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Evaluation of Potential Solutions to Mitigate Aircrew Neck Strain

CIMVHR contract W7714-125624/001/SV- task 14

Capt. Gabrielle S. Chafe

Defence R&D Canada
Technical Report
DRDC Toronto TR 2013-089
July 2014

Canada

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Abstract

Aircrew neck strain has become a prevalent problem for air forces around the world. Many factors have been linked to the problem, including the use of Night Vision Goggles (NVG). In order to address this problem over the short term, two multidisciplinary teams were contracted to propose potential solutions. A panel of eight experts from different fields of expertise subsequently evaluted these solutions. The highest rated solution—though not one selected by most members of the panel—was to reduce the helmet/NVG system weight, centre of gravity, and moment of inertia. The most popular solutions were procedural ones focussed on assisting the aircrew to reduce neck strain through education and an athletics-based exercise regime. The most popular engineering solutions were scored moderately and used different approaches, for example, reducing NVG use by removing or shifting NVG weight on the helmet, and replacing the current counterweight with an on-body elastomer system. In the short term, assessments of different approaches to mitigate aircrew neck pain will need to incorporate aircrew acceptance of these approaches if they are to have any significant effect.

Résumé

La fatigue de la nuque est aujourd’hui un problème répandu chez les membres d’équipage des aéronefs CH-146 Griffon. Ce problème touche également tous ceux qui servent à bord d’hélicoptères ailleurs dans le monde. Un grand nombre de facteurs ont été associés au problème, mais, d’après une étude internationale dirigée par des Canadiens, la fatigue de la nuque est liée à la durée des missions avec les lunettes de vision nocturne (LVN) et au nombre total d’heures de vol avec LVN. Pour trouver des solutions à court terme, on a embauché deux équipes multidisciplinaires à qui on a demandé de proposer des solutions potentielles. Les solutions ont été évaluées par un comité formé de huit experts issus de différents domaines d’expertise. La solution la mieux cotée (0,80) consistait à réduire le poids du casque/système de LVN, le centre de gravité et le moment d’inertie. Toutefois, cette solution n’a pas été retenue par la plupart des membres du comité. Les solutions les plus populaires étaient axées sur l’aide aux équipages d’aéronef par le biais de programmes d’éducation et d’exercices d’entraînement athlétique (0,79-0,76). Les solutions d’ingénierie les plus populaires ont obtenu un score modéré (0,66-0,56). Celles-ci adoptaient différentes approches : a) réduction de l’utilisation des LVN en retirant le poids de la LVN du casque ou en le transférant ailleurs sur le casque et b) remplacement du contrepoids actuel par un système élastomère corporel. À court terme, il faudra tenir compte, dans le cadre de l’évaluation des différentes approches pour atténuer les douleurs au cou des membres d’équipage des aéronefs, de l’acceptation des solutions par ces derniers pour obtenir un effet significatif.

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Executive summary

Evaluation of Potential Solutions to Mitigate Aircrew Neck Strain

Capt Gabrielle S. Chafe; DRDC Toronto TR 2013-089; Defence R&D Canada – Toronto; July 2014.

Introduction or background: Aircrew neck strain has become a prevalent problem for air forces around the world since the early 1990s when the use of Night Vision Goggles (NVG) became popular. Though many factors have been linked to this problem, a Canadian-led international study found that only NVG mission length and total NVG hours flown were associated with neck pain. In order to address this problem over the short term, two multidisciplinary teams were contracted to propose potential solutions. They were given a wide range of possibilities, including engineering, procedural, doctrinal, or policy changes. The two groups presented 25 potential solutions overall, some of which were very similar between the teams. The solutions were presented in a report and a briefing to an evaluation board consisting of eight experts from different fields of expertise: two pilots, one flight engineer, two aerospace engineers, an aviation life safety equipment expert, a flight surgeon, and a biomechanist. The solutions were evaluated on 11 criteria—including utility, usability, operational impact, and the potential to reduce the incidence and/or the severity of neck pain—using a five-point scale. Evaluators were also asked to select their top 10 choices as well as their recommendations for follow-up.

Results: The highest rated solution—though not one selected by most members of the panel—was to reduce the helmet/NVG system weight, centre of gravity, and moment of inertia. The most popular solutions were procedural, focussed on assisting the aircrew to reduce neck strain through education and an aircrew-specific exercise regime (0.79-0.76). These solutions may have been seen as easier to implement, which may explain their popularity.

The most popular engineering solutions were scored moderately (0.66-0.56). These took different approaches, for example, reducing NVG use by removing or shifting NVG weight on the helmet, and replacing the current counterweight system with a lighter-weight, on-body elastomer-type system to reduce total helmet system weight. In the short term, different approaches can be assessed to mitigate aircrew neck pain; however, aircrew acceptance and use is required if they are to have any significant effect.

Significance: The mitigation of neck pain has the potential to

(a) reduce the loss of qualified aircrew to medical problems,

(b) increase flight safety by reducing the distraction caused by discomfort,

(c) reduce health care costs within the Canadian Armed Forces (CAF) as the demand for treatment for neck pain falls, and

(d) maintain or increase the operational capacity of the tactical aviation community.

Future plans: In order to further assess the potential solutions, a task analysis and physical demands analysis will be done to better understand aircrew tasks, in the course of which capturing postures, forces, and loads. A test bed will be required to assess these solutions, involving characterization of the helmet/NVG system requirements with regards to center of mass, weight limits, and moments of inertia as well as human trials to ascertain the effectiveness and acceptance of the solutions.

Sommaire

Évaluation des solutions potentielles pour atténuer la fatigue de la nuque chez les membres d'équipage d'aéronefs

Capt Gabrielle S. Chafe; DRDC Toronto TR 2013-089 ; R & D pour la défense Canada – Toronto; juillet 2014.

Introduction ou contexte : Depuis le début des années 90, soit depuis que l'utilisation des lunettes de vision nocturne (LVN) est devenue plus populaire, la fatigue de la nuque est un problème répandu chez les membres d'équipage des aéronefs CH-146 Griffon. Ce problème touche également tous ceux qui servent à bord d'hélicoptères ailleurs dans le monde. Un grand nombre de facteurs ont été associés au problème, mais, d'après une étude internationale dirigée par des Canadiens, seuls la durée des missions avec LVN et le nombre total d'heures de vol avec LVN sont associés à la fatigue de la nuque. Pour trouver des solutions à court terme, on a embauché deux équipes multidisciplinaires à qui on a demandé de proposer des solutions potentielles. On leur a proposé un vaste éventail de possibilités, par exemple des modifications touchant l'ingénierie, les procédures, la doctrine ou les politiques. Au total, les deux groupes ont présenté 25 idées, dont certaines étaient très similaires. Les solutions ont été divulguées dans un rapport et à l'occasion d'une présentation devant un comité d'évaluation. Un comité formé de huit experts issus de différents domaines d'expertise a été réuni à Recherche et développement pour la défense Canada (RDDC), Toronto. Il était composé de membres d'équipage (deux pilotes et un mécanicien de bord), de deux ingénieurs en aéronautique, d'un spécialiste en équipement de sécurité des personnes pour aéronefs, d'un médecin de l'air et d'un biomécanicien. Les solutions ont été évaluées en fonction de 11 critères portant sur l'utilité, l'utilisabilité, les conséquences sur les opérations et le potentiel de réduction de l'incidence et/ou de la gravité des douleurs au cou. Tous les critères ont été évalués selon une échelle de 1 à 5 points. On a aussi demandé aux évaluateurs de nous faire part de leurs recommandations de suivi et de sélectionner leurs dix solutions favorites.

Résultats : La solution la mieux cotée (0,80) consistait à réduire le poids du casque/système de LVN, le centre de gravité et le moment d'inertie. Toutefois, cette solution n'a pas été retenue aux fins de suivi par la plupart des membres du comité. Les solutions les plus populaires, entre autres solutions procédurales, étaient axées sur l'aide aux équipages d'aéronef par le biais de programmes d'éducation et d'exercices d'entraînement athlétique (0,79-0,76). La popularité de ces solutions peut s'expliquer du fait qu'on les a jugées faciles à mettre en œuvre. Les solutions d'ingénierie les plus populaires ont obtenu un score modéré (0,66-0,56). Celles-ci adoptaient différentes approches : a) réduction de l'utilisation des LVN en retirant le poids de la LVN du casque ou en le transférant ailleurs sur le casque et b) remplacement du contrepoids actuel par un système élastomère corporel. À court terme, il faudra évaluer différentes approches visant à atténuer les douleurs au cou des membres d'équipage des aéronefs; toutefois, pour obtenir un effet significatif, il faut que ces derniers acceptent les solutions et les utilisent.

Importance : L'atténuation des douleurs au cou chez les membres d'équipage des aéronefs CH-146 offre le potentiel de réduire la perte de membres d'équipage qualifiés en raison de problèmes médicaux, d'augmenter la sécurité des vols grâce à la réduction de la distraction causée par l'inconfort, de réduire les coûts de santé pour les Forces armées canadiennes (FAC) par la

diminution des traitements pour les douleurs au cou, et, dans l'ensemble, de maintenir ou d'augmenter la capacité opérationnelle des membres de la communauté d'aviation tactique.

Perspectives : Pour évaluer plus en détail les solutions proposées, on procédera à une analyse des tâches et à une analyse des exigences physiques pour comprendre les tâches qu'exécutent un équipage et ce que celles-ci impliquent en ce qui a trait aux postures, aux forces et aux charges. Il faudra réaliser un banc d'essai pour évaluer les solutions et procéder à une caractérisation des exigences relatives au casque/système de LVN en ce qui touche le centre de gravité, les limites de poids et les moments d'inertie, dans le but de vérifier l'efficacité et l'acceptation des solutions.

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1 Introduction

1.1 Background

Aircrew neck strain is a recognized problem in many countries and associated with many airframes. Within the Royal Canadian Air Force (RCAF), Fraser, Crowley, Shender, and Lee (2014) determined that neck pain within the rotary-wing community was linked to the use of night vision goggles (NVG) and mission length. Many international studies have concluded that posture, vibration, flying hours (especially with NVG), and a previous history of neck pain are also contributors (Äng & Harms-Ringdahl, 2006; Van den Oord, De Loose, Meeuwsen, Sluitter, & Frings-Dresen, 2010; Wickes, Scott, & Greeves, 2005). Suggested methods of dealing with aircrew neck pain are to reduce exposure to head-supported mass and vibration, encourage exercise programs for aircrews,[1] and improve cockpit ergonomics. It has also been noted that reduced flying time would decrease the incidence of neck pain. However, this is not an option, as operational demands require a certain minimum of flying for training, proficiency, and currency.

In order to address the problem in the near-term, the Canadian Institute for Military Veterans Health Research (CIMVHR)—through two multidisciplinary teams subcontracted from Queen's University (QU) and the Toronto Rehabilitation Institute (TRI)—was tasked to propose potential solutions.

1.2 Potential Solutions

The potential solutions were described in two reports, Fischer et al. (2013) and Fernie and Mayich (2013), that were distributed to the evaluation panel prior to its first meeting. The teams presented their potential solutions and their proposed ways forward to the panel on 25 March 2013. From the draft reports, an evaluation booklet was prepared that identified the potential solutions to be evaluated (Table 1).

