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Aircrew Neck-Trouble Future Solutions

State-Of-the-Art-Report

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Abstract

Chronic neck pain is endemic among Royal Canadian Air Force (RCAF) helicopter aircrew. The wearing of a protective helmet, in addition to Night-Vision Goggles (NVGs) and their corresponding counterweights and battery packs, has been identified as a possible casual factor. This State-Of-the-Art-Report (SOAR) focuses on mid- and far-term technological solutions that may not be immediately implementable, and focuses on new body-borne equipment. The report begins with a description of current helmet systems worn by national air forces' aircrew, followed by brief descriptions of future helmets and helmet-mounted technologies that have the potential to lighten or support future helmet systems as well as other technological mitigating solutions. We conclude that while helmets and helmet-mounted technologies have been identified they may not be technologically mature enough, operationally implementable, or fiscally feasible to pursue at the moment.

Significance to defence and security

This work is part of the Royal Canadian Air Force (RCAF) and Defence Research Development Canada (DRDC) Air Agile Program Air Human Effectiveness project (03aa) Neck and Back Trouble Mitigation Solutions Work Breakdown Element (WBE). This report informs the client of the present state of technologies available and pending for the mitigation of neck strain among helicopter aircrew. It will serve as a reference document that provides a scope of knowledge regarding alternative helmet designs or other technological mitigating solutions to be considered in the near-, mid-, and far-term.

Résumé

La douleur chronique au cou constitue un problème endémique chez le personnel navigant des hélicoptères de l'Aviation Royale Canadienne (ARC). On a déterminé que le port d'un casque protecteur, en plus de lunettes de vision nocturne et de leur contrepoids et bloc-piles correspondants, en était une cause possible. Le rapport sur l'état actuel porte sur des solutions technologiques à moyen et à long terme dont la mise en oeuvre pourrait ne pas être immédiate, ainsi qu'au nouvel équipement qu'on porte sur soi. Le rapport débute par une description des systèmes de casques actuels que porte le personnel navigant des forces aériennes nationales, suivie d'une courte description des casques et technologies montées sur les casques du futur qui pourraient éventuellement les alléger ou les soutenir, ainsi que d'autres solutions technologiques d'atténuation. Bien que les casques et technologies montées sur casques soient connus, nous en concluons qu'ils sont pour le moment insuffisamment éprouvés sur le plan technologique, inapplicables sur le plan pratique ou irréalisables sur le plan financier.

Importance pour la défense et la sécurité

Ces travaux s'inscrivent dans le cadre du projet *Efficacité humaine de la Force aérienne* (03aa) du programme *Souplesse aérienne* de l'Aviation Royale Canadienne (ARC) et de Recherche et développement pour la défense Canada (RDDC) en vertu de l'Élément de Répartition du Travail (ERT) *Solutions d'atténuation des problèmes de cou et de dos*. Le présent rapport vise à informer le client de l'état actuel des technologies disponibles et à venir en vue d'atténuer la fatigue de la nuque au sein du personnel navigant d'un hélicoptère. Il servira de document de référence contenant un éventail de connaissances relatives à de nouveaux concepts de casques ou encore d'autres technologies d'atténuation comme solutions à envisager à court, moyen et long terme.

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Acknowledgements

The authors would like to acknowledge Captain Keith Lobo for the initial gathering of information for this report.

1 Introduction

1.1 Helmet-Induced Neck Pain

Neck pain is a serious and widespread problem among helicopter aircrew, affecting 75% of pilots and Flight Engineers (FEs) (Chafé & Farrell, 2016) over the course of their careers. This pain is believed to be the result of a combination of helmet system weight, profile, fit, posture, and centre of mass imbalance due to Night Vision Goggles (NVGs). As these are essential equipment, solutions must be found to mitigate their effects.

A 2014 survey of Royal Canadian Air Force (RCAF) CH-146 Griffon aircrew found that neck pain was positively correlated with increased NVG flight hours, helmet fit, mission flight time, and certain tasks (e.g. “downward scanning” for pilots, “laying prone” for FEs) (Chafé & Farrell, 2016). Neck pain was not correlated with age, gender, weight, height, or total flight hours.

