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FIGHTERS PILOT HELMET DESIGN FOR 5TH GENERATION AIRCRAFT

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ABSTRACT

Fighter pilots' helmets have become more complex and heavier resulting in long term implications to pilots musculoskeletal systems as they fly and experience high g-load. Current research has identified design changes to the helmet to accommodate the ancillary items fitted to assist pilots but at the expense of comfort and additional loading. Its manufacturing requirements and adaptations to offer bespoke solutions are addressed to allow for training and operational usage. To produce the next generation of helmets that reduce long-term injuries, from g-loads and asymmetrical ancillaries requires individual considerations, unique manufacturing requirements and the ability to support with service spares anywhere in the world at short notice. This paper will describe how manufacturing requirements are matched to ergonomic needs and bespoke components can support global demands.

Keywords: Pilot helmets, Bespoke manufacture, Global support.

1 INTRODUCTION

Hard helmets for military pilots were designed and issued when the jet age started place higher g-loads and more extensive training. Prior to the jet age Spitfire pilots were using leather helmets with the stereotypical goggles and silk scarves, more to keep warm than for protection, Roussel, M. (2013). To meet the high demands of jet fighters pilot training became extensive and expensive. It became apparent that to protect their investment in training the pilot heads needing protecting too; thus hard helmets were used that incorporated the oxygen, communication and anti-glare systems. These were of a fibre glass based design to maximise protection at a minimum weight. This classic type of helmet was used extensively throughout the world's military and incorporated in most military cockpits. Pilots were reporting unfit to fly due to neck strains and these were compounding to result in the long term issues, Anderson (1988). Procedures in training any flying were introduced, for example, g-warm, where warm up manoeuvres similar to the idea of sports people before matches.

The rapid expansion of electronics and software in the 1980s produced a wide range of equipment that offered operational advantages to pilots. Night Vision Glasses, NVG, being perhaps the most prominent example that could give air-to-air superiority in combat in a dog-fight or evasive low level flying. NVG weighs vary from anything between 1 – 2 kg and are attached to the side or overhead of the helmet for easy of deployment at a short notice, Lange, *et al.* (2011). Designs of helmets were changed and counter weighs added to compensate the asymmetrical loading. Such situations are not a problem for general use adding some weight, albeit there are limits that certainly vary for individuals and different missions. However, consider the operational requirements of fighter pilots for both training and conflict. Most pilots fortunately will not have to be in a real life-or-death dogfight, their training has to incorporate this aspect and low level, low speed manoeuvres that result in high g-loading situations. Combine this to long-term exposure, operational flying will be in the region of 12 years before senior ranks that limit flying time, to high g-loads on their neck and upper body and the musculoskeletal problems increase, Newman and Kaloupek,(2004). The very product deigned to protect the pilot is now the most likely feature to cause injury and even end a pilots career. To protect a pilot, the investment in training, ensuring pilots are fit for deployment is now dependent on the aircraft and also the most suitable helmet for 5th generation aircraft.

2 DESIGN REQUIREMENTS

A fundamental review and redesign of the helmet is needed if the issues resulting from current fighter aircraft are not replicated on modern 5th generation pilots and issues addressed and minimised. These modern 5th generation fighter aircraft have more extensive manoeuvring capability than the previous ones, require more training and operational use to maintain currency and this all goes to increase the risk of musculoskeletal damage to pilots NASA (2010). They are designed to operate at higher g-loads and manoeuvres in advanced of current aircraft and other nations 5th generation aircraft.

Intermediate solutions for high neck loading has been proposed, some similar to those in Formula 1 and Indy racing. It has to be added here that securing a helmet to the frame is not an option. Constantly looking in all aspects of flight that are visible, rotating the aircraft to allow for broader visual horizons and checking for situational awareness must not be compromised De Loose, *et al.* (2009). Any new design of helmet needs to be a self-contained head mounting unit that is free standing. Assuming NVG will drastically reduce in weight is not realistic, see figure 1 below. New designs are more efficient and capable, so if anything can be assumed they will at best stay the same weight but with improved capability.

Figure 1: A helmet with NVG.

Traditionally helmets have been sized according head size (small, medium or large), with limited bespoke allowances and internal strap adjustment to maintain a comfortable fit. A webbed inner section does allow for comfort and a form of shock absorbent action and air circulation. It does, also, add an extension to the mounting point of any asymmetrically loaded additions. This added space will further increase any applied bending moment to the pilots musculoskeletal system. A space of just 25 mm increases the torque loading on a spine for a typical 2 kg NVG system by 25%, Craig (2013).

Figure 1 above show that combining this weight with the face mask and any further ancillary items will likely compound this loading, which further exacerbate musculoskeletal risks to pilots.

