

# Catastrophic injuries in hang gliding:

What is the scope of the problem & is there a need for biomechanical intervention?



## Final Report to the NSW Sporting Injuries Committee

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**2009**

**In memory of**

**Stephen Hocking  
Honorary Secretary NSW Hang Gliding and Paragliding Association**

This was the eulogy given by Bill Moyes at Steve's funeral

*Hello, my name is Bill Moyes. I have been involved in the hang gliding community for many years and that is how I met Steve. In 1982 Steve took up the sport of hang gliding. He learnt to fly at the Kurnell sand dunes in Sydney and had been a great proponent of the sport ever since. He had always been interested in flying and told us about learning to fly with the air force in a tiger moth. The instructor insisted that he do barrel rolls in a straight line along the highway and only then would be signed off. He has made a selfless contribution to our sport especially in the last few years when he was physically unable to fly himself. He took care of relationships with government bodies, sporting bodies and the associated administration. He kept us all informed and gave us a bit of a nudge when we needed it. He was the Secretary of the NSW hang gliding association and Secretary of the Sydney club. In these roles he organised local clubs and made sure we looked after ourselves and that legally we were covered. He did this for the pilots, not for himself. His skill with the legal system and his gentlemanly manner has certainly helped to keep many pilots out of trouble. We acknowledged his contribution and he was made a life member of the Australian Hang Gliding Federation some years ago.*

*He always saw the good side of people and the beauty of our sport. We will miss him.*

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# Overview

An increasing number of pilots are participating in the sport of hang gliding. Although research pertaining to aircraft design, environmental flight conditions and rules and regulations governing the sport is abundant, there is a paucity of research identifying the frequency and type of injuries that occur or when in a flight these injuries occur. Furthermore, it is unknown whether there are common technique factors inherent in unsuccessful landing manoeuvres that may predispose the pilot to injury or whether these injuries occur through incorrect decision making and failure to adequately recognise environmental conditions alone. Therefore, two studies were conducted aiming to (1) determine the scope of injuries that occur in the sport of hang gliding, particularly catastrophic injuries that occur at landing; and (2) determine whether there are mitigating factors that will predispose pilots to injury, particularly catastrophic injury when landing.

To determine the scope of injuries that occur in the sport of hang gliding, a total of 1,189 accident and incident reports submitted by hang glider, paragliding and weight-shift microlight pilots between 1985 and 2006 were input into a newly developed Microsoft Access database. Of the 734 accidents, 50.9% were sustained during hang gliding and 33.2% during paragliding. Analysis of the database revealed that hang gliding pilots reported fewer injuries than paraglider pilots. However, both hang gliding and paragliding pilots sustained catastrophic injuries, mainly fractures (42.9%). Paraglider pilots also sustained more injuries to the lower limb and back compared to hang glider pilots who sustained more upper limb injuries. Restricted and intermediate pilots reported significantly ( $p = 0.004$ ) more injuries than student or advanced pilots and significantly ( $p < 0.001$ ) more injuries were sustained during landing (42.3%) compared to inflight (31.7%) or launch (21.7%) manoeuvres. The overall injury incidence calculated for both paragliding and hang gliding were low compared to other adventure sports. Modifications were made to the database to include greater detail for reporting injury. Although this will assist in future injury reporting, the current database had much incomplete data due to changing reporting systems. Despite this, the findings were in agreement with two of the three hypotheses.

To determine whether there were mitigating factors that predisposed pilots to injury, the landing manoeuvres performed by hang glider pilots were recorded by at least four video standard digital video cameras (25 Hz). For the 19 hang glider pilots, who provided consent, qualitative analysis, in the form of expert testimony from two experienced inland advanced pilots, was conducted. This analysis revealed that all pilots made errors during landing manoeuvres, although the most common error was not having the craft parallel. In the 20 landings that were deemed unsuccessful, the most common errors were slow trim speed, weight forwards and craft not parallel. It was deemed that these errors were common among coastal pilots flying inland and were due to "lazy" technique. Technique errors could also be easily detected through the use of video, and video feedback was welcomed by one pilot having difficulty landing when flying an advanced hang glider.

The sport of hang gliding is one that involves risk to the pilot, although many of these risks can be dictated by the pilot. With improved injury surveillance systems, if pilots comply with the Hang Gliding Federation of Australia (HGFA) Operations Manual, and if HGFA re-evaluate pilot training and license renewal regulations, particularly in paragliding, the risk of injury can be further reduced in both hang gliding and paragliding. Video could also be investigated as a way to further educate and assess pilots in both sports to develop their skills so that when flying in unpredictable situations, the injury risk can be further minimised and hang gliding and paragliding remain popular among all participants.

# Introduction

## The history of hang gliding and paragliding\*

Although often thought of as a “newcomer to aviation”, hang gliding is among the oldest forms of human flight. For example, sketchings from Leonardo da Vinci’s work detailed a craft based on the design of a bird’s wing, portraying his desire for human flight. However, the obvious practical advantages of powered airplanes over gliding craft effectively ended further development of gliding, as intensive effort was devoted to developing airplanes for both civilian and military use. Unpowered gliding as a form of sport aviation saw a rebirth after World War I, starting in post war Germany and then, in the late 1960's, several notable people participated in the re-birth of hang gliding.

An American engineer named Francis Rogallo invented a new type of wing, the “Rogallo wing” that essentially consisted of two sails joined along a central spar, forming a delta-shaped single surface fabric wing. The National Aeronautics and Space Administration (NASA) became interested in the wing as a possible re-entry vehicle for the Mercury space program and invested substantial time and money in researching its aerodynamic characteristics. The Rogallo wing design was then modified by an Australian engineer, John Dickenson, in 1963. Dickenson built a kite with all the basic features of today's hang glider wings, including the triangular control bar. However, it was not until William Moyes invented a simple A-frame that was fixed beneath the wing and allowed the pilot to control three axes of flight by movement of the frame that hang gliding was truly invented. From there, Australia became the world leader in hang glider development, showcasing its designs to the rest of the world. Following this international introduction, recreational hang gliding, a sport whereby the glider is capable of being carried, foot launched and landed solely by the energy and use of the pilot’s legs (Hang Gliding Federation of Australia (HGFA), 1995), has become increasingly popular.

In the 1970's paragliding, a new form of foot-launched gliding and soaring, was developed in Europe, although the sport has origins in the early 1960s when American parachutist Pierre Lemoigne successfully cut slots in a parachute canopy for air to flow through the canopy allowing the pilot to steer the chute in a predictable manner. In contrast to a hang glider, a paraglider is a special parachute with steering and brake lines that allow the pilot to launch from the ground without the need for aircraft (Gauler *et al.*, 2006). Paragliding now joins hang gliding as a popular sport enjoyed by pilots around the world. However, as with hang gliding, paragliding has been associated with a high risk of accidents resulting in injury.

## What do we know about the injuries sustained during hang gliding?

In the initial days of hang gliding, when the equipment and techniques used in the sport were primarily experimental, there was a high incidence of catastrophic injuries and fatalities, as evidenced by research papers detailing hang gliding injuries in the 1970s. For example, Krissoff (1976) analysed seven fatal and 11 nonfatal injuries sustained by pilots in Colorado between 1973 and 1975 and Margreiter & Lugger (1978) assessed 75 known hang gliding accidents that resulted in pilot injury between 1973 and 1976 in the Tyrol area, seven of which were fatal and 60 of which were severe. Krissoff (1976) reported fractures in 10 of the 11 (91%) non-fatal accidents, with the upper limbs (55%),

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\* Background developed from [http://open-site.org/Recreation/Aviation/Aircraft/Flex\\_Wing/Paraglider/](http://open-site.org/Recreation/Aviation/Aircraft/Flex_Wing/Paraglider/), <http://hobby.rin.ru/eng/articles/html/103.html>, <http://www.sky2glide.com/html/history.html>, [http://en.wikipedia.org/wiki/Hang\\_gliding](http://en.wikipedia.org/wiki/Hang_gliding), <http://www.flying-man.com/en/history.htm>, <http://www.hgfa.asn.au/> and information from Mr Stephen Hocking, NSW Hang Gliding Association Inc.

lower limbs (46%) and spine (46%) the commonly injured body regions. In comparison, Margreiter & Lugger (1978) reported fractures in only 66.4% of cases and the lower limbs (26%) were the most commonly injured body region followed by the upper limbs (22%), spine (19.7%), head (17%) and torso (10%). Both papers determined that, although most injuries occurred during the launch and landing manoeuvres performed by experienced pilots, the mechanisms of injury were multifactorial. That is, most accidents involved pilot error (>90%), equipment failure, terrain hazards and possible design shortcomings. Interestingly, both papers concluded that, despite the risk of hang gliding appearing unjustifiably high, emphasis on safety precautions, regulations and improved pilot training programs would reduce this injury incidence (Krissoff, 1976; Margreiter & Lugger, 1978).

Research conducted on injuries sustained in hang gliding approximately a decade later, still concluded that hang gliding was dangerous for participants. Stricker & Noesberger (1990) completed an analysis of 36 patients admitted to Interlaken hospital with injuries resulting from gliding accidents. Their results indicated that accidents occurred equally during launch and landing and resulted in 24 patients sustaining lower limb injuries and 10 patients sustaining spinal injuries with an additional 20 injuries requiring surgery. In this study, the authors concluded that most patients had very little experience in hang gliding or had undergone insufficient training. A retrospective investigation of traumatic hang gliding accidents in the army conducted by Lacombe *et al.* (1993) observed 133 cases of sprains, dislocations, fractures or muscular damage that prevented participation. Lower limb injuries were more commonly sustained by pilots (57%) compared to upper limbs injuries (23%), although the upper limb injuries were found to be more severe. Spinal injuries were reported in 21% of cases but only by skilled subjects and were more serious than other injuries. Interestingly, two technical errors, namely stalling and banking too low, were detected as the cause of these injuries (Lacombe *et al.*, 1993).

Finally, a retrospective analysis of 1,016 causes of traumatic spinal cord injury completed by Schmitt & Gerner (2001) between 1985 and 1997 in Germany found that of the 69 (7%) spinal cord injuries that were caused by sport, seven cases of paraplegia occurred during participation in hang gliding or paragliding. The authors concluded that these injuries most commonly occurred because of insufficient instruction and a participant's overestimation of their own ability. This was confirmed by Cereghetti & Martinoli (1990) who found that inexperience and flying site were the most common causes of hang gliding injuries, mandating appropriate training. Therefore, although accidents are sustained by pilots of all levels, all authors concluded that pilot training was considered to be the area requiring most development in terms of injury prevention.