The survey results led to proposed immediately implementable solutions: “smart-scheduling” of sorties that promote muscle rest and recovery, exercises, education, and the minimisation or adjustment of high-risk tasks. The 03aa01 Neck- and Back-trouble Mitigating Solutions Work Breakdown Element (WBE) was implemented to propose, develop, and assess solutions that reduce the risk of chronic neck pain. The primary WBE deliverable is advice on various near-term solutions that can be immediately implemented for CH-146 Helicopter aircrew.

However for purposes of completion, this State-Of-the-Art-Report (SOAR) presents some mid- and far-term technological solutions that may not be immediately implementable, but will require careful thought, planning, and significant resources in any integration into current aircraft platforms and Aviation Life Support Equipment (ALSE). It also focuses on body-borne equipment, which may have the potential to reduce neck loading intensity.

Chapter 2 begins with a description of current helmet systems worn by RCAF as well as other nations’ aircrew. Chapter 3 suggests future technologies that have the potential to lighten or support future helmet systems. The SOAR concludes with a summary of potential mid- and far-term mitigating solutions towards reducing chronic neck pain.

2 Current Helmet Systems

2.1 Griffon Aircrew Helmet Systems

Figure 1: Commercial version of Gentex HGU-56/P helmet without NVGs. (source: DRDC)

The helmet system presently in use by Griffon aircrew is the Gentex HGU-56/P (Figure 1). Flight-ready including liner and communication system with NVGs (Figure 2). The assembly varies for each aircrew and may weigh over 1.5 kg (Farrell et al., in review). In addition, the median NVG weight and its counter-weight value together may be another 1.5 kg. The approximate proportions of peripheral mass are broken down in Figure 3.

Figure 2: HGU-56/P system with NVGs. (source: DRDC)

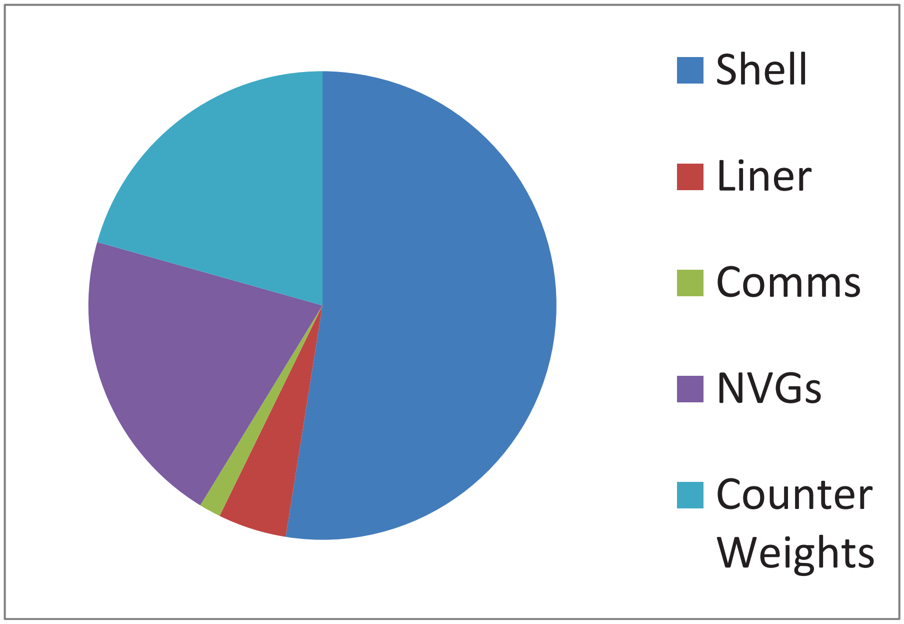

Figure 3: Distribution of weight in HGU 56/P helmet system by component.

From this, it is readily apparent that the largest potential for weight savings lies in the helmet shell, NVGs, and counter-weights. Intuitively, reducing the weight of the helmet system should decrease the strain on the neck; however, as above, the helmet profile (directly related to the helmet mass moment of inertia) increases the momentum necessary for head movements, that is a heavier and lower profile helmet may be preferable to a lighter but higher profile system. Anecdotally, some Griffon aircrew prefer the older, heavier, lower profile SPH 5 helmet than the lighter but higher profile HGU-56/P.

Beneath the shell are layers of Gentex Thermoplastic Liner (TPL) added by ALSE technicians to fit to the individual pilot's head. As seen in Figure 3, these do not add substantially to the weight of the helmet system, but they may impact helmet fit.

