Near-Term Ideas to Address Aircrew Helmet Systems-Induced Neck Pain

Mitigating Neck Pain in Aircrew

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

Neck pain is a growing concern among CH-146 Griffon aircrew. A simple, yet practical on-body elastomer balanced helmet system is provided as one of several feasible near-term solutions to alleviate the neck pain problem.

Following a rapid work domain assessment of the operational environment of CH-146 Griffon aircrew and an ergonomic hazard screen, the research team identified that sustained static postures (pilots) and extreme awkward postures (flight engineer) were primary risks. Moreover, the level of risk increases considerably with the additional head-borne mass of the night vision goggles system (NVGs). The addition of the NVGs increases the total mass on the head, adding more compressive load on the neck and requiring more work from the neck muscles in order to control and stabilize the head. Additionally, the NVGs alters the balance of forces acting about the head and neck joint (atlanto-occipital joint), requiring the small upper neck muscles to work even harder. The ideal solution entails a combination of redesigning the cockpit, cabin and helmet system. However, in the near-term the on-body elastomer-balanced helmet system provides an interim improvement. This counter measure provides a balancing force through the elastomer, off-loading the work from the neck muscles. In addition the total head-borne load is also reduced compared to the current weight based counter balancing method.

Résumé

Les douleurs au cou sont une préoccupation de plus en plus courante chez le personnel navigant des CH-146 Griffon. Un système de casque ergonomique équilibré avec un élastomère, simple mais pratique, est l'une des solutions réalisables à court terme qui sont proposées pour atténuer le problème des douleurs au cou.

À la suite d'une évaluation rapide du domaine de travail portant sur l'environnement opérationnel de l'équipage du CH-146 Griffon et d'un examen initial des risques ergonomiques, l'équipe de recherche a établi que les positions statiques prolongées (pilotes) et les positions contraignantes extrêmes (mécaniciens de bord) constituent les principaux risques. De plus, le degré de risque augmente considérablement en raison du poids qu'ajoute au casque le système de lunettes de vision nocturne (NVG). L'ajout des NVG augmente la masse totale qui est supportée par la tête, ce qui accroît la charge de compression sur le cou et exige un effort supplémentaire de la part des muscles du cou pour contrôler et stabiliser la tête. Qui plus est, les NVG modifient l'équilibre des forces au niveau de l'articulation entre la tête et le cou (articulation occipitoatloïdienne), ce qui entraîne une sollicitation accrue des petits muscles du haut du cou. Idéalement, il faudrait revoir la conception du poste de pilotage, de la cabine et du système de casque. Cependant, à court terme, le système de casque ergonomique équilibré avec un élastomère offre une amélioration provisoire. Cette mesure crée une force compensatrice grâce à l'élastomère, réduisant ainsi le travail requis par les muscles cervicaux. En outre, la charge totale sur la tête est réduite par rapport à la méthode actuelle de contre-balancement par le poids.

Executive summary

Near-Term Ideas to Address Aircrew Helmet Systems-Induced Neck Pain: Mitigating Neck Pain in Aircrew

Steven L. Fischer; Joan M. Stevenson; Wayne J. Albert; Michael F. Harrison; Tim Bryant; Tyson A.C. Beach; Susan A. Reid; Brendan Coffey; DRDC Toronto CR 2013-039; Defence R & D Canada - TorontoToronto; March 2013.

Introduction or background: Mitigating neck pain among aircrew has been identified as a priority within the military aerospace communities. Research and communications with aircrew personnel clearly indicate that neck pain impacts on the availability and readiness of aircrew worldwide and most indicators point to the night vision goggles system (NVGs) as a key contributor. A simple, yet practical on-body elastomer-balanced helmet system is described as one of several feasible near-term solutions to help alleviate this problem. This and other solutions were generated by a multi-disciplinary research team sub-contracted via the Canadian Institute for Military and Veteran Health Research, to complete the following objectives:

- Conduct a rapid work domain assessment to understand the operational environment of the CH-146 Griffon helicopter;
- Identify ergonomic and functional cockpit/cabin area deficiencies that may be contributing to musculoskeletal strain;
- Identify opportunities for intervention and propose potentially effective solutions;
- Prepare proposals to detail the tasks, resources and costs associated to further develop and test a selection of proposed solutions.

Results: NVGs are critical to support night missions; however in the context of neck pain they seem to be the “straw that broke the camel’s back”. Through a series of site visits and a familiarization flight, the research team identified a number of ergonomic and functional deficiencies regarding the layout of the cockpit (i.e. the location of the MX-15 Vision System), the cargo area (i.e. the use of rag and tube seating) and the required job tasks (i.e. the flight engineer hanging out of the aircraft to survey “blind spots”). Independently, these risks pose a concern; however, the level of risk and concern increases with vibration of the aircraft, the additional mass of the helmet, which increases considerably with the addition of the NVGs. While aircrew have reported periodic episodes of neck pain for many years, likely due to underlying ergonomic hazards; the increased use of the NVGs to support night missions has increased this problem substantially – “the straw that broke the camel’s back”.

The current design of the NVGs poses a number of problems for the musculature of the neck. Under normal conditions, neck muscles provide support to balance and stabilize the head. As more weight is added to the head, these muscles will work harder. Additionally, the further the added weight is from the head/neck joint (atlanto-occipital joint), the harder muscles will have to work to counter balance the added weight. A thorough review of literature included as Annex B substantiates this hypothesis.

In an ideal situation, the Canadian Forces would look to redesign the layout of the CH-146 Griffon helicopter to reduce underlying ergonomic hazards, in addition to evaluating and procuring a lighter helmet and NVGs, with a more centralized distribution of weight, such as the TopOwl® (Thales – Aerospace Division, Valence, France) as an example.

In the interim, an elastomer-balanced helmet system is proposed as one of several near-term solutions to alleviate the neck pain problem. The elastomer-balanced approach reduces the total weight of the NVGs systems (no counter weight, suggested removal of battery pack), and replaces the effective counter balancing force of this mass, and counter balancing forces required from the muscles by using a custom-designed dual stiffness elastomer system. This solution is expected to off-load the work performed by the neck muscles, reducing both the cumulative and average muscle activation.

Significance: An elastomer-balanced helmet system could provide a practical, feasible near-term solution to alleviate neck pain among CH-146 Griffon helicopter aircrew. The positive benefits of this solution can be enhanced further by integrating additional recommended solutions including improved self-care / post flight cool down options, targeted exercise training regiments developed using a periodization model, updated work load assignment procedures, updated rotor track balance standards and incorporating simple ergonomics enhancements.

Future plans: Pending review and consideration of solutions proposed here, the research team aims to further develop selected solutions and to support their implementation where required.

Sommaire

Idées à court terme en vue d'atténuer les douleurs au cou attribuables aux systèmes de casque chez le personnel navigant : Réduire les douleurs au cou chez le personnel navigant

Steven L. Fischer; Joan M. Stevenson; Wayne J. Albert; Michael F. Harrison; Tim Bryant; Tyson A.C. Beach; Susan A. Reid; Brendan Coffey ; DRDC Toronto CR 2013-039; R & D pour la défense Canada – Toronto Toronto; mars 2013.

Introduction: La réduction des douleurs au cou chez le personnel navigant fait partie des priorités cernées par la communauté de l'aérospatiale militaire. Les recherches et la consultation du personnel navigant révèlent clairement que les douleurs au cou ont une incidence sur la disponibilité et l'état de préparation des équipages du monde entier, et la plupart des données indiquent que le système de lunettes de vision nocturne (NVG) en serait un facteur important. Un système de casque ergonomique équilibré avec un élastomère, simple mais pratique, est décrit parmi d'autres solutions réalisables à court terme pour aider à atténuer ce problème. Ces solutions ont été mises au point par une équipe de recherche multidisciplinaire embauchée par contrat par l'Institut canadien de recherche sur la santé des militaires et des vétérans, afin de réaliser les tâches suivantes :

- Réaliser une évaluation rapide du domaine de travail afin de comprendre l'environnement opérationnel de l'hélicoptère CH-146 Griffon;

- Cerner les défauts ergonomiques et fonctionnels du poste de pilotage et de la cabine qui pourraient favoriser les contraintes musculo-squelettiques;

- Déterminer les interventions possibles et proposer des solutions potentiellement efficaces;

- Préparer des propositions dans lesquelles seront détaillées les tâches, les ressources et les coûts associés au développement et à la mise à l'essai d'un ensemble de solutions proposées.

Résultats : Les NVG fournissent un appui essentiel aux missions de nuit; cependant, du point de vue des douleurs cervicales, elles semblent être « la goutte d'eau qui fait déborder le vase ». Par une série de visites sur place et un vol de familiarisation, l'équipe de recherche a repéré un certain nombre de défauts ergonomiques et fonctionnels dans la configuration du poste de pilotage (soit l'emplacement du système de vision MX-15), la soute (soit l'utilisation de sièges faits de tubes et de toile) et les tâches du personnel (le mécanicien de bord qui sort de l'aéronef pour vérifier les « angles morts »). Individuellement, ces risques sont préoccupants; cependant, le niveau de risque et de préoccupation augmente en raison des vibrations de l'aéronef et de la masse additionnelle du casque, qu'accroît considérablement l'ajout des NVG. Bien que le personnel navigant fait état d'épisodes de douleurs au cou depuis un grand nombre d'années, probablement en raison des risques ergonomiques inhérents, l'utilisation accrue des NVG au cours des missions de nuit a intensifié grandement ce problème – c'est « la goutte d'eau qui a fait déborder le vase ».

La conception actuelle des NVG entraîne divers problèmes au niveau des muscles du cou. Dans des conditions normales, les muscles du cou contribuent à l'équilibre et à la stabilité de la tête. Plus le poids placé sur la tête est élevé, plus ces muscles seront sollicités. En outre, plus le poids

supplémentaire se situe au niveau de l'articulation entre la tête et le cou (articulation occipitoatloïdienne), plus les muscles doivent travailler fort pour contrebalancer ce poids. Une revue exhaustive de la littérature est incluse à l'annexe B pour étayer cette hypothèse.

Idéalement, il faudrait que les Forces canadiennes envisagent de modifier l'aménagement de l'hélicoptère CH-146 Griffon, de façon à réduire les risques ergonomiques inhérents, en plus de procéder à l'évaluation et à l'acquisition de casques et de NVG plus légers, dont le poids serait réparti de façon plus centrale, comme le TopOwl® (Thales Division Aéronautique, Valence, France), par exemple.

Entre-temps, un système de casque équilibré avec un élastomère compte parmi les solutions proposées à court terme pour atténuer le problème des douleurs au cou. Cette solution permet de réduire le poids total des systèmes de NVG (pas de contrepoids, retrait suggéré du bloc-piles), repositionne la force de contrepoids effective de cette masse, et réduit les forces de contrepoids requises par les muscles au moyen d'un système en élastomère fait sur mesure, à deux niveaux de rigidité. On prévoit que cette solution allégera le travail effectué par les muscles du cou, ce qui réduira l'activation musculaire cumulative et moyenne.

Importance: Un système de casque équilibré avec un élastomère pourrait représenter une solution pratique et applicable à court terme afin d'atténuer les douleurs au cou chez le personnel navigant de l'hélicoptère CH-146 Griffon. L'effet positif de cette solution peut être bonifié si l'on y adjoint d'autres solutions recommandées, dont l'amélioration des autosoins/des options de récupération après le vol, des programmes d'exercices périodisés et ciblés, la mise à jour des procédures d'attribution de la charge de travail, la mise à niveau des normes d'équilibrage et d'alignement des pales et la réalisation d'améliorations ergonomiques simples.

Perspectives: En attendant l'examen et la prise en considération des solutions proposées dans le présent document, l'équipe de recherche espère poursuivre le développement des solutions retenues et appuyer leur mise en œuvre, le cas échéant.

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1 Rapid work domain assessment

1.1 General operations - the role of the CH-146 Griffon helicopter in the Canadian Forces

(Excerpted from http://www.rcaf-arc.forces.gc.ca/v2/equip/ch146/index-eng.asp):

"In service with the Royal Canadian Air Force since 1995, the Griffon helicopter`s primary role is tactical transportation of troops and material. It is also used at home and abroad for search and rescue (SAR) missions, surveillance and reconnaissance, casualty evacuation and counter-drug operations. The helicopter has also played a key role in many national and international humanitarian relief operations.

When it joined Joint Task Force Afghanistan Air Wing, deployed on Operation Athena, the Griffon utility tactical transport helicopter helped reduce the risk of exposing personnel to ambushes, land mines and improvised explosive devices by providing increased protection to movement of troops by transport helicopter and road convoys.

The Griffon is used at home to support Army training, and for a wide variety of other missions. The Griffon can be equipped with a hoist that enables it to extract people and a cargo hook that lets it transport cargo from almost any terrain. The Griffon can also be equipped with a Forward-Looking Infrared (FLIR) system, a Wescam MX-15 electro-optical imaging system, a powerful Nitesun searchlight, and armoured floors and crew seats, helping the crew to accomplish their various missions. A variety of self-defence weapons can also be fitted for deployed operations.

The aircraft can carry up to 13 people (two pilots, a flight engineer and 10 passengers) and has a maximum gross weight of nearly 5400 kilograms. The Griffon can reach speeds up to 260 kilometres per hour."

1.2 General operations - flight schedules

Flight schedules vary considerably, especially between training and being in theatre. In terms of training, the minimum requirements for certification are: 50 hours every six months with 8 hours in night flying of which 5 hours are NVG flying. However, crew members normally fly 200-300 hours per year with approximately 25% of those hours spent night flying (with NVGs). Typical training flights were reported to last for 1.5 – 2.5 hours once or twice per week; however that schedule could vary if crews were preparing for an operation or trying to accumulate the necessary hours for continued certification. During specific missions or in theatre, operations could result in a wide variety of schedules, where aircrew could fly multiple missions in a row or over a few days. Each flight could be a maximum of 3-3.5 hours before a refuel is required.

1.3 Common operational manoeuvres / tactics

CH-146 Griffon helicopter aircrew conduct and support many operations for the Canadian Forces. When conducting operations, objectives may include person/cargo transport, search and rescue, reconnaissance, fire support and/or armed escort. Achieving the overarching objectives requires aircrew to carry out many different manoeuvres / tactics. A list of manoeuvres includes, but is not limited to: take-offs and landings (confined spaces / slopes), hovering, banking, forward flying, Nape-Of-the-Earth (NOE) flying, slinging, and weapons use. Although a complete analysis of operations is beyond the scope of this work, it is clear that aircrew perform many different manoeuvres / tactics during training or when in theatre.

Pilots and flight engineers (FE) work together to complete operational manoeuvres / tactics, but are responsible for specific activities to carry out these operations. Pilots are located in the cockpit and are responsible for piloting the aircraft, monitoring flight / aircraft controls, and performing flight tactics such as hovering, forward flying, NOE flying, and landing. Pilots also support operational duties such as monitoring the Forward-Looking Infrared (FLIR) system, or Wescam MX-15 electro-optical imaging system. The flight engineer is located in the cabin (Figure 1 – left pane) and is responsible for conducting the pre-flight and cargo checks, instrument check support and for providing visual support to aid flying operations. For example, the flight engineer is responsible for leaning out of the side-door to visually inspect that there is enough clearance for the main rotor blade and the tail rotor (i.e. visual inspection from 12 o'clock to 6 o'clock – as well as above and below checks). They are also responsible for checking clearances for the skids to ensure that the ground is clear of impediments or restrictions that will compromise the landing. The flight engineer is also responsible for several mission tactics including slinging and operating defence weapons (Figure 1 – right pane).

Figure 1- The flight engineer is located in the cabin and provides visual information/confirmation about the location of the helicopter relative to the terrain and supports many operational tactics. (Note: the picture on the far right is public domain and was obtained from http://www.flickr.com/photos/isafmedia/5032515620/).*

Flight Engineers also spend a portion of their time aiding in aircraft maintenance and repair. Griffon helicopters have a very tightly monitored maintenance schedule. All flight engineers evolve from the aircraft maintenance crew and continue to support helicopter maintenance to ensure they remain skilled in these operations.

Considerable differences exist in the physical and cognitive demands required to support each manoeuvre / tactic. During the site visits flight crew indicated that some manoeuvres / tactics were much more challenging than others. For example, flight engineers noted that slinging was a challenging task as they were required to observe the aircraft from front to back and under the helicopter while also monitoring the cargo. This requires considerable head and neck movement to complete. This feedback suggests that some operations are more demanding (and potentially impose more risk of developing neck troubles) than others; it was beyond the scope of this work to more comprehensively evaluate and contrast physical exposures for specific activities. Future work should aim to more comprehensively evaluate the demands required for each task such that the outcomes could be used to improve workload scheduling as a solution to prevent excessive exposures (i.e. rotate aircrew between operations requiring high demands and those that require lower demands).

1.4 Operational environment

Three operational environments were identified within the CH-146 Griffon helicopter: the cockpit-right seat, the cockpit-left seat and the cabin.

1.4.1 Right-seat pilot

The pilot in the right seat is primarily responsible for piloting the helicopter during flight operations. Right-seat pilots will move the head, neck and body (within the confines of the harness) to access and observe aircraft controls (Figure 2 – left pane) and to scan the outside environment (Figure 2 – remaining three panes). The space is confined, particularly by the rotor brake and communication cables overhead.

Figure 2- An illustration of the operational environment for the pilot in the right seat of the CH-146 Griffon helicopter.
The left pane demonstrates a pilot entering coordinates. The remaining panels demonstrate the range of postures that the right seat pilot may adopt while scanning the environment and other aircraft instrumentation.

1.4.2 Left-seat pilot

Left-seat pilots play a co-pilot role in operating the helicopter during flight operations, where their primary responsibility is monitoring the MX-15 Vision system. Similar to right-seat pilots, left-seat pilots will also move the head, neck and body to access and observe aircraft controls (Figure 3 – left pane) and to scan the outside environment. The MX-15 Vision system monitoring role requires additional side bending to adequately monitor the vision system (Figure 3- right pane). While the left-seat space is slightly less confined (no rotor brake overhead), communications cables overhead still pose a space restriction.

Figure 3- An illustration of the operational environment for the pilot in the left seat of the CH-146 Griffon helicopter.
The left panel demonstrates a pilot entering coordinates from left seat position. The panel on the right demonstrates the pilot in the left seat observing the MX-15 Vision system.