### **What do we know about injuries sustained during paragliding?**

In the sport of paragliding, similar injuries have been reported. Ballmer & Jakob (1989) analysed 23 patients who sustained 48 injuries over an 8 month period, presenting to a hospital in Berne, Switzerland. As a result of sustaining the injury, 74% were admitted to hospital, 26% were treated by ambulance, 44% required surgery, and 56% only required conservative treatment. The most commonly injured body region was the lower limb (50%) followed by the spine (29%). Ninety percent of the accidents occurred at either launch or landing and 96% were caused by human error, leading the authors to conclude that better training was required for beginner pilots and, that strict guidelines needed to be imposed on more experienced pilots when flying in unfavourable conditions.

In a retrospective study of helicopter rescues in 70 paragliding accidents and 43 patient interviews, Fasching *et al.* (1997) reported that 42% of injuries occurred during take-off, 44% during flight and 13% when landing. Accidents were incurred mostly by intermediate pilots, followed by novice, advanced and then student pilots. Injuries were

mainly incurred by the lower limbs (54%), spine (49%) and upper limbs (21%) and 84% of injuries were fractures. Similarly, when analysing 64 German-Swiss patients treated after paragliding accidents between 1994 to 1998, Schulze *et al.* (2000) found that 63% suffered spinal fractures and 28% of the injured pilots were admitted with lower limb injuries. While 54% of pilots sustained injuries that resulted in lasting functional problems, in contrast to Ballmer & Jakob (1989), only 5% could be treated in an ambulatory setting. Most injuries were sustained during landing (46%), flight (43%) and launch (11%) manoeuvres due to pilot error in handling the paraglider or a general lack of awareness about potential risk factors.

Finally, a study of 409 paragliding accidents in Germany between 1997 and 1999 by Schulze *et al.* (2002) found the most common causes of paraglider accidents included deflation of the glider (33%), landing errors (14%), oversteering (14%), collision with obstacles (12%), and take off errors (10%). These accidents were primarily sustained by pilots with fewer than 100 flights logged (40%). Three fatalities (8%) were reported with an additional 10 injuries (26%) deemed serious. One positive finding from this study was that accidents, specifically those resulting in spinal injuries, substantially decreased between 1997 and 1999 (Schulze *et al.*, 2002). The authors concluded that further reductions in accidents would be possible if safer gliders were used by beginner or intermediate pilots, with greater use of body protection, and if pilot skills were improved through performance and safety training. Therefore, once again, all authors concluded that improved pilot training, introduction of protective equipment and a better understanding of aerodynamics may reduce the risk of paragliding accidents (Bohnsack & Schroter, 2005; Exadaktylos *et al.*, 2003; Rekan *et al.*, 2008; Schulze *et al.*, 2000).

### **Do we need to research hang gliding and paragliding injuries in Australia?**

Today's gliders incorporate highly sophisticated technology and instrumentation, which must pass stringent "load" tests before they are certified as airworthy. Furthermore, pilots fly with altimeters, variometers, reserve parachutes and on-deck flight computers and must undergo rigorous training and examinations before they are certified to fly. In addition, all pilots wear helmets and generally carry one or more other safety items such as hook knives (for cutting their parachute bridle after impact or cutting their harness lines and straps in case of a tree or water landing), light ropes (for lowering from trees to haul up tools or climbing ropes), radios (for calling for help) and first aid equipment. Furthermore, paraglider pilots are encouraged to wear high collar shoes and back protectors (Exadaktylos *et al.*, 2003; Rekan *et al.*, 2008). These changes have been necessary considering that, rather than simply running and gliding down the hill, pilots now regularly fly distances exceeding 400 km. Although there is some evidence suggesting that these improvements in equipment and safety procedures have led to a reduction of injuries sustained in the sport of paragliding (Bohnsack & Schroter, 2005; Schulze *et al.*, 2002), there has been little research to systematically determine whether these improvements in safety and pilot training have impacted upon the number of injuries, particularly catastrophic injuries, sustained in the sport of hang gliding. Indeed, most studies providing injury reports in these sports suggest their reports should be considered under-estimates (Krissoff, 1976; Margreiter & Lugger, 1978). Consequently, members of the general public typically still view hang gliding as a "death sport", with fragile, unstable flying craft and the pilots as "thrill seekers" who recklessly disregard the inherent risks in what they do.

While there has been an abundance of research pertaining to the design and materials required to build a hang glider, there are very few studies assessing the injury mechanics or incidence of injury in the sport. For example, a literature search using the SportsDiscus (1975-present) and Medline (1966-present) databases revealed a total of

1,188 and 28 articles, respectively, when “hang gliding”, “hanggliding” or “paragliding” were entered as keywords. Interestingly, of the 28 Medline hang gliding articles, only 15 discussed the injuries involved, with four studies reporting on all injuries incurred by pilots, albeit predominantly focused on paraglider pilots. Three other papers reported only on spinal injury incidence, one review paper discussed spinal injuries, four papers were case study presentations and a further four papers reported on high risk sports in general. When limited by “injury”, SportsDiscus returned 1,108 but only 51 when limited to peer-reviewed articles of which only 25 highlighted injury incidence. Of these peer-reviewed articles, 14 detailed general injury incidences in the sport, four presented case studies, five were editorials, letters or comments on injuries in the sport of hang gliding and paragliding and two focused only on spinal injury incidence. There was substantial overlap between the two databases in terms of the injury research. Furthermore, apart from a case study published by Wilson (1990) and the abstract presented by the current research group at the Asics Conference in Science and Medicine in Sport (Munro *et al.*, 2006), no studies were located that investigated the injury incidence, particularly the catastrophic injury incidence, of pilots in Australia.

Therefore, although both the limited published research and anecdotal evidence suggests an injury problem in hang gliding and paragliding, particularly during landing and particularly with respect to catastrophic injuries, the true injury problem, particularly in Australia, is not fully understood and requires research. Furthermore, information as to whether these injuries are dependent upon human movement and landing technique or entirely due to the quality of pilot decision making, that is, recognition of, and the ability to change their movements due to changing environmental conditions, is unknown and requires investigation. Although hang gliding and paragliding do not record the highest claim counts with respect to other individual sports, they typically have the highest claim costs, suggesting greatest injury severity (Bentley *et al.*, 2007). Therefore, the incidence of injury in hang gliding requires investigation to both improve the safety of the sport as well as to improve the reputation of the sport among the general public, allowing it to expand and enjoy a greater number of active participants.

## Aims & Hypotheses

### What did we aim to achieve?

This study aimed to:

- 1) Determine the scope of injuries that occur in the sport of hang gliding\*, particularly those injuries that occur at landing.
- 2) Determine whether there are mitigating factors that will predispose hang gliding pilots to injury, particularly catastrophic injury when landing.

### What did we hypothesise?

Based on the limited literature and anecdotal evidence, we hypothesised that:

- 1) The sport of hang gliding will have a higher incidence of injury, particularly catastrophic injuries, compared to other sports.
- 2) Novice and intermediate pilots will have a higher incidence of injury compared to advanced pilots, although, advanced pilots will have a higher incidence of catastrophic injury compared to novice and intermediate pilots.

\* Hang gliding encompasses non-powered hang gliding and paragliding sport activities (Hang Gliding Federation of Australia, 1995).

- 3) Injuries will occur most frequently at landing compared to launch or during flight.
- 4) There will be common technique faults evident during landing manoeuvres, which predispose pilots to catastrophic injury.

## Part 1: Identifying the Scope of the Injury Problem in Hang Gliding

### Methods & Procedures

#### Data Collection

It is a requirement of all pilots and safety officers registered with the HGFA to complete an Accident and Incident Report Form (see Appendix A) within 48 hours of an accident\* and/or incident† occurring (HGFA, 1995). Therefore, to identify the scope of the injury problem in the sport, all Accident and Incident Report forms provided by the HGFA were input into a newly developed MS Access database (Microsoft, USA). The database was composed of a main menu and lookup screen and then a further seven screens that were derived from the paper-based Accident and Incident Report Form (pilot details, incident/accident details, aircraft & equipment details, site/location details, factors associated with incident/accident, details of incident/accident & safety officer recommendations and office use only; see Figure 1). However, the database was developed to have a greater focus on capturing the injuries sustained in the sport of hang gliding such that whereas the paper-based form simply requested details as to the severity (e.g. fatal, hosp, doc, minor, nil) of the injury and then provided limited space for details of the injuries (see Appendix A), the new database provides the ability to input details on the injured party(ies), the injury severity, the primary and secondary injury(ies) received, nature of injury(ies) and body region(s) injured.

The screenshot displays the 'Injury Details' screen of the Hang Gliding Federation of Australia Injury Database. The interface includes a header for 'Hang Gliders Federation Australia' and 'INCIDENT / ACCIDENT DATABASE'. Below this, there are input fields for 'Inc. or Acc.?' (set to 'Accident'), 'Date', 'Time', and 'No of Persons Involved' (set to '1'). A 'Witnesses:' section contains a table for recording names and contact details, with a checkbox for 'Author of Report?'. An 'Instructors:' section has a text input field. The main part of the screen is a table titled 'Injury Details For All Involved Persons:' with columns for 'Person Type', 'Name', 'Injury Severity', 'Primary Injury Received', 'Nature of injury', and 'Body region'. At the bottom, there are navigation buttons: 'Instructors', 'Persons', 'Person Types', 'Injury Severity Levels', 'Injuries', and '<-- BACK NEXT -->'. The 'Persons' button is highlighted.

**Figure 1:** The injury screen of the Hang Gliding Federation of Australia Injury Database, which was developed as part of this project.

\* "Accident" is associated with aircraft operation which takes place between the time any person attaches to the aircraft with the intention of flight until such time as such persons have detached themselves in which:

- any person suffers death or injury as a result of being in or upon the aircraft or anything attached to the aircraft, except when the injuries are from natural causes, are self-inflicted by other persons; or
- the aircraft incurs flight damage or structural failure that adversely affects flight, structure strength or performance of the aircraft and would require major repair or component replacement; or
- the aircraft is missing or inaccessible.

† "Incident" is an occurrence (not an accident), including hard landings, associated with the operation of the aircraft that affects or could affect the safety of the operation of the aircraft.