The center of mass affects the overall stress induced on the neck by the system. Despite adding mass over all, counter-weights act to relieve stress by shifting the center of mass back towards the center of the head; however, they do so only when the body is in a neutral position, such as during transit seated, where the resultant torque at night is less than the torque during the day (Figure 4). In all other postures adopted during flight, such as scan slung load, counter-weights add to the compression and shear forces, and torque experienced by aircrew (Farrell, Tack, Nakaza, Bray-Miners, & Farrell, 2014; Tack, Bray-Miners, Nakaza, Osborne, & Mangan, 2014).

Finally, as the sound reduction provided by the helmet alone is limited due to air pathways and the use of lightweight materials, ear cups augmented by in-ear protection are also worn beneath the helmet. Potential for weight savings in terms of communications equipment is limited; however, a reduced profile is possible with the use of alternative auditory equipment.

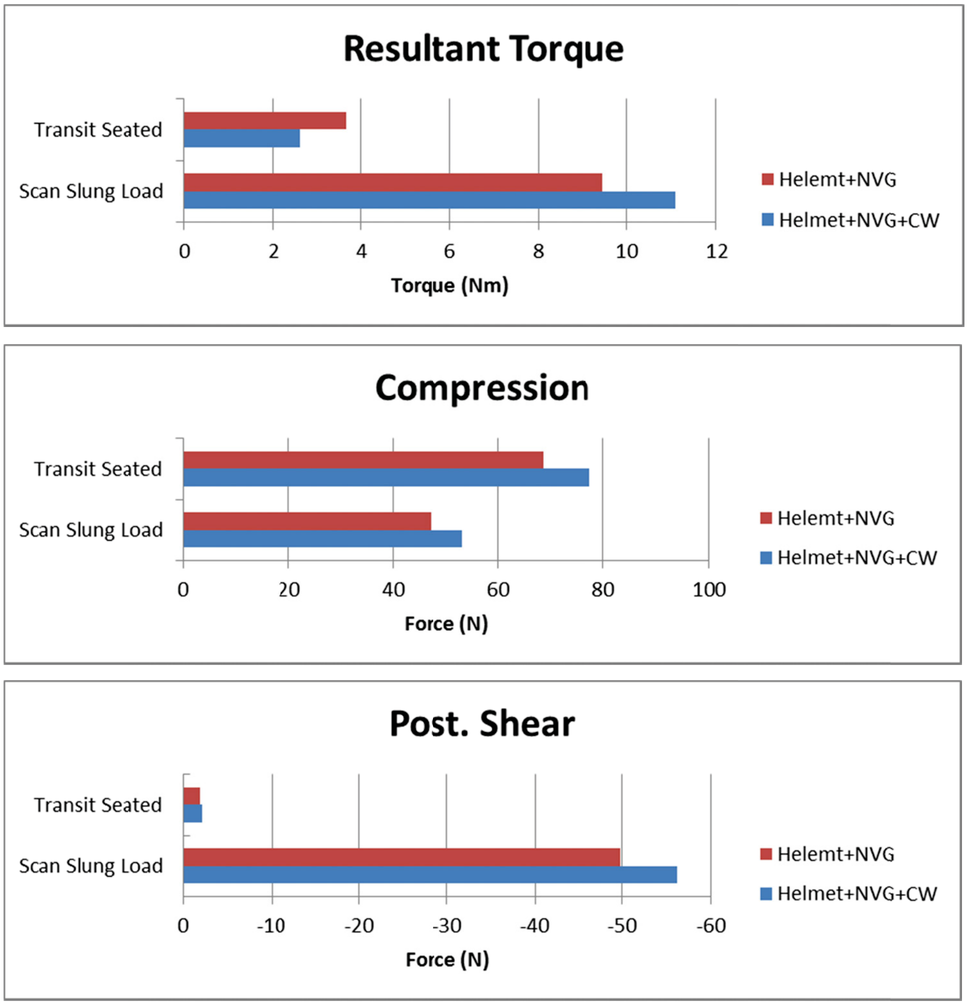

Figure 4: Aircrew neck loads with and without CW. Only Resultant Torque and Transit Seated show a benefit for using CW. (Tack et al., 2014)