1.4.3 Flight engineer

The flight engineer is located in the cabin and is primarily responsible for observing the aircraft during take-off, landing or other slow moving tactics; operating weapons, and general work inside the helicopter. The flight engineer will also play a secondary role observing aircraft control gauges. While the pilots are relatively confined within their operational environment, the flight engineer is less confined and regularly moves about the cabin. As such, the flight engineer will sit in many positions and locations including forward-facing (Figure 4 - left pane), or side-facing on the central rag and tube bench, side-facing on the side door seat (especially during weapons use), kneeling, crouching (Figure 4 – centre pane) or lying to observe outside the aircraft (Figure 4 – right pane), kneeling to observe instruments in the cockpit, and occasionally rear-facing while sitting on a milk-crate when the cabin is loaded with cargo or personnel. Although the cabin is less confined than the cockpit area, the height poses a considerable challenge as the flight engineer moves about the cabin and the available seating options pose considerable undue risk, relative to the cushioned support of the seating available in the cockpit.

Figure 4– A demonstration of the postures adopted by the flight engineer.
The left pane demonstrates the typical forward-facing seated posture adopted during forward flight. The centre pane demonstrates the flight engineer in a crouched position while moving about the cabin. The right pane demonstrates the posture adopted when monitoring the skids of the aircraft during landing.

1.5 Equipment worn by crew

Depending on the weather, crew will wear their flight suits and various levels of winter attire. In addition, both pilots and flight engineers wear a Life Preserver Safety Vest (LPSV). Pilots are strapped into their seats using a more conventional 4-point safety harness, whereas flight engineers must also wear a fall arrest harness with a long tether that anchors into the helicopter frame as they move about the cabin to conduct activities. Flight crew members are required to wear a helmet (HGU/56P – Gentex) for crash protection and to provide a platform to support communications (Figure 5 – top pane). Although no official technical specifications for the weight or distribution of weight of the helmet were available, Table 1 indicates the unofficial masses, as measured by hand-held scales

Table 1– Unofficial mass of the helmet and component parts.

Item	Mass (kg)	Mass (lbs)
HGU 56P helmet	1.4	3.0
NVG with mount	0.9	2.0
Counter weight and Battery	0.9	2.0
Total Mass	3.2	7.0

During daylight hours, the helmet is worn with its internal communications system and built in-visors by all crew members. Flight engineers may also wear the maxillofacial shield to protect against the wind and sun (Figure 5 – bottom right pane). During dusk / dawn / and night flying, the flight crew will also wear night vision goggles (AN/AVS-9 – ITT Night Vision) (Figure 5 – bottom left pane). According to the technical specifications from ITT night vision, the NVG's have a field of view of 40°, the binocular portion has a weight of 550 grams and the binocular mount has a weight of 330 grams. Aircrew may also choose to wear a lead counter weight on the back of the helmet which is inserted into a pocket between the NVG battery pack and helmet. There was considerable variety among crew members about the amount of counterweight used and where it was located on the back of the helmet.

Figure 5– Head mounted equipment worn by CH-146 Griffon helicopter aircrew.
The top pane illustrates the helmet systems with and without the night vision goggles. The lower left pane demonstrates the use of the night vision goggles system. The lower right pane illustrates the additional use of the maxillofacial shield.

2 Ergonomic hazards and functional deficiencies

2.1 A summary of musculoskeletal concerns of Griffon crew members

Many of the crew members reported musculoskeletal concerns with their necks and backs while describing their work to the research team during site visits. They felt these issues arose because of: (i) the weight and moment of inertia of the helmet, especially with NVGs; (ii) postural requirements; and (iii) vibration of the aircraft. They reported more intense symptoms when several missions occurred in rapid succession (i.e., in theatre or re-certification). However, the causes of these concerns varied based on job requirements. For pilots, the concerns were related to: a) the additional effort required to scan the instrumentation panels while wearing the NVGs, b) the sustained effort required to support the head from drooping while wearing the NVGs and c) vibration that comes through the seat and occurs most frequently during take-offs and landings. For flight engineers, the main concerns were related to sitting on the "rag and tube" seats (R&T seats) and performing duties during landings. The R&T seats forced extreme rounding of the back because of the location of the tube supports and stretch of the cloth seats. In turn, this causes the helmet and NVGs to drop further forward, requiring additional effort to maintain an upright head position. In addition, the design of the R&T seats creates a high pressure zone on the back of the thigh when flight engineers are seated, producing point compression on the underlying tissues, potentially restricting blood flow to the lower limbs.

The research team noted many similarities between the feedback received from aircrew during this project and the feedback reported previously by Capt. J. Adam (Technical Report - DRDC Toronto TR 2004-153). The 2004 report also identified a series of recommendations to help mitigate neck pain among rotary wing aircrew. We recommend that DRDC review these previous recommendations (of which many are repeated in this report) for additional engineering, administrative and personal controls that could be implemented to mitigate neck pain in aircrew.

2.2 Helmet, night vision goggles, counter weight

2.2.1 Helmet

Head-borne mass is not the only factor contributing to neck pain among aircrew, but it is likely a primary factor. During design, the mass of the helmet was considered by the manufacturer (Gentex – as indicated on their marketing documentation online) to ensure it remains at an acceptable weight (although this weight threshold limit value is not reported). Despite the fact that helmets are designed in consideration of this human factors / ergonomic criterion, the weight of the helmet on its own may increase the risk of developing neck pain. When helmet fit is not optimized to the individual, in combination with the vibration of the aircraft and prolonged static non-neutral postures, the risk of developing neck pain is likely to increase. However, it is not clear if the most recent design considered the moment of inertia of the helmet. The newer model (Figure 5 – top left) has a radius that is larger than the previous helmet. This larger radius requires further muscular effort to start and stop the helmet during dynamic motions. The additional mass and the locations of the NVGs, battery and counter weights only increases the moment of inertia, making it more difficult to rotate the head quickly.

2.2.2 Night vision goggles (NVGs)

The addition of the night vision goggles (NVGs) to the helmet system increases the head-borne mass. In addition, the NVG system shifts the centre-of-gravity (CoG) of the helmet and head system forward and superiorly, into the most problematic region (see Annex B – Literature Review – Section 5 – Helmets, Masses and Loads). Furthermore, use of the NVGs imposes a significant decrease in the visual field-of-view (effectively eliminating peripheral vision) requiring a considerable increase in head and neck movement to accommodate this restriction. In reviewing documentation from ITT Exelis, the manufacturer of the AN/AVS-9 NVGs, there was no indication that the design incorporated human factors / ergonomic guidelines to ensure aircrew safety or comfort while wearing the device. Recognizing that their primary objective is to provide and enhance night vision capability; this capability may not be useful if aircrew cannot wear the device long enough to effectively benefit from this enhancement. The limited consideration of human factors in the combined design of the helmet and NVG system is a primary concern likely precipitating the neck pain problem developing among rotary wing aircrew. Unless the combined helmet and NVG systems can be designed with human factors in mind, reactive, cost-prohibitive retrofit solutions will continue to be required.

2.2.3 Counter weight (CW)

A simple counter weight (CW) has been introduced to help maintain a more central CoG, while wearing the NVGs. Based on feedback obtained during the site visits, and on data previously reported in the literature (see Annex B – Literature Review – Section 5 – Helmets, Masses and Loads), CW usage is based on personal preference, with some aircrew preferring to wear it and others not. Notwithstanding the mixed usage among aircrew, a CW is most effective during upright neutral head and neck postures, which pilots and particularly flight engineers rarely adopt. Although a CW approach is plausible to help reduce the forward and superior migration of the CoG while wearing the NVGs, it does so by adding considerable extra mass to be supported by the head and neck, and its' effectiveness is chiefly dependent on the head and neck position relative to gravity. This limits the range of positions for which a CW is a useful technique for mitigating neck pain.

2.2.4 Biomechanics

The development of neck pain among rotary-wing aircrew is likely multi-factorial, limiting any opportunity to pinpoint a specific cause. However, previous research (see Annex B – Literature Review) indicates that the addition of NVGs has had a considerable impact on pain and injury reporting, likely because of the effect it has in shifting the CoG forward and up from the normal CoG of the head (Figure 6). When wearing the helmet and NVGs, the CoG is shifted up from the normal CoG of the head by 16.7 mm and forward by 10.6 mm. However, if the NVGs, mounting and battery pack are removed, leaving only the head and helmet, the CoG is shifted 12.2 mm up and 0.9 mm backwards – more closely matching the heads' natural CoG location.

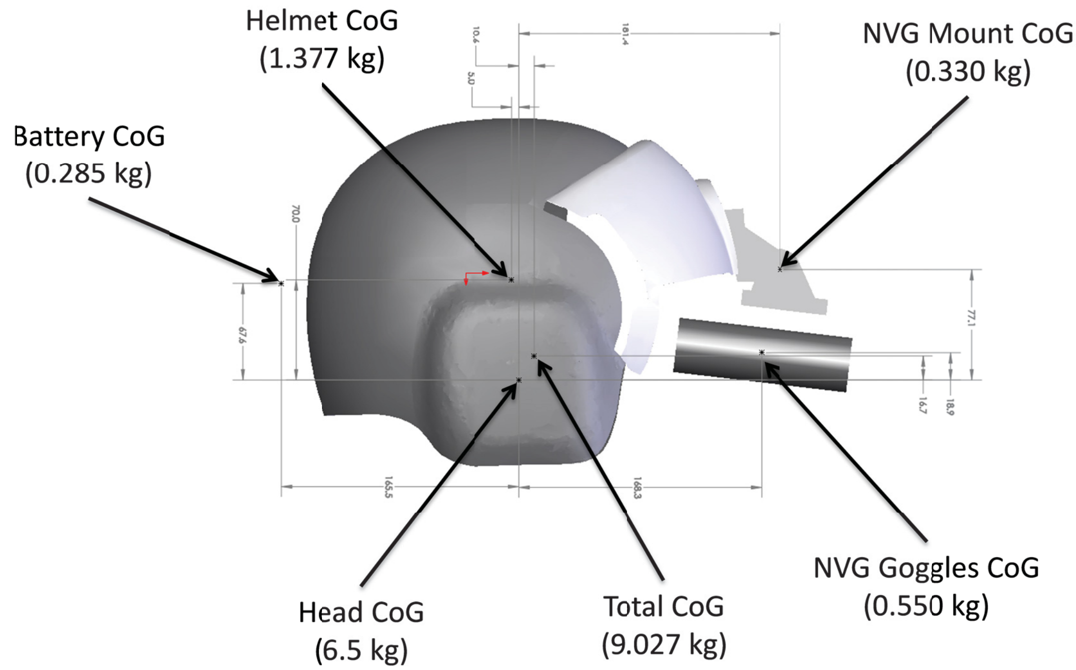

Figure 6 – A schematic illustration to demonstrate the effect of each component on the CoG. With the NVG system, the CoG is anterior to the normal head CoG; however if the NVG system is removed, the CoG shifts back towards the normal head CoG.

When considering motion at the neck, particularly small motions occurring between the base of the skull and the upper cervical spine (atlanto-occipital joint), a 10.6 mm forward shift can have a considerable impact on the muscle activity required to support the mass of the head and helmet system. For example, in an upright posture when wearing the helmet only, the weight of the head and helmet acts downward slightly posteriorly to the centre of rotation of the atlanto-occipital joint (assuming the centre of rotation is in line with the normal CoG of the head). As indicated in Figure 7 (red line), this results in a small moment acting about the atlanto-occipital joint that would need to be balanced by the muscles (likely the splenius capitis and sternocleidomastoid). As the head is flexed forward (simple nodding motions or full leaning forward motions – Figure 8) the moment increases as the CoG of the head/helmet moves further away from the centre of rotation of the atlanto-occipital joint. This increase in moment requires an increase in muscle force to counteract it and maintain head position. As indicated in the literature review (Annex B – Literature Review – Section 5 – Helmets, Masses and Loads) there appears to be a threshold limit value for the magnitude of moment that can be effectively balanced by the musculature for a given duration (indicated as the dotted horizontal line in Figure 7). When wearing only the helmet, it is unlikely that a pilot would ever lean forward enough to reach that threshold. However; once the NVG system is added, the forward shift in the CoG is enough to increase the moment beyond the threshold level even in the upright head position (blue line – Figure 7). This implies that prospective solutions should aim to restore the CoG of the helmet system towards the natural CoG of the head and/or reduce the muscle activity required to balance the moment corresponding to an anteriorly shifted CoG.

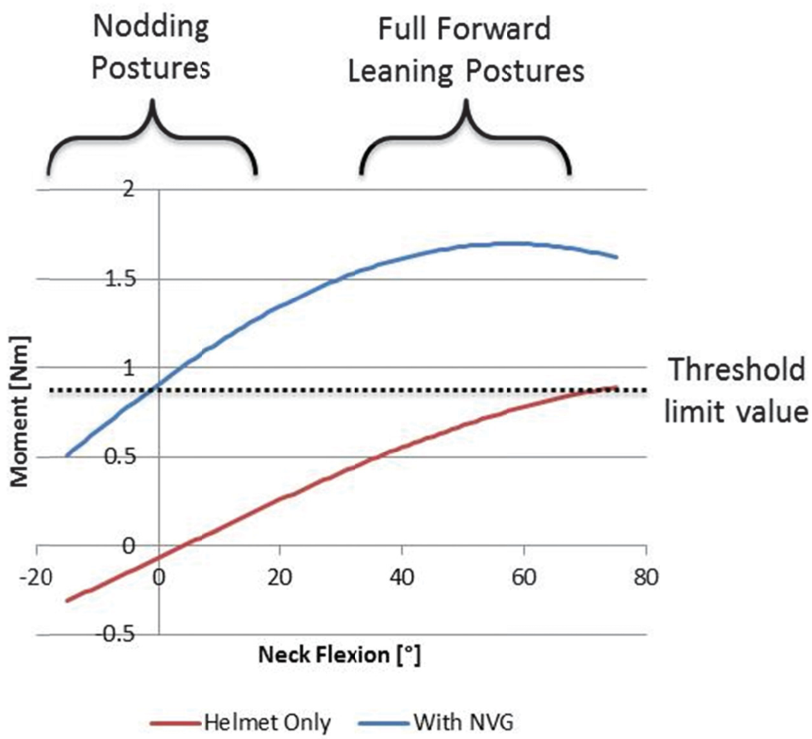

Figure 7- Predicted static moments experienced about the flexion/extension axis of the atlanto-occipital joint as a result of wearing the helmet (red line) and additional NVG system (blue line) as a function of neck posture.
Note: These data were generated based on the anthropometrics of a 50th percentile male.

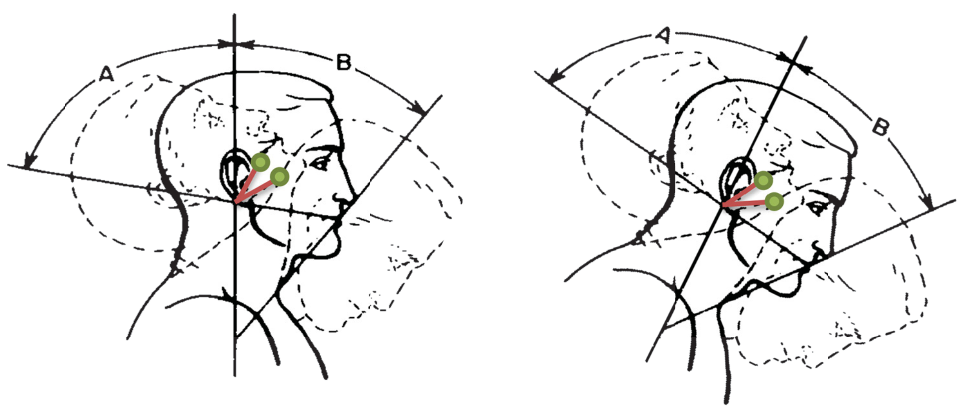

Figure 8 – An illustration of how the centre of gravity of the head moves in relation to the centre of rotation of the atlanto-occipital joint during neck flexion/extension.

2.2.5 Dynamic effects of helmet systems

Adding equipment to the helmet has effects beyond simply adding weight that the neck must support in static postures, the effect of increasing the inertia of the head / helmet deserves some discussion. A simple analysis using lumped spherical mass approximations for the NVGs, the CW/battery and the human head, and a spherical shell for the helmet, allows a rough comparison of the effect on the neck of the individual equipment masses and their positions. The current system with NVGs, batteries and counter weight has almost 4x the resistance to motion in the flexion/extension plane (Table 2) and 6x the resistance in side to side rotation (Table 3) compared to the head.

For the aircrew, the impact of this increase is felt at the starting and stopping points of motion, where the third derivative of motion (known as "jerk") becomes extreme creating very high torque levels that can quickly become unsafe at moderate or high rates of motion.

Table 2 –Flexion/Extension: Inertial effect of increasing helmet mass.

Condition	I ($kg.m^2$)	Normalized
Head alone	0.13	1.0
Head + Helmet	0.34	2.64
Head + Helmet + NVG	0.46	3.62
Head + Helmet + NVG + CW + Bat	0.49	3.85

Table 3- Side to side head rotation: Inertial effect of increasing helmet mass.

Condition	I ($kg.m^2$)	Normalized
Head alone	0.02	1.00
Head + Helmet	0.04	1.77
Head + Helmet +NVG	0.07	3.58
Head + Helmet + NVG +CW + Bat	0.12	5.85

Figure 9 illustrates the effect of this increasing inertia on neck torque for a quick (1 second) fore/aft head rotation visual check by the flight engineer. Solutions presented by the research team are expected to reduce the inertial effect to the level of Case 3: the Helmet + NVG only.

