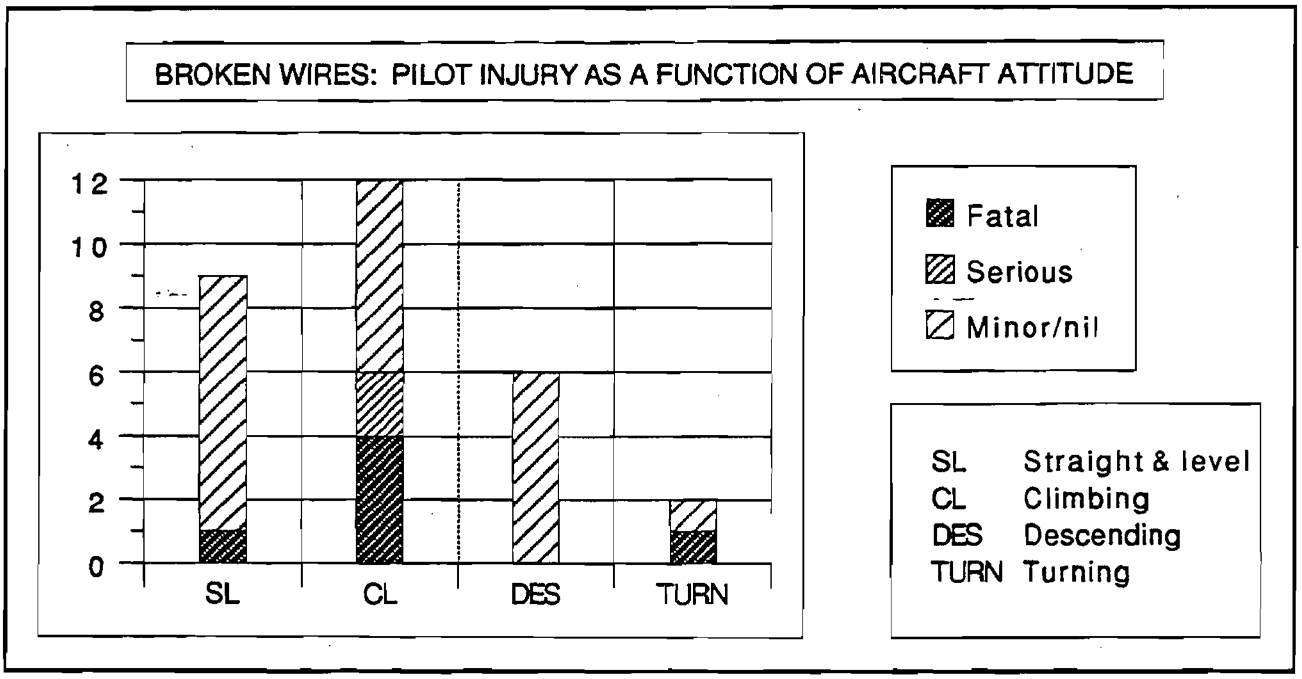
Copper wires of dimensions including 4/7/2, 7/2.6, 7/6.4.

One copper aerial cable involving railway communication lines.

