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From fatal accident to influencing aviation helmets safety standards

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I joined the Royal Air Force as an avionics technician in 1981 and was Commissioned as an engineering officer in 1993 after gaining a BEng (honours) degree in Electronic Systems Engineering at the Royal Military College Shrivenham. Awarded an MSc in Advanced Systems Engineering in 2006, I became a Chartered Engineer with the Institute of Engineering Technology (IET) in 2011. After three years as an Aircraft Accident Investigator in the Defence Accident Investigation Branch, I left the Royal Air Force in April 2020 to become an Air Accidents Investigator with the UK AAIB.

Synopsis/Executive Summary

The investigation of a microlight accident in 2022 revealed that pilots were not wearing upper torso restraints and their helmets provided inadequate protection for the type of impacts encountered. Without wearing the upper restraint during the accident sequence, the pilot's torso flailed forward allowing the head to strike the aircraft structure and the ground. Current test standards for airborne sports helmets only protect users from direct impacts. The most common head injuries in aircraft accidents are not caused by direct impacts, but by oblique impacts. These lead to rotational motion of the brain inside the skull, causing loss of consciousness and death.

The journey from aircraft accident to changing the safety standard of airborne sports helmets was due in no small part to following minor lines of inquiry that at first glance appeared likely to be dead ends. Simple inquiries soon resulted in the engagement of a specialist aviation medical organisation and cutting-edge research into protection from rotational brain injuries during aircraft accidents.

Introduction to a fatal accident

On a warm summer's day on the 1st June 2022, the AAIB was notified that a Pegasus Quik flexwing microlight had crashed in East Lothian in Scotland, seriously injuring the pilot who had been taken to hospital by air ambulance.

The subsequent investigation revealed that the pilot had attempted to start the engine four times before the fifth attempt was successful. However, the rpm immediately increased to such a high value that the brakes were unable to hold the aircraft stationary and it accelerated forwards. During the failed start attempts, CCTV showed the pilot had moved his left hand close to the manual throttle lever whilst his right hand was close to the engine ignition switches, allowing him to cut the engine in an emergency if necessary. The base bar, which enables the pilot to steer the aircraft, is cumbersome when trying to start the engine, so the pilot had tethered it to the aircraft's front strut to keep it out of the way. Once the aircraft started to move, the tether prevented the pilot from steering properly and the aircraft veered left before hitting a runway stop sign and gaining sufficient speed to takeoff.

It was likely that the pilot had started the engine with the hand throttle open and did not attempt to cut the engine power using the ignition switches after the aircraft had started to move.

Once airborne, the aircraft entered a wide left turn, climbing above the height of nearby hangars, before descending out of sight behind a hangar. Witnesses described hearing the engine "high revving" to the point of impact with the ground and observed a "cartwheeling" wingtip just visible behind the hangers. Although the pilot was alive when rescued, he died from head injuries eight days later.

Examination of the wreckage

Two of the items of interest in the investigation were the seats' safety harnesses and the pilot's helmet.

Seat safety harnesses

The aircraft had two seats installed in tandem, with the rear seat fitted with a 4-point harness. The front seat had a 3-point harness which featured a lap strap and an upper torso diagonal shoulder strap fixed between the King Post and the lap strap. When the flexwing was flown solo, the pilot was seated in the front seat whilst the rear seat was empty, so the loose rear seat harness was tied to prevent it from fouling the propeller during flight. The pilot did not wear the front seat diagonal shoulder strap, preferring instead to use just the lap strap.

The investigation found that some pilots in the flex wing community preferred not to use the front upper torso strap as they believed it limited the range of arm and torso movement when trying to use the base bar to steer the aircraft. There was an exception in BCAR Section S (1) which allowed aircraft that were not fitted with an upper torso restraint to operate using just a lap strap. This was widely regarded as justification that an upper torso belt was not necessary in the front seat. It was also believed that a helmet and lap strap combination would provide the equivalent protection to wearing an upper torso restraint during an accident.

Airborne Sports Helmets

To determine whether existing aviation sports helmets could provide the measure of protection assumed by the flex wing microlight community, we examined the helmet the pilot was wearing at the time of the accident. There was impact damage, scoring and scratches present on right rear quarter of the helmet where the pilot's head had contacted the aircraft structure and the ground during the crash sequence. The front face screen had also been torn off and the built-in headset's right ear shell had fractured and broken into pieces.

On the rear of the helmet was a sticker displaying a CE logo and EN 966:1996 '*Helmets for Airborne Sports'* (2). These standards for airborne helmets are published by the British Standards Institute (BSI) and European Conformité Européenne (CE).

Accidents that involve an oblique impact to the head causes rotational motion of the head and brain which can result in loss of consciousness, concussion and death. Existing research into brain injuries suffered during transport accidents, shows that rotational motion of the head produces a significantly greater risk of brain damage than injuries sustained from direct frontal, vertical or lateral impacts. Currently BS EN 966:2012 provides test parameters designed to protect wearers from direct impacts which can cause skull fractures, but not from oblique impacts. In this accident, the pilot died from a severe rotational head injury which his helmet was not designed to protect him from.