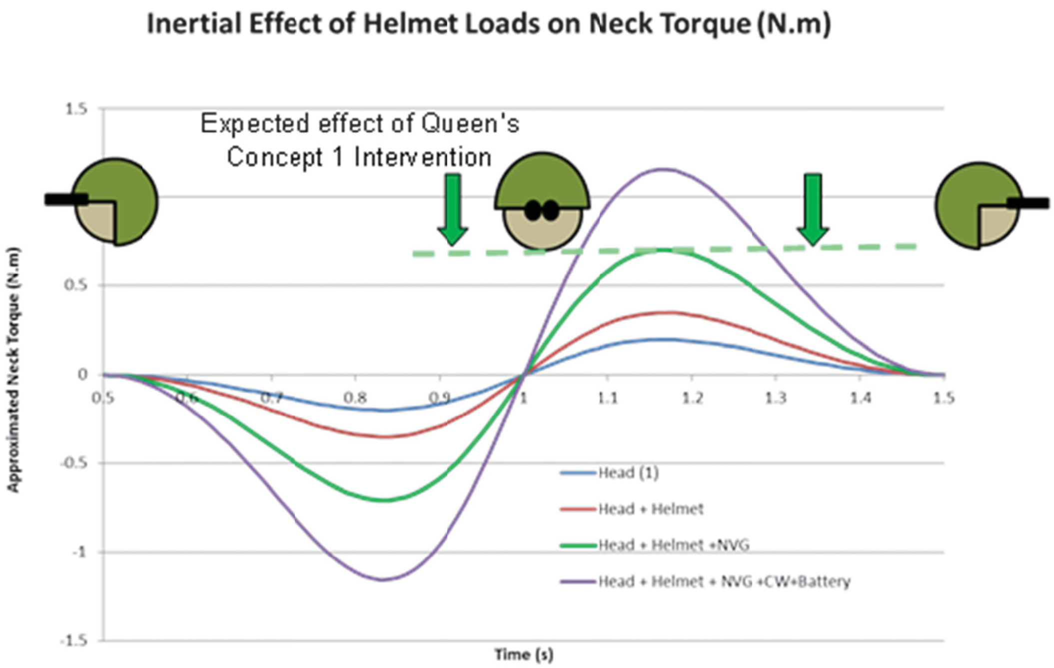

Figure 9 – Increases in moment loading of the neck with the addition of the helmet and current night vision goggles system.
NVG = night vision goggles, CW = counter weight

2.3 Cockpit (pilot)

The design and layout of the cockpit poses several ergonomic challenges and functional deficiencies that are likely to contribute to neck pain among pilots. The most pertinent challenges are the lack of open, unobstructed window space to permit pilots to easily scan the environment around the aircraft (awkward postures are required for viewing), the location of the instrumentation (requiring sustained flexed postures to view), and for the left-seat pilot, the location of the visioning system (required awkward laterally bent and forward flexed neck postures). During site visits, the research team noted that a heads-up display (HUD) was available to display instrumentation information, without the need to look directly at the panel; however, feedback from pilots indicated that this solution still had many limitations (e.g. not all information was displayed, pilots still needed to view the instrument panel). In isolation each of these hazards are likely to increase the risk of developing neck pain; however, the risk would likely increase further with the additional head-borne mass located forward and superiorly to the centre of gravity of the head, exposure to vibration, prolonged missions or a series of missions occurring in a concentrated time span.

Sustained static postures pose a considerable risk to pilots, particularly when supporting the additional mass of the NVGs. During a familiarization flight, the research team noted that the majority of the pilots time was spent in forward looking postures (±30° - see Figure 10); however, pilots noted that this could be considerably different depending on the mission, or when using the MX-15 Visioning System.

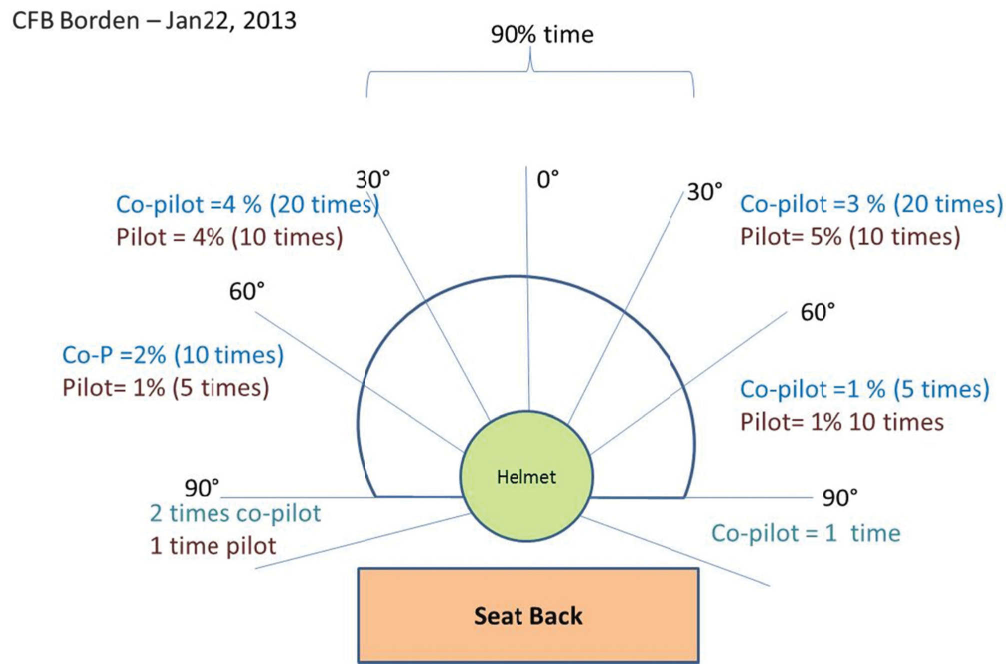

Figure 10 –An illustration of the percent time spent looking in different directions during a familiarization / training flight.

A complete ergonomics assessment of the cockpit area is beyond the scope of work outlined for this project. However, during the site visits and familiarization flight, the research team noted several ergonomic hazards and functional deficiencies. While some of these have been identified in this document; we recommend that a more comprehensive and complete ergonomics analysis be conducted.

2.4 Cabin (flight engineer)

The design and layout of the cabin poses many ergonomic challenges and functional deficiencies that are likely to contribute to neck and back pain in flight engineers. First and foremost, the research team identified the seating conditions as a primary concern. The “rag and tube” seating poses a number of problems, including limited comfort, limited support and a limited ability to reduce vibration transmitted from the aircraft. These concerns are likely to increase the risk of both back and neck pain. When seated on the rag and tube seat, flight engineers are forced into a rounded, slouched posture, promoting a forward flexed head and neck position. In concert with additional head-borne mass (NVGs), vibration, and prolonged exposure, the risk of injury is likely to continue to increase.

A second primary concern was the number and high physical demand of the visual checks that a flight engineer was required to perform. Flight engineers had to adopt a variety of awkward positions to survey the aircraft, cargo and environment around the aircraft. These visual assessments require considerable head and neck movement, occasionally against the resistance of the wind and rotor down draft, further increasing the likelihood of developing neck pain. Again, these risks are heightened with increased head-borne mass, vibration and prolonged exposure. While the ideal solution would be to eliminate the need for visual checks through the use of visual or other ranging capabilities, several small interventions could be introduced to help improve the ability of the flight engineer to brace and support themselves while carrying out these activities.

Again, the research team has not provided a comprehensive evaluation of all the ergonomics hazards present within the cabin environment. We understand that an ergonomic assessment of the flight engineer (within the cabin) was completed at CFB Gagetown in 2001 by Capt. B.T. Wierstra and again we recommend that DRDC consider the recommendations included in that report when considering solutions moving forward.

3 Opportunities for intervention and proposed solutions

This section of the report describes a series of proposed solutions that could be implemented in the near-term to help reduce the prevalence of neck pain among aircrew. Although beyond the scope of this work, it is highly recommended that overarching procurement processes be re-visited to make sure that criteria exist to ensure manufacturers are required to innovate products that not only meet the capability requirements of the Canadian Forces, but also comply with human factors and ergonomic considerations. While documentation suggests that human factors are considered in the design of the helmet to some extent, it is unclear if and how human factors were considered in the design of the night vision goggles systems. A reference to an example of how human factors considerations could be incorporated in the design of NVG systems is provided below. This referenced paper may provide an example of the type of criteria that the Canadian Forces could choose to impose when procuring equipment to provide night vision capability, while ensuring that military personnel can use this equipment without any undue injury risks:

> *Parush, A., Gauthier, M.S., Arseneau, L., Tang, D. 2011. The Human Factors of Night Vision Goggles: Perceptual, cognitive, and physical factors. Reviews of Human Factors and Ergonomics, 7(1):238-279. DOI: 10.1177/1557234X11410392.*

3.1 Helmet, night vision goggles, counter weight

The addition of the NVGs and its subcomponents causes the CoG of the head / helmet system to shift forward, increasing the activation of neck extensor muscles to maintain equilibrium of the head and helmet system. Currently, the combined mass of a battery pack and lead weights mounted on the back surface of the helmet create a gravity induced counter moment. This immediately increases the mass and the inertia of the head borne load. Additionally, when the orientation of the head is no longer orthogonal to gravity, the utility of the counterweight drops to the point where it becomes an additional liability to the user.

The following engineering solutions aim to achieve the following: reduce neck extensor muscle force requirements; reduce the total mass on the head, and reduce the moment of inertia of the head / helmet from the current configuration. Generally, these concepts propose methods of supplying a counterbalancing force without additional mass on the head and with no increase to the helmet inertia.

In addition to efforts to develop a retrofit product that could be introduced quickly to help mitigate neck strain arising from the existing helmet system, the research team advocates that DRDC consider conducting testing on other available helmet systems, such as the TopOwl®.

3.1.1 Engineering innovations

3.1.1.1 Elastomer-based helmet system support (on-body)

Rationale: Currently the combined mass of a battery pack and lead weights mounted on the back of the helmet are used to create a gravity induced counter moment to help reduce the work of neck extensor muscles in balancing the NVGs and helmet system.

The addition of the NVGs causes the CoG of the head / helmet system to shift forward, increasing the activation of the neck extensor muscles to maintain equilibrium of the head and helmet system. To assist the muscles in restoring equilibrium an elastomer-based strap could be attached to the helmet to aid the muscles in providing a counter moment. The amount of aid provided by the elastomer based material could be adjusted and tensioned according to individual preference and comfort.

Solution: To assist these muscles in restoring equilibrium, a secondary set of "extensor muscles' could be artificially provided using an elastomer attached to the helmet. This assistive "muscle" would act at a greater moment arm than the natural muscles so that quite modest levels of force would provide significant counter moments. The mass of the lead weight and the battery should be removed from the helmet. The batteries should be relocated to the torso.

Optimally the force deflection characteristics of the elastic substance would be designed to counter balance the NVG moment across a range of crew head / neck postures. In addition, the frequency and exposure duration requirements for particular crew positions would be used to optimize the development of the elastic force deflection characteristics such that the counter balancing moment induced would closely match the postural demands of a specific crew position.

The amount of counterbalance force provided by the elastomer could be adjusted and tensioned according to individual preference and comfort. Figure 11 illustrates a general embodiment of the Elastomer Balanced Helmet concept worn outside the personal floatation device collar although it may well be possible to have the element run underneath the floatation vest and under a Tactical vest inside an integrated sleeve.

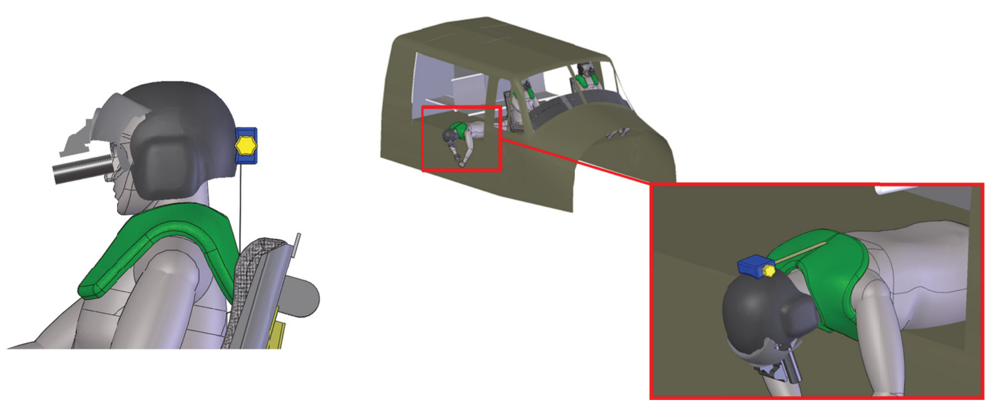

Figure 11 – A CAD representation of on-body elastomer-based helmet system support. This on-body device could be individually tuned for optimal comfort and it can be used by both pilots and flight engineers alike.

Explanation: The goal of this solution is to provide a mechanism to aid the neck extensor muscles in balancing the moment, particularly about the atlanto-occipital joint. To completely off-load the neck muscles, the elastomer-based strap would need to provide approximately 5.5 N of force in the neutral forward-facing posture (Figure 12 – left pane), increasing up to approximately 10.0 N when the head and neck are tilted forward (Figure 12 – right pane).

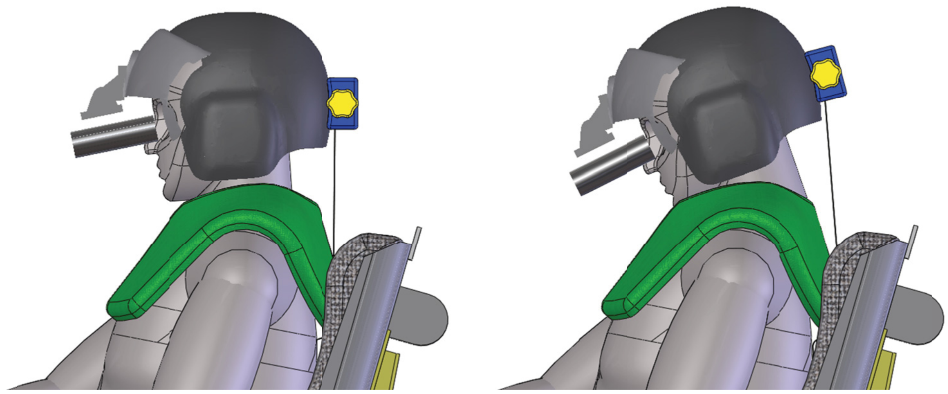

Figure 12- A CAD representation of the elastomer-based helmet system support in a neutral (left pane) and forward tilted (right pane) posture.

This solution has a number of advantages to support the need for further development.

1. Immediately offload the head and neck by the mass of the CW and batteries ~0.9kg, reducing the compressive load on the neck by ~15%.
2. Immediately reduce the inertia of the head / helmet by ~39% (horizontal rotation) and ~6% (forward flexion/extension)
3. Immediately reduce the shear loads on the neck in forward leaning postures by the removal of the CW and batteries, reducing shear by 5 – 9 N (1 – 2 lbs) at 45° and 90° respectively.
4. This intervention could be used by all members of the flight crew as it is an on-body solution.
5. The device is worn on-the-body and requires no modification to the aircraft, and minimal modification to the helmet and flight suit (i.e. Velcro attachment points and sewn-in material tubes)
6. Elastomer materials inherently provide increased force with increased stretch, consistent with the typical situational need for increased force as a function of increasing forward flexed postures. Forces required (5 – 10 N) are within the range of readily available materials.
7. The solution is simple.

There are also some anticipated drawbacks and areas requiring further development:

1. Extremes of motion may generate higher than desired return forces - this would need to be addressed during development and it is expected that this effect could be mitigated sufficiently with further design development.

2. The ability to provide the ideal counter balancing moment through a range of postures is unlikely; however, combination of elastomers with constant force spring elements should improve this.

3. The elastomer may increase the amount of muscle activity required to rotate the head and neck left and right (Figure 13). Considering the limited amount of time that pilots rotated through a full range, this limitation may not be impactful for them.

Figure 13 – A CAD example of a prospective limitation of the elastomer based helmet system support (on-body).

3.1.1.2 Seat mounted cable (off-body)

Rationale: The addition of the NVGs causes the CoG of the head / helmet system to shift forward, increasing the activation of the neck extensor muscles to maintain equilibrium of the head and helmet system. To assist the muscles in restoring equilibrium, a cable could be attached between the back of the seat and the helmet in order to aid the muscles in providing a counter moment. The amount of aid provided by the cable could be self-adjusted or regulated through an active control system (requiring more advanced development).

Solution: The seat mounted cable system could be fixed to the pilots' seat, where the helmet system could then be tethered via a cable (similar to the communications cable tethering) (Figure 14). The retractable cable device would provide active or passive tension to help counteract the forward pitching moment induced with the addition of the NVGs. The position of cable would be free to move (up, down, left right) to help accommodate the need to change its line of action during different postures. The combined ability to modulate force (active control element) and modulate the line of action will allow this solution to provide a more effective counter balancing moment.

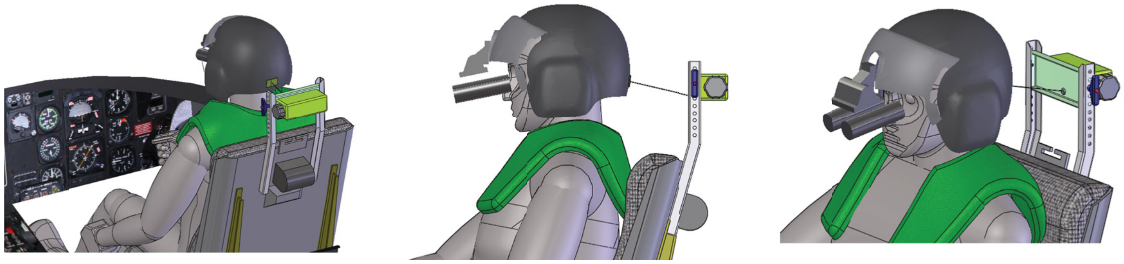

Figure 14- A CAD representation of the Seat mounted cable (off-body) innovation.

Explanation: The goal of this solution is to again provide a mechanism to aid the neck extensor muscles in balancing the moment, particularly about the atlanto-occipital joint. To completely off-load the neck muscles, the cable would need to provide a counter balancing moment of 0.9 N/cm up to nearly 2 N/cm (see Figure 7 – blue line). The flexibility in the design allows the line of action of the cable to be modified to help orient the line of action in a more favourable position. However, unlike the elastomer-based helmet system support, the line of action would not be as vertical, requiring more force (tension) through the cable.

This solution also has a number of “Pro’s” to support the need for further development. The device is highly adjustable in terms of the line of action of the supporting force and in the amount of force support provided (with an active force control element). This is a benefit compared to the elastomer based helmet support system, as the line of action of the cable can be adjusted left and right to reduce the amount of resistance that pilots would need to overcome when looking left and right (i.e. Figure 13). Additionally, this device could be mounted directly into the aircraft (two per helicopter), where an elastomer-based helmet system innovation would be required for each individual aircrew member. On the contrary, this solution requires that the seat mounted cable system by fitted within the aircraft, requiring additional certifications and evaluations to determine flight worthiness. Second, it will not be as beneficial to flight engineers, considering the diversity of their tasks and how often they must move about the cabin area. .

3.1.1.3 Shoulder girdle based helmet systems support (on-body)

Rationale: This solution was developed to help alleviate the muscular demand on the neck muscles in two ways. Similar to the aforementioned innovations, a cable / elastomer based strap is attached between the helmet and the shoulder girdle device to help counterbalance the moment about the atlanto-occipital joint. Second, the girdle device would also act as a neck brace, similar to a Head And Neck Support (HANS) style device used in automobile racing,

Solution: Where the previous solutions have been targeted at reducing the neck extensor muscle demand, this solution adds additional support through the HANS style device brace. This dual benefit would provide an on-body support system to counterbalance forward pitching moments and also help to provide additional structure to support and stabilize the head and neck system (Figure 15).