Current thought of design is to add more to the helmet, figure 2 below. Even if these could be symmetrical in weight and balance the applied torque in a g-load will place strain on the pilots necks and upper body. When items are developed they may improve, what they do not do is keep to the original specifications and compromises are made in fit, function and cost. Current fighter pilot helmet design has evolved and been developed from the initial ones first used at the start of the jet ages. These developments have no reached, probably exceeded, the limits of operational use for long-term musculoskeletal damage to pilots.

Figure 2: A 5th generation pilots helmet.

Fifth generation pilot helmets must now incorporate more that head protection and the standard array of additions. To address musculoskeletal risks for the pilots in both every day and long-term there are now issues to add to helmet design: light weight, ability to withstand impact, reduce asymmetrical loading of additions, a platform for any specific addition, not interfere with operational use requirements and comfort. Unlike many designs the cost is of secondary consideration.

3 ERGONOMIC CONSIDERATIONS

Human head dimensions do vary as considerably as other body parts in their ratio. The height of a head does not change significantly from 15 years old to adulthood. Nevertheless, the principal feature for helmet design is based on the maximum width of the head just above the ears and the sellion to the back of the head. The tables below shows the principal dimensions in inches for men and women for both these physical features.

If you consider that the three main sizes currently used as the shells then accommodating these with internal adjustable straps then there is a large level of variation between pilots, Wickens *et al.* (1997). As mentioned above this unnecessary space between the webbing and the pilots head, or at least keeping it to a minimum can drastically reduce loading on the pilots musculoskeletal system. This has to now be considered a core requirement for 5th generation aircraft pilots.

Table 1: Head breath dimensions for men and women in inches.

	1st	5th	50th	95th	99th
Men	5.1	5.6	6.0	6.3	6.5
Women	5.2	5.4	5.7	6.0	6.1

Table 2: Head length from sellion to back of head for men and women in inches.

	1st	5th	50th	95th	99th
Men	6.7	6.8	7.3	7.8	8.1
Women	6.1	6.4	6.9	7.4	7.6

Considering these two tables, there are variations in head width of 1 inch from the smallest woman to the largest man. Whilst there is also an inch difference from the sellion to the back of the head. It can, and should, be argued that it is the time for bespoke helmets for every pilot but also a unique design for operation use. For example, why not have a separate helmet for day flying as well as night flying, or a separate one for just flying where minimum loads will be applied externally as would be used in simple flights, performance checking, etc. A helmet that has its maximum weight is only used when in combat and sometimes in combat training.

4 MATERIAL SELECTION AND DESIGN

Taking the starting point as a bespoke helmet, for day, night, standard non-combat and combat flights it results in the need for four helmets to suit all operational usage. In order to suit individual requirement a design is needed that will be comfortable (which can vary from person to person), incorporate communications, life support systems, head protection and ancillary equipment, Lui, *et. Al.*., (2006). The 5th generation of fighters are being designed to incorporate 360^0 vision with camera projection onto a face screen.

Sports science has made parallel developments in head protection and none more than in the area of cyclists, see figure 3 below. Professional cyclist helmets can have weights below 250g, which if compared to a basic pilot's helmet without any ancillary parts weigh in excess of 1.5 kg. Yet, they are designed to do the same, minimise head injuries in low impact incidents. No helmet will save a life where high loads and speeds are involved or in excessive shock loads to the skull. Even if they could protect the skull at high loads the neck is unable to be protected and fatalities will result. A helmet must protect the head although this will have limitations.

Figure 3: Lightweight cycle helmet.

These designs for cyclists are a generation ahead of standard pilot helmets and if the aim is to reduce long-term head and neck injuries then any design must supply equipment that is commensurate with expectations. Clearly, these designs can use advanced materials and manufacturing techniques that are now available. These are available to include directional laminates on foam based lining that model the pilots head fully.

Light weight composites can be manufactured in bespoke configurations providing there is a pattern. The helmet can be built up layer by layer until it is the appropriate thickness for the corresponding requirements. Individual designs, applications and materials can be matched to suit pilots' needs. After all, Formula 1 seats are uniquely moulded to support individual driver comfort and assist in reducing the upper neck loads experience when g-loads are experienced in fast turns and overtaking, this may be an extension need to be further added to compliment the next generation of helmets.

5 MANUFACTURING ISSUES

Any bespoke helmet, regardless of material, will need a pattern. Previously this would have required individual methods to be taken manually and a wooden pattern hand made. This was traditionally how gentlemen's hats were produced, and the pattern (mould) kept for any new or replacements. Co-ordinate measuring machines and computer controlled milling machines allow for fast turnarounds to develop the patterns in a wide variety of materials. This is the basis needed to make a composite lattice structured of multi-layered parts. Three dimensional moulds for composite mould can be produced quickly with 3D printing, any changes likewise can also be incorporated in real time.