A total of 1,189 accident & incident reports from 1985 to 2006 were input into the database by two experienced research assistants with data entry quality being confirmed by a third independent research assistant. Unfortunately, complete data was not available in many records whereby some records contained only simple commentaries on how the accident/incident occurred and others contained insufficient information on the injuries sustained. In addition, changes to reporting regulations, the need for additional data and, in the past, poor follow-up from the HGFA, contributed to incomplete data in the submitted reports. Despite incomplete datasets, all data were included in the analysis of the database.

## Data Analysis

Upon completion of data entry, the data were divided into categories and frequency data were tabulated and expressed as a percentage of the total cases. Injury incidence was calculated using the data provided by the HGFA to the Department of Transport and Regional Services in terms of flying hours and number of aircraft from 1991 onwards (see Table 1). These data reveal that the total flying hours and registered craft in hang gliding were reduced from 1997 whereas there was an increase in the same variables for paragliding over the same period. The increasing popularity of paragliding is likely due to reduced equipment needs and an upright flying position. The database was then analysed using descriptive statistics with respect to injury incidence, nature of injuries, injury severity and body region injured. Descriptive subgroup analyses of these variables were carried out for the year of the accident (1991-2006), specific sport (hang gliding or paragliding), pilot qualification (novice, student, intermediate or advanced) and the flight phase in which the accident occurred (launch, flight or landing). Chi-Square statistical tests were used to determine whether there were any significant ( $p \leq 0.05$ ) differences in the distributions of the subgroups. All statistical procedures were completed using SPSS software.

**Table 1:** Details of hours flown (Australia and NSW) and total aircraft registered for all craft, hang gliding and paragliding from 1991-2006.

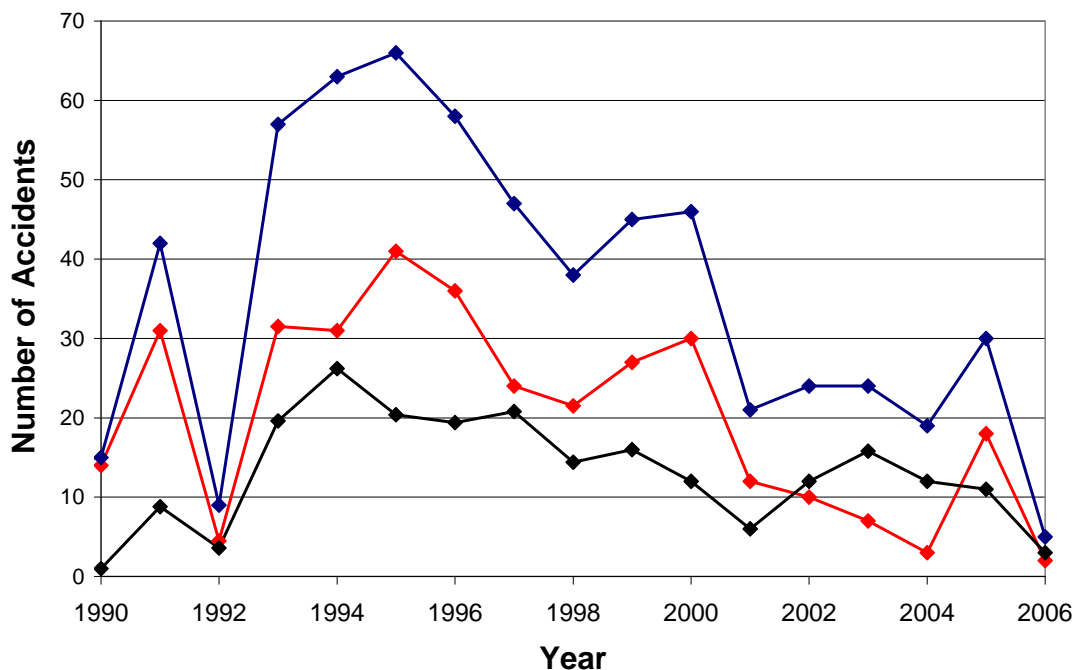
Year	All Craft*			Hang Gliding			Paragliding		
	Total Hours Flown ('000)		Total Aircraft	Total Hours Flown ('000)		Total Aircraft	Total Hours Flown ('000)		Total Aircraft
	Australia	NSW		Australia	NSW		Australia	NSW	
1991	63.7	----	----	53.6	----	----	4.0	----	----
1992	73.5	----	----	58.5	----	----	5.4	----	----
1993	86.2	----	2,654	64.7	----	2,160	7.7	----	390
1994	77.6	----	2,840	50.2	----	2,020	9.3	----	565
1995	86.4	----	3,022	49.2	----	2,045	12.3	----	657
1996	103.2	----	3,089	56.5	----	2,110	18.3	----	720
1997	102.3	----	3,260	57.3	----	2,100	17.3	----	890
1998	87.5	----	3,183	50.9	----	1,850	15.1	----	980
1999	104.6	----	3,263	50.4	----	1,845	24.2	----	1,042
2000	106.7	----	3,346	50.9	----	1,887	24.8	----	1,067
2001	120.0	46.8	3,382	53.4	21.7	1,864	32.2	12.0	1,121
2002	122.2	47.5	3,341	48.0	19.5	1,540	37.4	13.9	1,334
2003	124.7	53.8	3,393	48.8	22.8	1,590	44.8	17.2	1,326
2004	132.0	53.8	3,584	48.7	21.4	1,555	52.9	18.5	1,472
2005	134.2	46.9	3,577	43.3	18.3	1,403	59.0	15.4	1,445
2006	103.0	37.0	2,637	32.1	13.2	1,001	44.9	15.1	1,132

\* Includes hang gliding, paragliding and weight-shift microlight flying hours and aircraft.

## Results & Discussion

Of the 1,189 accident and incident reports entered into the database, there were 734 accidents (61.7%) and 448 incidents (37.7%), with 7 unclassified (0.6%), submitted by hang glider, paraglider and weight-shift microlight pilots. As the present study focused on injuries sustained by hang glider pilots or pilots of non-powered aircraft, the following results pertain to accident reports submitted by hang glider and paraglider pilots. However, it is assumed that, similar to past reports (Margreiter & Lugger, 1978; Schulze *et al.*, 2002), hang gliding and paragliding accidents are under-reported.

Figure 2 displays the accidents reported for hang gliders, paragliders and all craft from 1990-2006 ( $n = 605$ ). In hang gliding, accident reports peaked in 1991, 1995, 2000 and recently in 2005. In comparison, paragliding accidents displayed peaks in 1994, 1997 and 2003. Interestingly, although the sport of paragliding is gaining in popularity (see Table 1), the accident reports appear relatively stable (see Figure 2). It is suggested that the inflections displayed in Figure 2 for each sport may have resulted from changes in both legislation and safety procedures. For example, in 1991 a new constitution was adopted by which individual pilots registered directly with the HGFA (HGFA, 1995) and coincided with reduced accidents the following year. In 1995, the Department of Transport imposed a national regulating body on the sport of hang gliding, publishing the first set of regulations for the sport. Then, in 1997, because legislation changes to Australian civil aviation laws demanded self-regulation of the sport (Fogg, personal communication, 2008), the HGFA was incorporated so that all state bodies had a reporting body. In direct response to these legislative changes, as well as to increasing accident reports, amendments were made to the HGFA Operating Manual (Hang Gliding Federation of Australia, 1995). These amendments included updated safety procedures, training and equipment guidelines (issued in 1995), updated pilot qualifications details (issued in 1998) and updated regulations (issued in 2002).



**Figure 2:** The total number of accidents reported by hang glider (—) and paraglider (—) pilots per year. Total aircraft accidents per year are also displayed (—).

\* Weight-shift microlight data has not been included in any further analysis as these are powered aircraft.

Accidents occurred at 428 sites around Australia. There was a significant relationship between site and accident report ( $\chi^2 = 499.6$ ;  $p < 0.001$ ). That is, the greatest number of accidents were reported in NSW (37.4%), followed by Victoria (31.3%), Queensland (15.4%), WA (8.2%), SA (3.3%), ACT (1.9%), Tasmania (1.6%) and NT (0.7%). The higher number of accidents reported at these sites is in line with both the number of pilots and the number of sites listed from each state, whereby the most flying hours are typically recorded in NSW (see Table 1). Of those accidents which reported details of the site, most occurred inland (29.9%; see Table 2) and at sites designated as suitable for restricted pilots (11.9%; see Table 3). However, as many accident reports did not highlight site details, only descriptive results have been presented and no further analysis was conducted.

**Table 2:** Site type by state/territory for the accidents reported in the HGFA database ( $n = 428$ ).

State	Number	Site Type			
		Inland	Coastal	Other*	Not reported
NSW	161	54 (33.5%)	36 (22.4%)	20 (12.4%)	51 (31.7%)
Victoria	134	28 (20.9%)	24 (17.9%)	13 (9.7%)	69 (51.5%)
Queensland	66	28 (42.4%)	10 (15.2%)	4 (6.1%)	25 (37.9%)
WA	35	7 (20.0%)	13 (37.1%)	5 (14.3%)	10 (28.6%)
SA	14	3 (21.4%)	2 (14.3%)	2 (14.3%)	7 (50.0%)
ACT	8	5 (62.5%)	0 (0%)	0 (0%)	3 (37.5%)
Tasmania	7	3 (42.9%)	2 (28.6%)	0 (0%)	2 (28.6%)
NT	3	0 (0%)	0 (0%)	1 (33.3%)	2 (66.7%)

\* Includes tows, grass strips and sealed runways.