2.2 Other Aircrew Helmet Systems

One potential mitigating solution to neck strain issues experienced by RCAF members is to adopt the helmet systems or techniques commercially available or currently used by other nations' aircrews. These solutions must meet the standards for impact protection and be adaptable to, or integrated with night vision technology. Note that helmets are designed primarily to meet the impact protection requirements, which are as follows:

- Acceleration experienced by a mannequin headform not to exceed 150 G[1] for more than 6 milliseconds or 200 G for 3 milliseconds or 400 G absolutely, when impacted by 35 foot-pounds of energy; and

[1] G is a non-dimensional value and is calculated by dividing the actual acceleration of an object by the acceleration due to gravity (9.81 m/s^2). All stationary objects on earth experience 1 G.

- No more than 0.25 inches of penetration when impacted by a 16-ounce steel bob with a point of 0.015 inches radius, from a height of 10 feet.

This means that helmets must have a certain mass and size to withstand these impact forces. Some helmet manufacturers are clearly aware of aircrew neck pain prevalence and have considered neck pain mitigation in the design of their newest helmets (but minimising neck pain is not a current requirement for helmet design).

For example, an upgrade to the HGU-56/P is now available from Gentex. It has the same impact resistance, but is tens of grams lighter, features an improved field-of-view, and a new two-strap retention system for "increased stability and comfort" (Figure 5). Weight savings are minimal, and any reductions in neck strain offered by these alterations would have to be verified.

Figure 5: Retention system for the new HGU 56/P helmet. (source: DRDC)

Another commercially available helmet is the Alpha Eagle (Figure 6). It features an adjustable back-of-the-neck nape that affords an immediate custom fit to the wearer. However, the mass of Alpha Eagle is similar to the current HGU 56/P. In a recent experiment that involved the current HGU 56/P, the improved HGU 56/P, and the Alpha Eagle, it was found that both the improved HGU 56/P and the Alpha Eagle were better in reducing external neck loading and muscle activity than the current HGU 56/P, despite the Alpha Eagle having similar mass properties as the current in-service helmet (Farrell et al., in review). The reason that the Alpha Eagle outperformed the current helmet system was due to its superior helmet fit properties.

Figure 6: Alpha Eagle Helmet. (source: DRDC)

USAF-certified systems are available at two-thirds of the weight of the HGU-56/P, such as the MSA Gallet shown in Figure 7 (the Alpha Eagle is only certified for commercial and civilian use). But as mentioned, reducing the weight does not necessarily mean a reduction of the profile or, consequently, the force on the neck required for movement while wearing it.

Figure 7: MSA Gallet without NVGs. (Accessed from https://www.meritapparel.com/, reprinted with permission from Merit Apparel)

Another in-use mitigating solution is a NVG pre-integrated helmet system. This system was designed specifically for rotary wing aircraft and is currently used by 16 countries, including the US, and is operational on the Tiger NH90, Cobra AH-1Z, Huey UH-1Y, and Rooivalk. For example, Thales' TopOwl Helmet System utilizes two cameras that projects onto the Head-Up Display (HUD) of the visor.

Additionally, this HUD displays weapons and targeting information, impact detection functions, and FLIR. The weight of the overall system is similar to that of the HGU-56/P. However, the profile (inertia) is considerably larger. The center of mass is balanced on both sides of the head as opposed to at the front (and back, if using counterweights). This could potentially lead to fewer neck strain problems, but this would have to be verified.

The BAE Striker II helmet system is another integrated system that was developed for both fixed and rotary wing aircraft. This helmet system uses a single high definition night-vision camera mounted in a central location above the pilot's eyes, projected onto the visor. Use of the Striker II system would be identical to using helmet-mounted NVGs, only with a drastically improved field of view. This would allow the pilot to use peripheral vision for many maneuvers which would require turning the head with conventional NVGs. However, the profile of the Striker II (and presumably weight) is extended above and beyond the head. This will yield higher inertia values and therefore require additional muscle activation to move the helmet.

Another in-use strategy for reducing neck strain, discomfort, and hot spots is to include a liner customised for the aircrew member. As previously mentioned, multiple liners are used to ensure correct fit. Having a customised liner would reduce mass and bulk, and thus the moment of inertia required for head movements. 3D printing would allow for the scanning of an individual aircrew member's head, and the liner produced would be custom-fitted to that shape.