Loss of consciousness caused by oblique head contact with cockpit structures may also increase the time taken to egress the aircraft. In the event of a fire after a crash for example, any delay in escaping the aircraft could be fatal.

RAF Centre of Aviation Medicine comment on survivability of the accident

The Royal Air Force Centre of Aviation Medicine (RAFCAM) assisted the investigation in understanding the relationship between the aircraft impact forces and the injuries sustained by the pilot. RAFCAM reported that:

> '*The evidence from the helmet damage coupled with the post-mortem findings indicated that the pilot had sustained a severe blow to the right side of his head which ultimately resulted in his demise.'*

In describing the pilot's use of only the lap strap:

> *‘The lack of upper torso restraint, provided by just the lap straps being connected, would have permitted the pilot’s upper torso and head to flail forward excessively. This increased flailing would have resulted in the pilot more likely contacting the ground and cockpit structures during the impact, thereby increasing the severity of his head injuries. If the pilot had had his shoulder strap fitted it is likely that his forward and sideward flailing would have been lessened. It is then possible that this reduction in flailing could have reduced the severity of the head injury as the impact velocity of his head with the ground and cockpit structures would have been reduced. As a consequence of a reduction in the head impact velocity the outcome of the accident may have been altered such that he may have survived. However, it is difficult to quantify the magnitude of the reduction in impact velocity achieved by limiting flailing of his upper torso.’*

With regard to the helmet worn by the pilot:

> ‘*Although the pilot was wearing a helmet which was designed and conformed to the appropriate helmet standard: CSN EN 966 - Helmets for Airborne Sports, it is highly likely that the head impact energy and velocity were far in excess of those which the EN Standard dictates airborne sports helmets should attenuate.*’

Helmet performance testing

As part of RAFCAM’s analysis, impact testing was carried out on the same type and model of helmet worn by the pilot.

The purpose of the research was to assess the impact protection of a helmet widely used by the microlight community. The research was not intended to replicate the testing methodology used in helmet qualification standards, but to provide a comparison of impact protection using a highly biofidelic testing methodology. The results of the research was intended to better inform the end user community of the risk of brain injury following a significant impact to the head and to help design rotational protection measures for airborne helmets.

Methodology

Three unused medium sized helmets (A1, B1 and C1) were procured for testing at the Imperial College London Head Lab helmet drop tower. The testing schedule applied is shown in Table 1. The proposed impact speed was designed to match that of the certification standard BS EN 966:2012. Objective evidence from G-CCPC’s accident was used to reconstruct a real-world accident, with the impact angle and impact speed reflected by the test conditions.

Serial	Impact site	Anvil	Impact 1 (m/s)	BS EN 266 Pass/fail threshold
A1, B1, C1	Front	Flat	5.42	250G
A2, B2, C2	Crown	Flat	5.42	250G
A3, B3, C3	Rear	Flat	5.42	250G
A4, B4, C4	Side	Flat	5.42	250G

Table 1

Imperial College Head Lab aviation helmet test schedule

An instrumented Cellbond CEN/TC158 headform (Figure 1) was used in lieu of the metal headform specified in BS EN 960 (3), and was fitted with triaxial accelerometers (4). Helmeted headforms were dropped to reach the target impact speed (+/- 0.1G) onto a flat, oblique angled anvil. The headforms were allowed to fall unconstrained onto the anvil and were free to move in any direction following impact. Soft foam pads surrounded the base of the impact rig to prevent further damage to the helmet from occurring. Each impact was recorded using a high-speed capture camera with

damage to the shell and lining recorded. All impacts were carried out at ambient temperature and humidity.

Figure 1

CEN/TC158 Headform (5)

Peak Translational Acceleration (PTA), Peak Translational Velocity (PTV), Peak Rotational Acceleration (PRA) and Peak Rotational Velocity (PRV) were measured for each impact. The injury threshold values including the Head Injury Criteron (HIC) and Brain Injury Criterion (BrIC), were calculated (6). A fininte element model of the brain developed at the Imperial College Head Lab (Figure 2) was used to calculate the Maximum Principle Strain (MPS) for each impact. The results of the tests allowed a comparison of the risk of brain injury for the type of impact sustained in the testing methodology (7).