**Table 3:** Site ranking by state/territory for the accidents reported in the HGFA database ( $n = 428$ ).

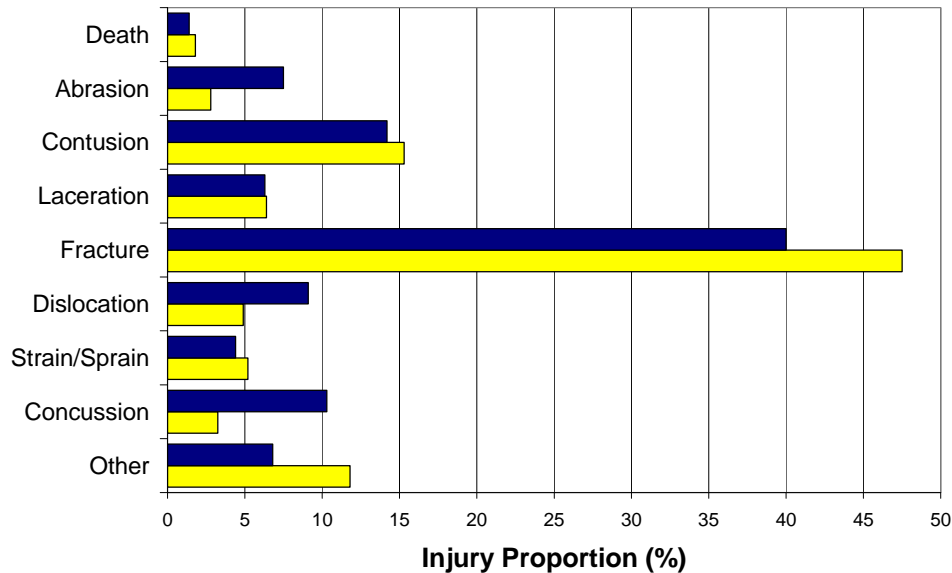
State	Number	Site Ranking				
		Student	Restricted	Intermediate	Advanced	Not reported
NSW	161	13 (8.1%)	14 (8.7%)	16 (9.9%)	10 (6.2%)	108 (67.1%)
Victoria	134	11 (8.2%)	10 (7.5%)	9 (6.7%)	4 (3.0%)	100 (74.6%)
Queensland	66	5 (7.6%)	11 (16.7%)	6 (9.1%)	1 (1.5%)	43 (65.2%)
WA	35	4 (11.4%)	9 (25.7%)	5 (14.3%)	1 (2.9%)	16 (45.7%)
SA	14	1 (7.1%)	0 (0%)	0 (0%)	0 (0%)	13 (92.9%)
ACT	8	3 (37.5%)	2 (25.0%)	1 (12.5%)	0 (0%)	2 (25.0%)
Tasmania	7	2 (28.6%)	1 (14.3%)	0 (0%)	0 (0%)	4 (57.1%)
NT	3	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (100%)

## 1) Incidence and Prevalence of Injury in Hang Gliding & Paragliding

Consistent with pilot age and gender ratios reported previously (Margreiter & Lugger, 1978), most accidents were sustained by males (90.1%) compared to females (9.9%) with the mean age of the injured pilots being  $37.8 \pm 10.6$  years. Of the total 734 accidents, 50.9% were sustained during hang gliding and 33.2% during paragliding.

A total 607 (82.7%) hang gliding and paragliding pilots reported sustaining an injury on their accident forms. However, fewer hang gliding pilots (67.8%) reported injuries to paraglider pilots (90.2%). This may reflect the stricter regulatory processes in place when paragliding started to gain popularity (see Table 1) compared to the longer established sport of hang gliding. When the injury reports were assessed for injury nature, fractures were the most common injury (42.9%) followed by substantial bruising (14.5%), concussions (7.8%), dislocations (7.6%), lacerations (6.5%), abrasions (5.8%),

sprains/strains (4.7%) and fatalities (1.6%). There was a significant ( $\chi^2 = 17.82$ ;  $p = 0.023$ ) relationship between sport and injury nature such that hang gliding pilots reported significantly more abrasions, dislocations and concussions compared to paraglider pilots who reported more fractures (see Figure 3). Therefore, catastrophic\* injuries were sustained in both hang gliding and paragliding.



**Figure 3:** The nature of the injuries reported by hang glider (■) and paraglider pilots (■).

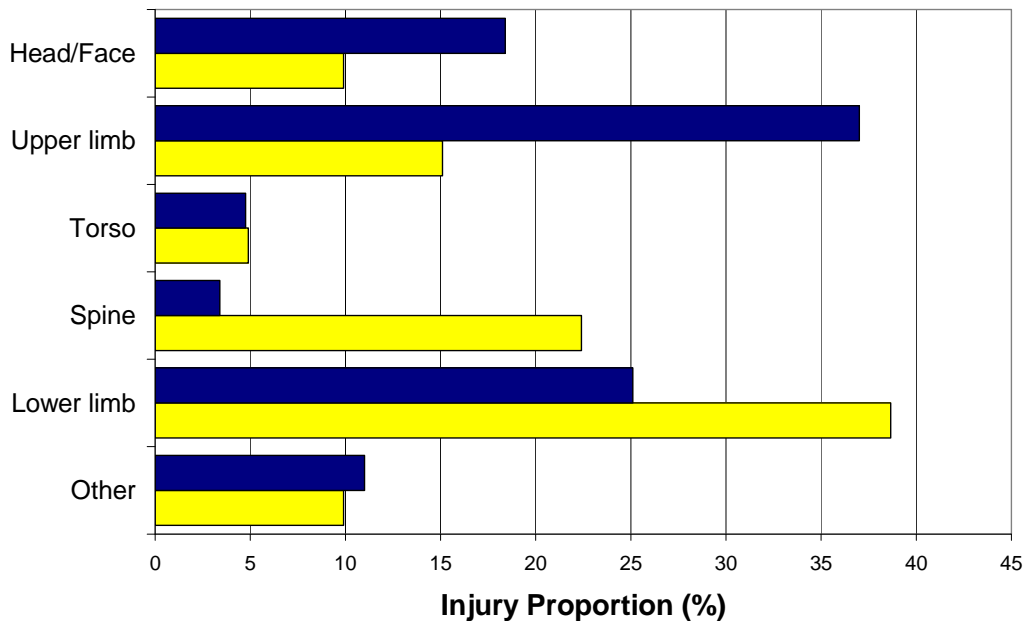
Although there were differences in the nature of the injuries reported, there were no significant differences between the treatment sought by hang glider or paraglider pilots. That is, when the fatalities were not considered, most pilots (44.6%) did not seek any medical attention or received only first aid (16.8%). However, over one third of pilots (33.9%) were hospitalised as a result of their injury with a further 4.6% visiting a doctor.

The lower limb (28.6%) was the most commonly injured body region followed by the upper limb (23.5%), head/face (15.5%), spine (10.1%), shoulder (5.9%), torso (4.5%) and groin/hip (1.4%). A number of other injuries, including internal injuries, puncture wounds, respiratory problems, numbness, shock, winding, blood nose, cardiac problems and dental injuries were classified in an “other” category (10.1%). Interestingly, Chi-square analysis revealed a significant ( $\chi^2 = 62.66$ ;  $p < 0.001$ ) relationship between sport and body region injured. That is, hang glider pilots sustained significantly more head/face and upper limb injuries than paraglider pilots, and paraglider pilots sustained significantly more spine and lower limb injuries than hang glider pilots (see Figure 4).

Injury incidence for total craft, hang gliding and paragliding from 1991-2006 is reported in Table 4. The highest incidence of injury for all craft was recorded in 1994 due to the highest calculated incidence of injury in paragliding. Paragliding injury incidence then showed a steady decrease until a second, although much lower, peak in 2003. The injury incidence in hang gliding appears to have a five year cycle with peaks in 1995, 2000 and 2005. Few reports were provided by the HGFA to the research team for 2006. However, the reports that were provided described accidents that occurred from January to December 2006. While these decreases reflect the important regulations governed by

\* Catastrophic injuries include those designated as “fatal” or “serious”. Serious injuries include those which require hospitalisation; fractures; severe haemorrhaging, nerve, muscle or tendon damage; injury to an internal organ; or significant burns (HGFA, 1995).

the HGFA, they are more impressive for paragliding which is undergoing a period of rapid growth in terms of participation. However, it should also be noted that, although these data provide a measure of injury incidence in hang gliding and paragliding, the accuracy of these data are unknown because flying hours, total number of craft and injuries are likely to be under-reported.



**Figure 4:** The location of the injuries reported by hang glider (■) and paraglider pilots (■).

**Table 4:** Injury incidence for hang gliding, paragliding and total craft per 1,000 flying hours and 100 craft from 1991-2006.

Year	All Craft*		Hang Gliding		Paragliding	
	Total Hours Flown ('000)	Total Aircraft ('00)	Total Hours Flown ('000)	Total Aircraft ('00)	Total Hours Flown ('000)	Total Aircraft ('00)
1991	0.66	----	0.60	----	2.50	----
1992	0.12	----	0.10	----	0.56	----
1993	0.82	2.68	0.15	0.46	1.56	3.08
1994	2.18	5.95	0.90	2.23	4.84	7.96
1995	1.67	4.77	1.54	3.72	2.60	4.87
1996	1.20	4.01	1.17	3.13	1.80	4.58
1997	0.88	2.76	0.70	1.90	1.91	3.71
1998	0.90	2.48	0.75	2.05	1.92	2.96
1999	0.76	2.42	0.91	2.49	0.99	2.30
2000	0.87	2.78	1.22	3.29	0.93	2.16
2001	0.30	1.06	0.32	0.91	0.31	0.89
2002	0.36	1.32	0.33	1.04	0.61	1.72
2003	0.51	1.89	0.25	0.75	0.87	2.94
2004	0.33	1.20	0.12	0.39	0.45	1.63
2005	0.41	1.54	0.74	2.28	0.34	1.38
2006 <sup>†</sup>	0.09	0.34	0.09	0.30	0.13	0.53

\* Includes hang gliding, paragliding and weight-shift microlight flying hours and aircraft.

<sup>†</sup> Few reports were received from HGFA for 2006; data may not be truly representative of the whole year.

The research team originally proposed to compare the injury incidence rates of hang gliding and paragliding with some of Australia's most popular participation sports, such as the football codes. However, the obvious differences between the sports make this comparison meaningless. Comparing the current results with previous hang gliding and paragliding injury reports is also difficult due to different sample groups and methods of data collection. Regardless, most of the injury incidence data presented in Table 4 are lower than other common and growing adventure activities such as surfing (4 per 1,000 days surfed), horse riding (28.6 per 1,000 participants), mountain biking (14.8 per 1,000 participants) and kite-surfing (7 per 1,000 hours) (Bentley *et al.*, 2006; Lowdon *et al.*, 1983; Nickel *et al.*, 2004). Although the different techniques and definitions used to describe injury incidence, as well as the setting (e.g. recreation vs competition), differ with these studies, hang gliding and paragliding appear to have a lower injury risk compared to other adventure activities. However, devising methods that can accurately capture total flying hours and registered craft will enable more precise calculations of risk.