Further details of the potential solutions are found in Annex C, which includes a brief description and Figures when available.

[1] The frequency of exercise has been identified as a predictor of pain (Fraser et al., 2014; Tucker, Netto, Hampson, Oppermann, & Aisbett, 2012).

Table 1. Potential solutions presented for evaluation.

	Toronto Rehabilitation Institute (TRI)
TRI1	Modified NVG support mechanism
TRI2	Quick release for NVG and HUD
TRI3	Reading glasses for NVG
TRI4	Low friction collar
TRI5	Mechanisms to redistribute the weight of the helmet from neck to shoulder
TRI6	Flexi-support
TRI7	Griffon simulator
TRI8	Shift of thinking—education and exercise program during work hours
	Queen's University (QU)
QU1	Elastomer-based helmet system support (on-body)
QU2	Seat-mounted cable
QU3	Shoulder girdle-based helmet systems support (on-body)
QU4	Procure a new helmet/NVG system (TopOwl®)
QU5	Improve the capacity of the neck system to withstand the head-borne mass
QU6	Conservative maintenance standards for rotor track balance
QU7	Revised process for workload distribution
QU8	Standardized process individually optimize helmet systems fit
QU9	Improved options/opportunities for self-care
QU10	Neck brace support system
QU11	Flexible mount to support the MX-15 visioning system
QU12	Fold-up seating
QU13	Enhanced visual capability
QU14	Duplicated instrumentation
QU15	Knee padding for flight engineers
QU16	Portable handles
QU17	Cabin door stops

2 Method and Analysis

2.1 Evaluation

A panel of experts from different backgrounds and expertise was gathered:

- two pilots (rotary wing and fixed wing),
- CH-146 flight engineer (FE),
- biomechanist,
- flight surgeon (FS),
- aviation life support equipment (ALSE) expert, and
- two aerospace engineers (AERE).

An evaluation scale was developed setting out the different criteria that could influence the success of potential solutions (Figure 1). These criteria were also outlined in the statement of work (SOW) from which the contractors (TRI and QU) were working. Each criterion was evaluated on a scale of 1 (low) to 5 (high) points. The potential solution could receive a maximum total score of 55 points.

Table 2. Evaluation criteria score sheet.

Evaluation Criteria	Low	Medium			High	Total	Criteria Importance Rating
	1	2	3	4	5		
Utility							
Usability:							
feasibility of airworthiness certification							
user impression							
ease of use							
ease of implementation							
conflict with existing equipment							
Operational impact							
Potential for reducing incidence/severity of neck pain:							
reduces forces on neck muscles							
reduces exposure to forces							
reduces compromising postures							
reduces compromising tasks							
TOTAL SCORE (max score=55)							

Recommend Follow-up: yes no maybe

Note: The space for notes and comments is not shown.

The panel of experts was asked its recommendation as to follow-up by answering Yes (Y), No (N), or Maybe (M). In order to determine if any given criterion was deemed more important, the panel was asked to rate the criterion on a scale of 1 (low) to 5 (high).

2.2 Normalizing and Averaging

In the event that a criterion was not relevant to the potential solution evaluated, the scores were normalized to the total score of the number of criteria answered. The score given was divided by the maximum total score of 55 when all criteria were evaluated. When a criterion was not evaluated, the maximum total score was reduced accordingly (i.e., if two criteria were not answered, the score was normalized on a total potential score of 45 rather than 55).

Each potential solution was evaluated by eight evaluators. The normalized individual scores given by the evaluators were averaged for a specific solution (Table 2).

2.3 Ranking

The potential solutions were ranked according to their average normalized score. The highest score was ranked first, and identical scores were given the same rank.

Each evaluator was also asked to rank their top 10 recommendations for follow-up. The frequency at which a solution was selected was compared with the average score ranking.

2.4 Importance Weighting

Each evaluator was asked to rate the importance of a criterion. Most evaluators were consistent in their importance rating; however, some did change the importance rating of the criterion with respect to the solution. As a result, the weighting of a criterion was averaged across the evaluators and for all solutions to give an overall weighting to each criterion (Table 6).

3 Results and Discussion

3.1 Ranking of Averages

The potential solutions were ranked according to their average normalized scores; solutions with identical scores were ranked at the same level (Table 2).

Table 3. The average normalized score and ranking for the potential solutions.

	Potential Solutions Evaluated	Averaged Normalized Score	Average Score Ranking
QU4	Procure a new helmet/NVG system (TopOwl®)	0.80	1
QU5	Improve the capacity of the neck system to withstand the head borne mass	0.79	2
TRI8	Shift of thinking—education and exercise program during work hours	0.76	3
QU9	Improved options / opportunities for self-care	0.75	4
QU8	Standardized process individually optimize helmet systems fit	0.70	5
QU15	Knee padding for flight engineers	0.69	6
QU12	Fold up seating	0.68	7
QU13	Enhanced visual capability	0.68	7
TRI2	Quick release for NVG and HUD	0.66	8
QU16	Portable handles	0.65	9
QU7	Revised process for workload distribution	0.65	9
QU6	Conservative maintenance standards for rotor track balance	0.63	10
QU14	Duplicated instrumentation	0.62	11
QU11	Flexible mount to support the MX-15 visioning system	0.60	12
TRI7	Griffon simulator	0.59	13
QU1	Elastomer- based helmet system support (on-body)	0.56	14
TRI1	Modified NVG support mechanism	0.56	14
QU17	Cabin door stops	0.55	15
TRI3	Reading glasses for NVG	0.53	16
TRI4	Low friction collar	0.50	17
TRI6	Flexi-support	0.48	18
QU2	Seat mounted cable	0.45	19
QU10	Neck brace support system	0.44	20
QU3	Shoulder girdle based helmet systems support (on-body)	0.42	21
TRI5	Mechanisms to redistribute the weight of the helmet from neck to shoulder	0.41	22

The data sheets for each potential solution, with the evaluator scores and averages, are found in Annex A. Note that some solutions were not evaluated by all participants.

The highest-ranked idea was QU4—to purchase a lighter-weight helmet. Reviewing the comments, defining and characterizing the ideal and maximum required mass properties of the helmet system would better achieve what the evaluators thought should be pursued. Table 18 in Annex A shows that only four evaluators scored the proposal, and only three of seven evaluators voted "Yes" for follow-up (Table 3). This suggestion appeared in the top 10 choices only four times (Table 4).

The next three highest-ranked proposals (QU5, TRI8, and QU9) related mostly towards individuals. For example, TRI8 proposes setting up an exercise program. This would not be just any exercise program, but one where the aircrew would be considered as athletes and in which the regimen would be developed specifically with their job requirements in mind. This is already being assessed (Hébert & Roy, 2012) as a result of previous work done by Äng, Monnier, and Harms-Ringdahl (2009). Drs Hébert and Roy's project is being funded by the Surgeon General Health Research Program. Any exercise regimen put into place would need to be easily accessible for aircrew, ideally within the hangar area. As well, time would need to be mandated during the aircrew work day (Fernie & Mayich, 2013; Fischer et al., 2013).

It was also noted in TRI8 that the aircrew should be educated with regards to how the neck musculature works and how best to prevent and recognize early symptoms of neck strain (Adam, 2004; Fernie & Mayich, 2013). This could be incorporated at different stages of the aircrew's career as part of flight safety and flight surgeon briefs as well as part of their phase and proficiency training.

Self-care, such as the use of massaging tools, or a training regime that takes into account operational requirements (Fischer et al., 2013) could be provided for after flight. These could be used alongside a work schedule regime similar to that of athletes. During non-combat, low operational status, the aircrew would have more stringent workouts. During high operational tempo, the level of training would be reduced similar to how an athlete scales down training prior to a competition.

The next highest scoring solution was helmet fit (QU8). Recently, Van den Oord, Steinman, Sluiter, and Frings-Dresen (2012) showed that a well fitted helmet significantly reduced helmet movement. A well fitted helmet with reduced helmet movement can reduce muscle compensation. It was brought to the author's attention, by personal communication, that helmet fitting within the Royal Canadian Air Force (RCAF) is not as effective as in previous years due to a gap in technician experience levels. Training on how to properly fit a helmet is done at the unit level, and with the reduction in available senior technicians, some techniques are no longer being demonstrated. The techniques that specialized technicians once used are not available nor are they transmitted to less experienced technicians. This training should be developed and reinstated. The standards for properly fitted helmets should be raised and shared within the community at all levels. It was also brought to our attention that aircrew are not aware of how well their helmet should fit. Education at the aircrew level as to how their Aviation Life Support Equipment (ALSE) should fit and work together will help to reduce the helmet-fit problems. Currently, aircrew have a tendency to keep their chin straps loose (for comfort) and may not be aware that their helmets should fit like a glove (personal communications).

The next three options—knee pads (QU15), fold-up seat (QU12), and enhanced visual capability (QU13)—focus on FE duties. All of these options focus on helping FEs maintain the postures that are required as part of their duties in order to reduce time spent in compromising postures (Fischer et al., 2013).

Of the proposed engineering solutions, *TRI2—quick release for NVG and HUD* was ranked eighth while *QU1—elastomer-based helmet system support (on-body)* and *TRI1—modified NVG support mechanism* were both ranked 14. However, only three users—two pilots and one FE—were part of our evaluation panel. It was determined that the usefulness of any of these solutions will need to be evaluated and developed with the users.

3.2 Follow-up Recommendation

The panel of experts was asked to recommend whether there should be follow-up for a potential solution by answering Yes (Y), No (N), or Maybe (M). These results were tabulated, showing votes received out of total votes given for each potential solution (Table 3).

The only solution the panel unanimously recommended for follow-up was *TRI8—education and exercise program* [specific to aircrew] *during working hours*. Conversely, three potential solutions were not recommended for follow-up: *TRI5—mechanisms to redistribute the weight of the helmet from the neck to the shoulder* (the collar jack), *TRI6—flexi-support* (for flight engineer prone position work), and *QU10—neck brace support system*. The shoulder girdle helmet system support (QU3) received equal votes of No and Maybe. It was noted that a body girdle rather than a shoulder girdle could also give back support to the FE, which could prove beneficial in light of the extreme postures they assume (Weirstra, 2001). All other solutions were thought to have some potential worth following up.

With regards to procuring a new helmet system, the evaluators mentioned that the ideal mass properties of a helmet system should be determined and evaluated, though not necessarily purchase the suggested TopOwl® (Section B.12, Annex B).

Table 4. Recommended follow-up votes (Y, N, M) and the vote tally (x/total votes).