The production of a custom liner is a service provided at an additional cost by Gentex as well as Thales' TopOwl. Gentex uses injection molding techniques while Thales employs 3D scanning. As 3D scanners are already used for equipment and clothing fit at major bases within the CAF itself, it would be possible to utilise this technology as an in-house mitigating solution: this is done for some USAF fast jet helmet systems where ALSE specialists obtain 3D scans of aircrew using a portable Minolta scanner, from which the liner is machine-produced.

Thus, there are a number of commercially available helmet systems that have better mass properties than the current helmet, which might mitigate neck strain as a result. These helmets, in combination with a customised liner, have the potential to reduce aircrew muscle activation and neck loading.

3 Future Technologies

3.1 Future Helmet Support Systems

A number of emergent technologies may assist in resolving the problem of neck strain, both in near- and far-term. These include supports, such as simple tethers and pneumatic devices, to robotically-assisted active support of the helmet system; these also include new integrated helmet systems with a wider field of view; and far-term technologies such as night-vision contact lenses.

The Buizza Mazzei Agency of Italy has developed an adjustable, detachable suspension device with a pneumatic lever that is affixed directly to the helmet itself. This device consists of an overhanging element and a suspension arch. It is installed behind the pilot seat with no other modification necessary. The retractable overhanging element supports the weight of the helmet while the suspension arch allows for freedom of movement.

This system has been flight-tested and shown to reduce pilot fatigue; however, such a system would not be usable by FEs, and only usable by pilots while seated, performing a limited range of movement. Installation of the equipment itself requires use of space within the cockpit. It has not yet been adopted operationally.

The Helmet System Support Device (HSSD), developed by researchers at Queens University and Thumbprint Solutions, consists of a spring attached to a lower collar mount and an upper slide on the back of the helmet, which is free to move with the rotation of the head, as seen in Figure 8 (Fischer et al, 2014). While this device has been shown to increase the postural endurance and decrease the time taken for tasks by the neck during a series of trials on naïve participants (Dibblee et al, 2015), an informal test by a pilot and FE resulted in complaints of problems fighting the spring tension and with the reliability of the automatic release mechanism (Fusina and Karakolis, 2015).

Figure 8: On the left is the HSSD design concept, and on the right is the HSSD attached to helmet and vest being trialed in flight. (source: DRDC)

Support to the helmet system could also be provided by active means such as the attachment of a robot mechanism (Figure 9) that would react to the wearer's movements and adjust the force and direction of the support accordingly so that there is minimal-to-negative force applied to the wearer's neck. This would require a power supply, and potentially be less intrusive and demanding of space than a tether or an overhanging suspension arm. Figure 10 and Figure 11 are plots of the theoretical force values for this type of support device, which are lower than those applied to the neck by the head itself.

Figure 9: Active support: robotic arm (Bailey, 2013). (source: DRDC)

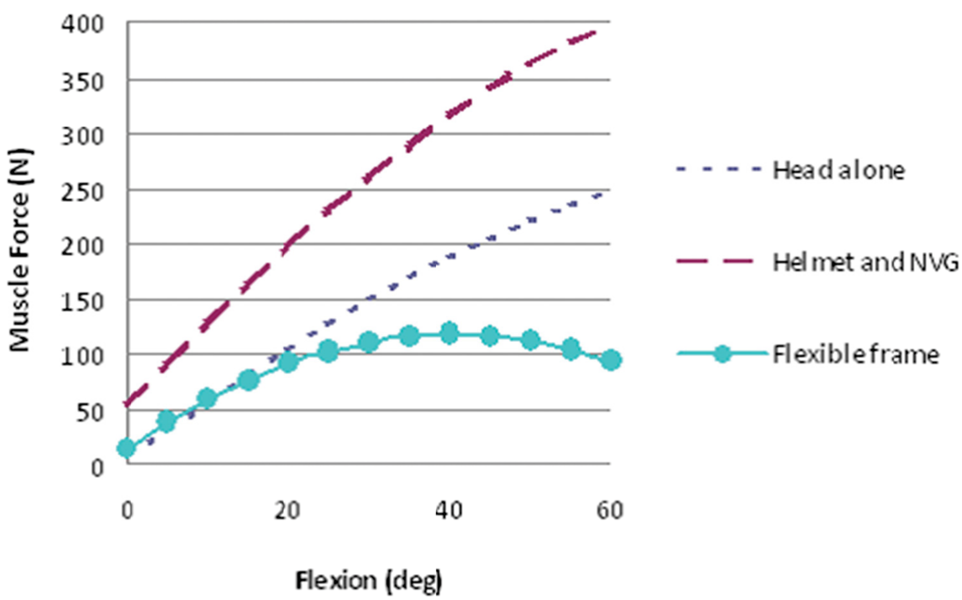

Figure 10: Muscle force required to support the head alone, the head with a helmet and NVG, and with a neck support.