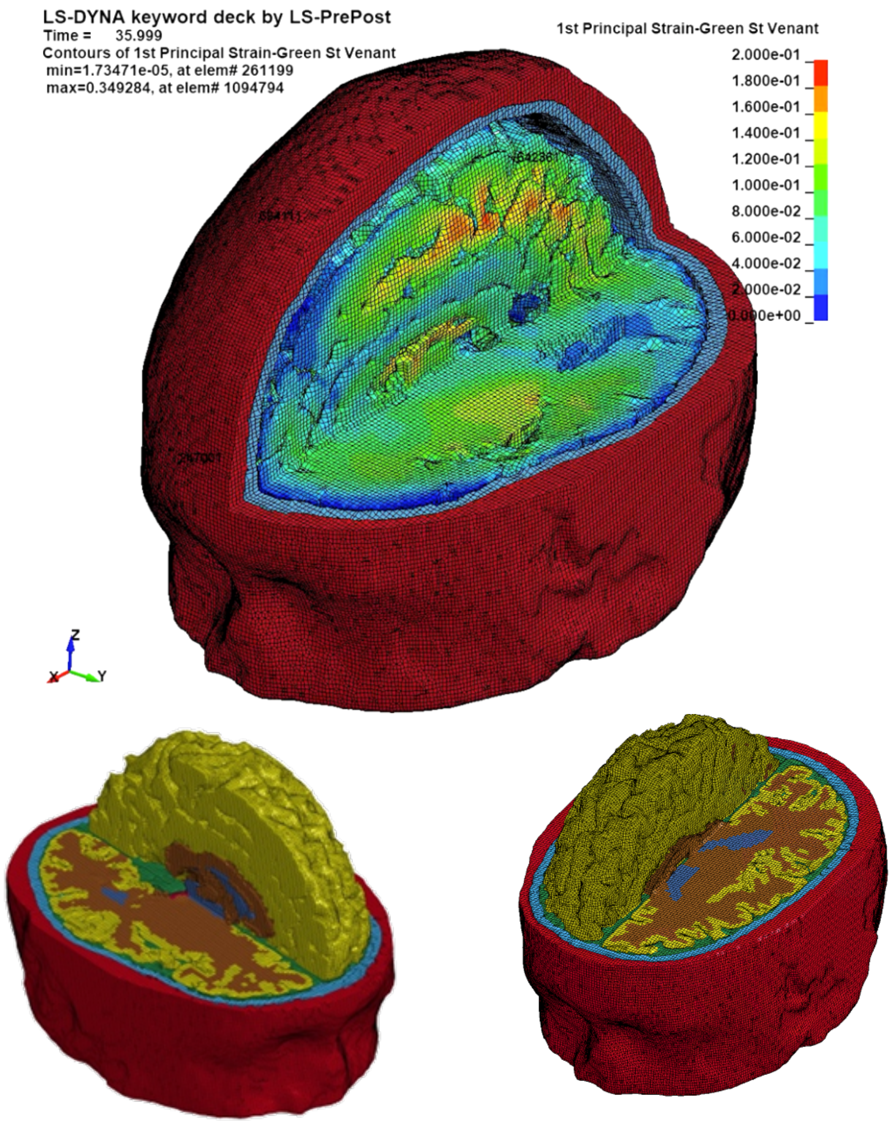

Figure 2

Imperial College Head Lab finite element models of the human brain

Current helmet technology

Rotation protection systems are already available for helmets used for cycling, climbing, construction, horse riding, motorsports and winter sports. For example, the current test standard for motorcycle helmets, BS 6658, was developed in 1985 and like the airborne sports helmet test standard, only requires protection from direct impacts. Despite this, UK motorcycle helmet manufacturers no longer manufacture to this standard, instead they produce helmets that far exceed BS 6658 and include protection from rotational brain injuries.

Discussion

The journey from accident to changing the safety standard of airborne sports helmets was due in no small part to following minor lines of inquiry. Simple inquiries made with no thought that they might lead to anything useful soon resulted in further inquiries. The helmet safety standard was found to be inadequate when compared to statistics for the type of head injuries sustained during transport and sports accidents. Moreover, manufacturers of sports and construction site helmets had already carried out extensive research and recognised that they could improve the product by providing rotational protection.

The Pegasus Quik accident report was used to justify the reformation of the Standards Committee to look at BS EN 966:2012 with a view to incorporating test parameters for rotational protection.

Research into concussion injuries is ongoing across many domains, particularly sports such as football and rugby, but the symptoms of concussion are broad and, therefore, not necessarily a good measure for acute injuries. Loss of consciousness provides a much more accurate measure of acute injury. The research being undertaken by RAFCAM is aiming to develop the most detailed rotational head injury model in the world, one which would exceed the current Euro NCAP safety ratings for road vehicles introduced in 2009 (8). Using the finite element model allows the development of highly detailed assessments of the potential damage that could be caused to the structures of the brain by rotational impacts. RAFCAM has access to historical records detailing real-world aircraft accidents which are matched to detailed aviation pathology reports of the type of injuries sustained by pilots and crew. Exploiting this data to confirm and refine the accuracy of their head injury model should lead to substantial improvements in the development of equipment designed to significantly increase survivability.

Conclusion

During the investigating of a fatal flex-wing microlight accident, a professional aviation medical organisation was tasked to review the deceased's pathology report and provide a survivability assessment. Their report is resulting in the development of cutting-edge technology to assess rotational brain injuries. This will lead to significant changes in the development of head protection systems for aviation helmets, not just in the civil aviation sector but also within the military sector.

References:

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