Due to limitations in calculating injury risk, a descriptive analysis of the injuries sustained in hang gliding may be more relevant. Contrary to the present study, both kite-surfing and surfing report the most common injuries as lacerations and soft-tissue injuries with the risk of sustaining a fracture very low (Lowdon *et al.*, 1983; Nickel *et al.*, 2004). However, similar to the findings of the present study, Nickel *et al.* (2004) found the most commonly injured body regions in kite-surfing were the lower limb (53.2%), upper limb (16.9%), head (13.7%), and torso (16.1%) with most injuries classified as mild (77%) compared to medium (19%) and severe (3%). The force at which the hang glider or paraglider pilot contacts either the ground or an object following an accident would be greater than during kite-surfing because of the higher altitude ascended by pilots. This explains the higher incidence of fractures in the present study when compared to these other adventure activities. Similarly, when examining insurance claim data for injury during participation in adventure activities, Bentley *et al.* (2007) found that, although horse riding, tramping, surfing and mountain biking had the highest claim counts, hang gliding/paragliding/parasailing and jet boating injuries had highest claim costs, suggesting greatest injury severity.

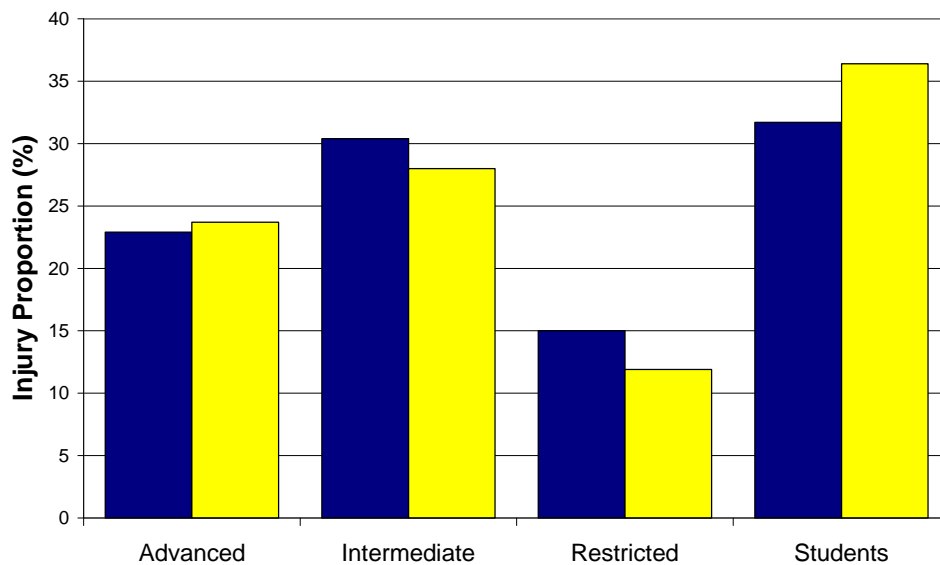
Of interest is the fatalities recorded in the present study. Whereas, McCrory *et al.*, (2000) retrospectively identified 25 deaths associated with Australian football between 1968 and 1999, the present study recorded a relatively low number of fatalities ( $n = 10$ ), particularly when considering hang glider and paraglider pilots have to manoeuvre an aircraft in changing environmental conditions. Nickel *et al.* (2004) reported one fatality in kite-surfing during a 6 month monitoring period.

Therefore, although the high number of fractures in hang gliding and paragliding warrants attention, these sports do not have a higher incidence of injury compared to other adventure activities. It is postulated that the strict training and safety regulations imposed by the HGFA, in conjunction with improved aircraft design, have assisted to reduce injury incidence in hang gliding and paragliding.

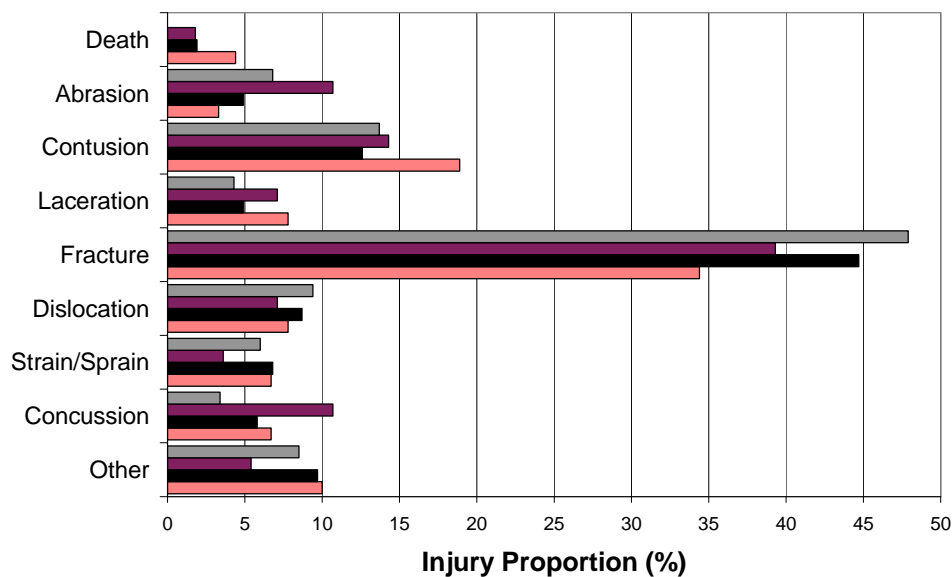
## **2) Prevalence of Injury Based on Pilot Qualification**

There was a significant ( $\chi^2 = 13.38$ ;  $p = 0.004$ ) relationship between pilot qualification and the number of accident reports submitted. That is, more accident reports were submitted by restricted (23.7%) and intermediate (22.8%) pilots compared to advanced (18.0%) and student (14.5%) pilots. Unfortunately, only 381 (51.9%) of all submitted accident reports detailed the qualifications of the pilot. Therefore, the following results do not represent the total injuries reported in the database but instead only those injuries in reports where pilot qualification was indicated.

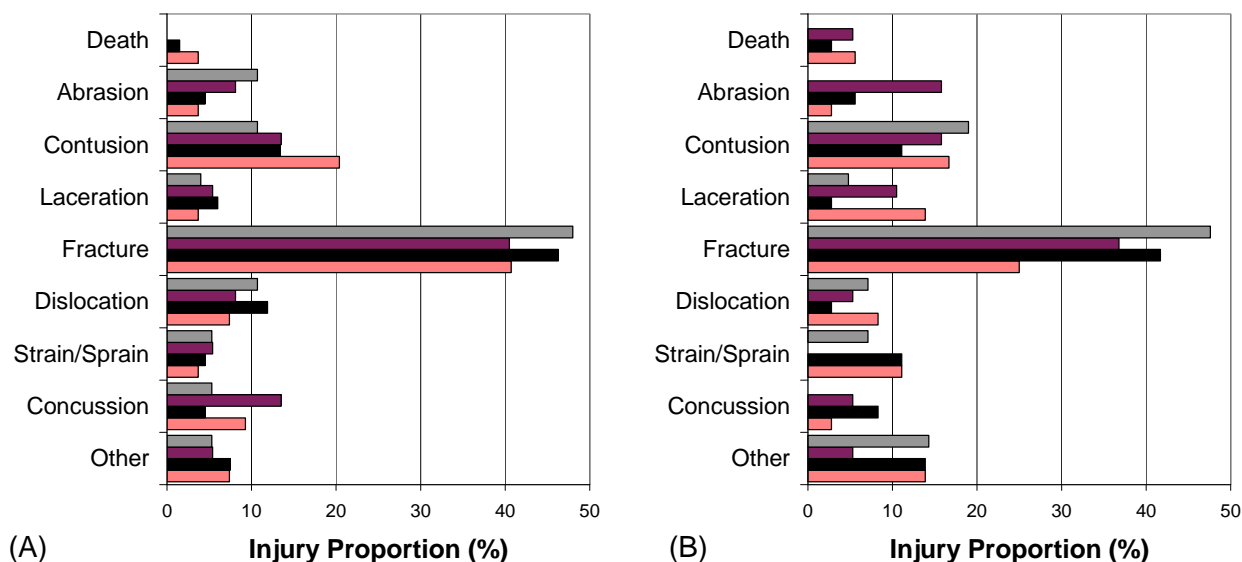
Despite incurring more accidents, student hang gliding and paragliding pilots reported more injuries than either intermediate or advanced pilots. The least number of injuries were sustained by restricted pilots (see Figure 5). However, despite confirming previous findings (Ballmer & Jakob, 1989; Schulze *et al.*, 2002), injury number and pilot qualification were not significantly related ( $\chi^2 = 1.28$ ;  $p = 0.773$ ). There was also no significant relationship between pilot qualification and injury severity when the data were grouped for hang gliding and paragliding ( $\chi^2 = 19.53$ ;  $p = 0.723$ ). However, when considering the more catastrophic and serious injuries, it was interesting to note that advanced pilots sustained the greater number of fatalities, student pilots sustained the greatest number of fractures and restricted pilots sustained the greatest number of concussions (see Figure 6). Similar patterns were found when the sports were considered independently (see Figure 7). However, due to the limited sample sizes, Chi-square analyses of the data could not be completed for each sport.



**Figure 5:** The total number of injuries reported by hang glider (■) and paraglider pilots (■) of differing levels of qualification.



**Figure 6:** The nature of injuries reported by student (■), restricted (■), intermediate (■) and advanced (■) pilots.



**Figure 7:** The nature of injuries reported by hang glider (A) and paraglider (B) pilots with student (■), restricted (■), intermediate (■) and advanced (■) qualifications.

In agreement with Hypothesis 2, novice and intermediate pilots had a higher incidence of injury compared to advanced pilots. However, advanced pilots recorded a higher incidence of catastrophic injury compared to novice and intermediate pilots. Therefore, as the craft are constantly being developed to fly faster and for longer, the suggestion that both beginner and advanced pilots practice common and unusual manoeuvres appears plausible if they are required to react correctly and consistently in changing environmental, if not dangerous, situations. Consequently, although the pilot qualifications details are clear and provide a clear progression in skill level, the renewal requirements to maintain pilot qualification may require revision (see Figure 8).