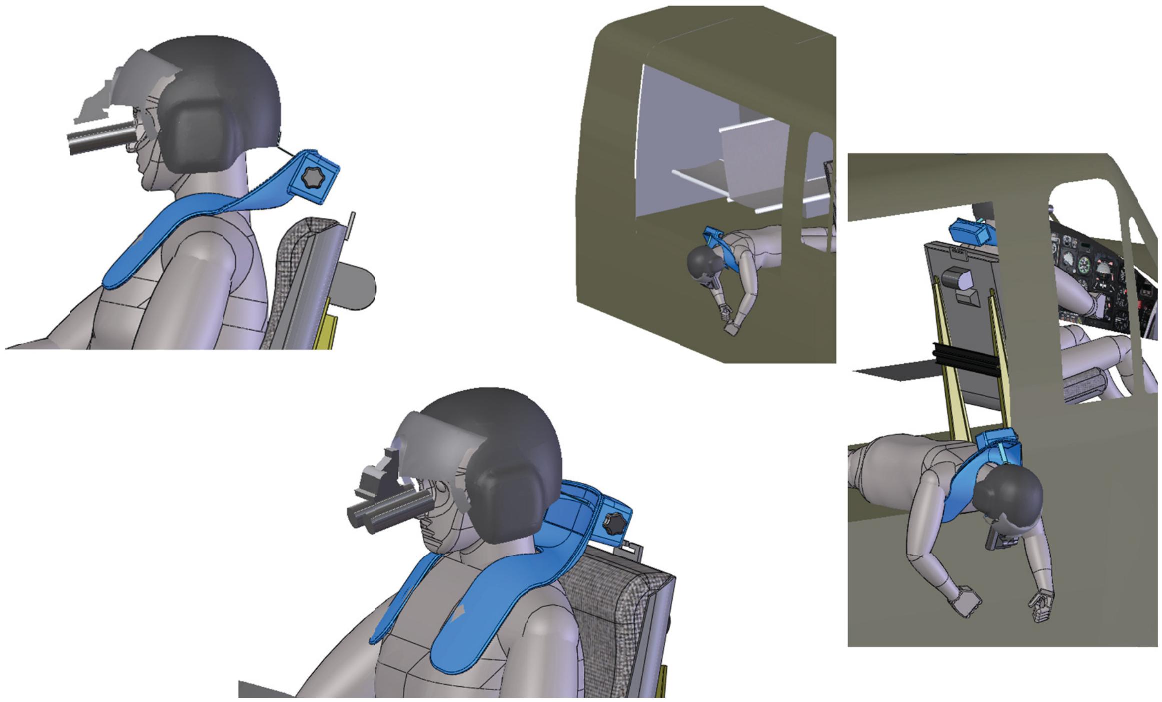

Figure 15- A CAD representation of the Shoulder girdle based helmet system support.
Note: The blue girdle device as illustrated would be designed to be more similar to a traditional HANS style device, commonly used for many other applications where users support a large head-borne mass.

Explanation: The combination counterbalance and neck brace system is appealing for a number of reasons. First the cabling system provides the same benefits as noted for the previous solutions, where the tension in the cable would be determined based on the line of action and the amount of moment to be balanced. The additional neck support would help to reduce the amount of stabilizing force required by the neck muscles, as the device would provide a hard-stop to constrain neck motions. However, this benefit could also pose a limitation, in that the design would need to balance stability and support needs with postural mobility needs.

The key strengths of this design are the dual purposes (reduce muscle demand and stability requirements); the adjustable force level, and the ability for all aircrew to benefit from this solution. Similar to the aforementioned solutions, it may be difficult to always provide the ideal counter balancing force, and left-right axial rotation may be challenging, both due to the increased resistance in the cable and due to the structure of the HANS style support. This limitation would be a key focal point during the design phase if this technology is operationalized. Lastly, the device would need to be integrated into the existing on-body equipment to ensure it did not interfere with clothing or protective equipment such as the LPSV.

3.1.2 Environmental / policy / procedural interventions / simple ergonomic aids

3.1.2.1 Procure a new helmet / NVG system

Rationale: The current design of the combined helmet and NVG system is problematic. The mass of the NVGs and particularly the distribution of mass, relative to the CoG of the head and helmet alone pose primary concerns. While much of this report is focussed on retrofit solutions that can be applied to offset the muscular demands required to support this mass, a new helmet system design could eliminate the problem.

Solution: The TopOwl® (Thales – Aerospace Division, Valence, France) helmet system solution addresses the mass and distribution of mass concerns. The TopOwl® is reportedly designed by pilots, for pilots, as a comfortable solution to provide helmet-mounted sight/display capability for helicopter pilots. The research team did not conduct a thorough analysis of its potential; however, based on the datasheet provided by the manufacturer (http://www.thalesgroup.com/Countries/United_Kingdom/FIA_2012/Documents/TopOwl_Datsheet/), the total head-borne weight is only 2.2 kg (4.85 lbs) in full configuration, and the design allows the mass to be located more centrally, rather than extended out in front of the pilot. The research team highly recommends that this option be considered further.

3.1.2.2 Improve the capacity of the neck system to withstand the head-borne mass

Rationale: Exercise is recognized by the Bone and Joint Decade Task Force on Neck Pain as one of the few solutions that has a positive effect on reducing neck pain among the general population, though it is acknowledged that mechanical demands imposed on the necks of aircraft crew exceed those of the general population. Aircrew identified that the squadron was allotted two physical training sessions per week to exercise, while conducting an additional training session or two, on their own time. While it is clear that in general aircrew are physically fit based on conventional standards, the current exercise regimen is not well structured to progressively improve specific capacities with respect to their work demands. Improving the capacity of the neck system to withstand the rigors of flying while supporting a considerable head-borne mass cannot be addressed by "strengthening" exercises alone; however, several studies have indicated successful exercise prescriptions to address this need (see Annex B - B6 - Benefits of Physical Fitness and Training on Aircrew Work Capacity).

Solution: This solution is two-fold. First, it is recommended that the CF implement the targeted exercise prescriptions as indicated in past research with CF personnel (see reference 75-77 listed in the reference section of Annex B), perhaps together with the self-care strategies proposed subsequently. Second, it is recommended that the location of, and equipment available within exercise spaces be evaluated to ensure that it remains easily accessible and useable. If small exercise areas can be created and equipped within the hangar area (similar to CFB Borden) and clear individualized exercise prescriptions are available (including periodization considerations, modalities, and other key consideration that would be included when developing a targeted program for an "occupational athlete"), then it is likely that aircrew would be more willing to participate in this form of capacity-building solution.

3.1.2.3 Conservative maintenance standards for rotor track balance

Rationale: Following maintenance routines, pilots fly the aircraft and monitor the balance of the rotor track to ensure it complies with the 0.5 inches per second standard. However, pilots indicated that the vibration of the aircraft was reduced if the rotor could be balanced within a tighter range (0.3-0.4 inches per second). While it may not be feasible to achieve a 0.3 inch standard for all helicopters, procedures should require maintenance personnel to achieve the tightest range possible (within reason). Reducing the vibration of the aircraft will directly reduce the vibration transmitted to the pilot, which in turn will reduce the neck muscle activation required to support and stabilize the head (with or without the additional mass of the NVGs).

Solution: Introduce a green-yellow-red graded standard (i.e. 0.3-0.4 inches/sec is ideal, 0.4 -0.5 inches/sec is tolerable, >0.5 inches/sec is not tolerable), for maintenance personnel to adhere to when balancing the rotor.

3.1.2.4 Revised process for workload distribution

Rationale: Not all flights are equal in terms of exposures to ergonomic hazards that may increase the risk of neck troubles. Further, longer duration missions or concentrated periods of frequent missions can dramatically increase the risk of injury, particularly when NVGs are worn. Consistent with the recommendations provided in the Technical Report - DRDC Toronto TR 2004-153 document, it is recommended that procedures be introduced to ensure the workload is balanced in order to limit periods of prolonged, frequent, or intense (with NVGs) exposures.

Solution: The TR 2004-153 document outlines a number of solutions that are reiterated and supplemented here including: restricting NVG flights to less than 2 hours when permissible; increasing the number of instructors to help prevent overexposure to current instructors; revisiting certification policies to limit aircrew in accumulating the majority of their hours in the weeks immediately preceding the deadline; educating aircrew on early symptoms of neck pain, and provide a mechanism to include them in the work load distribution to limit overexposure (respecting individual differences in the ability to withstand and/or recover from the physical demands); consider NVGs usage in work load scheduling (i.e. try to balance several non-NVGs flights with period NVGs flights as permissible); improve the scheduling of training flights to ensure aircrew are consistently exposed to the rigors of flying, opposed to clustering training activities in between long periods of limited flying time.

3.1.2.5 Standardized process individually optimize helmet systems fit

Rationale: The fit of the helmet is an important consideration to ensure the contact between the head and helmet is optimized. A loose helmet or a helmet with “hot spots” of higher pressure can be uncomfortable, and in concert with motion, vibration and the addition of the night vision goggles, can require additional muscle activity to control the head and wobbling helmet mass. Research has demonstrated that an individualized customized fit can reduce reported symptoms of neck pain (Annex B – B5 Helmets, Masses, and Loads).

Solution: Manufacturer guidelines exist to help customize the fit of the helmet. During site visits, aircrew noted that additional steps are taken to ensure a good fit. However, current research has suggested a more refined process that should be considered to ensure a proper, customized fit (see reference 89-90 listed in the reference section of Annex B). A refined process should continue to ensure that the size and inner liner type is correct; however, aircrew should conduct helmet fitting procedures with the NVG system on, where the fit is judged and evaluated during an active real or simulated flight, rather than evaluated based on a limited range of motion check while on firm ground. While we did not have permission to reproduce the diagram provided in the paper by Van den Oord and colleagues (reference 89 listed in the reference section of Annex B) it is recommended that DRDC review this diagram if they choose to develop a standardized process to customize the fit of the helmet (and NVGs) for aircrew.

3.1.2.6 Improved options / opportunities for self-care

Rationale: Many professional and occupational athletes incorporate "active rest" activities (i.e. ice-baths, massage, etc.) and "unloading" phases into periodized training programs. It is believed that such efforts facilitate regenerative and recovery processes in addition to eliciting "super-compensatory" responses to training. Given the considerable demand imposed on the neck region, particularly when supporting the additional mass of the NVGs, it is recommended that self-care opportunities be provided to help improve recovery, immediately post-flight (akin to a "debrief" for the body) and be included along with a targeted exercise program to improve the capacity of the neck system to withstand the head-borne mass.

Solution: The literature is limited regarding the specific modalities that could be introduced to help aircrew recover from extended duration flights or NVGs flights. However, the lack of research in this area should not prohibit the military from experimenting with solutions used by athletes and American military service members (personal communication), including massage, icing, "trigger point" or myofascial release techniques, etc. Many of these activities could be performed with or without a training partner and at low-cost (e.g., with a massage stick [neck and shoulder muscles] or foam roll [thoracic spine mobilization]). Moreover, efforts to coordinate variations in current training loads, intensities, durations, and modalities with time spent wearing helmets could attenuate cumulative mechanical exposures imposed on the neck region. While this solution would require more investigation prior to implementation (i.e., it would ideally be coordinated with existing exercise and flying schedules), similar methods are very common and are believed by athletes and their coaches to expedite recovery and enhance training adaptations. For example, akin to an athlete's training schedule, aircrew could be exposed to higher exercise based training loads, intensities and durations, during non-combat time; however, exercise and training would be tapered down to a minimum during combat time (as NVGs usage and flight time are increased).

3.1.2.7 Neck brace support system

Rationale: During site visits, flight engineers noted that they often leaned their head to the side where it could be supported by the underlying vest structure. Rather than leaning to the side, a simple neck support could be provided, for use by flight engineers during the portion of the flight where they remain seated in the cabin.

Solution: A flexible, adaptable low-profile neck brace can be purchased to provide added support for flight engineers. Indicated in Figure 16, a simple neck brace could be used by flight engineers while they are stationary during flight. This device could then be quickly removed when the flight engineer is required to begin moving about the cabin to carry out their activities.

Figure 16 – An example of a low-profile, simple neck brace that could be provided to flight engineers for use during the static-seated portion of the flight.
Image from: http://shanesneckbrace.com/

3.2 Cockpit (pilot)

3.2.1 Engineering innovations

3.2.1.1 Flexible mount to support the MX-15 Visioning system

Rationale: Beyond the concerns arising from the addition of the NVGs, the postures required to monitor the MX-15 visioning system pose a considerable ergonomic hazard. To alleviate the need to laterally bend and forward flex the neck, a flexible mounting system could be developed to allow the position of the screen to be easily adjusted to encourage more ideal viewing positions.

Solution: Akin to the flexible mounting systems used to support GPS devices in automobiles, or computer terminals within police vehicles, the MX-15 Vision Screen could be detached from the cockpit and mounted on a flexible mount support (Figure 17).

Figure 17 –An example of a flex mount system used to support a HAM radio device.
A similar system could be developed to support the MX-15 Visioning system screen to reduce extreme neck postures for pilots. Image from http://www.fiat500owners.com/forum/35-fiat-500-sound-systems-electronics/6502-ham-radio-amateur-radio-install-my-abarth.html

3.2.2 Environmental / policy / procedural interventions / simple ergonomic aids

A complete ergonomics evaluation was not within the scope of work of this project. As indicated in section 2.3 a comprehensive ergonomic evaluation should be conducted to identify and intervene on ergonomic hazards.

3.3 Cabin (flight engineer)

3.3.1 Engineering innovations

3.3.1.1 Fold up seating

Rationale: Currently, flight engineers are forced to sit on R&T seating, causing them to adopt hazardous postures for the neck and back. From a design standpoint the R&T seating is ideal as it is light and portable, allowing the cabin to be easily reconfigured for various applications. Despite the need for versatility, the seat poses a primary ergonomic challenge for flight engineers or other personnel seated in the cabin area. While seating may not be implicitly connected to neck pain, it was clear that seating was a primary concern for flight engineers and that the current R&T seats required them to adopt forward flexed neck postures.

Solution: A fold-up seating system could be developed to provide the dual benefit of more support for flight engineers, while also allowing the cabin to be easily reconfigured for other purposes (Figure 18). Considering the number of available options on the market, a specific design is not provided here; however, it is recommended that available options in like aircraft be reviewed and a seat selected that will reduce the considerable ergonomics hazards associated with the R&T seating. During the site visits flight engineers indicated that the US Military has already developed and adopted a more ideal seat design to overcome this problem.

Figure 18 – A fold-up seat that could be implemented into the cabin to reduce the ergonomics hazards associated with sitting on the existing R&T seating.

During site visits we learned that the GAU 21 project made seat extenders that fit over top of the current seats (Figure 19). Aircrew felt that this could be a viable short-term solution. However, the aforementioned report is considered controlled goods and was not available to the research team, so no formal recommendation can be made regarding the utility of the current seat insert / extender design.

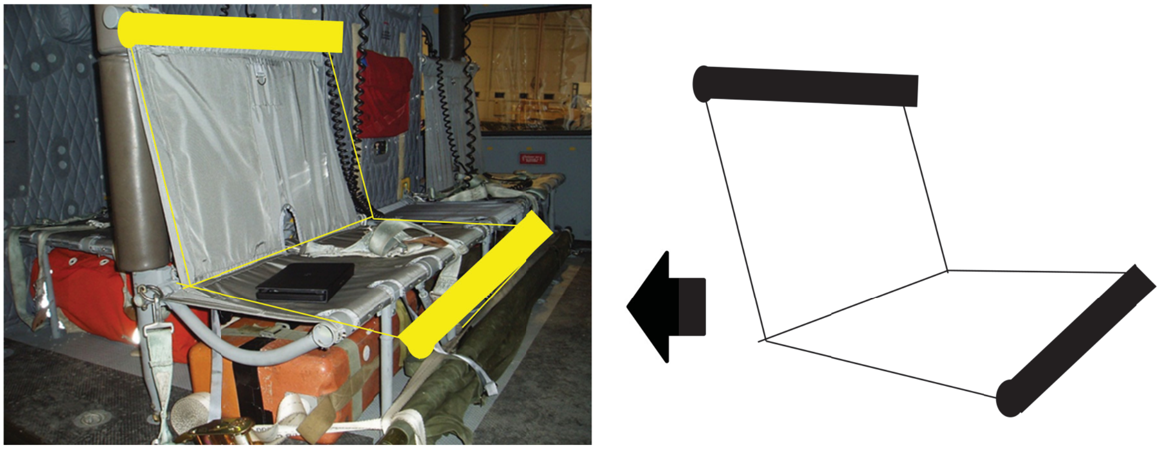

Figure 19 – An example demonstrating how a seat insert / extender could be designed to improve the seated posture for flight engineers.

3.3.1.2 Enhanced visual capability

Rationale: Visual scanning is a primary task performed by the flight engineer. Particularly during landing or specific tactics, the flight engineer will survey the aircraft rotors and skids to ensure there are no restrictions that might compromise the landing / tactical objective. These tasks require the flight engineer to move through a wide range of whole-body and head and neck postures, where the range of motion is increased with the use of NVGs (to overcome the reduced field-of-view). Considering all of the existing technologies available to provide enhanced range detection or visual capability, the research team recommends that capabilities be introduced to allow the flight engineer to monitor the environment around the aircraft, without having to physically move about the space to observe the environment first hand.

Solution: While several capabilities exist to provide enhanced visual capability, a periscope device may be the simplest to introduce. Periscopes have been used for many years within other military equipment, to provide enhanced visual capability. A periscope device could be developed and implemented to reduce the need to have the flight engineer lie on the floor of the cabin, hang out of the door and observe the skids first hand (i.e. Figure 20). Conversely, alternative technologies could be evaluated such as a camera based system or a **Li**ght **D**etection **A**nd **R**anging (LiDAR) system. While this solution likely remains as a more long-term solution, exposure to extreme postural hazards and the need to overcome considerable wind resistance remain as considerable concerns for all flight engineers.