	Potential Solutions Evaluated	Recommended for follow-up
TRI1	Modified NVG support mechanism	M (6/8)
TRI2	Quick release for NVG and HUD	Y (5/8)
TRI3	Reading glasses for NVG	Y (4/7)
TRI4	Low friction collar	M (3/7)
TRI5	Mechanisms to redistribute the weight of the helmet from neck to shoulder	N (5/8)
TRI6	Flexi-support	N (4/7)
TRI7	Griffon simulator	Y (4/7)
TRI8	Shift of thinking—education and exercise program during work hours	Y (8/8)
QU1	Elastomer- based helmet system support (on-body)	Y (5/7)
QU2	Seat mounted cable	M (5/7)
QU3	Shoulder girdle based helmet systems support (on-body)	M,N (3/6)
QU4	Procure a new helmet/NVG system (TopOwl®)	Y (3/7)
QU5	Improve the capacity of the neck system to withstand the head borne mass	Y (5/5)
QU6	Conservative maintenance standards for rotor track balance	Y (5/7)
QU7	Revised process for workload distribution	Y (5/6)
QU8	Standardized process individually optimize helmet systems fit	Y (4/5)
QU9	Improved options / opportunities for self-care	Y (4/5)
QU10	Neck brace support system	N (4/6)
QU11	Flexible mount to support the MX-15 visioning system	M (3/5)
QU12	Fold up seating	Y (5/5)
QU13	Enhanced visual capability	Y (3/5)
QU14	Duplicated instrumentation	Y (3/5)
QU15	Knee padding for flight engineers	Y (5/5)
QU16	Portable handles	Y (4/4)
QU17	Cabin door stops	Y (3/4)

3.3 Overall Ranking

The evaluation panel was asked to rank its top 10 choices of solutions with which to move forward. Table 4 shows these results and the frequency of selection among the eight participants.

Table 5. Ranking of the top 10 choices by participant, and frequency of selection among the eight participants.

	Potential Solutions Evaluated	**Participant Ranking**								**Frequency of Selection**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
TRI2	Quick release for NVG and HUD	6		4	8	3	4	2	1	7
TRI8	Shift of thinking—education and exercise program during work hours	7	4	1	3	2	1	9		7
TRI1	Modified NVG support mechanism	5	10			4	5	3	8	6
TRI3	Reading glasses for NVG	4	8	8		8		5	5	6
QU8	Standardized process individually optimize helmet systems fit		5	9	2	2	6	4		6
TRI7	Griffon simulator	1		3		5	10		3	5
QU1	Elastomer-based helmet system support (on-body)	3		2		9	2		6	5
QU9	Improved options/opportunities for self-care		6	10	4	1	1			5
QU12	Fold up seating	10	2	5	9			8		5
QU4	Procure a new helmet/NVG system (TopOwl®)		1	6	7			1		4
QU5	Improve capacity of the neck system to withstand the head borne mass	8		1	1		1			4
QU7	Revised process for workload distribution				5	10		5	2	4
TRI4	Low friction collar					7	3		7	3
QU6	Conservative maintenance standards for rotor track balance	2			6			6		3
QU15	Knee padding for flight engineers			7	10		7			3
TRI5	Mechanisms to redistribute the weight of the helmet from neck to shoulder					6			10	2
QU3	Shoulder girdle-based helmet systems support (on-body)		9						9	2
QU16	Portable handles						8	10		2
TRI6	Flexi-support								4	1
QU2	Seat mounted cable	9								1
QU11	Flexible mount to support the MX-15 visioning system							7		1
QU13	Enhanced visual capability		7							1
QU14	Duplicated instrumentation		3							1
QU17	Cabin door stops						9			1
QU10	Neck brace support system									

Most of the panel selected the shift of thinking and exercise (TRI8) and the quick release NVG (TRI2) solutions in their top 10 choices. The other engineering solutions mentioned previously—

modified NVG support (TRI1) and elastomer-based helmet support (QU1)—were selected six and five times, respectively.

3.4 Ranking Comparison

The most frequently selected options were not necessarily the most highly-ranked options. Table 5 shows that the two highest scored solutions were only selected four times. This suggests that not all participants were in agreement when considering which solutions to pursue.

Table 6. Comparison of the average score ranking and the frequency of selection for the potential solutions evaluated.

	Potential Solutions Evaluated	Average Score Ranking	Frequency of Selection
QU4	Procure a new helmet/NVG system (TopOwl®)	1	4
QU5	Improve capacity of the neck system to withstand the head borne mass	2	4
TRI8	Shift of thinking—education and exercise program during work hours	3	7
QU9	Improved options/opportunities for self-care	4	5
QU8	Standardized process individually optimize helmet systems fit	5	6
QU15	Knee padding for flight engineers	6	3
QU12	Fold up seating	7	5
QU13	Enhanced visual capability	7	1
TRI2	Quick release for NVG and HUD	8	7
QU16	Portable handles	9	2
QU7	Revised process for workload distribution	9	4
QU6	Conservative maintenance standards for rotor track balance	10	3
QU14	Duplicated instrumentation	11	1
QU11	Flexible mount to support the MX-15 visioning system	12	1
TRI7	Griffon simulator	13	5
QU1	Elastomer-based helmet system support (on-body)	14	5
TRI1	Modified NVG support mechanism	14	6
QU17	Cabin door stops	15	1
TRI3	Reading glasses for NVG	16	6
TRI4	Low friction collar	17	3
TRI6	Flexi-support	18	1
QU2	Seat mounted cable	19	1
QU10	Neck brace support system	20	
QU3	Shoulder girdle based helmet systems support (on-body)	21	2
TRI5	Mechanisms to redistribute the weight of the helmet from neck to shoulder	22	2

This could be explained by the different backgrounds and experience of the panel members. There may be a consensus if only users were asked to evaluate the solutions.

3.5 Criterion Weighting

In order to determine if a certain criterion should receive a weighted score, the evaluators were asked to rate the importance of the criteria. Table 6 shows the average of all evaluator scores given to all the solutions. Most evaluators ranked criteria importance the same for all potential solutions. However, a few did change criteria importance specific to the potential solution. For example, "ease of use" was considered more important for an engineering solution than for a procedural solution.

Table 7. Average importance weighting for evaluation criteria.

Evaluation Criteria	Average Importance Weighting
Utility	3
Usability:	
feasibility of airworthiness certification	4
user impression	4
ease of use	4
ease of implementation	3
conflict with existing equipment	5
Operational impact	5
Potential for reducing incidence/severity of neck pain:	
reduces forces on neck muscles	4
reduces exposure to forces	4
reduces compromising postures	4
reduces compromising tasks	4

The most important criteria were *operational impact* and *conflict with existing equipment* (each rated as 5). *Utility* and *ease of implementation* were deemed least important (each rated as 3). Overall, most criteria were rated as 4. For the purposes of this evaluation, no weighted scores were used.

3.6 Evaluator Comments

Evaluator comments are listed in Annex B. Most of the comments are informative and reflect the specific perspective and expertise of individual members of the multidisciplinary panel. Nevertheless, many of the concerns raised were common to most of the group.

To take one example, group discussions were held with members of the Directorate of Technical Airworthiness and Engineering System (DTAES) and the Directorate Aerospace Equipment Program Management (DAEPM) concerning the lighter helmet option. It was observed that, in order to change the requirements of the helmet, the demand for change had to come down the chain of command. Moreover, the weight, CoG, and moment of inertia limitations had to be scientifically validated in order to write a statement of requirements (SOR) that would allow the directorates to work with industry in order to resolve these issues.

4 Conclusions and Recommendations

4.1 Conclusions

The top ranked solution is the purchase of a lighter helmet/NVG system. However, the requirements of a new helmet system need to be better understood and characterized. Procuring a new helmet is more a mid-term than a short-term solution. It will also be influenced by current and future NVG technology.

Overall, most ideas are thought to have some promise. Only three were not recommended for follow-up. The procedural solutions were deemed more favorable compared to engineering solutions. This could be explained by the apparent ease of implementing procedural solutions, whereas an engineering solution requires airworthiness certification, which can be a long process (note, however, that a change in operational procedures may also require airworthiness certification).

Aircrew education and specialized exercise programs were the most selected and highest scored options. An exercise program is currently being evaluated. In order to move forward with educating aircrew, the implementation of such a program and the means to deliver the information within the training process must be determined.

Both contractor teams had original ideas, and some of their proposed solutions were similar, especially the procedural suggestions. Their proposals going forward are explicit and are detailed in their reports (Fernie & Mayich, 2013; Fischer et al., 2013).

During the evaluation process, it became evident that the scale for evaluating the "operational impact" and the "conflict with existing equipment" criteria was not clear. The intent was that a solution with good operational impact or little conflict with existing equipment would score a maximum five points. The scale did not specify nor did the chairman's instructions clearly indicate that a solution having bad impact should receive fewer points. Moreover, a solution assessed as having low conflict with existing equipment (deemed to be a good thing) could mistakenly be coded as "low" on the evaluation scale, and assigned 1 point rather than the maximum 5 points it should have been given. To avoid these problems, the scale should have been tested prior to the evaluation.

Note that some solutions were not evaluated by all participants. This was due to several factors:

(a) some participants had not read the reports prior to the presentations, and if the solution was not briefed in the presentation, the participants were not in a position to evaluate it;

(b) there was not enough time to evaluate all of the solutions;

(c) some participants simply voted "no" to follow-up and did not take the time to evaluate the potential solutions using the scale provided;

(d) others simply did not feel like there was enough information available to make an evaluation.

4.2 Recommendations

1. Canadian Forces Health Services (CFHS) under the Surgeon General (Surg Gen) should use the exercise program study results (Hebert and Roy, 2012) and incorporate neck musculature awareness into flight surgeon briefs to aircrew. These briefs should include demonstrations of neck stretching and self-massage. The exercise program study should also indicate the proper exercise equipment that would then be made available to aircrew.

2. 1 Canadian Air Division (1 CAD)/Division Surgeon General should staff an Air Command Order (ACO) or CAD Order (CADO) that mandates a preventative exercise program.

3. 1CAD A4 Maintenance should investigate and evaluate the helmet fitting process and technician training. Technicians should also educate the aircrew on proper helmet fit.

4. 1 CAD/1 Wing, with Flight Surgeon input, should investigate and quantify the ergonomic deficiency of existing “rag and tube” seating. A Statement of Capability Deficiency (SOCD) should be generated for 1 CAD review and support.

5. Through AIR SUSTAIN Thrust Advisory Group processes, DRDC/CFEME should investigate the decrease of head supported mass by characterizing better limits for helmet requirements (i.e., CoG, moment of inertia, and maximum weight limits) as well as conduct technology watch activities on new NVG technologies.

6. 1 CAD should explore opportunities to modify and optimize Force Generation (FG) activities so as to reduce the average NVG mission duration and head-mounted mass exposure during low operational demand.

7. Through DTAES, DRDC/CFEME should undertake a mission function task analysis and physical demands analysis in order to better understand the tasks within the mission preparation and mission execution environment to determine best areas of potential intervention.

8. Through AIR SUSTAIN Thrust Advisory Group processes, DRDC/CFEME will contract the production of on-body, elastomer-based, helmet support prototype systems. These prototypes could be linked to a body girdle prototype to increase back support, especially for the flight engineer and possibly the pilots. These prototypes will be evaluated for usefulness, efficacy, and user acceptance.

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Annex A Tabulated Evaluation Data

The evaluation data was tabulated for each potential solution.