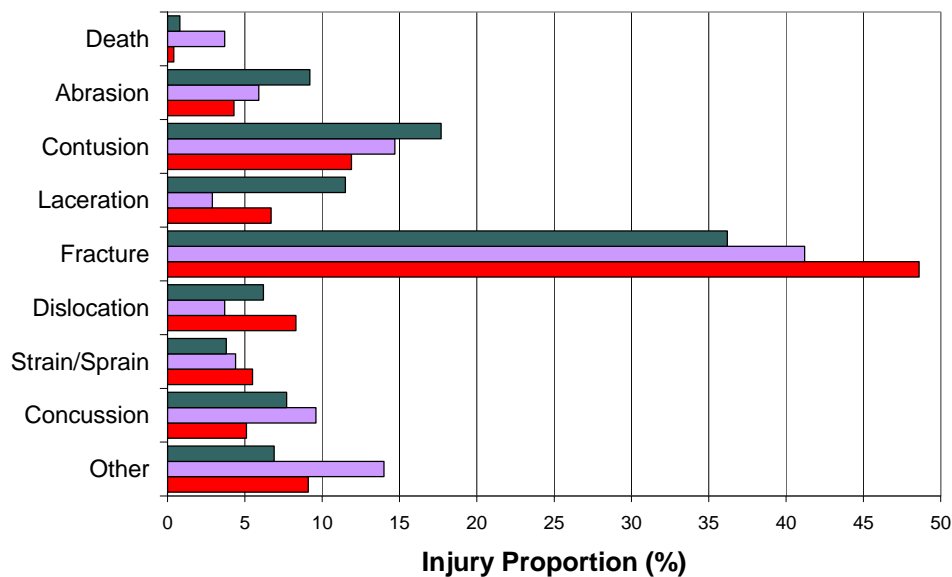
Requirement	Pilot Certificate			
	Student	Restricted	Intermediate	Advanced
Prerequisite Qualification	None	Student	Restricted	Intermediate
Medical Standard	Equivalent to that required for issue of drivers licence			
Flight Skill Test	None	Yes	Yes	Yes
Aeronautical Knowledge Test	None	Yes	Yes	Yes
HGFA Membership	Instructional, STM or Full	STM or Full	Full	Full
Aeronautical <sup>1</sup> Experience	None	Minimum of 6 training days.	Minimum of 25 hours logged on 25 flying days.	Minimum of 80 hours logged and a minimum of 12 months since issue of Intermediate Certificate
Privileges	See following Sections			
Validity	Maximum of 12 months or termination of membership (whichever is the sooner)			
Renewal Requirements <sup>2</sup>	None	Minimum of 5 hours logged.	Minimum of 10 hours logged.	Minimum of 10 hours logged.
Approved By	Instructor	Instructor	Member's Club Senior Safety Officer or Instructor	HGFA Operations Manager or as delegated.

**Figure 8:** The conditions required to qualify for each level of pilot certificate (taken from HGFA Training Manual Operations Manual (Hang Gliding Federation of Australia, 1995)).

### 3) Prevalence of Injury during Landing

Chi-Square analysis revealed that, of all the accidents reported by hang gliding and paragliding pilots, significantly ( $\chi^2 = 63.53$ ;  $p < 0.001$ ) more accidents occurred during landing (42.3%) compared to inflight (31.7%) or launch (21.7%) manoeuvres. A further 4.2% of accidents occurred during towing exercises and ground handling with 30.2% of reports not detailing when the accident occurred.

There was a significant ( $\chi^2 = 33.24$ ;  $p = 0.007$ ) relationship between flight section and injury severity. That is, there were a greater number of fractures sustained during landing than during launch or inflight manoeuvres whereas launch manoeuvres appeared to result in a greater number of abrasions, contusions and lacerations compared to inflight or landing manoeuvres (see Figure 9). It was interesting to note that fatalities were attributed to accidents that occurred during inflight manoeuvres.

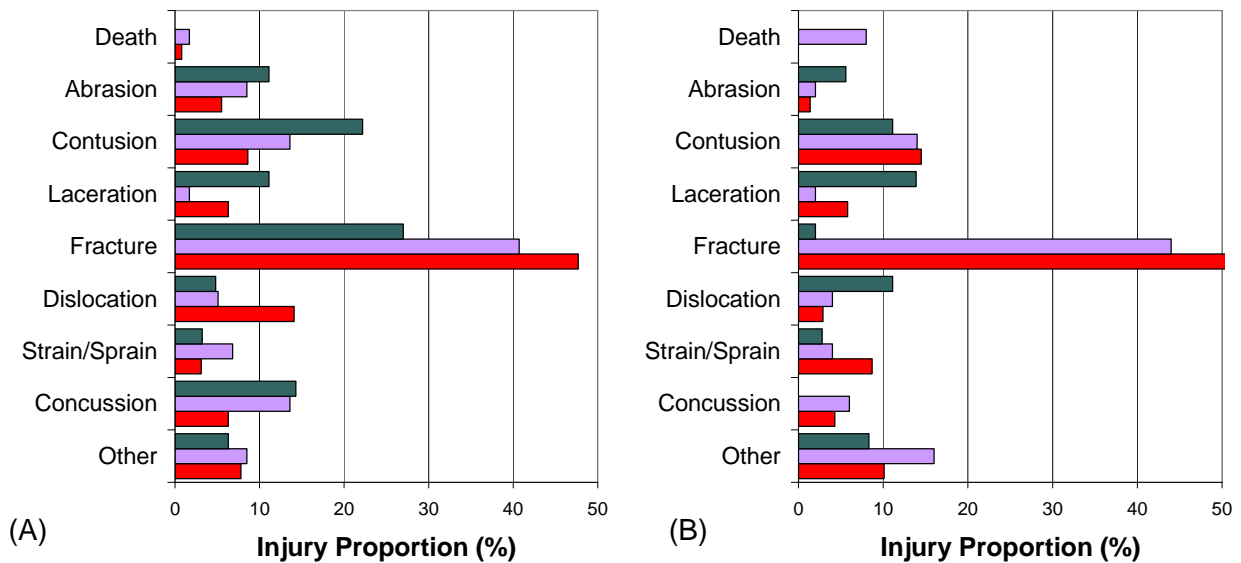


**Figure 9:** The nature of the injuries reported by pilots during launch (■;  $n = 130$ ), inflight (■;  $n = 136$ ) and landing (■;  $n = 253$ ) manoeuvres.

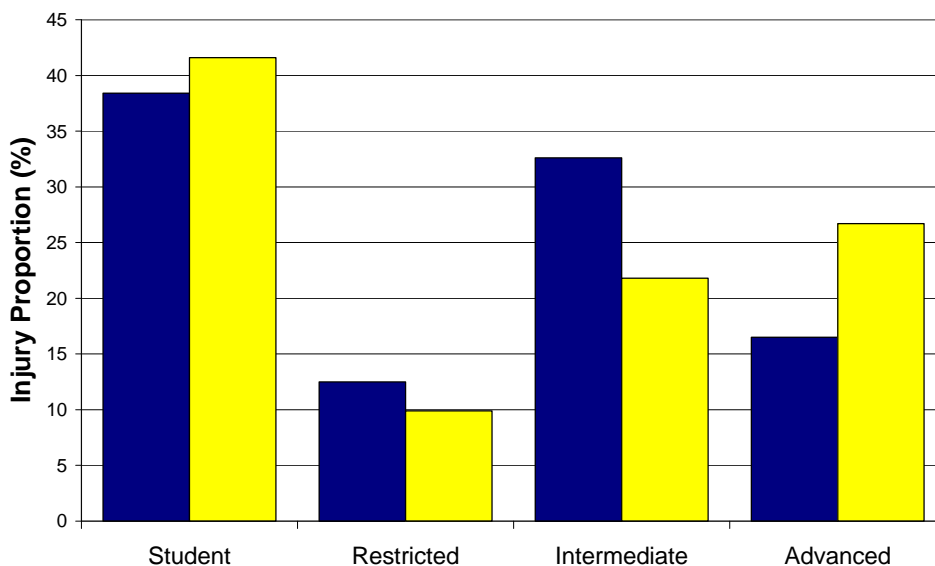
Although the limited sample size precluded statistical analysis, the results for each sport displayed different patterns with respect to when injuries were sustained. That is, in paragliding, very few injuries were sustained during launch manoeuvres compared to hang gliding (see Figure 10 (B)). In fact, there were no concussions and very few fractures sustained by paraglider pilots (see Figure 10 (B)). Furthermore, all fatalities recorded for paraglider pilots were sustained during inflight manoeuvres (see Figure 10 (B)). In contrast, hang glider pilots appeared to sustain many more injuries during all three phases of flying with concussions, contusions and abrasions more prevalent during launch manoeuvres and fractures more prevalent during landing manoeuvres (see Figure 10 (A)). Concussions and fractures were also sustained during inflight manoeuvres (see Figure 10 (A)).

When the accidents that occurred during the landing phase of the flight were isolated, although it neared significance ( $\chi^2 = 7.05$ ;  $p = 0.070$ ), there was no relationship between sport and the level of pilot qualification. However, when the number of injuries for each sport were considered individually, significant relationships were found to exist between qualification level and injury incidence (hang gliding:  $\chi^2 = 41.68$ ;  $p < 0.001$ ; paragliding:  $\chi^2 = 20.86$ ;  $p < 0.001$ ). That is, student pilots sustained significantly more

injuries and restricted pilots significantly less injuries than expected compared to intermediate and advanced pilots (see Figure 11). Interestingly, human factors were the cause of 78.8% of all landing accidents, compared to environmental (17.5%) or aircraft (3.8%) factors.



**Figure 10:** The nature of injuries reported by hang glider (A) and paraglider (B) pilots during launch (■), inflight (■) and landing (■) manoeuvres.



**Figure 11:** The total number of injuries reported by hang glider (■; n = 224) and paraglider pilots (■; n = 101) sustained during landing manoeuvres.

In agreement with Hypothesis 3 and consistent with past research (Krissoff, 1976; Margreiter & Lugger, 1978; Schulze *et al.*, 2002), injuries were found to occur most frequently at landing compared to launch or during flight. Landing success is mostly dictated by the pilot based on their theoretical knowledge and practical skills. Therefore, it is not surprising that most accidents were incurred by student pilots at landing as a result of human error. In addition, intermediate pilots have more freedom to fly than student and restricted pilots and, while having more flight experience, are also still

developing their theoretical knowledge and practical skill, which may account for the large number of injuries sustained during landing manoeuvres in the sport of hang gliding. The interesting result was that advanced paraglider pilots sustained a large number of injuries. This high number could be a combination of several factors. Perhaps advanced paraglider pilots are selecting poor flying conditions or taking more risks than are required. Alternatively, perhaps these pilots are appropriately completing the Incident and Accident Forms whereas other pilots are not. Regardless, as paraglider pilots sustain a large proportion of lower limb and spinal injuries (see Figure 4), particularly fractures (see Figure 3), the HGFA needs to re-evaluate paraglider pilot training and safety regulations, particularly as the popularity of paragliding increases (see Table 1). However, as the cause of landing injuries is largely unknown, further research is warranted to determine whether there are specific landing problems that can be input into pilot training programs to reduce the number of landing injuries.