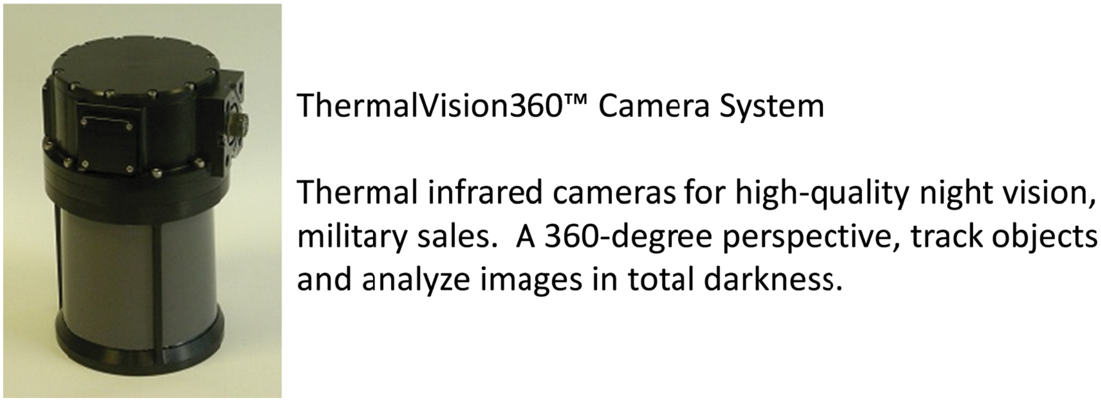

Figure 20 –An example periscope based night vision system that could be introduced to the CH-146 Griffon to reduce the extreme postural demands placed on the flight engineer.

3.3.1.3 Duplicated instrumentation

Rationale: The flight engineer is often asked to support the pilots in monitoring instrumentation, flight coordinates, etc., during in-flight operations. To aid in monitoring instrumentation, the flight engineer must kneel behind the centre console, to view the instrumentation panels positioned in front of each pilot. Not only is this position unsafe, particularly in the event of a sudden manoeuver, but it exposed the flight engineer to a hazardous posture, forcing them to lean and flex forward to view the panels.

Solution: A duplicate of select instrumentation could be displayed in the cabin area (i.e altimeter). By feeding instrument panel information to a screen that could be folded down from the ceiling for example, the flight engineer could provide assistance without being exposed to additional postural demands. Similarly, the provision of a heads-up display as afforded by the TopOwl® for example may also provide an appropriate solution.

3.3.2 Environmental / policy / procedural interventions / simple ergonomic aids

3.3.2.1 Knee padding for flight engineers

Rationale: Flight engineers perform several tasks from their knees (i.e., check instrument panel, slinging, etc.). Because of flight suit zippers, floor tie down points and cargo, FE may be kneeling for extended periods thus causing unnecessary discomfort and pain, and potentially restricting overall body postures.

Solution: Flight engineers will benefit immediately by inserting kneepads into the flight suit. Similar capability already exists for civilian flight suits (i.e. Figure 21). Consider adapting existing Canadian Forces flight suits to allow the ability to insert knee padding, particularly for flight engineers.

Figure 21- Example flight suit with option for slide in knee-pads.
Image from http://www.aviationsurvival.com/Switlik-U-ZIP-IT-Aircrew-Flight-Suit_p_397.html

3.3.2.2 Portable handles

Rationale: Flight engineers perform a range of activities, many that require them to hang or lean out of the aircraft. One of the challenges with leaning or hanging out of the aircraft is the ability to properly grip onto the cabin to help brace the body. The current cabin design does not afford flight engineers many options to adequately grip and brace / support their bodies as they perform their duties.

Solution: A simple removable handle could be easily implemented using existing load rated cargo securement points that would allow flight engineers to position a handle where they need/prefer it most. For example, an air transport certified 12 Jaw Fitting, (Figure 22) is a viable mounting technology. Flight engineers could have access to strong stabilizing handles, which could be easily attached to the aircraft, as needed, to provide additional hand supports. Equipped with additional hand supports, flight engineers would be able to adopt better postures and would also be more stable and secure in the event of a sudden unexpected movement of the aircraft.

Alternatively, a series of loop handles (similar to those used on a city bus) could be added using the Delta ring form of the 12 Jaw Fitting. Added to the helicopter cabin these would provide improved options for the flight engineers to grip and support while conducting their in-flight duties.

Figure 22 –An example of a load certified connecter that flight engineers could use to help them brace and support their bodies in order to adopt better postures.

3.3.2.3 Cabin door stops

Rationale: Throughout a typical flight, the flight engineer will open and close the cabin door several times. Depending on aircraft, the door may be hard to open (rain, worn rubber gaskets, etc.) posing a considerable demand on the flight engineer. Conversely, the door can only be locked in either the closed or 100% open position, requiring flight engineers to control and stabilize the door when their objectives only require it to be partially opened, and particularly when fighting against wind resistance.

Solution: The research team recommends considering a more ideal design including frictionless rollers (or a friction resistance bead of Teflon or the like), and well-positioned door stops. If flight engineers could lock the door in partially opened positions, it would reduce the physical demands on their body (they no longer need to support the door) while also providing a new rigid fixture that they might brace against to support and stabilize their body while conducting in-flight duties.

4 Proposals to develop and evaluate proposed solutions

4.1 Solutions that can be implemented immediately

A number of practical, feasible near-term solutions have been described through this report. The research team agrees that many of these, in addition to recommendations noted in previous reports could be feasibly implemented with limited additional resources being devoted to research and development. For example, based on the informal interviews with flight crew within this squadron, several simple practical solutions (knee pads, portable handles, neck brace, rotor track maintenance standards, etc.) were identified that could have an immediate impact on the health and performance of flight crew. Soliciting feedback from flight crew on possible solutions, or even “custom-made” solutions can yield valuable insights. As such the research team recommends that flight crew be given an opportunity to speak candidly sharing their ideas or home-made innovations in hopes that they might be adopted across all tactical helicopter squadrons. It is likely that this approach will also yield insight about opportunities to advance or revise training protocols.

4.2 Solutions requiring additional development

Developing innovations into a wearable solution requires a deliberate process. The Ergonomics Research Group at Queen’s University applies a process integrating design, biomechanics and human factors considerations (Figure 23).

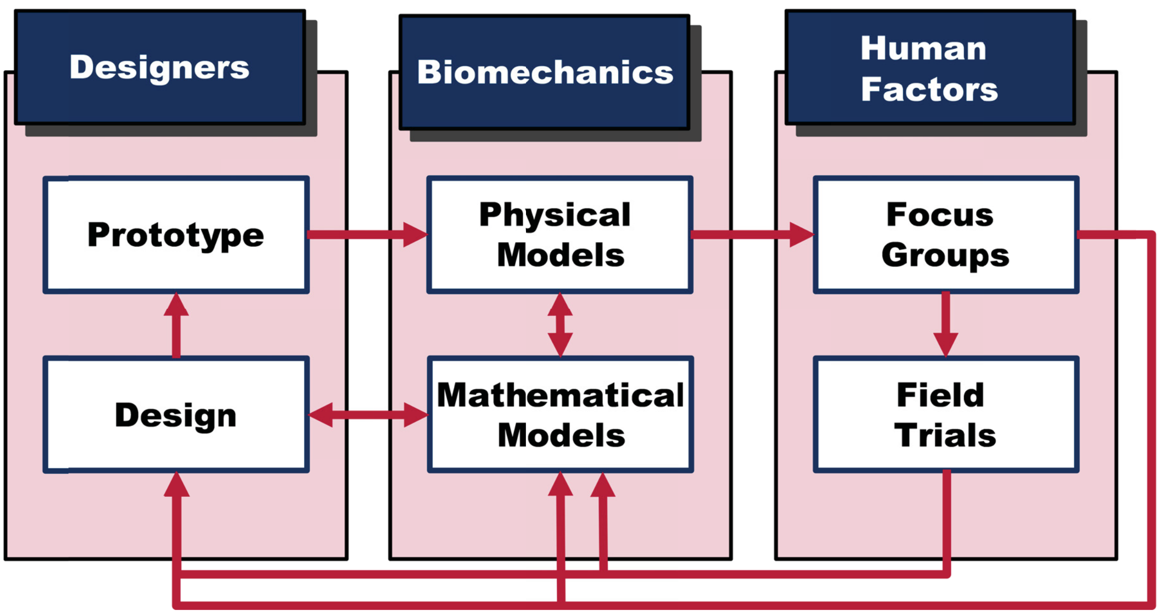

Figure 23 –The Queen’s Ergonomics Research Group model for design-based solution development.

Throughout this report we have begun to develop preliminary prototypes, designs and mathematical models to help demonstrate the feasibility of our proposed solutions. If selected for further development, through this iterative process we would aim to develop physical prototypes and models to investigate the biomechanics and ensure that solutions are providing assistance to reduce muscular demands, and then move to conduct focus groups and field trials to investigate the feasibility, comfort and wear-ability of the innovation as indicated below.

4.3 Technology development roadmap (proposal)

The roadmap shown in Figure 24 identifies our proposed activities to discover, develop and evaluate several design concepts through to the point of proof-of-concept prototype. This process considers all aspects of the product development process including a more detailed survey of commercially available solutions (either stand-alone, or ones which could be part of an integrated solution), development of product and engineering specifications, initial cost and manufacturing evaluation and field testing. Following successfully passing Gate 2, would be Production Development and Production phases.

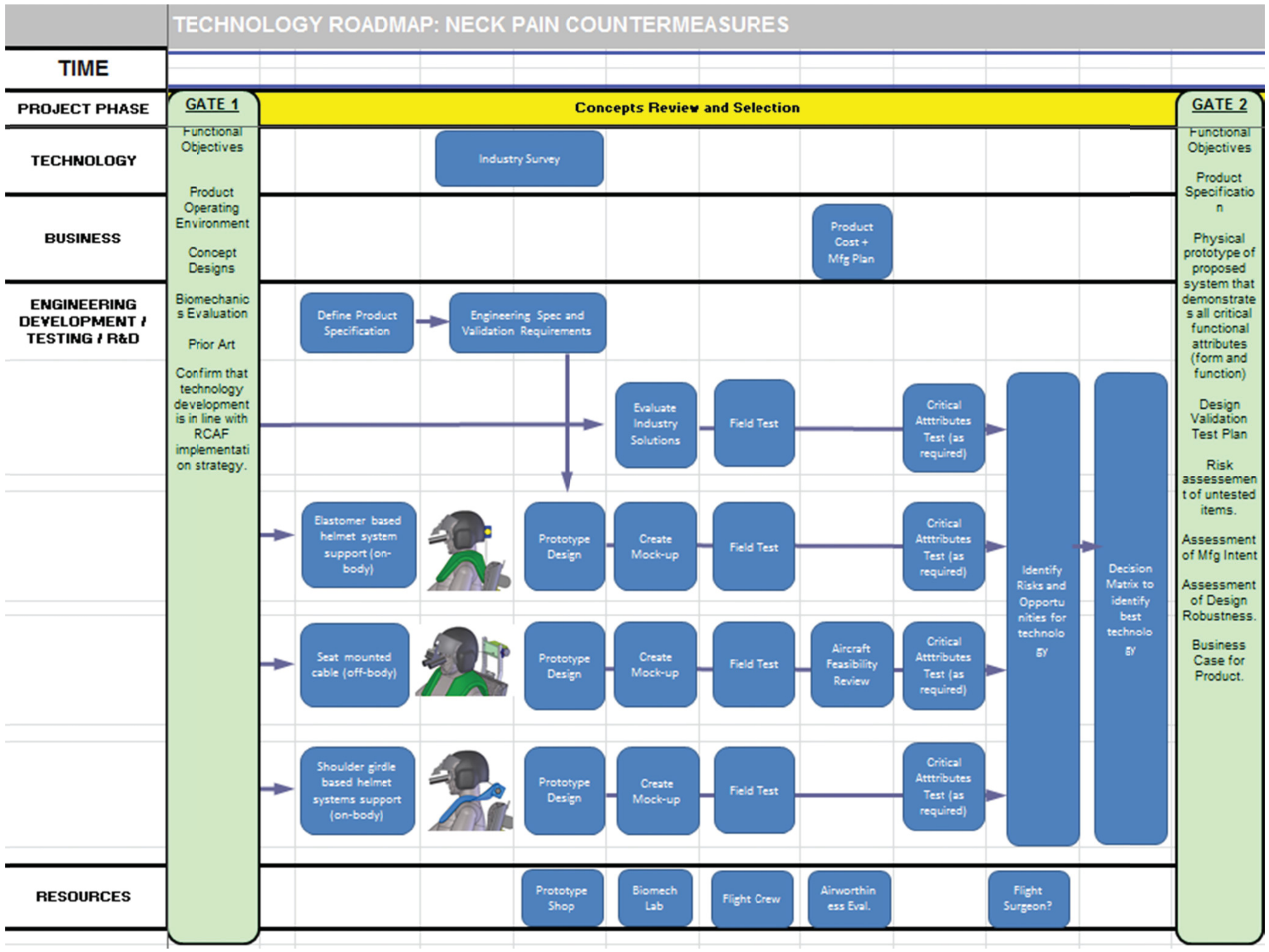

Figure 24- A technology road map indicating the proposed plan to further develop and test proposed solutions.

The starting point for this work is for the development team to work closely with all key stakeholders to understand the operational and any other implementation constraints and requirements. For example, flight-safety, mobility and airworthiness considerations will have to be understood as they pertain to the designs. The outcome will be product and engineering design specifications that will enable objective evaluations of the designs. Subsequently, the various concepts will be engineered, prototyped and tested in a variety of situations to ensure they will provide the necessary benefits to off-load neck muscle demands. Flight crew testing under actual flight conditions would be the ideal outcome.

4.3.1 Cost model

The cost to develop the three design based proposals are summarized in Table 4.

Table 4- Proposed budget to develop and test proposed solutions.

		Concept 1 Elastomer based helmet system support (on-body)		Concept 2 Seat mounted cable (off-body)		Concept 3 Shoulder girdle based solution (on-body)	
		time (wks)	cost	time (wks)	cost	time (wks)	cost
Concepts Review and Selection							
Program Engineering	spec development, prog mgmt, design documentation, admin	3	$ 11,400	3	$ 11,400	3	$ 11,400
Product Design	Engineering	4	$ 15,200	5	$ 19,000	5	$ 19,000
Prototype	Physical part fabrication (qty 2)	2	$ 10,100	2	$ 14,500	2	$ 15,100
Lab Testing	critical attributes	6	$ 22,800	6	$ 22,800	6	$ 22,800
Field Testing	crew testing, simulator test, flight-safety review (?)	6	$ 22,800	6	$ 22,800	6	$ 22,800
In-direct costs	standard 65% rate set by Queen's		$53,495.00		$58,825.00		$59,215.00
Total			$135,795		$149,325		$150,315

5 Concluding remarks

Through this work two things are clear: aircrew suffer from neck pain and the problem is both complex and multifactorial. In consideration of the multitude of factors that can influence whether or not an individual aircrew member may develop neck pain, this report outlines a range of possible interventions ranging from quite simple (knee pads embedded into flight suits) to more long term (enhanced vision systems to monitor helicopter "blind spots"). However, the elephant in the room continues to be the night vision goggles system. The current model used by CH-146 Griffon aircrew provides the night vision capability required, but at a significant cost to the neck health of aircrew. The research team strongly recommends that military aerospace communities unite and then engage with NVG manufactures to require that they innovate new designs that are both lighter and maintain the total head/helmet/NVG systems CoG at the mid-point of the ear canals.

In the interim, this report provides near-term innovations that can be developed to help alleviate the problem rising from the use of NVGs. A simple elastomer balanced helmet system shows promise as a practical, viable near term fix. The benefit could be even greater if this innovation is developed and implemented along with other recommendations aimed at helping aircrew improve their bodies in order to withstand and recover from the demands of flying while wearing NVGs, and procedural modifications to improve the distribution of NVG flying time, or maintenance standards regarding rotor balance.

Lastly, it was clear that this problem has not arisen overnight and several reports, both peer-reviewed research and in internal reports, describe a range of solutions to help alleviate the neck pain problem. Based on our on-site interviews and discussions it seems as though these and other solutions have yet to be implemented. While it is unlikely, that any one solution will completely eliminate the problem, a combination of two, three or more may have a considerable positive impact. However, it is 100% clear that implementing no changes will result in no improvement. As such, the research team strongly recommend feasible near-term solutions be identified and implemented as soon as possible, even if the net benefit from an implemented solution is modest. By applying this Kaizen type approach of continuously improving the neck pain problem, the Canadian Forces can expect to yield a considerable gain.

References

Please refer to Annex B – Section 9 – References for a complete list of all research referenced throughout this report

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Annex A Individual debriefing notes from site visits to CFB Borden

A.1 Notes on design features of Griffon helicopters that may affect solutions

A.1.1 Some design features

1. Griffons used for many tasks, including search and rescue, training and in theatre.
2. Most Griffons has access to power (centre back) that was used for medical equipment. Nowadays, this power source is not accessed very often.
3. Power supplies are 28 V, 26.5 V and 115 V with standard 3-prong plug.
4. Pilots' seats are form-fitted and reasonably-well designed with no arm rests.
5. Pilots' seats have no shock absorbing capability (neither a floor mount nor a vibration damping cushion seat).
6. Flight Engineers' seat is a removable 'tube and rag' seat that is in 3 parts but extends 1.32 m (52") across the back of the cargo area.
7. Flight Engineer has same "tube and rag' seat on side (gun) areas.
8. Cargo area has many attachment points with yellow paint indicating secure attachment points.
9. Cargo area has very few hand holds devices.
10. Doors can open a long way unless held: there are no intermediate stops.
11. Doors sometimes have high frictional resistance.

A.1.2 Design features that may facilitate potential solutions

1. Pilots' seat frames have excellent possibility for attaching framework for an off-body helmet support device.
2. Pilots' area directly overhead has some potential for an off-body helmet support device.
3. Pilots' area door frame area has some potential for an off-body helmet support device.
4. Pilots' head clearance from top of helicopter very small. Need adjustable support system.
5. FE's Rag and Tube (R&T) seat ergonomically unacceptable: however, replacement seat(s) must be safely secured, easily removed, and more comfortable. Good if FE's seat was interchangeable at sides (for gun mount use)
6. Through conversations with aircrew it was noted that other helicopters may have seating designs that could be improvements over the existing R&T seating (i.e., UH1Y has a seat that slides from door to door on rails; Cormorant helicopters have seats that are on rails and swivel)
7. It is possible to access the power source in the cargo area for FE solutions. This could be used for a mounted radar-based digital altimeter to assist FE.
8. The attachment points excellent for more detachable hand holds to help stabilize FE during flight and access the cargo area when loaded or FE wearing full gear.

A.2 Notes on Griffon helicopter personnel

A.2.1 Background information

1. At CFB Gagetown, 4 flight engineers train at one time for 2.5 days which includes 5 training flights.
2. Typical training flights are ~2 hours duration with a minimum of 25 minutes preparation/flight
3. FEs interviewed noted back pain, neck pain and shoulder pain. This was mainly attributed to the T&R seat which caused other postural problems.