Table 8. Evaluation data for TRI1—modified NVG support system.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	1	2	3	n/a	3	4	3	
Usability:									
feasibility of airworthiness certification	3	2	3	2	3	4	3	3	
user impression	2	3	2	3	4	3	4	3	
ease of use	4	2	4	4	4	2	4	3	
ease of implementation	3	4	4	1	3	3	2	3	
conflict with existing equipment	2	3	3	2	4	4	3	2	
Operational impact	3	4	2	3	1	n/a	4	3	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	2	2	2	5	3	4	3	
reduces exposure to forces	3	1	2	3	4	3	4	3	
reduces compromising postures	1	1	1	2	3	2	4	2	
reduces compromising tasks	2	2	1	3	3	1	4	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.53	0.45	0.47	0.51	0.68	0.56	0.73	0.53	**0.56**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	M	M	M	M	Y	M	Y	M	M (6/8)

Table 9. Evaluation data for TRI2—quick release for NVG and HUD.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	2	4	4	n/a	3	4	5	
Usability:									
feasibility of airworthiness certification	4	4	3	2	3	4	3	4	
user impression	3	4	4	4	4	3	5	4	
ease of use	4	4	5	4	4	3	5	4	
ease of implementation	3	3	5	1	2	4	3	4	
conflict with existing equipment	2	1	4	3	4	3	2	5	
Operational impact	2	3	4	3	1	n/a	5	5	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	3	3	2	3	1	5	5	
reduces exposure to forces	3	4	3	3	4	1	5	5	
reduces compromising postures	1	5	2	2	4	3	4	3	
reduces compromising tasks	2	3	2	3	4	1	4	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.51	0.65	0.71	0.56	0.66	0.52	0.82	0.82	**0.66**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	M	M	Y	Y	Y	M	Y	Y	Y (5/8)

Table 10. Evaluation data for TRI3—reading glasses for NVG.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	5	3	1	n/a	3	3	3	
Usability:									
feasibility of airworthiness certification	4	4	4	1	1	3	3	4	
user impression	3	5	3	1	1	3	3	4	
ease of use	4	5	4	2	1	3	4	5	
ease of implementation	4	1	4	2	1	4	4	4	
conflict with existing equipment	3	1	3	3	1	4	4	4	
Operational impact	2	5	3	3	n/a	n/a	5	3	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	1	3	1	1	1	n/a	1	
reduces exposure to forces	1	1	3	1	1	1	n/a	1	
reduces compromising postures	2	1	3	1	1	3	5	3	
reduces compromising tasks	1	1	3	1	1	3	5	3	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.53	0.55	0.65	0.31	0.20	0.56	0.80	0.64	**0.53**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	n/a	Y	Y	N	N	M	Y	Y	Y (4/7)

Table 11. Evaluation data for TRI4—low friction collar.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	3	2	1	n/a	4	3	3	
Usability:									
feasibility of airworthiness certification	3	3	4	3	2	4	4	2	
user impression	2	2	2	1	1	4	3	3	
ease of use	4	4	4	2	1	4	4	5	
ease of implementation	4	5	3	3	1	4	3	3	
conflict with existing equipment	2	1	3	4	1	3	2	5	
Operational impact	2	2	2	2	5	n/a	3	3	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	1	2	1	2	3	3	2	
reduces exposure to forces	2	1	2	1	1	2	3	2	
reduces compromising postures	1	1	1	3	1	3	n/a	4	
reduces compromising tasks	1	1	1	3	1	2	n/a	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.47	0.44	0.47	0.44	0.32	0.66	0.62	0.60	**0.50**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	n/a	M	N	M	N	Y	Y	M	M (3/7)

Table 12. Evaluation data for TRI5—mechanisms to redistribute the weight of the helmet from the neck to the shoulder (collar jack).

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	1	4	1	n/a	1	2	2	
Usability:									
feasibility of airworthiness certification	1	1	2	1	1	1	2	2	
user impression	2	1	2	1	1	1	2	2	
ease of use	2	1	3	1	1	1	2	4	
ease of implementation	1	1	2	1	1	1	2	2	
conflict with existing equipment	1	1	3	5	1	1	1	1	
Operational impact	2	n/a	3	5	5	n/a	2	2	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	3	4	1	3	4	4	5	
reduces exposure to forces	3	3	4	1	3	4	4	5	
reduces compromising postures	2	1	2	1	4	3	2	1	
reduces compromising tasks	1	1	2	1	1	3	2	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.36	0.28	0.56	0.35	0.42	0.40	0.45	0.49	**0.41**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	N	N	M	N	N	N	M	M	N (5/8)

Table 13. Evaluation data for TRI6—flexi-support.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	1	3	2	n/a	2	2	3	
Usability:									
feasibility of airworthiness certification	3	1	2	1	1	2	3	4	
user impression	2	1	3	1	1	2	3	3	
ease of use	3	3	3	2	1	3	2	5	
ease of implementation	3	1	2	2	1	2	2	4	
conflict with existing equipment	2	5	3	5	1	3	2	4	
Operational impact	2	1	3	3	1	n/a	3	3	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	1	3	2	3	1	3	3	
reduces exposure to forces	3	1	3	3	3	1	4	3	
reduces compromising postures	3	4	3	3	3	2	4	4	
reduces compromising tasks	1	1	3	1	2	2	4	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.49	0.36	0.56	0.45	0.34	0.40	0.58	0.67	**0.48**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	n/a	N	M	N	N	N	M	Y	N (4/7)

Table 14. Evaluation data for TRI7—Griffon simulator.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	4	3	4	3	n/a		3	4	
Usability:									
feasibility of airworthiness certification	n/a	3	n/a	1	1		n/a	n/a	
user impression	3	3	4	2	3		4	4	
ease of use	n/a	5	4	1	1		4	4	
ease of implementation	2	1	3	1	1		n/a	4	
conflict with existing equipment	4	1	5	1	n/a		n/a	n/a	
Operational impact	3	n/a	4	1	n/a		4	4	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	n/a	n/a	n/a	n/a	n/a		4	4	
reduces exposure to forces	n/a	n/a	n/a	n/a	n/a		4	4	
reduces compromising postures	n/a	n/a	n/a	n/a	n/a		4	4	
reduces compromising tasks	n/a	n/a	n/a	n/a	n/a		4	4	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.64	0.53	0.80	0.29	0.30		0.78	0.80	**0.59**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	M	Y	Y	M	Y		M	Y	Y (4/7)

Table 15. Evaluation data for TRI8—shift of thinking–education and exercise program during work hours.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	4	5	5	5	5	n/a	4	4	
Usability:									
feasibility of airworthiness certification	n/a	5	5	n/a	5	n/a	n/a	n/a	
user impression	4	5	5	5	5	4	4	4	
ease of use	4	5	3	4	5	4	4	4	
ease of implementation	4	5	3	4	5	3	4	4	
conflict with existing equipment	n/a	1	n/a	1	1	n/a	n/a	n/a	
Operational impact	3	n/a	5	1	5	n/a	4	3	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	5	4	5	4	n/a	4	2	
reduces exposure to forces	2	5	4	5	3	n/a	4	3	
reduces compromising postures	3	n/a	4	5	3	n/a	n/a	2	
reduces compromising tasks	1	5	4	5	3	n/a	n/a	2	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.60	0.91	0.84	0.80	0.80	0.73	0.80	0.62	**0.76**
Suggested for follow up (**Y**es, **N**o, **M**aybe)	Y	Y	Y	Y	Y	Y	Y	Y	Y (8/8)

Table 16. Evaluation data for QU1—elastomer-based helmet system support (on-body).

	Participants								
	1	2	3	4	5	6	7	8	
Utility	4	4	4	2	3	n/a	3	3	
Usability:									
feasibility of airworthiness certification	3	3	3	3	2	3	3	2	
user impression	3	2	4	3	2	4	3	3	
ease of use	4	2	4	2	3	4	2	3	
ease of implementation	3	3	4	2	1	4	2	3	
conflict with existing equipment	2	4	3	4	1	4	2	2	
Operational impact	3	3	4	3	1	n/a	2	2	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	4	4	3	1	4	3	3	
reduces exposure to forces	3	4	4	2	1	4	3	4	
reduces compromising postures	1	5	3	2	1	4	1	1	
reduces compromising tasks	1	4	3	2	1	4	1	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.55	0.69	0.73	0.51	0.31	0.78	0.45	0.49	**0.56**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	Y	Y	Y	M	n/a	Y	M	Y	Y (5/7)

Table 17. Evaluation data for QU2—seat mounted cable.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	n/a	2	1	3	n/a	3	3	
Usability:									
feasibility of airworthiness certification	2	1	2	1	1	1	2	2	
user impression	3	2	2	1	1	2	2	2	
ease of use	3	3	3	2	1	2	3	3	
ease of implementation	3	2	2	1	1	2	2	2	
conflict with existing equipment	2	4	3	4	1	2	2	2	
Operational impact	3	3	n/a	5	n/a	n/a	2	2	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	3	2	3	1	5	3	3	
reduces exposure to forces	3	3	2	2	1	4	3	4	
reduces compromising postures	2	2	3	2	1	4	1	1	
reduces compromising tasks	1	2	2	2	1	4	1	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.49	0.50	0.46	0.44	0.24	0.58	0.44	0.45	**0.45**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	M	M	N	n/a	N	M	M	M (5/7)

Table 18. Evaluation data for QU3—shoulder girdle based helmet systems support (on-body).

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	n/a	3	2	1	n/a	1	3	
Usability:		n/a							
feasibility of airworthiness certification	2	n/a	3	3	1	1	2	2	
user impression	2	n/a	2	3	1	3	1	3	
ease of use	3	n/a	2	2	1	3	1	3	
ease of implementation	2	n/a	2	2	1	1	2	2	
conflict with existing equipment	2	n/a	2	4	1	1	1	2	
Operational impact	2	n/a	2	3	n/a	n/a	1	2	
Potential for reducing incidence/severity of neck pain:		n/a							
reduces forces on neck muscles	2	n/a	4	3	1	4	2	3	
reduces exposure to forces	2	n/a	4	2	1	4	2	4	
reduces compromising postures	1	n/a	4	2	1	4	1	1	
reduces compromising tasks	1	n/a	4	2	1	4	1	1	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.38		0.58	0.51	0.20	0.56	0.27	0.47	**0.42**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	N		M	M	n/a	N	N	M	M,N (3/6)

Table 19. Evaluation data for QU4—procure a new helmet/NVG system (TopOwl®).