Accident and incident reporting is mandatory under the HGFA Operations Manual (Hang Gliding Federation of Australia, 1995). However, perhaps due to paper reporting and changing report forms, the number of accidents and incidence, and therefore injuries, are under-reported. There has also been limited follow-up of these reports in past years leading to incomplete datasets. Therefore, the mode of reporting needs to be changed to a more accessible system that ensures all data is appropriately captured. These reports also need to be evaluated for consistency. As a result of the present study, an online Accident and Incident submission form is currently in preparation. This form will directly input into the database and greatly improve the capacity of the HGFA to assess injury risk and other pertinent information such as dangerous hang gliding sites. In addition, it is hoped that combining the database with online reporting will greatly improve adherence of pilots to the reporting guidelines, facilitate a fast follow-up process and enable easy generation of pertinent statistics. In addition, to be able to determine a true incidence of injury in hang gliding and paragliding, log books regulations must be followed by pilots to ensure real knowledge of the number of flights and flight hours for appropriate calculation of injury incidence.

## **Conclusion**

While the information in the HGFA Injury Database may be under-reported, some interesting findings were evident. That is, although paragliding has a higher injury incidence than hang gliding, both have a lower incidence than other popular adventure activities. However, the number of serious injuries sustained by hang glider and paraglider pilots is much greater than comparable sports, particularly in terms of lower limb and back fractures in paraglider pilots and upper limb injuries in hang gliding pilots. In addition, while student and intermediate pilots sustain a greater number of injuries compared to pilots of higher qualifications, advanced pilots sustain a greater number of serious injuries. As anticipated, most of these injuries are sustained during landing manoeuvres, although most fatalities are reported to result from errors caused during flight rather than landing. Therefore, the HGFA needs to be vigilant in their approach to pilot training, particularly investigating whether the pilot renewal requirements need updating, particularly for advanced pilots, as well as ensuring all pilots adhere to regulations documented in the HGFA Operations Manual, most importantly log book completion. In particular, with the growing popularity of paragliding, pilot training and safety regulations in this sport may require re-evaluation to reduce the injuries sustained in this sport.

# Part 2: Identifying the Mitigating Factors for Injury in Hang Gliding

## Methods & Procedures

### Data Collection

The research team from the Biomechanics Research Laboratory travelled to Bright, Victoria and Tumut, NSW at Easter (14-17 April) 2006 to collect video data of the landing manoeuvres completed by hang glider and paraglider pilots at specific hang gliding and paragliding participation events. As these participation events were open to all levels of pilot (restricted, student, intermediate and advanced) with sponsorship from the NSW Government, they provided a unique opportunity for the research team to video the landing manoeuvres being performed by pilots of all experience levels. At each event, morning briefing and evening debriefing sessions were conducted daily and focused on safety procedures, landing mechanics, any incidents or accidents that occurred, environmental conditions and flight schedules.

A minimum of four video cameras and operators recorded the landing manoeuvres performed by pilots at 25 Hz using standard digital video cameras. Operators were located in different positions within each designated landing zone to ensure the pilot and craft were in the field of view and that video images could be collected from different views. Filming began when the pilots were approximately 50 m out from their landing zone and ceased when the pilot had come to a complete stop (i.e. completed their landing manoeuvre). The filming positions were chosen to ensure video data could be collected even when the pilot missed the designated landing zone.

Written informed consent was obtained from all pilots, and all biomechanical testing was conducted according to the NHMRC Statement on Human Experimentation (National Health and Medical Research Council, 1994) after being approved by the University of Wollongong Human Research Ethics Committee. Consequently, video data were only collected for those pilots who provided written consent.

### Data Analysis

A total 19 hang glider and 41 paraglider pilots provided their written consent to be filmed when conducting their landing manoeuvres during the Easter participation event in Tumut, NSW and Bright, Victoria, respectively. Participants were mainly from NSW and Victorian clubs. However, the ability to conduct real descents onto a designated landing zone is weather-dependent and, due to poor weather conditions at Bright, few paraglider pilots launched. As a consequence, only 11 paraglider pilots (one tandem pilot and passenger, eight advanced pilots and two intermediate pilots) flew in the time the research team were present and, although video were collected for all pilots, only one poor landing was collected. As this poor landing was by the tandem pilot and weather affected, no further analysis of the paragliding landing manoeuvres was conducted.

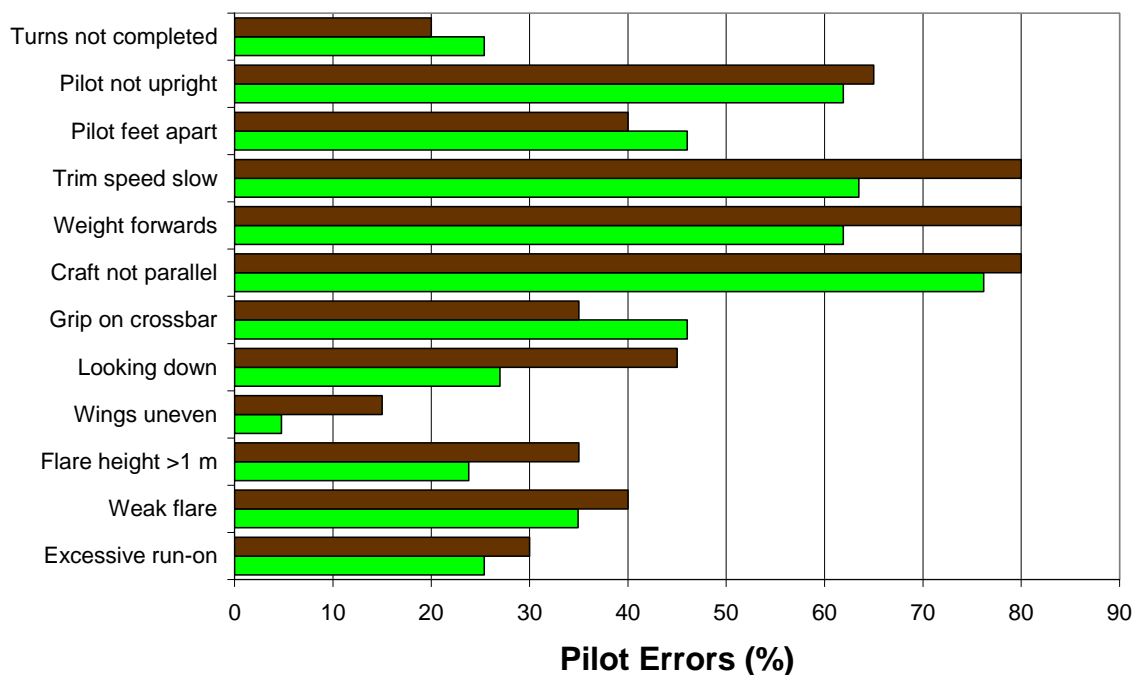
For the 19 hang glider pilots, who provided consent, 63 landing manoeuvres captured on video were assessed for quality and only those videos of good visual quality were further analysed by the research team. Prior to analysis the research team received detailed education sessions from experienced hang gliding and paragliding personnel outlining the steps that pilots should follow when landing the hang glider. Qualitative analysis of the videos of each pilot's landing technique, in the form of expert testimony from two experienced inland advanced pilots (also hang gliding instructors) was then conducted on the 20 poor landings, that is, landings in which the pilots were unable to

control the hang glider at the end of their flare. Expert testimony from the advanced pilots was considered acceptable as there is currently no checklist to follow in regards to a “successful and safe” landing but rather “critical tasks” that should be performed at defined times within the landing manoeuvre.

**Results & Discussion**

**4) Pilot Errors during Landing Manoeuvres**

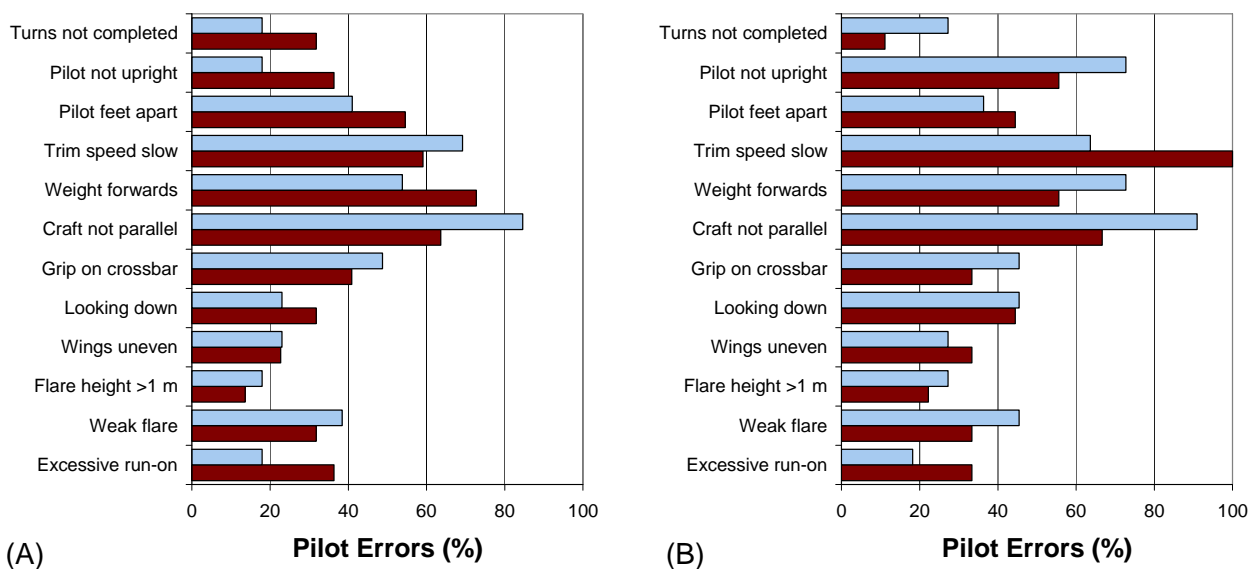
Of the 63 landings manoeuvres captured on video, 20 (31.7%) resulted in the pilot having a less than optimal landing. Of these poor landings, the most common result was the hang glider rotating forwards (e.g. “nose-over”; n = 12). However, the hang glider rotated backwards in three cases, two landings were classified as “hard”\* and the remaining three required the pilot to run-on excessively to keep the glider from rotating. An analysis of the poor landings relative to all other landings, and the reasons provided by the “experts” as to why the landings were less than optimal is provided in Figure 12. It is evident that attempting to land with a slow trim speed, not having the craft parallel and the pilot not being in an upright position with their weight backwards are the most common pilot errors that result in poor landings. As these errors were common among the pilots filmed, a number of the pilots were placing themselves at risk of a poor landing and therefore, injury. Interestingly, there were different technique errors when pilots were flying hang glider craft that were classified as intermediate or advanced† (see Figure 13).