APPENDIX D

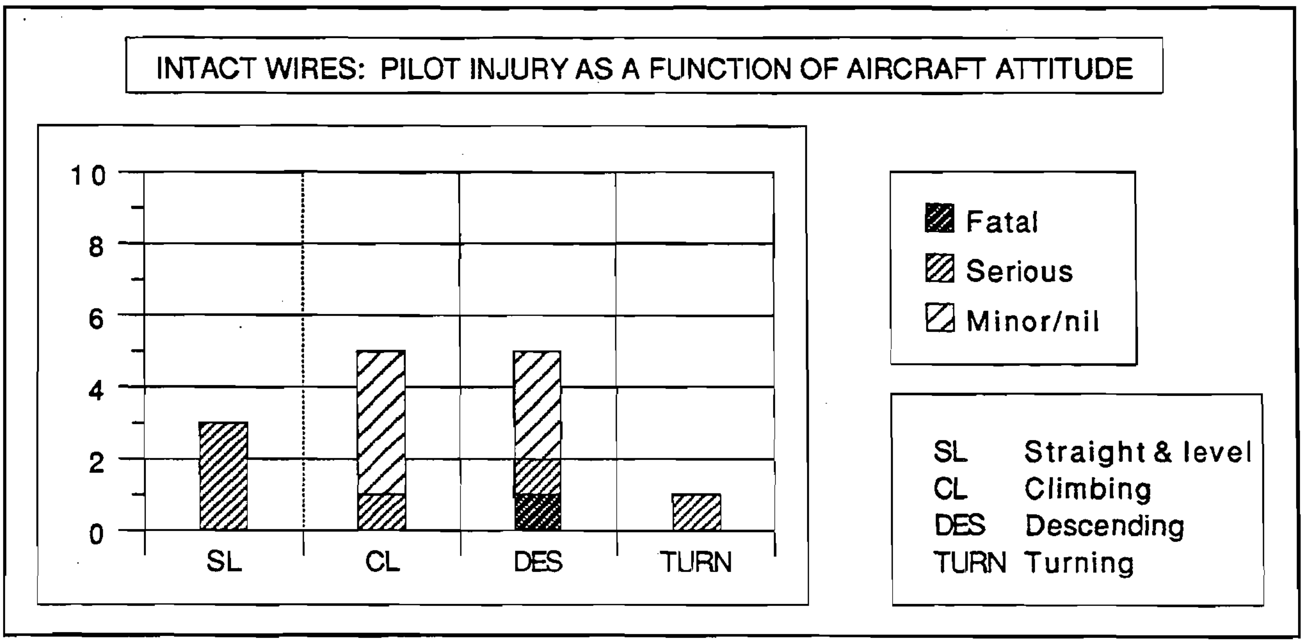
CONTACT WITH THE LANDING GEAR

Breakdown of accidents in which the cables were broken as a function of aircraft attitude:



Note: unknown data were eliminated

Breakdown of accidents in which the wires remained intact as a function of aircraft attitude:

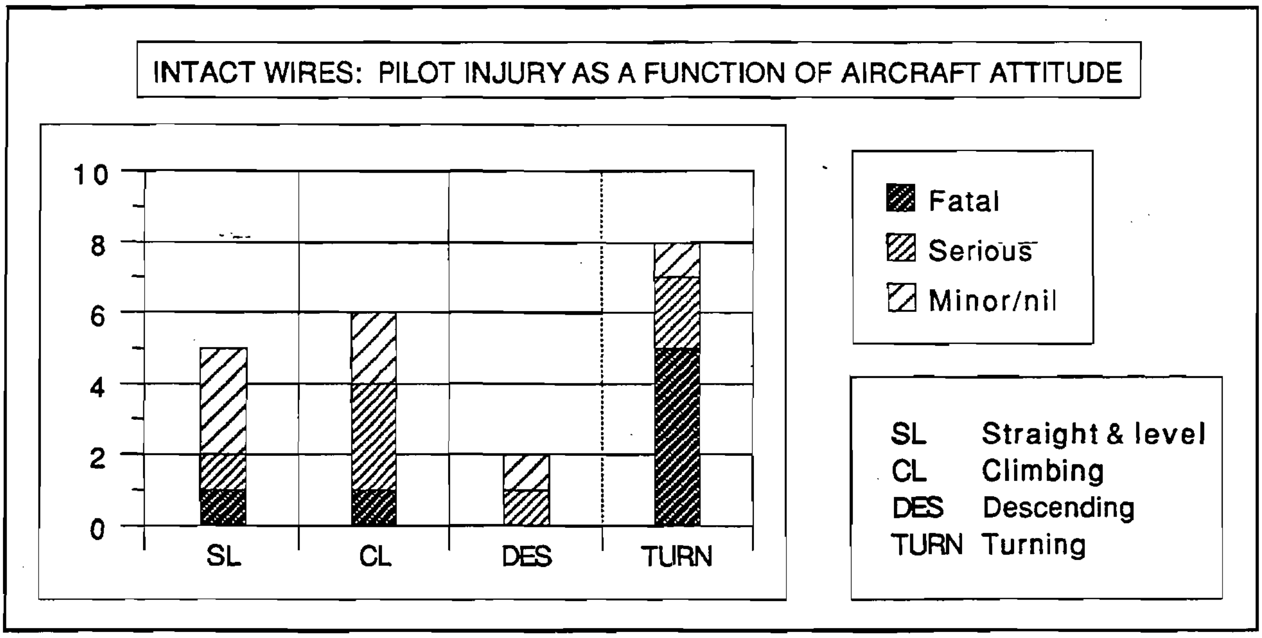


Note: unknown data were eliminated

APPENDIX E

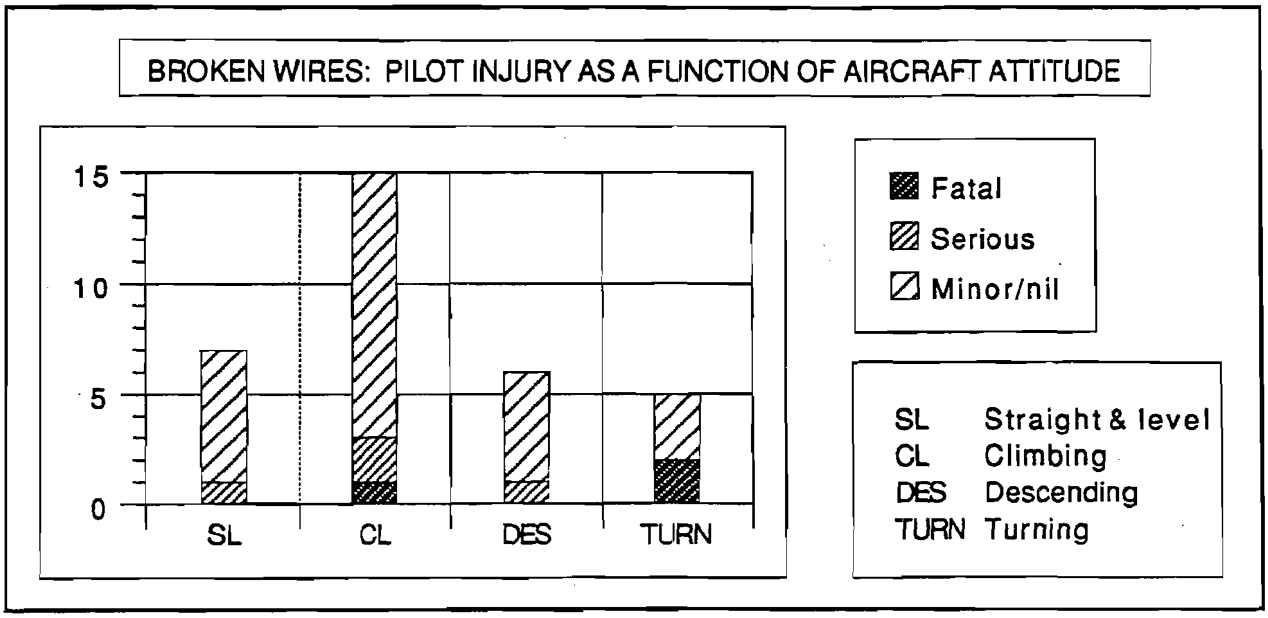
CONTACT WITH OTHER PARTS OF THE AIRCRAFT

Breakdown of accidents occurring on parts of the aircraft termed as other, in which the wires remained intact, as a function of aircraft attitude:



Note: unknown data were excluded from the analysis

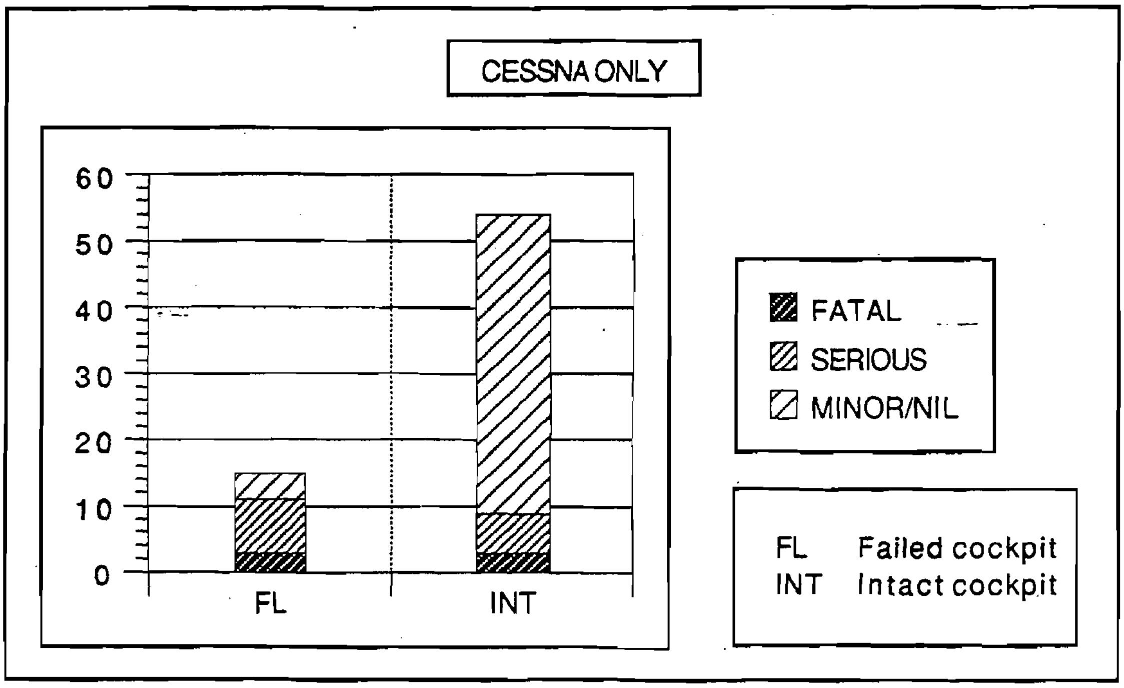
Breakdown of accidents occurring on parts of the aircraft termed as other, in which the wires were broken, as a function of aircraft attitude:



Note: unknown data were excluded from the analysis

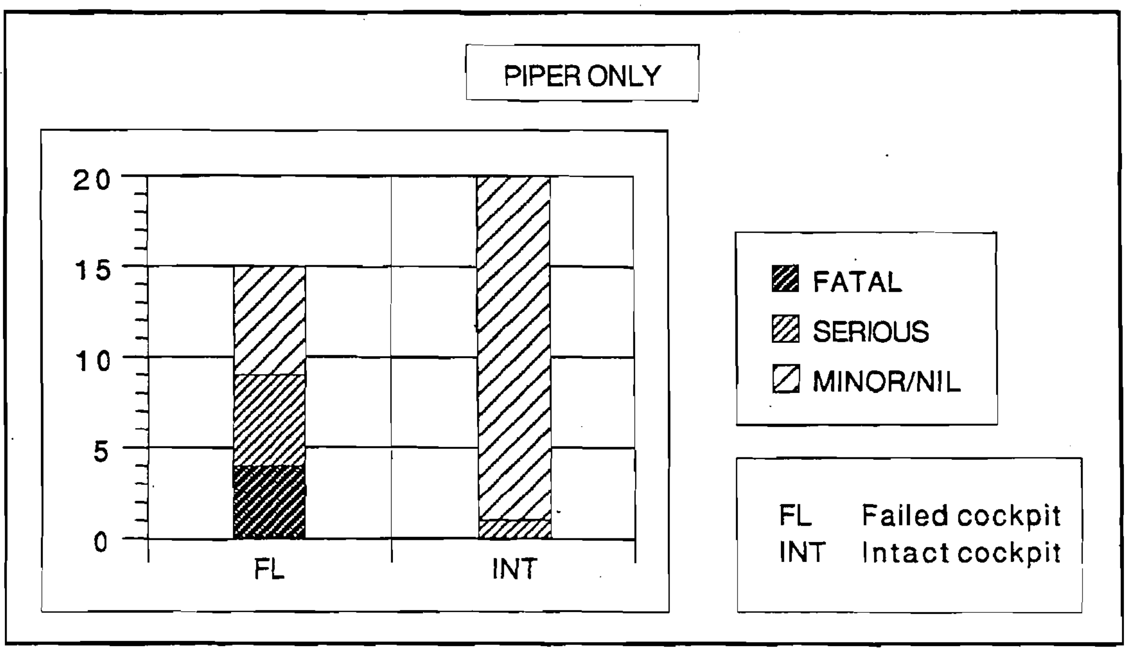
APPENDIX F

Status of the cockpit for each category of injury for the Cessna C-188 series:



Note: unknown data were eliminated

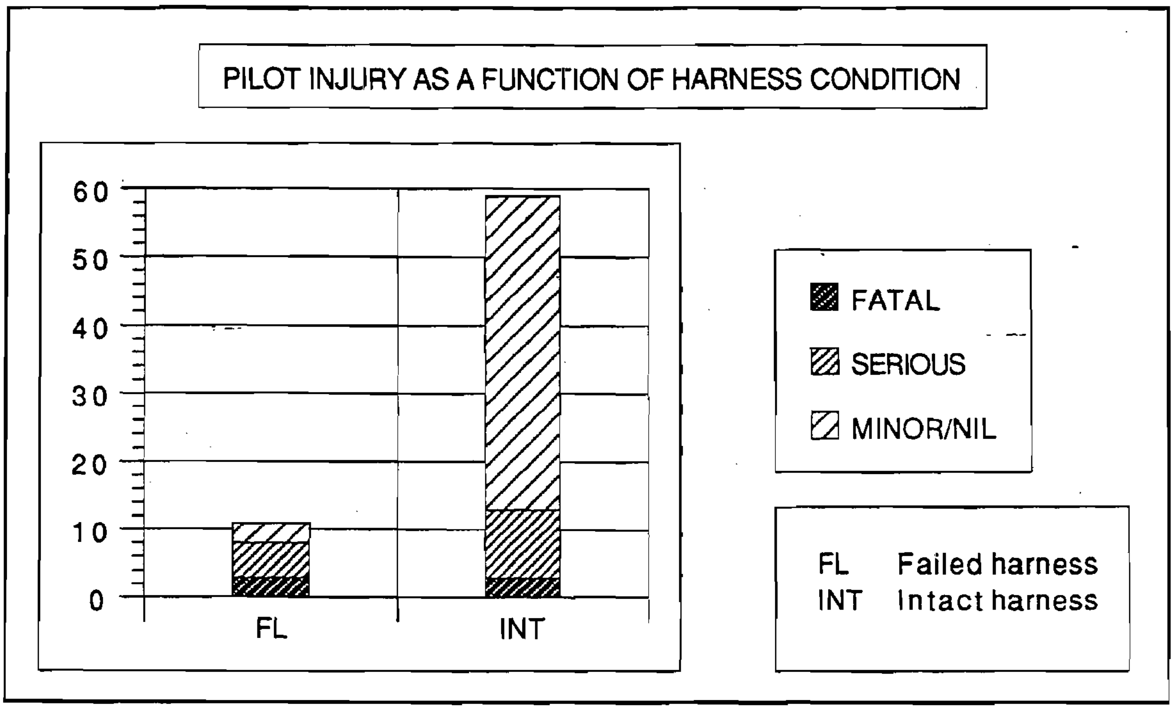
Status of the cockpit for each category of injury for the Piper PA-25 series:



Note: unknown data were eliminated

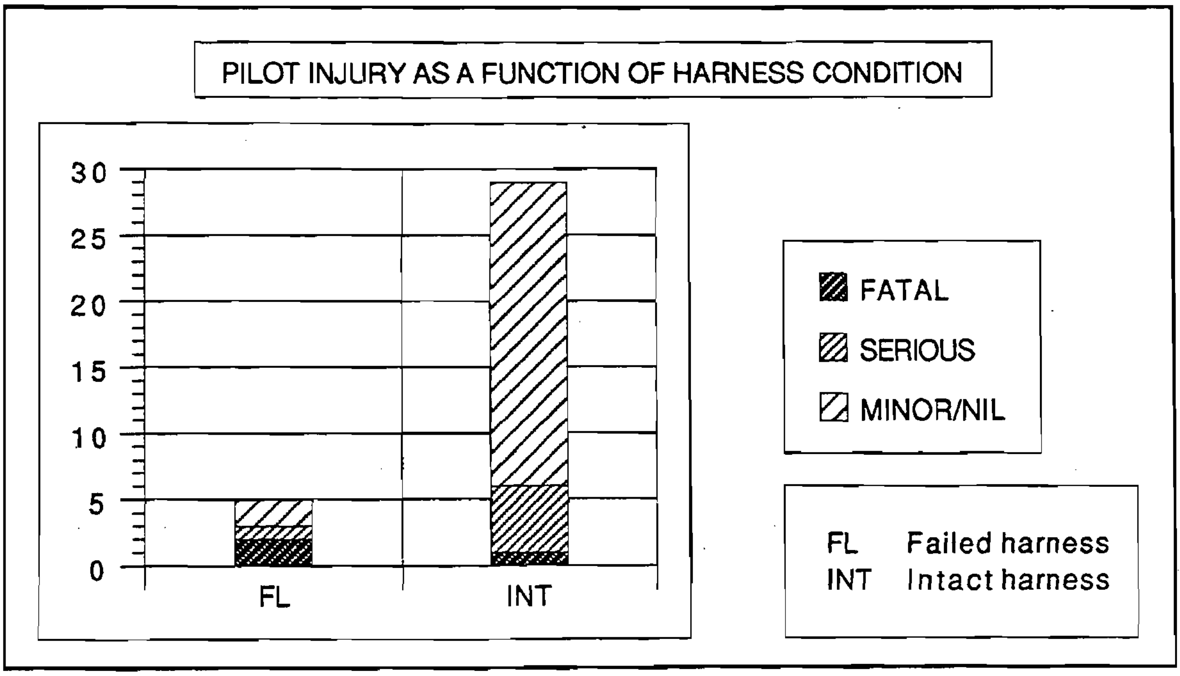
APPENDIX G

Status of the restraint system for each category of injury for the Cessna C-188 series:



Note: unknown data were not included

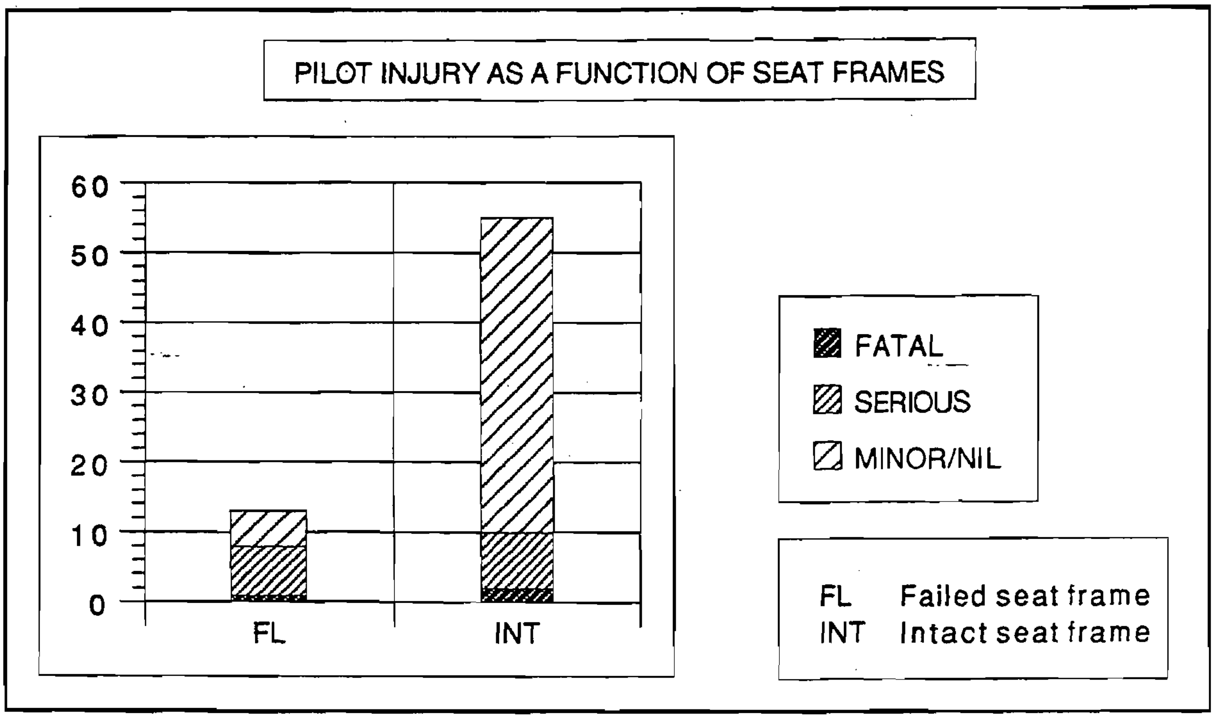
Status of the restraint system for each category of injury for the Piper PA-25 series:



Note: unknown data were not included

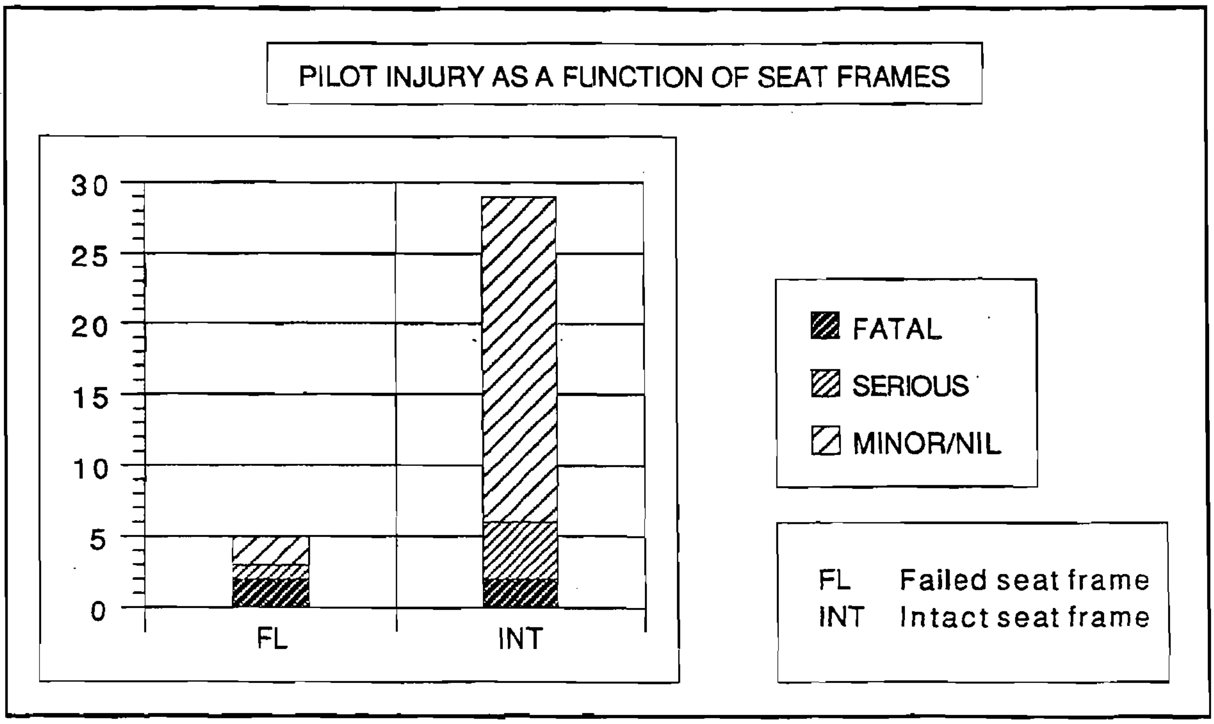
APPENDIX H

Status of the seat frames for each category of injury for the Cessna C-188 series:



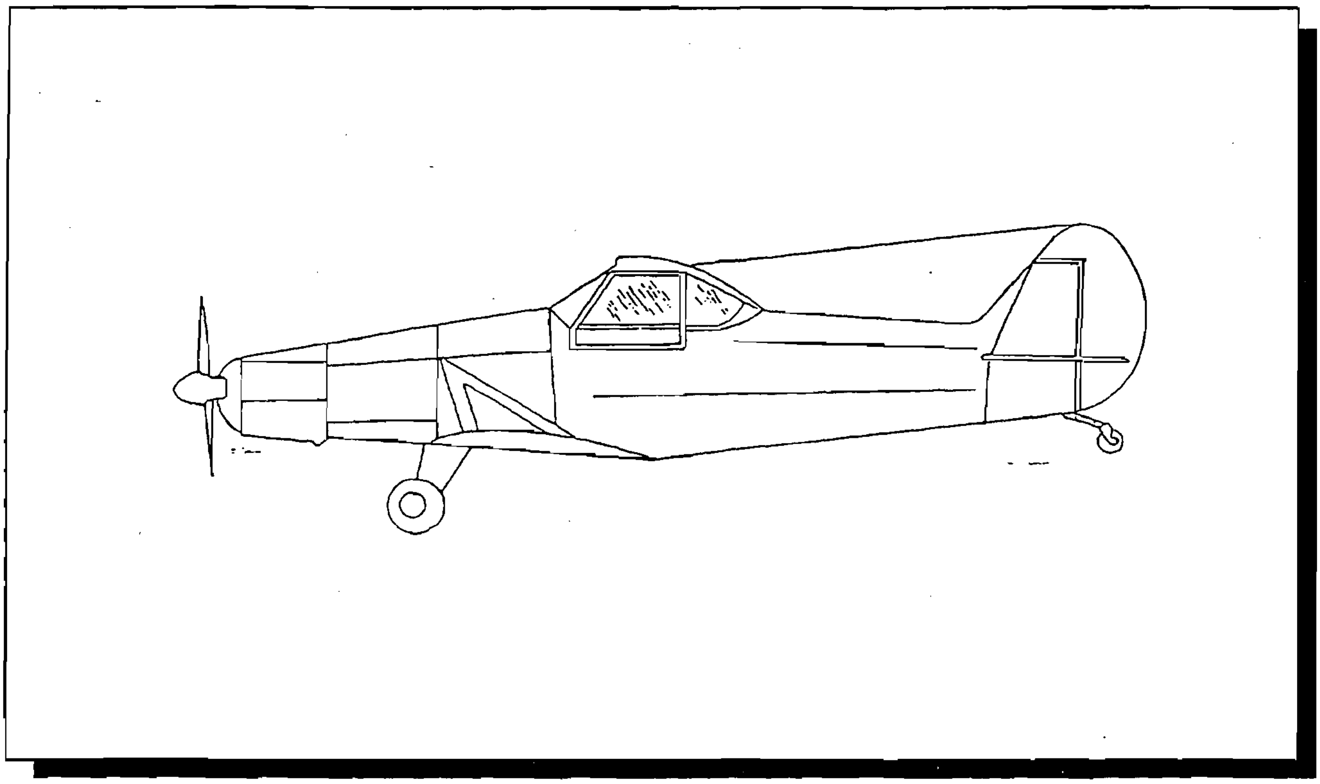
Note: unknown data were eliminated

Status of the seat frames for each category of injury for the Piper PA-25 series:

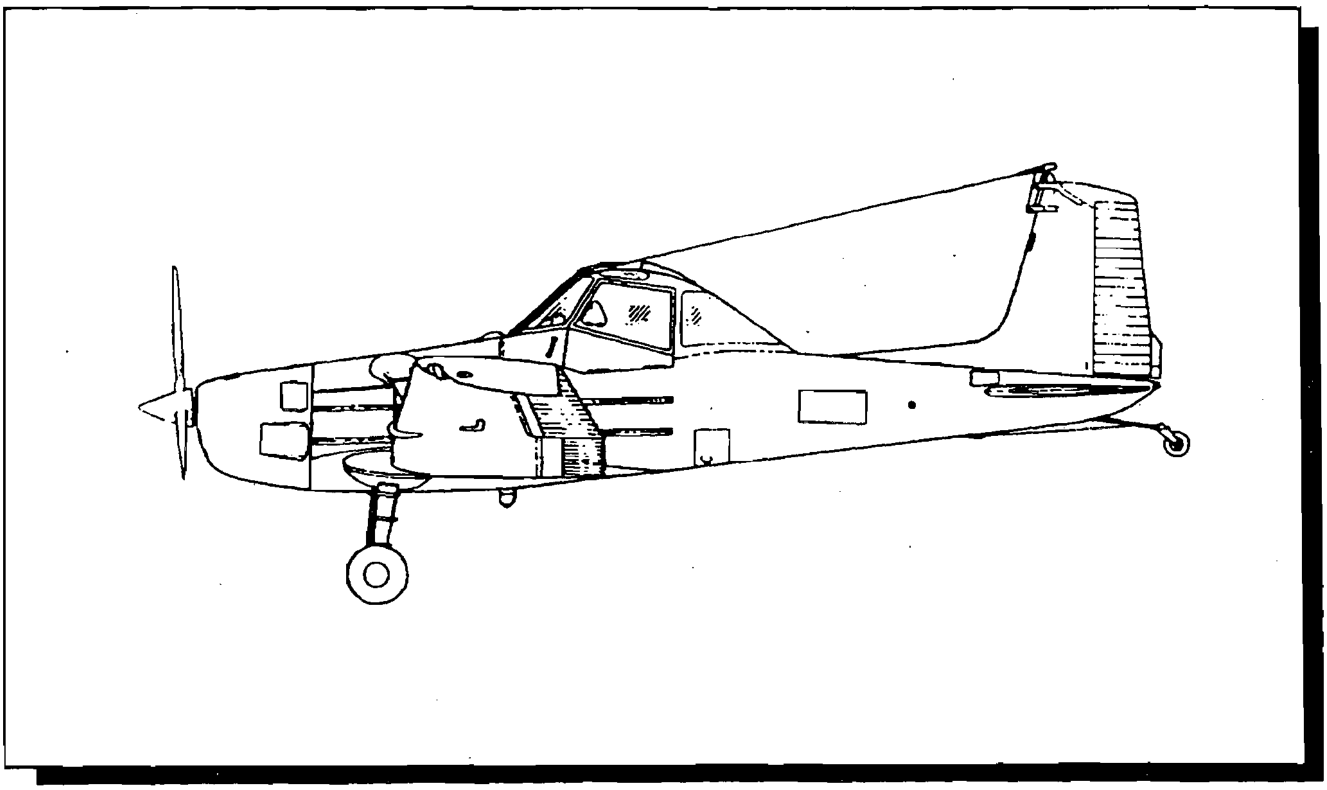


Note: unknown data were eliminated

APPENDIX I



Piper PA-25-235 Pawnee



Cessna A188B Ag Wagon

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BASI CONTACTS

basi@dot.gov.au

Australia-wide 24-hour toll-free number: 1800 011 034

Brisbane

PO Box 10024
Adelaide St Brisbane Qld 4000
Level 2, Samuel Griffith Place,
340 Adelaide Street
Brisbane Qld 4000
Facsimile: (07) 3832 1386

Canberra (Central Office)

PO Box 967
Civic Square ACT 2608
26 Mort Street
Braddon ACT 2612
Facsimile: (02) 6247 1290

Canberra Field Office

24 Mort Street
Braddon ACT 2612
Facsimile: (02) 6274 6604

Melbourne

Level 9
Casselden Place
2 Lonsdale Street
Melbourne Vic 3000
Facsimile: (03) 9285 6674

Perth

PO Box 327
Belmont WA 6104
Suite 2
Pastoral House
277–279 Great Eastern H'way
Belmont WA 6104
Facsimile: (08) 9479 1550

Sydney

PO Box Q78
Queen Victoria Bldg NSW 1230
Level 7 BT Tower
1 Market Street
Sydney NSW 2000
Facsimile: (02) 9283 1679

CAIR

Reply Paid 22
The Manager
CAIR
PO Box 600
Civic Square ACT 2608
24 Mort Street
Braddon ACT 2612
Facsimile: (02) 6247 4691