	Participants								
	1	2	3	4	5	6	7	8	
Utility	n/a	5	4	4	n/a	n/a	5	n/a	
Usability:									
feasibility of airworthiness certification	n/a	4	3	4	n/a	n/a	5	n/a	
user impression	n/a	5	3	4	n/a	n/a	5	n/a	
ease of use	n/a	5	4	4	n/a	n/a	5	n/a	
ease of implementation	n/a	2	2	1	n/a	n/a	5	n/a	
conflict with existing equipment	n/a	1	4	3	n/a	n/a	5	n/a	
Operational impact	n/a	5	4	2	n/a	n/a	5	n/a	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	n/a	4	4	5	n/a	n/a	5	n/a	
reduces exposure to forces	n/a	4	3	5	n/a	n/a	5	n/a	
reduces compromising postures	n/a	4	3	5	n/a	n/a	5	n/a	
reduces compromising tasks	n/a	4	3	5	n/a	n/a	5	n/a	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)		0.78	0.67	0.76			1.00		**0.80**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	Y	M	Y	N	N	Y	n/a	Y (3/7)

Table 20. Evaluation data for QU5—improve capacity of the neck system to withstand the head borne mass.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	4	5	4	5	5	n/a	4	n/a	
Usability:									
feasibility of airworthiness certification	n/a	5	4	n/a	5	n/a	n/a	n/a	
user impression	4	5	4	5	5	n/a	4	n/a	
ease of use	4	5	3	4	5	n/a	4	n/a	
ease of implementation	3	5	3	4	4	n/a	4	n/a	
conflict with existing equipment	n/a	1	5	1	5	n/a	n/a	n/a	
Operational impact	3	5	4	1	5	n/a	4	n/a	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	1	5	4	5	4	n/a	4	n/a	
reduces exposure to forces	1	5	4	5	4	n/a	4	n/a	
reduces compromising postures	2	5	4	5	4	n/a	n/a	n/a	
reduces compromising tasks	1	5	4	5	4	n/a	n/a	n/a	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.51	0.93	0.78	0.80	0.91		0.80		**0.79**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	n/a	Y	Y	Y	n/a	Y	Y		Y (5/5)

Table 21. Evaluation data for QU6—conservative maintenance standards for rotor track balance.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	4	4	4	n/a	2	3	n/a	
Usability:									
feasibility of airworthiness certification	4	5	4	n/a	n/a	4	3	n/a	
user impression	4	4	3	4	n/a	3	3	n/a	
ease of use	3	3	3	4	n/a	4	4	n/a	
ease of implementation	3	4	3	3	n/a	2	4	n/a	
conflict with existing equipment	5	1	4	3	n/a	4	3	n/a	
Operational impact	3	4	3	n/a	n/a	n/a	3	n/a	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	3	2	3	n/a	n/a	2	n/a	
reduces exposure to forces	3	3	2	3	n/a	n/a	2	n/a	
reduces compromising postures	1	3	2	3	n/a	n/a	n/a	n/a	
reduces compromising tasks	1	3	2	3	n/a	n/a	n/a	n/a	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.60	0.67	0.58	0.67		0.63	0.60		**0.63**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	Y	Y	M	Y	N	Y	Y		Y (5/7)

Table 22. Evaluation data for QU7—revised process for workload distribution.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	4	4	5	3	n/a	4	n/a	
Usability:									
feasibility of airworthiness certification	2	3	4	n/a	5	n/a	n/a	n/a	
user impression	2	3	4	4	3	n/a	n/a	n/a	
ease of use	2	3	3	3	3	n/a	n/a	n/a	
ease of implementation	2	3	3	3	4	n/a	n/a	n/a	
conflict with existing equipment	5	2	4	1	5	n/a	n/a	n/a	
Operational impact	2	3	4	5	5	n/a	4	n/a	
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	1	3	4	4	3	n/a	4	n/a	
reduces exposure to forces	3	3	4	3	3	n/a	4	n/a	
reduces compromising postures	1	3	4	3	3	n/a	2	n/a	
reduces compromising tasks	2	3	4	4	3	n/a	2	n/a	**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.45	0.60	0.76	0.70	0.73		0.67		**0.65**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	n/a	Y	Y	n/a	Y	Y	Y	Y (5/6)

Table 23. Evaluation data for QU8—standardized process individually optimize helmet systems fit.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	5	3	5	5	n/a	5		
Usability:									
feasibility of airworthiness certification	n/a	3	4	n/a	5	n/a	n/a		
user impression	3	4	3	5	5	n/a	4		
ease of use	3	4	4	5	4	n/a	4		
ease of implementation	2	4	3	5	4	n/a	4		
conflict with existing equipment	5	n/a	4	1	5	n/a	4		
Operational impact	3	5	3	2	5	n/a	5		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	3	3	4	3	n/a	4		
reduces exposure to forces	1	3	3	3	3	n/a	4		
reduces compromising postures	2	3	3	4	3	n/a	2		
reduces compromising tasks	1	3	3	3	3	n/a	2		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.48	0.74	0.65	0.74	0.82		0.76		**0.70**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	n/a	Y	Y	n/a	Y	Y		Y (4/5)

Table 24. Evaluation data for QU9—improved options/opportunities for self-care.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	5	4	5	5	n/a	4		
Usability:									
feasibility of airworthiness certification	n/a	n/a	4	n/a	5	n/a	n/a		
user impression	3	5	4	5	5	n/a	4		
ease of use	3	5	3	5	4	n/a	4		
ease of implementation	1	3	3	4	4	n/a	4		
conflict with existing equipment	5	n/a	4	1	4	n/a	n/a		
Operational impact	3	5	4	2	5	n/a	4		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	1	5	4	4	3	n/a	4		
reduces exposure to forces	1	5	4	3	3	n/a	4		
reduces compromising postures	1	5	4	5	3	n/a	n/a		
reduces compromising tasks	1	5	4	5	3	n/a	n/a		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.42	0.96	0.76	0.78	0.80		0.80		**0.75**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	Y	Y	Y	n/a		Y		Y (4/5)

Table 25. Evaluation data for QU10—neck brace support system.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	1	3	1			2		
Usability:									
feasibility of airworthiness certification	2	1	3	1			2		
user impression	2	1	2	1			2		
ease of use	3	1	2	2			2		
ease of implementation	3	1	2	2			2		
conflict with existing equipment	2	1	2	5			1		
Operational impact	3	5	3	4			1		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	3	3	3			4		
reduces exposure to forces	3	2	3	2			4		
reduces compromising postures	1	3	3	3			1		
reduces compromising tasks	1	3	3	1			1		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.44	0.40	0.53	0.45			0.40		**0.44**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	N	M	N	N		N		N (4/6)

Table 26. Evaluation data for QU11—flexible mount to support the MX-15 visioning system.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	4	4	2			3		
Usability:									
feasibility of airworthiness certification	2	2	4	1			3		
user impression	3	3	2	2			3		
ease of use	2	4	4	3			3		
ease of implementation	2	4	2	1			3		
conflict with existing equipment	1	4	2	4			2		
Operational impact	3	3	4	3			3		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	4	4	3			n/a		
reduces exposure to forces	3	4	4	2			n/a		
reduces compromising postures	3	4	4	4			4		
reduces compromising tasks	1	4	4	3			4		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.47	0.73	0.69	0.51			0.62		**0.60**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	M	Y	M	M			Y		M (3/5)

Table 27. Evaluation data for QU12—fold up seating.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	3	5	4	4			3		
Usability:									
feasibility of airworthiness certification	3	5	3	2			3		
user impression	3	5	4	4			4		
ease of use	3	5	4	3			4		
ease of implementation	2	5	2	1			3		
conflict with existing equipment	3	1	2	3			2		
Operational impact	3	5	4	3			2		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	5	4	3			n/a		
reduces exposure to forces	3	5	4	4			n/a		
reduces compromising postures	3	5	4	4			4		
reduces compromising tasks	1	5	4	2			4		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.53	0.93	0.71	0.60			0.64		**0.68**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	Y	**Y**	Y	Y			Y		Y (5/5)

Table 28. Evaluation data for QU13—enhanced visual capability.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	1	5	4	2			4		
Usability:									
feasibility of airworthiness certification	2	4	2	1			4		
user impression	1	5	4	2			4		
ease of use	2	5	4	1			4		
ease of implementation	1	4	2	1			4		
conflict with existing equipment	2	2	3	5			4		
Operational impact	2	5	4	4			4		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	3	5	4	2			n/a		
reduces exposure to forces	3	5	4	2			n/a		
reduces compromising postures	3	5	4	4			5		
reduces compromising tasks	3	5	4	4			5		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.42	0.91	0.71	0.51			0.84		**0.68**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	N	Y	Y	M			Y		Y (3/5)

Table 29. Evaluation data for QU14—duplicated instrumentation.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	1	5	4	2			4		
Usability:									
feasibility of airworthiness certification	2	5	3	1			3		
user impression	1	5	4	1			3		
ease of use	2	5	4	2			3		
ease of implementation	2	5	2	1			3		
conflict with existing equipment	2	1	2	5			3		
Operational impact	2	5	4	5			3		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	4	4	2			3		
reduces exposure to forces	3	4	4	2			3		
reduces compromising postures	2	4	4	2			5		
reduces compromising tasks	2	4	4	2			5		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.38	0.85	0.71	0.45			0.69		**0.62**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	N	**Y**	Y	N			Y		Y (3/5)

Table 30. Evaluation data for QU15—knee padding for flight engineers.

	Participants								
	1	2	3	4	5	6	7	8	
Utility	2	5	4	3	n/a		3		
Usability:									
feasibility of airworthiness certification	3	5	4	3	5		3		
user impression	2	5	4	3	5		3		
ease of use	3	5	4	3	5		3		
ease of implementation	3	5	3	2	5		3		
conflict with existing equipment	2	1	4	3	5		3		
Operational impact	2	5	3	2	5		3		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles	2	4	3	2	5		n/a		
reduces exposure to forces	2	4	3	3	5		4		
reduces compromising postures	1	4	3	3	5		4		
reduces compromising tasks	1	4	3	3	5		n/a		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)	0.42	0.85	0.69	0.55	1.00		0.64		**0.69**
Recommend for follow up (**Y**es, **N**o, **M**aybe)	n/a	Y	Y	Y	Y		Y		Y (5/5)

Table 31. Evaluation data for QU16—portable handles.

	Participants								
	1	2	3	4	5	6	7	8	
Utility		5	4	3			3		
Usability:									
feasibility of airworthiness certification		5	2	2			3		
user impression		5	3	3			3		
ease of use		5	3	3			3		
ease of implementation		5	2	2			3		
conflict with existing equipment		1	2	4			3		
Operational impact		4	4	3			3		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles		3	4	2			4		
reduces exposure to forces		3	4	2			4		
reduces compromising postures		4	4	3			3		
reduces compromising tasks		3	4	3			3		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)		0.78	0.65	0.55			0.64		**0.65**
Recommend for follow up (**Y**es, **N**o, **M**aybe)		Y	Y	Y			Y		Y (4/4)

Table 32. Evaluation data for QU17—cabin door stops.

	Participants								
	1	2	3	4	5	6	7	8	
Utility		5	4	1			3		
Usability:									
feasibility of airworthiness certification		3	2	1			3		
user impression		4	3	2			3		
ease of use		5	3	3			3		
ease of implementation		2	2	1			3		
conflict with existing equipment		1	2	1			3		
Operational impact		4	4	2			3		
Potential for reducing incidence/severity of neck pain:									
reduces forces on neck muscles		3	4	1			3		
reduces exposure to forces		3	4	1			4		
reduces compromising postures		3	4	1			4		
reduces compromising tasks		3	4	1			3		**Averaged normalized score**
NORMALIZED TOTAL SCORE (on max score=55)		0.65	0.65	0.27			0.64		**0.55**
Recommend for follow up (**Y**es, **N**o, **M**aybe)		Y	Y	N			Y		Y (3/4)

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Annex B Evaluator Comments and Notes

Comments and notes are presented verbatim from evaluation sheets in point form for each potential solution. Comments made at the bottom of the evaluation sheets are presented first followed by any notes made next to an evaluaton criterion (a semicolon dividing comments and notes).