**Figure 12:** Common hang gliding pilot errors when performing landing manoeuvres inland for all landings (■; n = 63) and poor landings (■; n = 20).

\* A hard landing is one made while the aircraft is experiencing an excessive rate of descent or excessive ground speed (Hang Gliding Federation of Australia. (1995). *Operations Manual*. Sydney, Hang Gliding Federation of Australia).

† Hang gliders are divided into different classes based ranging from entry level craft which have high levels of stability, are easy to handle, have slow stall speed and are forgiving of errors; intermediate level craft which still have slow stall speed but better performance and therefore decreased handling; and advanced level craft which are designed for performance, are the most demanding to land due to faster stall speed and react directly to pilot input and so are difficult to handle (<http://www.willswing.com>).



**Figure 13:** Common landing errors displayed during all landings (A) and poor landings (B) by pilots flying intermediate (■; all = 39; poor = 11) and advanced (■; all = 22; poor = 9) hang gliders.

That is, when pilots flew advanced hang gliders, their main error was attempting to land with a slow trim speed. Slow trim speed reduces the amount of momentum able to assist with successfully flaring to a stop. An advanced hang glider travels faster in flight than other less advanced hang gliders. We speculate that pilots flying these craft may feel that they are travelling too fast to stop safely and, consequently, reduce their trim speed more than recommended. Short training sessions with other experienced pilots are recommended for these pilots when upgrading their hang gliding craft to reduce the chance of unsuccessful landings. Interestingly, one pilot, who recently upgraded from an intermediate to an advanced hang glider, was recorded performing several poor landings. As this pilot was unable to land successfully, qualified instructors who were at the event offered training to this pilot. Interestingly, in this case, the research team assisted the instructor by providing video footage to the instructor and pilot for instant feedback following each landing attempt. In doing so, the instructor was able to specifically target faults in the pilot's landing technique and the pilot was able to see exactly what the problem was. Following this immediate feedback, the pilot recorded three successful landings.

The most common unsuccessful landing resulted in the "nose-over", in which the base tube stops abruptly on contact with the ground, the glider pitches forwards and downwards sharply and the pilot's remaining forward momentum is arrested by the ground and/or glider. In the nose-over landings that were filmed by the research group, no injuries resulted and there was no damage to the hang glider. However, nose-over landings have accounted for serious injuries (Johns, 2003) and can cause extensive damage to the aircraft.

The event that the filming took place at was a participation event that aimed to provide pilots of varying levels instruction and assistance with an opportunity to improve their flying. Interestingly, the "experienced reviewers" indicated that most of the pilots appeared to be using a coastal landing technique rather than what is required for inland flying. They suggested that when a pilot flies on the coast, the terrain and environmental conditions often differ to that found inland, requiring slight adjustments to the landing strategy used. This was highlighted as many of the pilots were deemed as "lucky" to get away with their landings as they were "lazy". That is, if the conditions were more difficult,

they believed that many more of the pilots would have recorded unsuccessful landings both due to the pilots not following the appropriate landing steps as well as pilots displaying techniques that suggested they had never flown inland. The expert reviewers recommended that pilots should receive instruction in both flying at coastal sites as well as inland flights; noting that spending just 1 hour training in the correct technique for different sites/locations could avoid the common pilot errors that led to poor landings seen in the present study. However, when reviewing the pilot training syllabus, there is no specific mention of gaining aeronautical experience at different site types. Therefore, it is recommended that the HGFA incorporate training at specific sites/sectors in their qualification levels, splitting the training and aeronautical experience conducted at each location to ensure well-rounded pilot skills in addition to the theoretical knowledge provided.

In the present study, qualitative video analysis was able to identify the pilot errors, independent of environmental conditions, which could result in an unsuccessful landing. Therefore, it is proposed that the flight skill test could be completed through video analysis, accompanied by a checklist of steps and technique characteristics that should be adhered to by pilots for a safe landing. Such a checklist is routinely used in the training of parachute landings at military parachute training schools. The use of a checklist would assist the pilot by highlighting the areas that they require development, as well as ensure quality control in the awarding of licenses to pilots at the appropriate skill level. In addition, video could be used to provide instantaneous feedback to the pilot during training, assisting them to modify their technique according to qualification level, site or craft. Although this video assessment was only completed for landing manoeuvres in the sport of hang gliding, it is envisaged that it would also be relevant for launch manoeuvres in both hang gliding and paragliding.

## Conclusions

The sport of hang gliding is one that inherently involves risk to the pilot and, as such, hang gliding and paragliding are classed as adventure sports. However, due to the strict guidelines imposed by the HGFA and Civil Aviation Authority, the overall injury incidence in these sports is not higher than other adventure sports or popular participation sports in Australia. However, due to the nature of the sports, hang gliding and paragliding are associated with a greater number of serious injuries, most of which are largely governed by flying position. That is, paragliding records a large number of lower limb and back fractures whereas hang gliding typically record upper limb fractures. In addition, as student and restricted pilots record the most number of injuries, particularly when landing, the use of video feedback, accompanied by landing technique checklists, are recommended to assist in pilot training programs and during the flight skills test to ensure all techniques have been appropriately mastered by each pilot. In addition, as advanced pilots sustained a large number of injuries and, in particular the serious injuries and fatalities, it is recommended that the HGFA re-evaluate license renewal guidelines, in particular for paragliding, which is increasing in its popularity.

Improvements to the HGFA Injury Database gained from this study will elicit improved injury data and an interface to enable online reporting of incidents/accidents. As such it is envisaged that future data will enable a better analysis of the incidence and prevalence of injuries in the sport of hang gliding, upon which to base more effective injury prevention strategies, such as improvements in training progressions, aircraft development and pilot knowledge. However, these possibilities are dependent upon pilots adhering to HGFA rules and regulations and therefore, the HGFA must ensure

pilots are accountable for safety in their sport by having them report all minor incidents through to major accidents. These necessary steps will ensure that all pilots and passengers, no matter what age or experience, can enjoy the sports of hang gliding and paragliding, at a reduced injury risk.

## **Recommendations for HGFA**

Based on the findings of the present study, the following are recommendations for the HGFA:

1. Improve the injury surveillance system with online and paper reporting modalities and follow up the reports submitted to ensure consistency in reporting. The injury surveillance system should also be regularly assessed for quality and ease of data input by members of the HGFA.
2. Develop strategies to ensure appropriate completion of pilot log books and accurate knowledge of the number of flights taken and flight hours logged in both hang gliding and paragliding.
3. Evaluate current pilot training guidelines, particularly with reference to the pilot gaining aeronautical experience specific to site, training when upgrading craft type, and license renewal guidelines particularly for advance pilots.
4. Investigate the option of developing a landing technique checklist to use in association with video during the flight skill test, as well as incorporating video feedback into the pilot training programs.
5. Continue to endorse participation events for pilots of all levels.

## **Acknowledgements**

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# Appendix A

## ACCIDENT and INCIDENT REPORT FORM

Form 14 – Issued July, 1995 NOTE: Please complete all details in BLOCK letters.

<b>PILOT DETAILS</b>		
HGFA No: _____	Surname: _____	First Name: _____
Pilot Quals: _____	Date of Birth: _____	Sex: M/F Telephone: _____
Address: _____		
Pilot Total Hours: _____	Hours last 90 days: _____	Hours Experience on aircraft: _____

<b>ACCIDENT / INCIDENT DETAILS</b>		
Acc or Inc: A / I: _____	Acc/Inc Date: _____	Acc/Inc Time: _____ No. of Persons Involved: _____
Witness Name: _____		Telephone: _____
Instructor Name & School if Acc/Inc Happened During Training: _____		
Pilot Injury: Fatal / Hosp / Doc / Minor / Nil	Passenger / Bystander Injury: Fatal / Hosp / Doc / Minor/Nil	
Details Pilot Inj. _____		
Details Pass / Byst Inj: _____		

<b>AIRCRAFT &amp; EQUIPMENT DETAILS</b>		
Aircraft Type: HG / PG / WM	Make: _____	Model: _____ Size: _____
Year of Manufacture: _____	Total airframe hours: _____	Hours since last airframe inspection: _____
Parachute Fitted: Yes / No	If WM: Registration No.: _____	Engine Type & Model: _____
Harness Type: _____	Harness Make: _____	Harness age: _____
Aircraft Damage: _____		

<b>SITE / LOCATION DETAILS</b>	
Site Type: Inland/Coastal/Tow/Grass Strip/Sealed Runway	Site Rate (if applic.): Restricted / Intermediate / Advanced
Site Name: _____	Site Location: _____
Launch Type if Launch Acc/Inc: Gentle / Steep / Cliff / Ramp / Tow / Other: _____	
Landing Type if Landing Acc / inc: Nominated L/Z Site Non L/Z XC / Top / Other: _____	

<b>ASSOCIATED DETAIL</b>		
Acc / Inc Occurred When: Taking Off / Landing / In Flight / Winch Tow / Car Tow / ATOL Tow / Aerotow		
Acc/Inc Occurred During: Recreational Flying / Competition / Under Instruction		
Pilot New to Site: Y / N	Pilot New to Type of Operation: Y / N	Temperature: _____
Wind Direction: Head / Cross / Tail	Wind Speed: _____	Knots Turbulence: Nil / Light / Mod / Strong

PLEASE COMPLETE THE OTHER SIDE OF THIS FORM AND ATTACH DRAWINGS AND PHOTOGRAPHS IF APPLICABLE  
**Hang Gliding Federation of Australia**  
**OPERATIONS MANUAL**



## Appendix B

During the tenure of the grant, the research conducted in this study has been featured in The Illawarra Mercury and the following presentation has been made on the outcomes of this project:

- Munro BJ, Dassen J, Wijnen A, Fogg C & Steele JR. What is the nature of hang gliding injuries in Australia? *Asics Conference of Science and Medicine in Sport*. Fiji, October 2004.

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