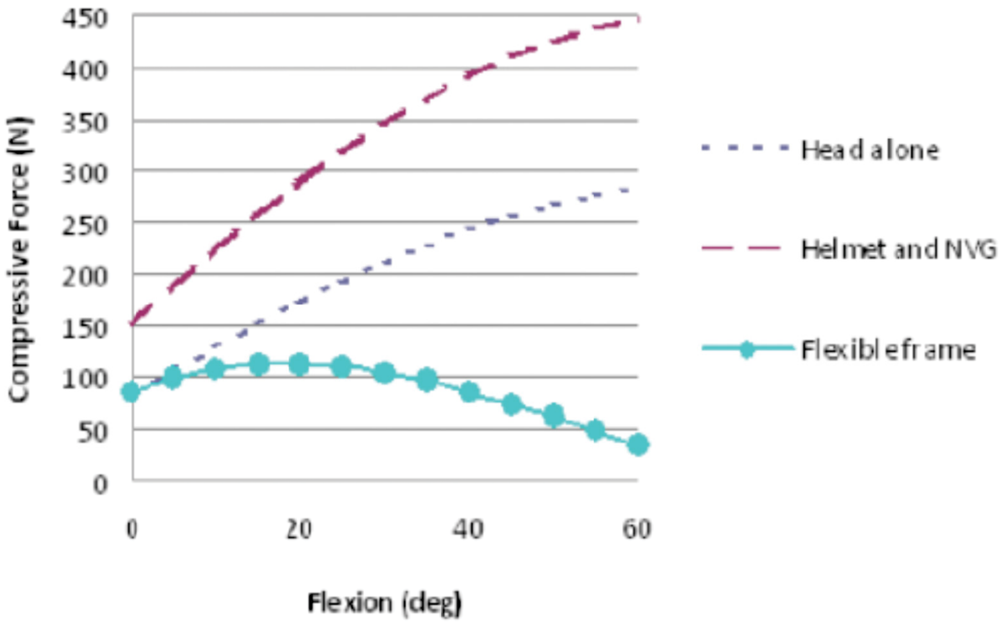

Figure 11: Compressive forces on the neck with the head alone, then helmet and NVG added to the head, and then with a flexible frame neck support device added to the entire head/helmet system. (Bailey, 2013)

3.2 Other Head-borne Technologies

Other head-borne peripherals also contribute to the total mass of the helmet system such as communication systems, NVGs, HUDs, counterbalances, and battery packs. There have been advances in these technologies such that their weight is reduced. For example, a custom earplug and throat microphone (see Figure 12) as well as bone conduction ear pieces may provide improved speech intelligibility, while at the same time weighs hundreds of grams less than our current communication systems that include the ear cups and boom microphone. This technology also has potential savings in inertia as the helmet would be redesigned with a slimmer fit or lower volumetric profile.

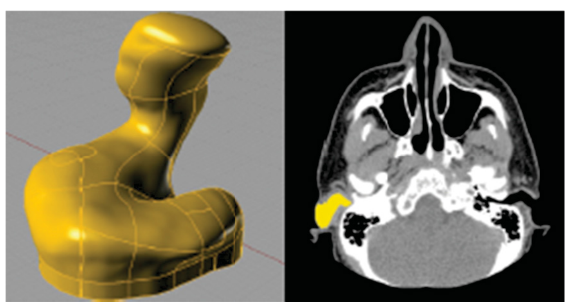

Figure 12: Custom earplug created using digital imaging. (Red_Tail_Hawk, 2014) (Accessed from http://www.rthcorp.com/, reprinted with permission from Red Tail Hawk)