B.1 TRI1- Modified NVG Support Mechanism

- HGU-56 vice SPH-5; snagging/egress issues (under water!); doffing/donning
- Requires aerodynamic testing; follow-up maybe if integrated into a different helmet; limited use in stowed position where there is most benefit.
- Intuitively the periods when this solution would be of benefit (because NVG would be in up/stowed position to improve CoG), i.e. before and after the flight, are relatively short. Little or no reduction in moments for most of flight.
- Cost dev, AW
- Value over the existing installation is not clearly apparent as no direct comparison was provided. The use of the extra shell will increase the moment arm while bending is occurring. Provides improvement when head is in neutral or near neutral. Is there an overall increase of HMM? i.e. increase over existing setup?; egress/snag hazard and ease of use most concerning; appears fairly easy to implement; moves CoG closer to head in 2 of 3 positions but is worst since further away from head in other positions.
- Definitely worth investigating, concern about kinesthetic awareness with NVG in stowed position on head. Evaluate the effect of mass at vertex on rotational moments, are we transferring issue to rotational axis? (to lesser extent given reduced moment arm); need to define % time NVG worn but not used.
- FE SME suggests NVGs not used preflight. This is contrary to collateral info and needs to be clarified (helmet worn in winter, etc.)The greater the time NVGs worn when not required the greater the utility and operational impact.; operational impact depends on time NVG worn but not used..

B.2 TRI2- Quick Release for NVG and HUD

- Crash loads? (AW)
- Note that NVGs are always worn unless transitioning between dusk to night (SAR). Removing and reinstalling NVGs is not a prudent practice in dark conditions and conflicts with situational awareness.; may be useful to SAR.
- Having possibility to quickly remove the weight of NVGs for a short time under most strenuous (i.e. while working on CDUs) positions may offer a good improvement; operational impact high (4) in a positive way; when NVGs removed temporarily to access CDU=reduces neck forces.

- Good idea, need to look at quick release during high impact.

- Permits NVGs to be stowed when not needed, may reduce time wearing NVGs. Re-engineering of connections to/from helmet/NVGs required may be more involved than anticipated. Little apparent improvement over existing mount/ connectors. Concerns with impact of NVG removed if using counter weight; breakaway hazards associated with installation and removal while flying; storage may be an issue.

- Excellent to reduce head supported mass. Evaluate force to actuate quick release. Does the quick release mechanism (doc station) add additional moment arm. HF usability- any concerns with sensitivity of NVG (would this effect calibration?); reduce mass (operational impact).

- Unnecessary time with goggles/helmet worn is possibly unclear and will determine potential impact to reduce exposure (know association with pain). Should investigate whether goggles need to be refocused when removed/ reinserted.

B.3 TRI3- Reading Glasses for NVG

- Different illumination requirements?

- If integrated into the goggle with a lever that drops in the lense, like an optometrists sight tester. Must be integrated into the goggle.; Clarity is key to accuracy!

- May serve pilots as well as FEs however add a few more grams away from head CoG (increased moments); may help avoid over extension to view switches on overhead panel.

- Not a req for this project.

- Windblast issues/dirt/etc. may be difficult to meet.; impact of glare on lenses; reduced transmittance of NVGs; FOV reductions; in advertent deployment; windblast; seems to add weight to NVGs.

- Excellent! Great way to address postural conditions that arises from FOV and visual acuity issues. Eliminates hyperextension at neck *address posture. Evaluate in conjunction wrt other engineer soln.; verify integration with NVG (conflict with existing equ.)

- Not likely a factor for neck strain but appears to have potential benefit to operational effectiveness which should be explored. Some benefit due to awkward posture looking under goggles but not sure how much this happens.

B.4 TRI4- Low Friction Collar

- Materials (FR) (fire resistance)

- If used in conjunction with LPSV bladder improvements.

- Friction against head movement is not a significant contributor to neck pain.

- Too much interference with other ALSE would require complete re-design of LP/SV.

- Easy solution if it is shown to make an improvement. Further quantitative tests should be undertaken to attempt to measure the potential improvement as significant effort would be required to implement this change to all LPSVs and helmet edges.; easy solution; fire resistance; ballistic protection; requires modification of current LPSV materials.

- Some investigation is required to understand if bulk or friction that causes "hang ups". Marginal reduction in forces and postures.

- If material meeting friction/ fire resistant/ballistic properties required for function and airworthiness should investigate how much this contributes to pain/ discomfort and poor postures.

B.5 TRI5- Mechanisms to Redistribute the Weight of the Helmet from Neck to Shoulder (Collar Jack)

- Seems to run counter to CT-155 issues (reducing contact with base of helmet)

- Impacts range of movement, interferes with LPSV and crewmen's harness.

- Seems like a difficult solution to adapt to existing equipment and body sizes.

- Dangerous idea!

- Added holes to shell, reduce impact protection possibly added weight, height could lend to cockpit interference.

- Very unlikely to find a suitability solution that meets airworthiness requirements. Does not seem suitability for pilot/co-pilot.; significant issues regarding egress, snags, and integration; with existing ALSE; use of compressed air introduces. FOV and ROM would be restricted; only addresses backend issue.

- Mobility and postural issues, possible safety concern because of restricted ROM, voted maybe per Dr Fernie comments need to follow through the mechanism.; possible ROM restriction.

- Issue for pilots especially is the need for immediate head mobility for flight safety and performance. Maybe less of an issue for FE/ SAR; user impression maybe different between pilot and FE.

B.6 TRI6- Flexi-Support

- Risk to expose body more.

- Does not appear feasible. Need to understand amounts of time spent in extended posture.; egress issues; installation issues on floor; hazard

- FE comments posture to search and look out is minimal. Reduces high forces at lumbar spine. Addresses posture when performing scanning- search and rescue. Off load upper torso BW while in prone position.

- Unloads torso but not neck. May decrease whole spine muscle activation and indirectly help neck, would need to be validated with user trials.

B.7 TRI7- Griffon Simulator

- Useful for isolating cause factors, controlled environment for development.

- This would be a unique research tool that seems to have a great potential. We may be able to sell "time" on it to other national armed forces.; This is a research tool that may results in achieving these objectives (reducing neck pain).

- Long and costly venture.

- High cost. Need to determine the fidelity or resolution of simulation required. What is necessary for ARP?; important to evaluate design concepts (ops impact); enables all of these to be measured and evaluates (reduce neck pain).

- Enabler of robust controlled experiments can reduce requirements for in flight testing at earlier stages.; indirectly has strong operational impact.

B.8 TRI8- Shift of Thinking- Education, Exercise Program During Work Hours.

- The premise of being treated and thought of as athletes and implementing preventive and targeted programs is brilliant.

- More likely will improve personal resilience to existing stressors/ prevent onset of pain/ injury.

- Absolutely DO- implement!! Expand training audience to include aircrew and ALSE techs (for importance of ensuring helmets and ALSE fit perfectly on aircrew!)

- Should be targeted first as cheaper and less effort to achieve.

- Concept of proscribing an exercise program should also include posture education. Should also include "routine/regular" re-assessments of posture.; unknown but results should lead to stronger necks. (reducing neck strain)

- Definitely pursue exercise intervention and "shift of thinking" is a critical enabler: requires buy-in. Needs to be in conjunction with engineering solutions. Ensure top-down support from CF.

- Exercise program is already approved and about to commence FSG recently published on DSurg website- could be modified. Education and change in philosophy should be explored further.

B.9 QU1- Elastomer-Based Helmet System Support (On-Body)

- Explore different configs to allow more motion (e.g. 2 straps in "X"). Advantage over C.W. is that force vector is maintained relative to helmet axis regardless of body position.; anchoring and integration issues.

- If integrated into a garment that reduces loads to the back and can attach to back of helmet.; if integrated to a body harness/ girdle; maybe if used with a weight bearing girdle; possible snag issues; possible if done right.

- Must strive to make back of helmet as flush as possible to reduce interferences.

- Custom fitted? Extreme too much tension? life of elastomer.

- At first glance this does not seem very feasible however working through, it would be a very good solution if the concerns of egress/ snag hazard can be significantly reduced.; will definitely be more work; needs work; should be easy to integrate; should be easy to integrate with LPSV; high potential.

- A potential to transfer this from forward-flexion to moments about axial axis (medial-lateral rotation). Requiring additional neck extensor moments. Where would the elastomer attach on the body? Where is focal point?

- Snag hazard- feed inside LPSV; rotation restriction needs to be addressed; dynamic issues; needs validation of primary neck flexion as problem.

B.10 QU2- Seat Mounted Cable

- Forces axis is function of torso height. Less effective for short people.; egress issues.

- Can become an egress issue.

- Not ideal due to connect to seat.; difficult to certify due to connection to A/C seat.; need to address issues of quick release.

- Where is the focal point for the cable? Specify the attachment strategies- difference to this will affect the overall effectiveness of the counterbalance. Potential to increase moments in moment and lever and axial rotational axes. Safety concerns with being tied off to seat?; affects forward flexion rotational moment only.

- Need to address rapid egress in dark/ underwater, etc. Needs to conform to torso shifting.

B.11 QU3-Shoulder Girdle Based Helmet Systems Support (On-Body)

- Appears to generate a pivot /load point on the lower neck- similar to LPSV problem.; egress/ snagging; integration with LPSV, tether, body armour.

- Not ideal due to bulk- little to no perceived benefit to simple on body choice.; already too much bulk on individual.

- Same concerns as previous tethered designs.

- ALSE integration issues. Need to avoid interference inducing poor posture.; need LPSV integration; snag hazard.

B.12 QU4-Procure a New Helmet/ NVG System (TopOwl®)

- Other helmets may be worthy of consideration (alpha Series, Gallet). Not enough info to assess Top Owl.

- Concerns for Top Owl: cost, significant impact on depth perception. Pros: flight msn symbology, head tracking?; stereo? (for 3D audio potential).

- Too many issues to implement.

- Review of helmet integration for state of the art across the board would be of value after setting / defining requirements and limitations.

- Clearly a new helmet that models mass distribution to centre of mass of head is the 100% solution.

- No proposal put forward.

B.13 QU5-Improve Capacity of the Neck System to Withstand the Head Borne Mass (Exercise)

- Athletic based exercise program with specific and targeted muscle group exercise.

- May reduce sensitivity to existing loads / stressors.

- Exercise program is an excellent initiative, both for aircrew, ALSE tech who fit helmets and ALSE.

- Treat as athletes.; hopefully improves neck pain reduction.

- Surgeon General DRDC lead exercise program, same rating as TRI exercise program.

B.14 QU6-Conservative Maintenance Standards for Rotor Track Balance

- New procedures?; Additional equipment required?; longer to bring aircraft into service.

- May improve wear and tear on a/c as well as aircrew.

- Has to meet ISO standard for Bell Helicopters.

- Current T&B is driven by airworthiness safety of flight not personnel comfort. Offering a WBV aspect to accommodate the comfort may be reasonable.; potential to reduce neck pain.

- DND-DRDC lead activity (NRC). Need to understand the implications of vibration. Understood that it is a mitigating factor (1°or 2°?). If this is a process that can be standardized- definitely worth investigating.

- Admin/ procedural changes are generally implementable in short term. This specifically is dependent on feasibility to further optimize balancing.

B.15 QU7-Revised Process for Workload Distribution

- Operational airworthiness/ availability; scheduling costs.