Laser based Co-ordinate measuring Machines, CMM, can scan a head and profile to process the data for 3D printing or machining at any manufacturing facility in the world. A true bespoke helmet can be achieved rapidly from composites, and according to the individual requirements. Layered composites and head/foam protection as the frame is possible to be combined that will hug the head profile, allow air-flow for comfort whilst still performing all the operational requirements of current pilot helmets. Skeletal external frames that allow for air-flow, localised mass to secure ancillary items can be matched accordingly. It can offer any of the four potential types recommended to be match in minimum weight.

It is feasible that a standard helmet for basic flying, transportation between regions and routine maintenance checks could be below 1 kg even with communication and life support systems. The heaviest helmet will always be the full system for high end training and combat flying. Nevertheless, the weight can be reduced, loads reduced and thus reducing the potential immediate and long term risks to the musculoskeletal system.

Composite layering also allows for directional strength to be localised where maximum stress or loads will be expected, Autar (2005). This has the advantage of allowing for weight loss in other areas and keeping the overall weight as low as possible. Composite layering over a bespoke foam skeletal frame is the fundamental that may have the most significant influence on long-term problems for pilots. The matching of these aspects to bespoke design is paralleled in research with the material selection and design for 5^{th} generation fighter pilot helmets.

6 LOGISTIC PRACTICALATIES

If a pilot needs four helmets to support full requirements and any accident, knock, damage or incident will require a replacement; it will not be possible to acquisition a standard replacement form any localised stores. This raises the question of if there should be a standard emergency replacement as it would seem pointless not to have an available fighter aircraft, pilot but not operational due to no helmet, Wallenburg (2011). Each type would need a local spare as any critical aircraft part. Incorporating this is a minor exercise although one that needs organisation as any other.

Emergency replacement for helmet replacement would be accomplished by replacing the spare that has been acquisitioned and minimise the replacement, logistics of getting to a critical zone. Alternatively, having localised manufacturing sites allied to deployments will offer assistance. If this is not suitable, practical and logical the fall-back can be the existing options for emergency use to suit a couple of combat sorties.

7 CONCLUSIONS

This paper has addressed the needs for 5^{th} generation pilots helmet designs and requirements. The focus of this work has been to reduce the long-term risks to the musculoskeletal system of pilots that has implications to end a fighter pilots career early, and hence all the investments in time and money.

It has addressed how current designs have been less than adequate and will fall short for current requirements. It has proposed that there should be four helmets to suit flight requirements. These subsequently can be manufactured using advanced and real time methods; spares produced and incorporated into the standard list of operational

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REFERENCES

Anderson, H. T., Neck injuries sustained during exposure to high g-forces in the F16B. Aviation Space Environment Medicine, 1988; 59:356-8.

Autar K. Kaw (2005). Mechanics of Composite Materials (2nd ed.). CRC

Craig, P., (2013), The Killing Zone, a guide for new pilots, 2nd Edition, McGraw-Hill Education - Europe McGraw-Hill Professional.

De Loose, V., Kesser, I., Bernotte, F., and Tiggerlan, D. MRI Study in morphometry of cervical musculature nin F-16 pilots. Aviation Space Environment Medicine, 2009; 80: 727-31.

Lange, B., Torp-Svendsen, J. and Torfe, P. Neck pain among fighter pilots after the introduction of JHMCS Helmets and NVG in their environment. Aviation Space Environment Medicine, 2011; 82: 559-63.

Liu, B. C.; Ivers, R.; Norton, R.; Boufous, S.; Blows, S.; Lo, S. K. (2008). Helmets for preventing injury in motorcycle riders. In Liu, Bette C. "Cochrane Database of Systematic Reviews". Cochrane Database Syst Rev (1): CD004333.

NASA, Human Integration Handbook (HIDH), SP-2010-3407, Washington DC: NASA; January 27th, 2010:102.

Newman, E. and Kaloupek, D. G. (2004) The risks and benefits of participating in trauma-based research studies. Journal of traumatic Stress, 17(5): 57-59.

Roussel, M., (2013), Spitfire’s forgotten Designer, Blackwell’s.

Wallenburg, C., Cahill, D., Michael Knemeyer, A., and Goldsby, T. (2011): Commitment and Trust as Drivers of Loyalty in Logistics Outsourcing Relationships: Cultural Differences Between the United States and Germany. Journal of Business Logistics, Vol. 32, No. 1, pp. 83-98.

Wickens, C.D.; Lee J.D.; Liu Y.; Gorden Becker S.E. (1997). An Introduction to Human Factors Engineering, 2nd Edition. Prentice Hall.