Another technology that has the potential to drastically reduce the weight of helmet systems is night vision/infrared-capable Graphene-sensor embedded contact lenses (Nield, 2015). Graphene sensors the size of a fingernail and one atom thick have been produced that detect waves across the entire infrared spectrum, as well as the ultra violet. Conventional night vision optics requires multiple sensors to cover the infrared spectrum; a single graphene sensor does this, without the aid of cryogenic cooling. Adapting this technology to a wearable lens would dramatically reduce both the weight and profile of helmet systems, as the NVGs, HUDs, counterbalance, and battery packs account for approximately one-third to one-half of the weight, combined (Farrell et al., in review). As with new light-weight communications systems, there would be a reduction in the overall helmet system profile and therefore a reduction in inertia.

3.3 Vibration Attenuation

The effects of vibration are amplified and compounded with aircrew bearing head supported masses (helmet, NVG system, counter weights, etc.). NRC studied two commercial-off-the-shelf seat cushions that were considered to augment the current cloth and tube seating used by the flight engineer and passengers on CH146 Griffon helicopters. They found that the MitiGator by Sea Systems (cushion D in Figure 13) reduces whole body vibration up to 75% as compared to standard 2-inch thick viscoelastic foam (Chen, Yapa, Price, & Wickramasinghe, 2016). Also NRC is exploring active seat vibration mitigation technologies that, like an active noise reduction system, senses the vibration at the seat pan and uses mechanical motors to replicate the inverse vibration function to cancel out the vibration.

Figure 13: Candidate Seat Cushions: A) Blake Medical Geo-Matrix Bronze Seat Cushion B) Oregon Softseat ® - Certified for U60 (Wide), C) Oregon Softseat ®, D) Mitigator Thin Seat Cushion, E) Skydex – Certified for U60 (Wide), F) Skydex, G) Gunner Full Two-Seat Replacement Bench. (Chen et al., 2016) (Reprinted with permission from authors)

4 Conclusions

With a prevalence rate as high as 75%, neck strain is endemic throughout the rotary wing aircrew population of the RCAF. The current in-service helmet, the HGU-56P with counterbalance, has not mitigated this effect; though lighter than the previous SPH 5 service helmet, it is higher in inertia properties. Accordingly both mass, centre of mass, and inertia must be taken into account for any helmet systems adopted in the future.

In addition to other immediately implementable measures, such as exercise, education, and smart scheduling, the adoption of a new helmet system may afford a potential mid- to far-term mitigating solution. Other helmet systems introduced in this report, offer reduced mass and profile (and therefore reduced inertia), as well as a better balanced system. Up-front costs for a new system may be offset by savings in treatment for affected pilots.

Other technologies presently available to augment the current helmet system offer another potential solution. 3D liner printing is already in use by other nations; use of this technology results in lower profile and better, custom fit. Custom earplugs, bone conduction ear pieces, and throat mics could replace the ear cups and boom mic — beyond savings in weight, this would allow for the helmet shell itself to be redesigned smaller, fitted closer to the head, thus minimising inertia.

Finally, far-term solutions may offer the possibility of eliminating NVG/counterweight, and even helmet weight, altogether. Tethers, overhead suspension systems, and active support systems could support the helmet in place of the neck; however, these require alterations to the already densely packed aircraft and have the potential to interfere with life-saving equipment or obstruct egress. Graphene-embedded contact lenses will have a negligible profile and mass. Mitigating vibration with passive (near-term mitigating solutions) and active cushion systems (far-term mitigating solutions) will also reduce the effect of head-borne mass properties on the neck.

We conclude that while helmets and helmet-mounted technologies have been identified they may not be technologically mature enough, operationally implementable, or fiscally feasible to pursue at the moment.

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List of Symbols/Abbreviations/Acronyms/Initialisms

3D	3 Dimension
ALSE	Aviation Life Support Equipment
DND	Department of National Defence
DRDC	Defence Research and Development Canada
FEs	Flight Engineers
HSSD	Helmet System Support Device
HUD	Head-Up Display
NRC	National Research Council Canada
NVGs	Night Vision Goggles
RCAF	Royal Canadian Air Force
SOAR	State-Of-the-Art-Report
WBE	Work Breakdown Element

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Muscle Activation; Neck Load; neck pain; tbody-borne equipment; helmet systems, Night Vision Goggles, Head Up Displays, Counter Weights