- Excellent initiative to balance neck pain induced tasks/ missions via administrative tracking of flying program for each aircrew member.

- This has potential.

- This should be integrated into ARP: survey (pain), mission log for NVG over time, MFTA. Inputs from ARP that can be used to develop workload distribution procedures.; Mid-long term effort.

- I like the concept but we need data for evidence-based guidelines. Epidemiological.

B.16 QU8-Standardized Process Individually Optimize Helmet Systems Fit

- Excellent focus to improve awareness of ALSE techs. Bring back qualifications that require refresher training and requalification requirements.

- Already pursuing. Other nations (US Army, Netherlands) are using zeto liners and improved fitting. Info provided to Mr. Poulin (LCMM).

- Customized fit of helmet has been identified as critical element of mass distribution. Need to follow, this again should be led by DND. Model CFAS head scan data 3D model of shape ↔ helmet fit and size.; customization/ finesse/ learned shell.

B.17 QU9-Improved Options/ Opportunities for Self-Care

- Would be nice.; costs/ personnel support

- Must be mandated.

- May improve resistance to loads and stressors.

- Excellent Initiative, educating all aircrew on what specifically is stress areas of neck and methods to avoid overstress, prevention and exercises to assist.

- Exercise- rating is the same as TRI.

B.18 QU10-Neck Brace Support System

- emergency considerations/ FOD
- Dangerous
- Too much interference with other ALSE.

B.19 QU11-Flexible Mount to Support the MX-15 Visioning System

- Challenging to make mount that is light footprint/ easy to use and crashworthy.
- Would improve postures adopted with NVG while monitoring the MX-15 visioning system.

B.20 QU12-Fold-Up Seating

- Not necessarily needs to be a fold up seat however the FE seat must be made a focus for any type of improvement i.e. shape, cushion, posture, etc.
- Improve posture for FE while seated in Griffon. Rag and tube seating does enable FE to reposition and align themselves relative to task.

B.21 QU13-Enhanced Visual Capability (Cameras)

- Low profile
- Under carriage camera/ periscope may be worth consideration. FE input required.
- This would eliminate the FE having to open doors and scan from prone or awkward positions.

B.22 QU14- Duplicated Instrumentation

- Digital radar altimeter for FE.
- Address posture and need to kneel at console b/w pilot and co-pilot. Reduce exposure to awkward postures.

B.23 QU15- Knee Padding for FE

- Would reduce impact on other part of body that affect neck and posture issues.
- Need improved knee pads.
- Would reduce forces at knees during monitor of instruments FE.

B.24 QU16- Portable Handles

- Not enough info, where mounted?
- Worth considering /addressing by Fes/DGs

B.25 QU17- Cabin Door Stops

- Not enough info

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Annex C Brief Description of Potential Solutions

All images and information were taken from Fernie and Mayich (2013) (TRI solutions) and Fischer et al. (2013) (Queen's University solutions).

C.1 TRI1- Modified NVG support mechanism

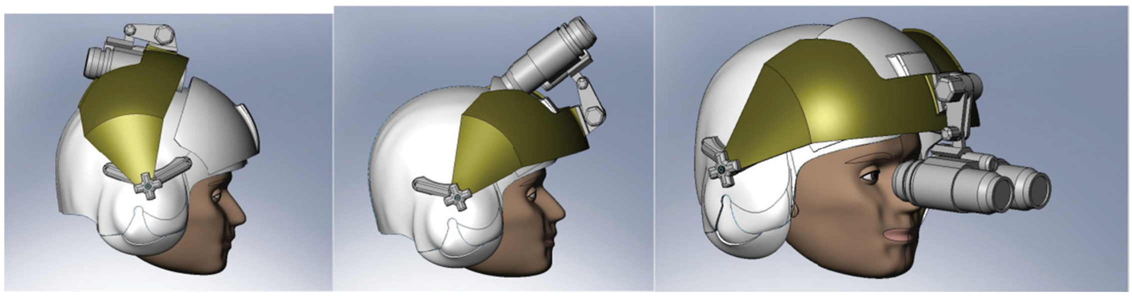

Figure 1. Modified NVG support mechanism.

Note: The support mechanism allows for easier interim use and a stowage position with the weight in a neutral position.

C.2 TRI2- Quick release for NVG and HUD

Figure 2. An example of a quick release system.

Note: The electronics of the NVG are mounted onto the helmet, and the lens portion can be easily removed and stowed.

C.3 TRI3- Reading glasses for NVG

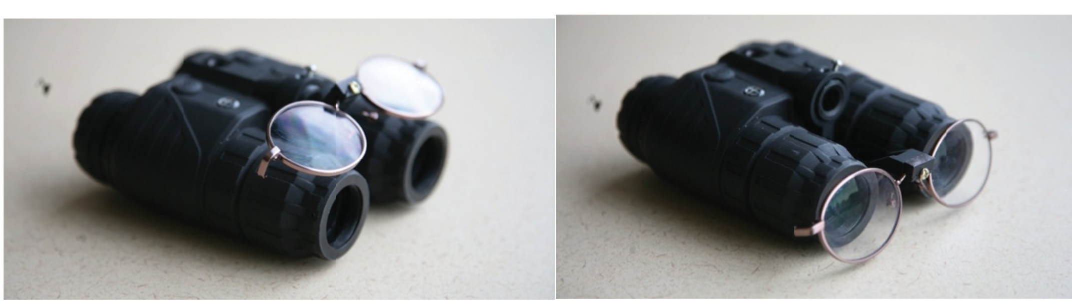

Figure 3. Reading glasses for NVG.

Note: Reading glasses were added to the tip of the NVG lens to change the focal point of viewing. This would only be useful to the FE to focus on proximal tasks through the NVG rather than looking underneath the NVG system.

C.4 TRI4- Low friction collar

Figure 4. Low friction collar.

Note: Low friction collar materials could reduce the forces required for rotation by reducing any resistance between the LPSV collar and helmet.

C.5 TRI5- Mechanisms to redistribute the weight of the helmet from neck to shoulder (collar jack)

Figure 5. Collar jack prototype.

Note: The prototype shows the concept of reducing the helmet forces from the neck to the shoulders.

C.6 TRI6- Flexi-support

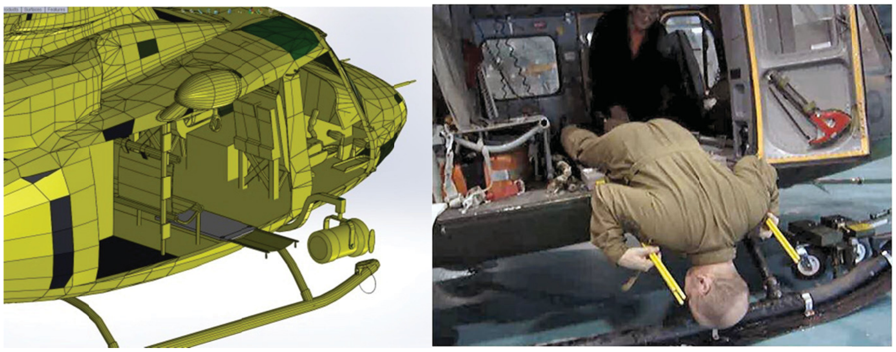

Figure 6. Flexi-support.

Note: The flexi-support is a concept that would assist the FE when scanning on landings. The material chosen could also offer ballistic protection if kevlar was used.

C.7 TRI7- Griffon simulator

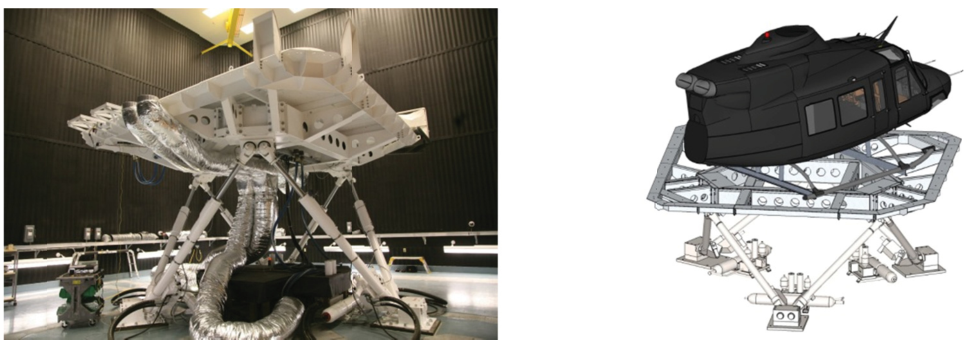

Figure 7. TRI motion platform.

Note: The current motion platform operating at TRI could be mounted with a Griffon shell that would allow for test and evaluation of concepts as well as motion and physiologic data capture.

C.8 TRI8- Shift of thinking- education, exercise program during work hours.

Aircrew should be educated on the mechanics, symptoms, and demands that neck musculature endures during operations. This knowledge will allow them to better treat themselves and give them a better understanding of how to exercise, along with exercise programs designed specifically for the aircrew (Hébert and Roy, 2012 protocol; Äng et al., 2009).

C.9 QU1-Elastomer-based helmet system support (on-body).

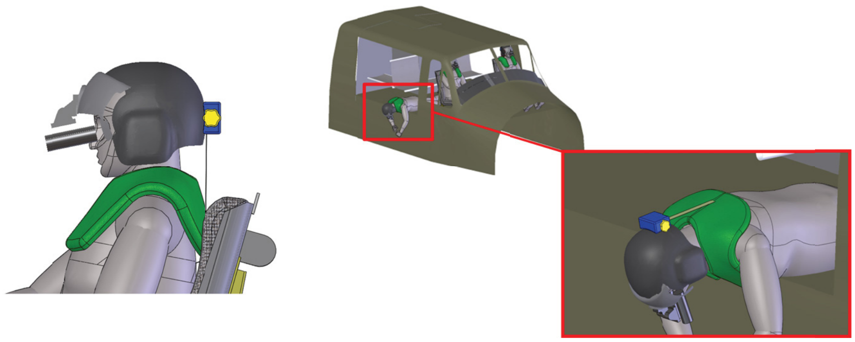

Figure 8. Elastomer support concept.

Note: An elastomer support is attached to the helmet and body, with adjustable tension, that can balance the load of the NVG rather than a counterweight.

C.10 QU2- Seat mounted cable

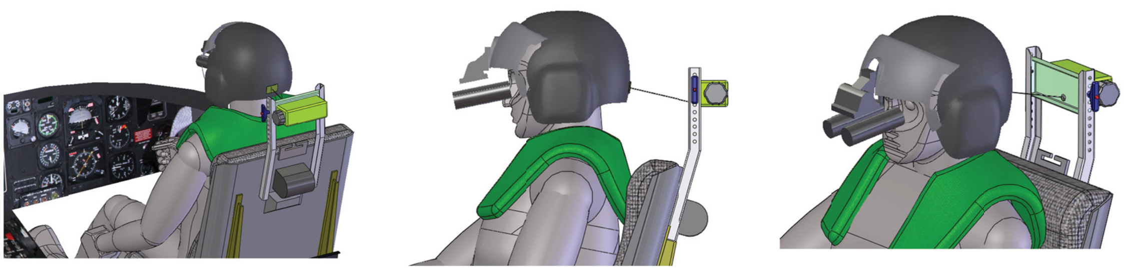

Figure 9. Seat-mounted counterweight concept.