4. Currently there is no post-flight "cool down" protocol as would be in place for any athlete exposed to high demands (i.e. the way a pitcher ices their arm, or a basketball player ices their knee, or the way a golfer receives a massage).
5. The squadron has two allotted "physical training" session per week and some participate in additional training. Although there is no clear exercise prescription, most pilots and FEs work out as least twice a week with strengthening and aerobic exercises. Many train using mixed martial arts techniques.

A.2.2 Possible solutions

1. A policy change could be made to implement exercise routines that are better suited to strengthening the appropriate muscles.
2. A policy change could be made to implement an athlete-type cool-down period to allow the muscles to recover better.

A.3 Notes on in-flight operations in the Griffon helicopter

A.3.1 Background information

1. Flight altitudes vary between 50' to 3000' above ground level (a.g.l).
2. Banked turns normally ~ 1.1G to 1.3G at 30° with maximum banked turn at 50°.
3. FEs prepare for landing by opening door ~ ½ mile away when speed is ~60 knot and/or about 300' above the ground.
4. FE's start calling out distances when helicopter is 15-20 ft above ground level (a.g.l.).
5. During theatre conditions, crews wear ~50-60 lbs of kit with majority on the torso. (i.e., helmet, NVG, safety harness, life preserver safety vest, survival kit, pistol and mags, ~10 lbs weighs 50-60 lbs.).
6. During training, the cargo space is normally empty. During missions, cargo space may be full. FE may have to sit on cargo or milk carton.
7. If NVGs are required, pilots' and FE's typically calibrate them but do not put them on until they are in the craft and powering up the engines.
8. The configuration of the aircraft can be different in theatre versus in training as helicopter is armoured (less comfortable) and weapons monitoring screens are added.
9. Most of the work during a typical flight is during take-off, landing and while performing various tactics. Pilots will use the autopilot function during continuous, uninterrupted flight (i.e. consistent airspeed and altitude).
10. When moving through the "transitional zone" transferring from upwards to forwards, there is a considerable vibration through the aircraft as the aerodynamics of the airflow through the blades is altered.
11. There is no "set" policy that states that the left seat is the "pilot" and the right seat is the co-pilot" or vice-versa.

A.4 Notes on basic information about pilots and their tasks

A.4.1 Background information

1. Pilots will move through a considerable range of neck postures to view the environment around them, including looking up, particularly when banking through turns. Movement of the torso is restricted by the harness system.
2. Pilots interviewed noted some neck pain and some back pain. They attributed the pain to a combination of vibration and the NVGs.

3. During night flights, pilots wear a monocle-based Heads-Up-Display system that provides information about the altitude and airspeed of the aircraft. Warning signals about the engine also pop up when necessary. However, details about the engine (causes for the warning) are not provided and the pilot must deliberately view those gauges.
4. The monocle can be placed over the right or left lens of the NVG. Typically pilots will place it over the NON-dominant eye to avoid too much eye strain on the dominant eye.
5. Pilots also have a monocle for daytime flights; however it must be worn only over the right eye.
6. NOTE: The pilot we spoke with mentioned that he will often lift his head up and look under the NVGs to the actual gauges rather than take information from the HUD monocle. His reasoning was that he could never remember the purpose of all numbers on the HUD.
7. On occasion, they will even open the door to view outside of the aircraft to check clearances.
8. Pilots DO NOT spend a lot of time entering in coordinates or way points in the computer, as they are usually pre-programmed and inserted via a hard disk.
9. The computer system in the Griffon for navigation is very old and built around a 486 computer.
10. Flight data entry is often made with the non-dominant hand so that the dominant hand could continue to control the aircraft “almost unconsciously”.
11. Pilots can spend considerable time monitoring a screen (in theatre) for weapon positioning purposes.
12. Some of the more challenging tactics included: slow hovering (less than 40 knots) and NOE (Nape Of the Earth) flying (very low altitude flying).
13. In theatre and combat training, pilots wear up to 60 lbs of kit with the majority on the torso. They do have hand-holds to help lift themselves and their gear into the cockpit.
14. During combat, pilots could be flying up to 7-8 hours in "viscous aggressive flying style" designed to intimidate. Then, the cool-down, debriefing and eating food could be 3 hours with 6 hours of sleep before repeating. This type of routine results in fatigue that exacerbates neck strain, lumbar and thoracic strain and general muscular fatigue.
15. In theatre, pilots start flights at variable times to avoid being targeted. Hence flights start sometimes days, sometimes nights, and even at 3 am. Pilot fatigue and disrupted circadian rhythm occur.
16. Given the considerable inter-pilot variability in pain, various anthropometry, and personal “style” when conducting tactics, it is clear that there is no single solution to mitigate this problem.
17. Pilots report that this helicopter is considered to have poor “human factors” within the aircraft.

A.4.2 Main problems

1. Pilots would consider the helmet with NVGs the main problem followed by vibration.
2. Maintaining static postures for long periods of time caused muscular fatigue.
3. Postures needed to input navigation coordinates is problematic, especially with NVGs.

A.4.3 Possible solutions

1. Reduce the weight of the helmet through counterbalances or off-body support system. Off-body support system would be accepted by pilots unless they were guaranteed they could exit it easily and immediately.
2. Develop a mechanism to control length/tension of helmet impulse tether. This could be designed so that the pilot could set the forward flexion range of motion to the necessary distance thus allowing the neck extensor muscles to relax in this forward leaning position.
3. Reduce the vibration by inserting damping materials under the seat attachment or new seat cushions. This is being evaluated by DTAES with additional consultants.
4. More conservative standards for maintenance, particularly with respect to the clearance for the rotor tracks. While Griffon helicopters are notorious for vibration, the test pilots (pilots that test the aircraft after maintenance) at CFB Borden are adamant that the maintenance crew ensure that the rotor is balanced to about 0.2 - 0.3 inches per second, while the Military Standard is a more

liberal 0.5 inches. He noted that not all helicopters can be maintained to the more conservative standard, the pilots at CFB Borden championed the push to seek a more conservative balance whenever possible.

5. Develop a regime of specific neck strengthening exercises. Results from Salmon et al. (2010) suggest that neck and core strengthening exercises strongly mitigate neck pain in aircrew population.
6. Addition of detachable armrests to reduce shoulder fatigue during long flights. This would allow the pilots to reduce shoulder fatigue by resting elbows on arm rest to alleviate stress.
7. Reduce the mass worn on the head.
   a. Given that the helmets are for crash protection and communications, there are alternate designs using lighter materials that could maintain the overarching objectives while reducing the mass worn on the head.
   b. Determine why the binocular portion of the NVGs must be so heavy (> 1 lb) or why that mass needs to be so far away from the head.
8. Can the Griffon navigation system be upgraded from the old 486 computer so data entry is easier and the controls are in a better location?

A.5 Notes on basic information about flight engineers and their tasks

A.5.1 Background information

1. Flight engineers emerge from the pool of maintenance staff. As such, they are tasked with performing all pre-flight inspections (30-60 minutes in length) and often assist in helicopter maintenance operations to remain current. Remaining time is spent doing paper work and completing tests to maintain credentials.
2. The flight engineer was primarily responsible for most aircraft check clearances during pre-flight and during flights for “12-6” O’clock take-off and landing clearances as well as various other tasks within the aircraft related to mission objectives.
3. Tactics that were perceived as being demanding included: landing in a confined space (particularly, monitoring the skids and the tail rotor); slinging (additionally monitoring a sling being loaded or unloaded from the aircraft while it hovers); “hot refueling” (fueling the aircraft without shutting it off); and slopes (landing on a slope where possible); and, performing cargo checks underneath aircraft before take-off.
4. During toughest tasks, the Flight Engineer felt that his time was spent crouching (25%), kneeling (30%), lying prone (15%) and being ready to move (30%).
5. Flight Engineers normally view landings and take-off from the right side of the helicopter.
6. Flight Engineers moved through a wide range of postures acting as a “camera” to monitor the position of the aircraft relative to the ground and surrounding environment.
7. Many of the FEs reported pain or discomfort mainly due to the R&T seats. Flight engineers at CFB Borden had a tendency to have more pain in the lower back compared to neck.
8. FEs reported working out at least twice a week with strengthening and aerobic exercises. However, there were no specific neck and back strengthening exercises.
9. There is no pre-flight or post-flight routine to warm-up or cool down from flights.

A.5.2 Concern #1: Rag and tube seating

1. Seat design causes back to be rounded and thus no lumbar support.
2. Seat-back tube bar located at upper back thus causing back to be rounded.
3. Seat tube bar places pressure on back of thighs thus applying pressure onto nerves and blood vessels.

4. Rounded back posture forces FE to hyper-extension neck to look straight ahead.
5. Rounded back posture forces FE to rotate in horizontal posture to look sideways.
6. Helmet (with and without NVGs slides) forward because of posture, helmet weight distribution and other clothing.
7. Rag seat stretches over time or when wet. Very uncomfortable.
8. No vibration dampening.
9. Poor distribution of forces.

A.5.3 Possible solutions

1. There was a simple seat extender manufactured and pilot tested on a project called GAU 21 project. It was never implemented.
2. There are better seats in other helicopters (i.e., (a) UH1Y has a good seat that slides from door to door on rails; and (b) Cormorant helicopters which are on rails and swivel).
3. The FE is exposed to a wide range of awkward postures, simply because he/she must monitor clearances. Given all the recent technologies added to cars and trucks to meet this objective, it is possible to develop similar systems to retrofit the helicopter to reduce the current need to manually monitor all landing and take-off clearances.

A.5.4 Concern #2 : Helmet and night vision goggles (NVG)

1. Landing checks cause the following problems when the wind catches the helmet (with NVGs)
   a. High resistive force when wind catches NVG/helmet.
   b. Current style ear cups catch wind and cause buffeting. This causes vibration of helmet with respect to head. This is more of a problem with the new helmets because they are more "square" and allow air pockets in ear wells which causes the helmet to rattle.
   c. Neck muscles must support the full weight of helmet and NVG when clearing under helicopter. Hence adding counter weights only adds to the total neck muscle force requirements.
   d. Head posture is fully flexed and positioned as much as 270^{o} from vertical to check opposite skid, to accomplish this task, the engineer's body can be ⅓ to ½ out of helicopter.
   e. Head posture is fully rotated to see aft (tail rotor) and fore (landscape).
2. Helmet catches Rescue Vest on:
   a. On both ear flaps and add resistance to rotation at neck.
   b. At back of head and adds resistance to extension at neck.
3. Helmet and NVG have off-balance forces because of:
   a. Nature of heavy NVG at front of head.
   b. Rounded back causes clothing to push the helmet forward.
   c. Neck muscles get tired moving helmet with NVG because of high moment of inertia.
4. Vibration and G forces with head in awkward postures:
   a. No dampening in seat cushion.
   b. FEs often do not know when pilots will bank and create other high G forces. This creates a sudden necessity to contract neck muscles when FE is not in a good stable posture.

A.5.5 Possible solutions

a. Find ways to prevent helmet from tipping forward when seated. This could be an on-body or off-body system.
b. Find alternate ways to avoid the need to assume all/some landing check postures (some possibilities are: camera system, telescope system, add radar-based digital altimeter system in cargo area for easier viewing.
c. Improved night vision goggles in terms of profile and weight.

A.5.6 Concern #3: Back doors

1. Doors sticks and are hard to open (i.e., rain, rubber gasket, rollers). Creates difficulty for the shoulders as heavy and/or hard to reach.
2. Must maintain control of door opening at all times. Difficult when wind catches it as it will open all of the way.

A.5.7 Possible solutions

1. Apply friction-resistant bead (Teflon, etc.) between upper gasket and door.
2. Place better frictionless rollers in two centre support locations.
3. Possibly improve frictional factors on lower guide rail as well.
4. Add door stops at logical places so that flight engineers are not required to constantly hold the door.

A.5.8 Concern #4: Need for visual display screen(s) in the cargo area

1. Sometimes difficult to see outside due to seated posture, executing tasks or IFR flying. FEs feel some instruments duplicated in the cargo area would help solve problem, especially a radar altimeter such as the ones used by the pilots in the cockpit.

A.5.9 Possible solutions

1. Investigate the addition of the radar altimeter in the cargo area to assist FEs with landing preparedness. Since there is power in the cargo area, this could be used to charge it.

A.5.10 Concern #5: Difficulty in moving safely around cargo area

1. FEs sometimes trip over cargo or floor grommets because:
   a. They feel stiff and uncomfortable particularly after long periods of inactivity or long flights.
   b. They cannot brace themselves from sudden changes in helicopter directions or flight weather conditions.
2. Additional gear (helmet, NVG, harness, on-flight bag, water, LPSV, ballistic vest) can weigh up to 100lbs. Flight Engineers must pull themselves into the helicopter (~80cm elevation). Although this is an infrequent movement it may cause a strain to the upper extremity.

A.5.11 Possible solutions

1. Add more detachable hand-holds to various locations on the walls and in the ceiling of the helicopter
   - "Loop" handles attached to the ceiling of helicopter interior and/or above door to assist flight engineer in getting in/out of the helicopter and rising from the kneeling/prone positions.

A.5.12 Concern #6. Manning the gun

1. Manning a gun was also a great challenge for FE because they are very exposed to awkward, non-neutral postures (as well as increased stress - which may manifest itself in tightening of neck musculature.

2. Body anthropometric plays a significant factor. The FE with the greatest complaints was also the largest framed individual. They are cramped in the confined quarters of the helicopter, especially in the gun locations and when the helicopter is loaded.

A.5.13 Possible solutions

1. A seat extender or a swivel seat would be best for this location. The short R&T seating does not allow FEs to get into proper shooting position.

A.5.14 Concern #7: Increase the capacity of the aircrew

1. There is no warm-up or cool-down period for Flight Engineers. They immediately perform their helicopter checks and shut downs.
2. All appeared to be in good physical condition, but may not be incorporating proper strengthening of the neck or proper post mission exercises to rehab tired muscles.

A.5.15 Possible solutions

1. If athletes can achieve better performance and sustain less severe injuries, less often when enrolled in carefully designed exercise programs, than why not try the same with pilots. A cleverly designed program could be developed to improve their overall fitness, including neck strength to help them become more robust to handle the added weight of the helmet and to be more adept at managing all the subtle perturbations that occur during flight.
2. Institute a recovery program to help restore capacity more quickly following extended exposures. It seems that much of the pain could be considered “cumulative” in nature so a post-flight program to help restore capacity quicker could help intervene on any vicious cycling that may occur with repeated exposures.

Annex B Night vision goggle-induced neck strain in helicopter aircrew: a review of current literature

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B.1 Introduction

The flight helmet is a vital component of the protective gear used by Canadian Forces (CF) aircrew. The primary design goal is to protect the head from impact during a hard landing or other flight hazards (Butler & Alem, 1997; Brozoski et al., 1998) but it is also being more frequently used as a “mounting platform for numerous combat-essential devices” (Brozoski et al., 1998). With advances in modern technology, the attachment of additional information devices, such as night vision goggles (NVG) or heads-up display (HUD), are becoming frequent to allow pilots to maintain their vision during flights without having to look down or away from the horizon in order to obtain information from their instruments. Additional devices, however, come at the cost of the increased mass and the altered centre of gravity of the helmet (Knight & Barbar, 1994).

NVG–induced neck strain is a concern amongst the helicopter aircrew of many national militaries, including the United Kingdom (Wickes et al., 2005), Sweden (Ang et al., 2005; Thuresson, 2005; Ang and Harsm-Ringdahl, 2006; Ang, 2007), Holland (van den Oord, 2010a, van den Oord et al., 2010b), the United States (Butler, 1992; Fraser et al., 2006; Walters et al., 2012), and Canada (Adam, 2004; Forde, 2009; Harrison, 2009; Salmon, 2009). The rates of injury vary from nation to nation but Canadian investigations demonstrate lifetime rates of injury that approach 90% among experienced aircrew in the CF’s CH-146 Griffon aircrew (Adam, 2004). Most concerning, research has repeatedly suggested that prior injury is an excellent predictor of future injury when it comes to the spinal column of helicopter aircrew (Thomae et al., 1998; Ang & Harms-Ringdahl, 2006).

The estimated point prevalence in the civilian population ranges from 10-20% (Holmstrom, Lindell, & Moritz, 1992) with more recent investigations using adults from Canada and the United States confirming this rate, more precisely, at 15% and 14%, respectively (Côté et al., 2004; Deyo et al., 2006). Côté et al. (1997, 2004) further suggest the lifetime prevalence of neck pain among adult Canadians to be approximately 67%. The prevalence of neck pain amongst helicopter aircrew is consistently described as higher than the general population (Adam, 2004; Ang & Harms-Ringdahl, 2006) but the rates vary amongst militaries from which data are available in the published literature. In Australia, the overall prevalence rate is reported as 29% (Thomae et al., 1998). In Sweden, the 3-month prevalence of reported neck pain is 57%. In the United Kingdom, the prevalence ranges by squadron from 38% to 81% amongst helicopter pilots and airload masters (Wickes et al., 2005) while a recent report from the United States Army reveals 58% of helicopter aircrew report neck pain related to flying (Walters et al., 2012). The lifetime prevalence of neck pain in CF helicopter pilots and flight engineers operating the CH-146 Griffon helicopter is reported in the range of 81-84% and exceeds 90% amongst a subset of the population that have logged more than 150hrs of NVG-flight hours during their career (Adam, 2004).

While the issue of cervical pain may be a more recent concern and the primary focus of this review, the issue of spinal column injuries and discomfort in helicopter aircrew should not be omitted from this document. Lower back pain (LBP) is among the most common occupational health problems (Waddell & Burton, 2001) and prevalence of LBP in the Canadian and American adult population is 18% (Cassidy et al., 2005) and 26%, respectively (Deyo et al., 2006). LBP is a well-documented issue in helicopter pilots with a lifetime prevalence of 61-80% worldwide (Thomae et al., 1998; Bridger et al., 2002; Sargent & Bachmann, 2006; Grossman et al., 2012). Findings from an epidemiological review of occupational LBP report helicopter pilots have the highest rates of LBP among occupations requiring a seated position for more than half of the workday (Lis et al., 2007). Survey data from United States Navy helicopter pilots by Phillips (2011) indicate that 88% of pilots report experiencing LPB during at least half of their flights and 34% of these pilots admit that their LBP negatively affects their situational awareness. LBP continues to be more prevalent than neck pain amongst helicopter aircrew (Walters et al., 2012) but logic and this review will suggest these injuries are more likely related rather than exclusive.

When the spinal column is considered as a whole, helicopter aircrew are at increased risk for chronic injuries of the spinal column related to the specifics of their working environment. This review of literature will focus on these specifics as they pertain to neck injuries but will discuss the related elements of the back pain epidemic that is well documented in this population. The reasoning for this is multi-fold:

1) The spinal column acts in concert to support the weight of the head in a caudal direction; mass on the head is supported by the cervical spine, which is in turn supported by the thoracic spine, which is further supported by the lumbar and sacral spine as the load is ultimately supported by the pelvic girdle.

2) The posture required to perform occupational duties is one of the most commonly discussed factors in investigations of back and neck injuries in this population.

3) The vibration associated with the working environment, also commonly cited as a stressor, is transmitted and augmented in a rostral direction as found by multiple teams of researchers.

This review will briefly discuss the anatomy of the spinal column, specific hypotheses related to neck injuries, the differences between flying in the day and night environment from an ergonomic perspective, specifics related to the helmet loads and masses currently employed by helicopter aircrew, and the benefits offered by physical training to optimize fitness and increase the physiologic work capacity.

B.2 Spinal anatomy

The spinal column consists of 26 bones that articulate in more than 30 joints to form a curved and flexible structure that is supported and moved by more than 20 pairs of muscles (Marieb, 1998; Coakwell et al., 2004; Ang et al., 2005). This structure serves multiple purposes including protection for the spinal cord, support for the axial skeleton, the transfer of the load of the trunk to the lower limbs, articulation sites for the ribs, attachments for muscles of the rib cage, the back and the shoulders, and, perhaps most importantly, support for the skull. The head support allows the body's command and control center, the brain, to observe its environment and the use of NVG enhances this functional requirement under low-light conditions.

The cervical spine is composed of seven bones, the smallest and most delicate of the spinal column, providing attachment sites for the muscles of the lower jaw and the neck (Marieb, 1998). The structure of the bones of the cervical spine and the locations of the muscles associated with the cervical spine allow for the significant amount of head movement of which the human body is capable – flexion, extension, rotation, and combinations of flexion or extension with rotation. However, it is this delicacy in the design that makes the cervical spine a fragile region when large forces are applied instantaneously (i.e. as a result of sudden impact in a motor vehicle accident or contact sports) or over an extended period of time (i.e. cumulative loading as seen in normal NVG flight over an aircrew member's career).

Studies have evaluated objective image findings of degenerative symptoms caused by repeated cervical and lumbar spine loading amongst pilots. Radiological evaluations report increased osteophytic spurring and arthrosis deformans in the cervical spine of helicopter pilots (Hendriksen & Holewijn, 1999). Aydog et al.(2004) report helicopter pilots to be the most likely to have cervical spondylarthritic or spondylitic changes on radiographs, suggestive of osteoarthritis, as compared to their fixed wing colleagues who fly either transport or fast-jet. In the same study, no differences were observed between aircraft type and prevalence of degenerative changes in the lumbar spine. Landau et al.(2006) used magnetic resonance imaging (MRI) to assess the prevalence of lumbar and cervical degenerative changes in three sub-populations of pilots (fighter pilots, transport pilots, and helicopter pilots) who did not have a history of significant neck or back trauma. Cervical disc degeneration was found in 50% of the helicopter pilots, most commonly in the C5-C6 and C6-C7 joints. As compared to the sample of transport pilots, the helicopter pilot sample had a greater degree of spinal column disease despite being, on average, 8 years younger (Landau et al., 2006). Alternatively, flight trainees were found to have increased bone mineral density of the cervical spine as compared to age-matched civilians (Naumann et al., 2004). Caution should be used when interpreting these results as MRI findings are poorly associated with severity of back and neck pain symptoms in the general population (Videman et al., 2003) and, for the purpose of this review, that caveat will shift the focus back to neuromuscular causes and solutions of neck pain amongst the helicopter community.

Estimates suggest the maximum tolerance for single exposure to compressive forces without risk of injury is 2414 N for individuals 20 to 40 years of age and 1738 N for individuals over the age of 40 (Hidalgo et al., 1992). While normal military helicopter flight will not exceed those values, the same study estimates that prolonged loads should not exceed 1% of an individual's maximal voluntary contraction (MVC). However, simply the helmet alone in neutral posture can result in an 18-28% increase in muscular activity in the neck as assessed with EMG prior to the addition of NVG or exposure to +Gz forces (Sovelius et al., 2008). The difficulty with interpreting these values as they relate to helicopter aircrew is the complexity of the job and the mobility it demands. Helicopter aircrew do not maintain a static neutral position while in flight and, as demonstrated mathematically by Hidalgo et al.(1992), small changes in cervical posture can result in large increases in the forces placed upon the ligaments, bone, intervertebral discs, and muscles. Forde et al.(2011) demonstrate the increased cumulative load to be more pronounced over the duration of a simulated mission when the neck must support an NVG-equipped flight helmet as compared to the helmet alone.

B.3 Neck pain definitions & injury hypotheses

A common definition of neck pain is difficult to locate in the scientific literature. When the pain is muscular in nature, the term neck myalgia is often used. Further to this, neck myalgia is a component of the category of injuries referred to as upper extremity muscle disorders (UEMD) (Lupajärvi et al., 1979; Viikari-Juntura, 1983). Visser and Dieën's (2006) definition UEMD as "disorders of muscle tissue proper, excluding tendon disorders and disorders of the tendinous insertions" with injuries characterized by subjective symptoms such as sensation of constant muscle fatigue, muscle stiffness, and radiating pain may be too limiting due to its exclusion of tendinous injuries. Further difficulties in defining neck pain consistently relates to the mechanism of injury; the forces and duration of application of these forces can vary greatly between injuries and high impulse load injuries (e.g. what is often seen in fast-jet aircrew exposed to >+4 Gz) are difficult to compare to cumulative loading injuries (e.g. helicopter aircrew exposed to low +Gz and helmets with increased mass).

Most neck pain research indicates that pain and dysfunction are multifactorial. External psychosocial factors, physical loading factors, and the psychological and biological characteristics of the individual are important (Bronfort et al., 2001; Oldervoll et al., 2001; Ylinen et al., 2003; Nikander et al., 2006; Ylinen et al., 2006) in addition to other factors such as muscle degeneration and/or impaired neuromuscular function resulting from chronic overuse (Conley et al., 1997a; Conley et al., 2007b). Posture, low +Gz forces while using NVG, vibration while using NVG, and the overall weight and weight distribution of the helmet are reported as perceived causes of neck pain amongst aircrew (Wickes et al., 2005; van den Oord et al., 2010b; van den Oord et al., 2012a). Two studies have suggested a link between sex and neck pain, with a decreased tolerance of certain helmet mounted loads, particularly aft-loaded helmets such as the case would be with the use of NVG with a counterweight (NVGcw), amongst female aircrew (Barazanji & Alem, 2000), and an increased incidence of neck pain as compared to their male colleagues (van den Oord et al., 2010b). Other studies have not supported this finding but cannot refute them due to a male predominance amongst research participants (Harrison et al., 2011).

With a poor correlation between radiographic findings and neck pain, applicable theories should focus on the soft tissue of the cervical region. Panjabi (2006) presents a clear and logical multifactorial hypothesis for neck and back pain that incorporates the soft tissue structures. The proposed mechanism is cumulative microtrauma to the ligamentous structures of the cervical spine as a result of an extended period of submaximal loading. The microtrauma results in minor injuries and ruptures of the ligaments of the cervical spine that results in impaired muscle function, including "muscle coordination and individual muscle force characteristics, i.e. onset, magnitude, and shut-off" (Panjabi, 2006). Other proposed mechanisms for injury in the literature include the "Cinderella hypothesis" (Hagg, 1991; Sjoogaard et al., 2000; Knardahl, 2002; Thorn, 2005) or the "nitric oxide/oxygen ratio" hypothesis (Eriksen, 2004). These similar hypotheses propose that sustained submaximal muscular contractions, particularly in the trapezius muscles, result in occlusion of capillaries and arterioles within the muscle. The occlusion severity is more pronounced as a result of physiological vasoconstriction in the setting of stress (including sustained periods of mental alertness) or as a result of head-forward posture (Eriksen, 2004; Thorn, 2005). As will be presented in a later section, decreased muscular perfusion and oxygenation also occurs as a result of whole body vibration (WBV) (Maikala and Bhambhani, 2004). Oxygen delivery and aerobic respiration at the cellular level is not possible in the heterogeneously occluded regions of the muscle. Such an occurrence is measurable through a shift in the red-ox state of cytochrome-c oxidase (CtOx), the final enzyme in the electron transport chain. Eriksen (2004) states, with respect to the ischemic factors that can contribute to neck pain, that the "most effective non-pharmocological measure may be to reduce exposure to prolonged head-down neck flexions and psychosocial stress at work".

Specific to CF helicopter aircrew, individual articles stemming from recent dissertation documents strongly suggest a significant muscular component to the cervical injuries associated with NVG-use (Forde, 2009; Harrison, 2009; Salmon, 2009). Using near infrared spectroscopy (NIRS), muscle perfusion to the trapezius muscles increased during simulated NVG missions as compared to day missions (Harrison et al., 2007a) that occurred regardless of cockpit seat side (Harrison et al., 2007c). While this may seem to contradict the "nitric oxide/oxygen ratio" hypothesis, Eriksen (2004) states that even small regions of occlusion, perhaps not appreciable by NIRS evaluation, may be sufficient to cause frequent exacerbations of neck pain. In support of the hypotheses identifying heterogeneous occlusion and hypoxia as a cause of myalgia, an acute decrease in the concentration of CtOx was observed during simulated NVG missions while an increase was observed to occur during day missions. Forde et al.(2011) found an increase in time spent in a flexion or head-down posture during simulated NVG missions as compared to day missions. To further support the muscular component of neck strain, Salmon et al.(2011a) reported increased cervical muscle strength and endurance as a result of a 12-week training program with decreased self-reports of pain. The benefits offered by physical training will be discussed in greater detail in a later section.

B.4 Day and night working environments

The working environment of helicopter aircrew has been the subject of much scrutiny due to the long-documented issue of LBP amongst this population (Froom et al., 1986; Froom et al., 1987; Thomae et al., 1998; Hansen and Wagstaff, 2001; Orsello et al., 2013). Posture, pilot height and vibration are the most often cited concerns for increased risk of low back pain. A helicopter pilot's posture has been linked to physiological findings of increased spinal muscle activity or fatigue during simulated flight (Pope et al., 1986) and during flight (Lopez-Lopez et al., 2001). The in-flight spinal posture of helicopter pilots has been described as being hunched and twisted due to the location of particular flight controls (Lopez-Lopez et al., 2001; de Oliviera and Nadal, 2004; Pelham et al., 2005). Specifically, this posture allows the pilot to operate the collective control, responsible for the pitch of the rotor blades, which is located to the left and below the pilot's seat.

For military aircrew, flight-related neck pain is multi-faceted in the causal factors specifically related to their job performance. Previous studies have identified increased G-force exposure, accumulated flying hours, head position, vibration, body posture, airframe and cockpit ergonomics, and head supported device use as the most common causative factors while overall physical fitness is described as protective (Adam, 2004; Wickes et al., 2005; Pelham et al., 2005; Ang & Harms-Ringdahl, 2006; van den Oord et al., 2010b). Perhaps most concerning given a large proportion of pilots and aircrew report neck pain at some point during their careers, prior episodes of neck pain are cited as a risk factor for and predictor of subsequent neck pain (Ang & Harms-Ringdahl, 2006). All of these factors are similar to the factors associated with low back pain amongst helicopter pilots (Thomae et al., 1998).

The majority of the available literature related to neck pain has focused primarily on fast-jet aircrew (Hamalainen & Vanaranta, 1992; Hamalainen, 1993; Hamalainen et al., 1994; Oksa et al., 1996) with a more recent shift towards the inclusion of helicopter aircrew (Thuresson, 2005; Forde, 2009; Harrison, 2009; Salmon, 2009). Substantial differences exist between the working environments of fast-jet and helicopter aircrew and these differences influence both the mechanism of injury and the subsequent methods of mitigation. Fast-jet operations may expose aircrew to forces between +4.0Gz and +7.0Gz while helicopter aircrew rarely exceed +2.0Gz (Hamalainen & Vanaranta, 1992; Oksa et al., 1996; Weirstra, 2001). The helmets of fast-jet aircrew range in mass from 1.31kg – 2.15kg (Hamalainen, 1993; Hamalainen et al., 1994) while a CF helicopter flight helmet, when equipped with NVGcw, may have a mass of 3.7kg (Weirstra, 2001). In fast-jet aircrew, the mean muscular strain, as indicated by percentage of a maximal voluntary contraction (MVC), has been reported to fall between 5-20% MVC during most missions (Oksa et al., 1996). Under high +Gz exposure, the muscular strain of cervical neck flexors reportedly ranges from 40-80% of MVC, with the highest recorded value of in-flight MVC being 257% (Green & Brown, 2004; Oksa et al., 1996). Hamalaien (1993) suggests the mass of the helmet alone accounts for a load that is comparable to 15% MVC during high +Gz maneuvers. In helicopter pilots, the weight of the helmet alone can cause an 18% and 28% increase in muscular activity in the sternocleidomastoid and cervical erector spinae muscles, respectively, as compared to resting conditions; with NVG, this increase becomes 29% and 34% for the sternocleidomastoid and cervical erector spinae, respectively (Sovelius et al., 2008). Fast-jet aircrew can often identify the moment at which their injury occurred. For helicopter aircrew, the injury is often more insidious as a result of chronic exposure to forces countered by submaximal muscular contractions.

Experienced helicopter aircrew report posture, low +Gz forces while using NVG, vibration while using NVG, and the overall weight and weight distribution of the helmet as their perceived causes of neck pain (Wickes et al., 2005; Van den Oord et al., 2012a). Specific to the CF, only 2 variables are required to accurately predict risk of neck pain – the height of the crewmember and the length in hours of their longest NVG mission (Harrison et al., 2012). This is consistent with a recent U.S. Army study in which aircrew members at anthropometric extremes for body mass, neck circumference, leg length and height were at an increased risk of both back and neck pain (Walters et al., 2012). To further support the argument that a link exists between low back and neck pain in this population, height was recently identified as the most important predictor of back pain among United States Navy helicopter aircrew (Orsello et al., 2013).

Research using CF helicopter pilots in a flight simulator documented the effects of additional mass in the form of NVG on the metabolic activity, assessed by NIRS, in the trapezius muscles (Harrison et al., 2007a) as compared to non-NVG training missions. The increased metabolic activity continued to increase for the duration of the simulated mission without an obvious plateau (Harrison et al., 2007a) and was observed to be independent of cockpit seat, (i.e. left seat vs right seat) (Harrison et al., 2007c). While NVGcw did provide metabolic relief to the trapezius muscles (Harrison et al., 2007b), more recent work suggests the smaller neck muscles, such as the sternocleidomastoid and splenius capitis, may experience increased muscular activity, as assessed by electromyography (EMG), in a laboratory setting with dynamic postures designed to simulate in-flight tasks with NVG and NVGcw (Harrison et al., In Press (a)).

In addition to the increased muscular activity as a result of the increased helmet mass, NVG do have another limitation. While they do provide optical clarity during low-light conditions that the naked eye cannot, they do so through a much smaller field of view. Normally, the human eyes provide a field of view of approximately 2000 horizontally and 1350 vertically (Werner, 1991). NVG can reduce that field of view significantly to approximately 400 both horizontally and vertically (Craig et al., 1997; Geiselman and Craig, 1999). As a result, the aircrew member cannot rely on peripheral vision at night the same as they can during the day. They must move their head and neck more in order to bring objects of interest directly into this limited field of view. For pilots assuming neck flexion, extension, and rotational postures, the C7/T1 joint serves as the point of rotation for moment calculation using the head's center of gravity. The additional anterior mass of the NVG shifts the centre of gravity forward and up, thus increasing the distance of the perpendicular moment arm while also requiring an increased muscular force to compensate for its weight (Sovelius et al., 2008). Forde et al.(2011) demonstrated that this resulted in increased mobility and changes in posture that, when combined with the increased mass of the helmet with NVG or NVGcw, resulted in increased moments, peak loads, cumulative loads, and shear forces as compared to simulated day missions.

Another constant in the environment of helicopter aircrew is vibration, with one source describing helicopters as "thousands of parts vibrating in close formation" (Young, 1982). In the case of helicopter flight, the vibration is a result of the main rotors and while it can be increased operationally (flight speed, in-flight maneuvers, environmental conditions, and altitude), it can only be decreased by careful aircraft and seat design (Hart, 1988). Whole body vibration (WBV) is vibration transmitted throughout the entire body, often experienced through the seat of moving vehicles (Maikala & Bhambhani, 2004) and is linked to performance decrements such as fatigue, and to medical problems such as chronic pain, degenerative disease in the spinal column (Hart, 1988). A critical survey of WBV literature using a large population of subjects indicate WBV is linked to increased health risk of the spine and the peripheral nervous system (Seidel & Heide, 1986). Similar to the previous presented hypotheses linking low-level muscular contractions of the trapezius during head-forward posture and decreased muscle perfusion (Eriksen, 2004; Thorn, 2005), Maikala & Bhambhani (2004) report WBV can cause acute changes in blood volume, perfusion, and oxygenation in a working muscle; the same authors also report that 4.5 – 5.5Hz is the frequency range at which the maximum WBV energy transfer to the human spine occurs.

Currently, the unmodified helicopter cockpit seat only suppresses 6 -15% of vibration transmission (Hiemenz et al., 2008). Recent work in a helicopter and seat identical to what is employed by the CF's tactical helicopter squadrons indicates this range to be one of the principal harmonics of the aircraft's vibration spectrum (Chen et al., 2007; Chen et al., 2009). As a result, the magnitude of vibration experienced by pilots at the head and neck is roughly double that of the magnitude of vibration experienced at the lower back (Chen et al., 2007; Chen et al., 2009). This correlates with earlier findings that posture and helmet load positively influences seat-to-head vibration transmissibility and muscle activity (Thuresson, 2005a).

Therefore it would seem reasonable to hypothesize the vibration profile of the CH-146 in the setting of an unbalanced helmet load such as with NVG could be synergistic in their contribution to the rates of neck pain reported by the CF's helicopter aircrew. Indeed, Salmon et al.(2011b) did suggest that propagation of vibration along the spine is a significant factor related to neck dysfunction. Efforts to reduce WBV may offer benefit in reducing and preventing lumbar and cervical pain. Chen et al.(2009) report an adaptive seat cushion prototype effectively suppressed vibration in the range of approximately 5Hz while the use of magneto-rheological seat suspension system suppressed vertical vibration transmission by 76% on a 50th percentile male helicopter pilot (Hiemenz et al., 2008).