Note: The weight and moment of the NVG system would be counterbalanced by a cable attached to the seat.

C.11 QU3- Shoulder girdle based helmet systems support (on-body)

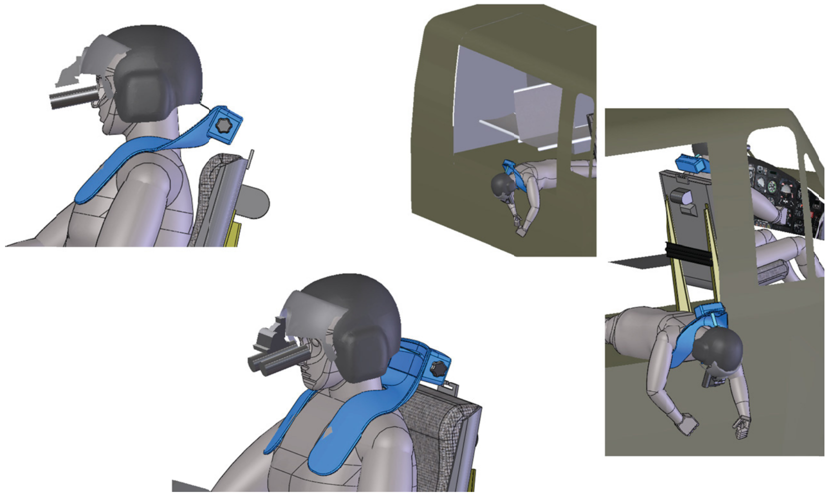

Figure 10. Shoulder girdle counterweight concept.

Note: A shoulder girdle which is worn on the body would counter balance the weight of the NVG system, reducing the forces required from the neck.

C.12 QU4- Procure a new helemt/ NVG system (TopOwl®)

The procurement of a lighter helmet and a NVG integrated system with a shorter moment arm would reduce the forces endured by the neck musculature. More investigation is required.

C.13 QU5- Improve capacity of the neck system to withstand the head borne mass

Consider aircrew as athletes and provide an athletic-based exercise program specific to aircrew that focuses on specific muscle groups and movements. Also, provide exercise space and equipment that is readily and easily accessible during work hours.

C.14 QU6- Conservative maintenance standards for rotor track balance

Introduce a simple system (such as a color coded scale) to ensure that maintenance personnel can adhere to balancing the rotor. A rotor balance of 0.3–0.4 inches/sec—more stringent than the current standard of 0.5 inches/sec as determined by Bell, the helicopter manufacturer—reduces vibrations.

C.15 QU7- Revised process for workload distribution

Scheduling should consider NVG time, previous flight time, length of flights, and individual resistance to muscle discomforts to balance and avoid hurting aircrew.

C.16 QU8- Standardized process individually optimize helmet systems fit.

Ensure that all aircrew have properly fitted helmets.

C.17 QU9- Improved options / opportunities for self-care

Massage therapy (or any similar therapy deemed to be useful) provided by a physiotherapist or professional massage therapist, or a self-use massaging tool—both accessible immediately after flight—should reduce possible damage and decrease recovery time.

C.18 QU10- Neck brace support system

Figure 11. Neck brace.

Note: The brace supports the head borne mass to relieve the demands on neck muscles. This is recommended mostly for when the FE is sitting in the cabin, to replace the need to hold their head/helmet up with their hands.

C.19 QU11- Flexible mount to support the MX-15 visioning system

Figure 12: Flexible mount system.

Note: Using a flexible mount allows pilots to pull the system closer to read rather than lean forward in a compromising posture with the head supported mass.

C.20 QU12- Fold up seating

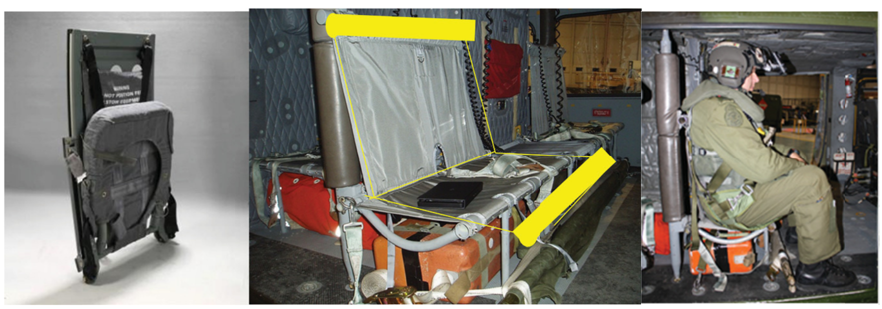

Figure 13. Current and potential seating.

Note: A similar seat is recommended to replace the rag and tube seating currently available to the FE in the cabin. A firmer seat would allow for a better seated posture, reducing the tendency to curve the back and placing the head supported mass in a more neutral posture.

C.21 QU13- Enhanced visual capability

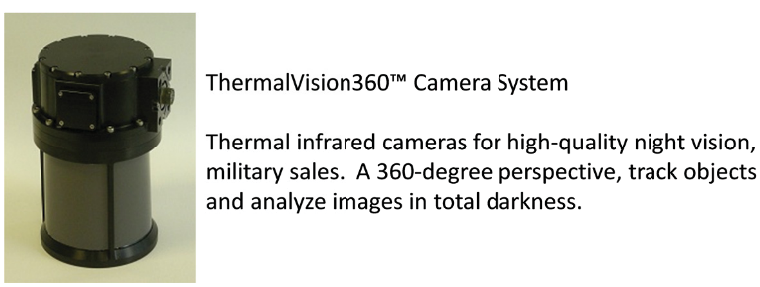

Figure 14. Thermal camera system.

Note: The use of camera systems is recommended to view external areas such as skid to ground distances and tail rotor clearance. The use of cameras could reduce the need for the FE to use extreme postures like looking under the aircraft (Figure 6) and leaning out the open side doors.

C.22 QU14- Duplicated instrumentation

The FE are required to kneel down and verify certain cockpit instruments during flight. If these instruments were duplicated in the cabin, the kneeling posture as well as the back extension of the neck could be avoided.

C.23 QU15- Knee padding for FE

Figure 15. Flight suit with incorporated knee pads.

Note: Incorporating knee pads into the FE flight suits would reduce stress on the knees during kneeling positions. Current zipper locations also cause discomfort in the kneeling position, which can create awkward postures.

C.24 QU16- Portable handles

Figure 16. Portable handle.

Note: Handles could be placed in locations that would allow the FE to hold on while in compromising positions, such as looking out the door. This in turn would decrease the demands on neck muscles to support the head supported mass as well.

C.25 QU17- Cabin Door Stops

The current door system does not allow for partial door openings, other than having a person holding the door partially open. If a multiple door stop system was used, the FE would not need to use force to keep the door partially open during flight and could potentially also use the steadied door as a support.

List of symbols/abbreviations/acronyms/initialisms

1 CAD	1 Canadian Air Division
ACO	Air Command Order
AERE	Aerospace Engineer
ALSE	Aviation Life Safety Equipment
CADO	CAD Order
CAF	Canadian Armed Forces
CFEME	Canadian Forces Environmental Medicine Establishment
CIMVHR	Canadian Institute for Military Veterans Health Research
DAEPM	Directorate of Aerospace Equipment Program Management
DRDC	Defence Research and Development Canada
DTAES	Directorate of Technical Airworthiness and Engineering Support
FAC	Forces armées canadiennes
FE	Flight Engineer
FG	Force Generation
FS	Flight Surgeon
LVN	Lunettes de vision nocturne
NVG	Night Vision Goggles
QU	Queen’s University
RCAF	Royal Canadian Air Force
RDDC	Recherche et développement pour la défense Canada
SOCD	Statement of Capability Deficiency
SOW	Statement of Work
SOR	Statement of Requirements
Surg Gen	Surgeon General
TRI	Toronto Rehabilitation Institute

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3. TITLE (The complete document title as indicated on the title page. Its classification is indicated by the appropriate abbreviation (S, C, R, or U) in parenthesis at the end of the title)

Evaluation of Potential Solutions to Mitigate Aircrew Neck Strain: CIMVHR contract W7714-125624/001/SV- task 14 (U)
Évaluation des solutions potentielles pour atténuer la fatigue de la nuque chez les membres d'équipage d'aéronefs. (U)

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

Gabrielle S. Chafe

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(U) Aircrew neck strain in the CH-146 Griffon community has become a prevalent problem. This problem also extends to the international rotary-wing community. Many factors have been linked to the problem, however according to a Canadian led international study, the night vision goggles (NVG) mission length and the total NVG hours flown are linked to neck pain. In order to find short term solutions, 2 multidisciplinary teams were contracted to propose possible solutions. The solutions were evaluated by a panel of 8 experts from different fields of expertise. The highest rated (0.80) solution was to reduce the helmet/NVG system weight, centre of gravity and moment of inertia, however this was not selected by most members of the panel. The most popular solutions were procedural solutions focussed on assisting the aircrew with education and an athletic based exercise regime (0.79-0.76). The most popular engineering solutions were scored moderately (0.66-0.56). Using different approaches: a) reduce the NVG use by removing or shifting the NVG weight on the helmet and b) replace the current counterweight with an on-body elastomer system. In the short term, assessing different approaches to mitigate aircrew neck pain will need to incorporate aircrew acceptance to have any significant effect.

(U) La fatigue de la nuque est aujourd hui un problème répandu chez les membres d équipage des aéronefs CH-146 Griffon. Ce problème touche également tous ceux qui servent à bord d hélicoptères ailleurs dans le monde. Un grand nombre de facteurs ont été associés au problème, mais, d après une étude internationale dirigée par des Canadiens, la fatigue de la nuque est liée à la durée des missions avec les lunettes de vision nocturne (LVN) et au nombre total d heures de vol avec LVN. Pour trouver des solutions à court terme, on a embauché deux équipes multidisciplinaires à qui on a demandé de proposer des solutions potentielles. Les solutions ont été évaluées par un comité formé de huit experts issus de différents domaines d expertise. La solution la mieux cotée (0,80) consistait à réduire le poids du casque/système de LVN, le centre de gravité et le moment d inertie. Toutefois, cette solution n a pas été retenue par la plupart des membres du comité. Les solutions les plus populaires étaient axées sur l aide aux équipages d aéronef par le biais de programmes d éducation et d exercices d entraînement athlétique (0,79-0,76). Les solutions d ingénierie les plus populaires ont obtenu un score modéré (0,66-0,56). Celles-ci adoptaient différentes approches : a) réduction de l utilisation des LVN en retirant le poids de la LVN du casque ou en le transférant ailleurs sur le casque et b) remplacement du contrepoids actuel par un système élastomère corporel. À court terme, il faudra tenir compte, dans le cadre de l évaluation des différentes approches pour atténuer les douleurs au cou des membres d équipage des aéronefs, de l acceptation des solutions par ces derniers pour obtenir un effet significatif.

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(U) neck strain; aircrew; engineering solutions; CH-146; pilot; flight engineer; mitigation of neck strain; solutions

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