B.5 Helmets, masses, and loads

Typical flight helmets weigh approximately 1.5kg (Butler, 1992). More specifically, a CF helicopter flight helmet has a mass of 1.4kg while a CF helmet equipped with NVGcw has a mass of approximately 3.7kg (Weirstra, 2001). Of that mass, NVGcw represents an additional mass of 0.05-0.4kg as compared to NVG (Weirstra, 2001; Van den Oord et al., 2012b). The weight of the NVG helmet alone, prior to loading as a result of vibration or exposure to G-forces, is significant enough to increase the muscular activity of the neck musculature (Sovelius et al., 2008). The additional mass associated with the use of an NVG-equipped helmet during simulated flight conditions significantly increases the metabolic activity of the shoulder and neck musculature (Harrison et al., 2007a; Harrison et al., 2007b; Harrison et al., 2007c). Beyond simply the mass of the additional equipment, the location of its center of gravity is a significant contributor to stress on the musculature. Improved helmet fit and balance alone are enough to decrease the subjective discomfort reported by helicopter aircrew (Van den Oord et al., 2012b).

The center of mass of a flight helmet typically resides forward and superior to the natural pivot point of the neck (Butler, 1992; Harms-Ringdahl et al., 1996; Sovelius et al., 2008; Forde et al., 2011). The result is constant moment acting on the muscles of the neck, in particular the extensor groups, to counterbalance the moment generated by the forward and superiorly positioned helmet system. When the head is in a neutral position, Butler and Alem (1997) suggested an upper limit of 90 N•cm during long duration helicopter flight (>4hrs) in male subjects to limit the biomechanical stress on the cervical structures; Barazanji and Alem (2000) confirmed this upper limit for female subjects during static laboratory testing with different helmet configurations.

However, as Butler (1992) points out and as Forde et al.(2011) quantifies, very little time is spent in flight in a neutral posture while wearing either a helmet or NVG. Forde et al.(2011) identified the location of the centers of mass of the various different configurations of the CF helicopter flight helmet – helmet alone vs helmet with NVG vs helmet with NVGcw – and reported slightly different results than Butler (1992). Forde et al. (2011) suggest the CF helmet alone configuration results in a center of mass that is superior and posterior to the center of mass of the head. However, the other configurations – NVG and NVGcw still remain forward and superior (Figure B1), as reported by others Butler, 1992; Harms-Ringdahl et al., 1996; Sovelius et al., 2008).

Figure B1 – The centres of mass of the various helmet configurations used by CF helicopter aircrew.
A) the head, alone; B) the helmet alone; C) NVG; D) NVGcw. From Forde et al., 2011; reproduced with permission from the authors.

Sovelius et al. (2008) suggest that lowering the location of the center of gravity of a helmet's weight has a more significant impact on relieving cervical muscle loading than decreasing the weight of the NVG systems currently in use. This is consistent with pioneering work in the realm of helmet masses, centers of gravity, and neck muscle fatigue; however, it would seem this information – a "forward and high" configuration is the least desirable - has not been applied despite being available for 30 years (Phillips and Petrofsky, 1983). Phillips and Petrofsky (1983) suggested, using loads comparable to the current NVG and NVGcw system employed by the CF, that if a balanced helmet load could not be achieved, it was more desirable to have a load that was "forward and low", "aftward and low", or "right lateral and low" as compared to "center and high". The benefit of a load that is centered in a lower position than the current model, in relation to the occiput and atlantio-axial joint, has benefits beyond just comfort while performing regular flight duties. In the extreme circumstances during which loading may be instantaneously increased (i.e. during impact in a crash scenario), Ashrafiuon et al.(1997) used manikin models to support the increased emergency safety associated with a load with a lower center of gravity specific to helicopter flight helmets and NVG equipment. Brozoski et al.(1998) similarly demonstrated decreased tolerance for deviation from the natural center of gravity of the head as the helmet mass increased during simulated impacts.

More recent work does not fully support the inclusion of a lateral imbalance favoring increased loading on the right side. Isometric testing has demonstrated a decreased strength and endurance capacity of the right–sided cervical muscles as compared to the left in the CF helicopter aircrew population (Harrison et al., 2009; Harrison et al., 2011). Further, when monitoring muscle metabolism with NIRS during simulated missions results indicated increased muscle metabolism in the musculature on the right side of the cervical spine (Harrison et al., 2007a) regardless of cockpit seat side (Harrison et al., 2007c). Additional work in the lumbar region has noted increased EMG activity in the musculature on the right side of the lumbar spinal column (Lopez-Lopez et al., 2001) and multiple sources hypothesize that the left-leaning in-flight posture demanded by the operation of the collective and cyclic controls contributes to this phenomenon (Pope et al., 1986; Pelham et al., 2005). Regardless, despite the use of NVGcw in an effort to move the center of mass towards a more natural location, it remains forward and high as compared to the natural anatomy (Forde et al., 2011). Using static biomechanical analysis, Thuresson et al.(2005b) found the moment-reducing effect from NVGcw decreased in the neutral position as compared to NVG. But, in the flexed non-neutral posture, the moment reducing effect of NVGcw is not apparent. This supported previous research reporting an inverse relationship between neck flexion and NVGcw based relief; where the NVGcw provided less relief as the neck was increasingly flexed (Harms-Ringdahl et al., 1996). This leads to the conclusion that, with increased neck flexion, NVGcw may actually add to the loading moment on the neck.

The addition of mass to a flight helmet does not automatically result in a balanced load. Gallagher et al.(2007), in a laboratory setting with 4kg and 6kg helmets, reported that aircrew preferred to wear a heavier but balanced helmet for a prolonged period of time as compared to a lighter helmet with centers of gravity similar to the current CF model. Most recently, Van de Oord et al.(2012a, 2012b) suggested and demonstrated that optimizing the fit of the helmet with a novel method for fitting the helmet that is customized to the individual crewmember can reduce neck pain and discomfort despite the current imbalance in the operational load. These results suggest that helmet balance and helmet fit contribute significantly to the development or prevention of neck pain amongst aircrew members. Research with United States Army aircrew reported helmet size did not correlate with head circumference (Walters et al., 2012). This strongly suggests there is room for improvement in optimizing helmet fit to enhance balance and decrease neck strain. Currently, the most commonly used method to enhance balance is the NVGcw.

The choice to use the NVGcw remains an individual preference and has not been clearly supported or refuted in the literature at present. Early work suggested counterbalancing the front-mounted load resulted in increased muscular activity, as assessed with EMG, with variations in head postures that were similar to in-flight requirements (Knight & Baber, 2004). Harrison et al.(2007b), using NIRS during simulated missions in a full-motion flight simulator, suggested NVGcw mitigated the metabolic demand experienced by the trapezius muscles during NVG flights. More recent work pending publication suggests that NVGcw does increase the work of the neck musculature, particularly when the field of vision requires the crewmember to look below the horizon (Harrison et al., In Press (a)). The difference is most likely due to the muscles in question. The projects demonstrating a deleterious effect as a result of NVGcw investigated the smaller muscles of the cervical spine using EMG (Knight and Baber, 2004; Harrison et al., In Press (a)) whereas the work supporting the use of NVGcw only investigated a single larger muscle group, the trapezius, using NIRS (Harrison et al., 2007). As will be discussed in a subsequent section in greater detail, isometric testing to volitional fatigue in this same population suggests that it is the smaller muscles and muscle groups that are most prone to fatigue, and potentially, subsequent injury (Harrison et al., 2009; Harrison et al., 2011). Coupled with other recent results that report decreased neck pain with an optimized and individualized helmet fitting process to enhance stability (van de Oord et al., 2012a; van den Oord et al., 2012b), it would seem prudent and cost effective for future work to prioritize the development of a more balanced helmet with customizable fit rather than focusing solely on a lighter helmet and NVG system.

B.6 Benefits of physical fitness and training on aircrew work capacity

In the general population with chronic neck pain, the addition of exercise to the treatment regimen is beneficial in both the short- and the long-term (Bronfort et al., 2001; Chiu et al., 2005; Haldeman et al., 2008). In flight-related neck pain, a recent shift towards physical fitness and training has occurred to provide "better muscle conditioning..., enhanced muscle coordination, and head support strategies…to prevent neck injuries stemming from the extra mass of the helmet" (Sovelius et al., 2008). Research to evaluate the associated factors of flight-related neck pain in the British aircrew suggest aerobic exercise, weight training, and neck strength training were all preventative in their relationship with neck pain (Wickes & Greeves, 2006). Van den Oord et al. (2010) measured differences in neck muscle strength and cervical range of motion between aircrew with and without neck pain. Their results indicate those without pain tend to have trend, though not statistically significant, towards greater strength and cervical range of motion as compared to their symptomatic colleagues.

In fast-jet aircrew, increased neck muscle strength is suggested to protect and stabilize the head and neck muscles during brief episodes of increased loading as a result of +Gz (Ang et al., 2005) while other studies suggest it is the cumulative +Gz loading rather than the peak +Gz load that is a better predictor of neck pain among fixed-wing aircrew (Kang et al., 2011). The ideology behind the link in strength and injury is functionally stronger neck muscles will be able to maintain the head in a neutral position to overcome the gravitational accelerations. However, in helicopter aircrew, the link between decreased neck strength in terms of a maximal voluntary contraction and injury is not supported by the literature (Ang et al., 2005; Harrison et al., 2009; van den Oord et al., 2010b; Harrison et al., 2011); one study reports increased "physical fatigue" at the end of NVG flight duties among aircrew with neck pain as compared to their pain-free colleagues (van den Oord et al., 2010b). This is supported by work with EMG in which differences were observed between the normalized median frequency of neck muscles in either flexion (Ang et al., 2005) or extension (Harrison et al., In Press (b)) in helicopter aircrew with and without pain; those with pain tended to have a blunted EMG signal as compared to their healthy colleagues. Furthermore, Ang et al. (2009) provide evidence that specific training of the neck musculature can improve the work capacity of those muscles as assessed by EMG and decrease reports of pain amongst helicopter aircrew. Thus, the hypothesis specific to helicopter aircrew suggests training programs focus on muscular endurance and general fitness to limit the effects of cumulative exposure to the multiple factors that contribute to neck pain as opposed to programs intending to increase strength (Wickes et al., 2005; Harrison et al., 2009; Salmon et al., 2011a; Salmon et al., 2011b).

After Wickes et al.(2005) suggested a protective link between regular physical exercise, in this case aerobic fitness in the form of participation in a self-selected activity (e.g. jogging, soccer, racquet sports), researchers have tested either the relationship between neck muscle function or the efficacy of neck strengthening programs on reported pain. Harrison et al.(2009) report the smaller muscles of the neck (i.e sternocleidomastoid and splenius capitis) are more prone to fatigue during submaximal endurance testing as compared to the larger muscle groups (i.e. the mid and lower trapezius) while seated in a cockpit chair. Similarly, Sovelius et al.(2008) note it is the sternocleidomastoid that demonstrated increased EMG activity in order to maintain a neutral posture in response to the additional load of either a flight helmet or a flight helmet with NVG. Ang et al.(2009) found that a supervised exercise regimen, specifically focused on neck and shoulder exercises, significantly reduced rates of neck injury in a 1-year follow-up. Additionally, this benefit is possible with as little as 1 hour per week for 6 weeks dedicated to performing the specific exercises. With respect to addressing the neuromuscular component of training specificity, Sovelius et al. (2008) suggest a benefit from the use of head loading and trampoline training. While simulating changes in +Gz loading (approximately 0-4 +Gz), the trampoline also provides a means by which to introduce low-level repetitive loading to an aircrew training program.

Specific to the CF, Salmon et al. (2011a) randomly distributed a group of CF helicopter pilots and flight engineers for a 12-week intervention as participants in either an endurance-training program (ETP) or a coordination-training program (CTP). The ETP group performed dynamic movements with resistance designed to equal 30% of each participant's baseline MVC while the CTP participants performed low load isometric exercises focused on the deep cervical stabilizer muscles. Compared to control subjects, both ETP and CTP groups resulted in significantly reduced subjective neck pain, and additionally, increased MVC and muscular endurance. These results further suggest that neck-specific exercise programs can reduce neck pain in an efficient and inexpensive manner.

B.7 Recommendations

The factors that contribute to the occurrence of neck pain among CF helicopter aircrew are multifactorial. Helmet mass, the distribution and balance of the helmet mass, the number of flight hours logged with NVG, the use of NVGcw, the height of the crewmember, the vibration of the helicopter, the in-flight posture required to perform essential duties, the overall fitness of the crewmember, and the neck/shoulder specific fitness of the crewmember are just some of the examples of factors identified in the literature as being contributory. The question now is what can be done about these factors?

The focus of future research should address all of these issues as it is highly unlikely that any one of them, alone, will be sufficient to prevent neck pain amongst helicopter aircrew. Ergonomists and industry should make a conscious effort to design equipment that has a lower center of gravity as suggested by research, the earliest of which is 30 years old (Philips and Petrofsky, 1983; Sovelius et al., 2008). As has already started, industry and research should continue to design new seats that meet the safety requirements for military flight while reducing vibration transmission to the crewmember (Hiemenz et al., 2008; Chen et al., 2009).

Future ergonomic and biomechanical work should quantify the duration of time, in flight, that each crewmember spends in specific postures and make certain each crewmember has a customized helmet fit performed. Head forward flexion is linked to reports of neck pain and discomfort in the general population (Eriksen, 2004; Thorn, 2005) but other than what is reported by Weirstra (2001) and Forde et al. (2011), little is known about the in-flight tasks and postures of helicopter crewmembers, particularly flight engineers. Obtaining this information would likely dictate changes to the unregulated manner in which aircrew choose to use NVGcw based on personal preference. Better fitting helmets, will also likely help to decrease neck pain and irritation during night flights (van den Oord et al., 2012b). Beyond the optimized fit, perhaps not every crewmember has an in-flight posture and loading profile that warrants the use of NVGcw.

Lastly, fitness is an obvious solution that often appears to be overlooked. In the helicopter community, encouragement of a structured fitness program that regularly includes either aerobic fitness (Wickes et al., 2005) or neck-specific exercises to address muscular endurance and posture (Ang et al., 2009; Salmon et al., 2011a) is the most likely to provide nearly immediate improvements in the current neck pain situation in the CF helicopter community (Adam, 2004).

B.8 Conclusions

The issue of neck pain as a result of military helicopter operations persists. Numerous research projects are publishing results that consistently highlight the same areas of concerns (Thuresson, 2005; Wickes et al., 2005; Ang & Harms-Ringdahl, 2006; Forde et al., 2009; Harrison, 2009) as have been highlighted by this review. The underlying commonality amongst the factors is the need for a kinesiological approach that incorporates both a human-factors engineering perspective as well as a focus on the neuromuscular and hemodynamic physiology in order to fully address the issues.

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6 List of symbols/abbreviations/acronyms/initialisms

CF	Canadian Forces
CoG	Centre of Gravity
CtOx	Cytochrome-c-oxidase
CTP	Coordination training program
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
EMG	Electromyography
ETP	Endurance training program
FLIR	Forward Looking Infrared
HUD	Heads-Up Display
LBP	Low back pain
LiDAR	Light Detection And Ranging
LPSV	Life Preserver Safety Vest
MRI	Magnetic resonance imaging
MVC	Maximum voluntary contraction
NIRS	Near infrared spectroscopy
NOE	Nape of the Earth
NVG	Night vision goggles
NVGcw	Night vision goggles with counter weight
NVGs	Night Vision Goggles System
R&D	Research & Development
R&T	Rag and Tube
SAR	Search and Rescue
UEMD	Upper extremity muscle disorders
WBV	Whole body vibration

DOCUMENT CONTROL DATA

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Near-Term Ideas to Address Aircrew Helmet Systems-Induced Neck Pain: Mitigating Neck Pain in Aircrew (U)
Idées à court terme en vue d atténuer les douleurs au cou attribuables aux systèmes de casque chez le personnel navigant: Réduire les douleurs au cou chez le personnel navigant (U)

4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

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(U) Neck pain is a growing concern among CH-146 Griffon aircrew. A simple, yet practical on-body elastomer-balanced helmet system is provided as one of several feasible near-term solutions to alleviate the neck pain problem.
Following a rapid work domain assessment of the operational environment of CH-146 Griffon aircrew and an ergonomic hazard screen, the research team identified that sustained static postures (pilots) and extreme awkward postures (flight engineer) were primary risks. Moreover, the level of risk increases considerably with the additional head-borne mass of the night vision goggles system (NVGs). The addition of the NVGs increases the total mass on the head, adding more compressive load on the neck and requiring more work from the neck muscles in order to control and stabilize the head. Additionally, the NVGs alters the balance of forces acting about the head and neck joint (atlanto-occipital joint), requiring the small upper neck muscles to work even harder. The ideal solution entails a combination of redesigning the cockpit, cabin and helmet system. However, in the near-term the on-body elastomer-balanced helmet system provides an interim improvement. This counter measure provides a balancing force through the elastomer, off-loading the work from the neck muscles. In addition the total head-borne load is also reduced compared to the current weight based counter balancing method.

(U) Les douleurs au cou sont une préoccupation de plus en plus courante chez le personnel navigant des CH 146 Griffon. Un système de casque ergonomique équilibré avec un élastomère, simple mais pratique, est l une des solutions réalisables à court terme qui sont proposées pour atténuer le problème des douleurs au cou.
À la suite d une évaluation rapide du domaine de travail portant sur l environnement opérationnel de l équipage du CH-146 Griffon et d un examen initial des risques ergonomiques, l équipe de recherche a établi que les positions statiques prolongées (pilotes) et les positions contraignantes extrêmes (mécaniciens de bord) constituent les principaux risques. De plus, le degré de risque augmente considérablement en raison du poids qu ajoute au casque le système de lunettes de vision nocturne (NVG). L ajout des NVG augmente la masse totale qui est supportée par la tête, ce qui accroît la charge de compression sur le cou et exige un effort supplémentaire de la part des muscles du cou pour contrôler et stabiliser la tête. Qui plus est, les NVG modifient l équilibre des forces au niveau de l articulation entre la tête et le cou (articulation occipitoatloïdienne), ce qui entraîne une sollicitation accrue des petits muscles du haut du cou. Idéalement, il faudrait revoir la conception du poste de pilotage, de la cabine et du système de casque. Cependant, à court terme, le système de casque ergonomique équilibré avec un élastomère offre une amélioration provisoire. Cette mesure crée une force compensatrice grâce à l élastomère, réduisant ainsi le travail requis par les muscles cervicaux. En outre, la charge totale sur la tête est réduite par rapport à la méthode actuelle de contre-balancement par le poids.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) neck pain; neck strain; NVG; night vision goggles; HUD; heads up display; head borne mass; head mounted mass; pilot; flight engineer; CH-146 Griffon helicopter; FE