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FLIGHT TASK PERFORMANCE WITH HIGH AND LOW GAIN NIGHT VISION GOGGLES

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Abstract

The National Research Council of Canada (NRC) conducted a series of flight tests in collaboration with Transport Canada (TC) to compare manoeuvre performance with high and low gain night vision goggles (NVG). A series of four low-altitude manoeuvres were developed to assess the pilots' ability to perform precision and dynamic tasks with the high and low gain NVG. The manoeuvres consisted of a hover task, a vertical re-mask (bob-up) task, a shallow-descent landing task and a confined area tail-clearing task (tail-turn). To simulate a low gain goggle that would meet currently mandated minimum performance standard, a set of neutral density filters were used to limit light entry. The image presented to the pilot from the filtered NVG approximated the image from a low gain NVG while maintaining other characteristics such as resolution. The subjective data comprised visual cue ratings and a rating of the texture cues apparent in the NVG. The objective data consisted of the measurements of position error for each of the manoeuvres. Examination of the subjective data indicated that the ratings for horizontal and vertical translation cues were significantly better with the high gain NVG than with the low gain NVG. Examination of the objective data showed that only the horizontal position error in the tail-turn task resulted in a statistically significant difference between the low and high gain NVG. Specifically, the pilots tended to drift out of position more when using the low gain NVG than when using the high gain NVG. The results are discussed in terms of NVG contrast and texture perception and the implications for performance standards.

Introduction

Night vision goggles (NVGs) aid night time flying by allowing pilots to see more detail during periods of low light by amplifying existing ambient light from sources such as the moon, stars and cultural lighting. While NVGs have been used by the military since the 1940's (ground operations), civilian operators have only recently started to use the technology to enhance night flight operations. Military users have specific requirements for NVG performance, whereas the only specification governing performance for civilian operators is the Radio Technical Commission for Aeronautics DO-275[1]. DO-275 provides definitions of the minimum acceptable performance of the NVG technology for military and civilian operations [2,3,4].

The DO 275 provides useful guidelines for testing the performance of several aspects of NVG systems, but limitations to the original specifications become apparent as technology improves. For example, the specification for the minimum resolution of an NVG is based on high contrast target stimuli but piloting rotorcraft involves viewing a variety of contrast levels [5]. There are no specifications in DO 275 for NVGs in terms of testing the resolution with low to moderate contrast targets. Some NVGs are better at displaying low contrast imagery, which is an important capability because of the monochrome display. Without color as a cue, a pilot is left with only luminance differences between the target and the background (i.e., contrast) to enable the detection of objects or the judgment of motion. Better rendering of low contrast detail will likely improve the quality of the NVG image.

DO 275 resolution testing methodology also indicates that resolution testing be done at an optimal lighting level to attain the best resolution of the NVG. However, in poorer light conditions, low contrast targets are typically less visible or detectable than high contrast targets [6]. In a review of the visual deficits associated with NVGs, Mason [6] noted that the ability to detect contrast through the goggles was diminished at low illumination levels and in the presence of bright light sources where the goggle gain was reduced. Improvements in technology have substantially increased goggle performance (e.g., gain, resolution, signal to noise, modulation transfer function (MTF)) since DO 275 was released. However, the relationship between acuity, contrast and utility for NVGs requires further exploration. The question that remains is how to test NVGs on low contrast targets without specialized equipment and controlled laboratory conditions.

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While some laboratory research on contrast sensitivity of NVG technology has been conducted [7, 8, 9, 10, 11], there have been few field studies of NVG performance in detecting low contrast targets. Tjernstrom [5] constructed a series of simple line charts of varying contrast and tested them in a field at a distance of 50 feet. The participants in the experiment were asked to identify the smallest series of lines that could be resolved with the NVGs. The results showed that acuity was worse as the light levels decreased and (at any light level) when the chart contrast was low. Tjernstrom noted that the contrast levels that pilots encounter in flight are typically lower than the high contrast stimuli that are used to determine the goggle resolution specifications. While Tjernstrom [5] conducted his study outside using constructed targets of various contrast levels, objects and obstacles encountered in flight are usually highly complex, with multiple levels of features of varying contrast (e.g., trees, vehicles, buildings etc.).

Craig, Brulotte, Carignan and Macuda [12] conducted a test in which pilots rated the visibility of various targets with different types of NVG. The targets consisted of various man-made objects located around the airfield chosen as the test site (e.g., traffic cone, picnic table, tool shed). The pilots rated the visibility of the targets as poorer with the low quality NVG and higher with the normal quality NVG. While this test was able to discriminate the quality of the different NVG tested, the targets were all artificial and had little to do with the types of cues that pilots would commonly use to fly the aircraft. For example, as part of this experiment, the pilots also flew an Aeronautical Design Standard (ADS)-33 [13] pirouette maneuver to collect visual cue ratings (VCR). Even though the worst set of NVG used was far below the minimum performance standard listed in DO-275 [1], there were no differences in the VCR between the best and worst NVG. The pilots noted in the post-flight debriefings that the predominant cues were the traffic cones used to mark the course for the maneuver. Since the cones were visible for even the worst set of NVG, the VCR were consistent between the different NVG tested. Cues such as ground texture that the pilots typically use to judge drift, height and speed [14, 15, 16, 17] were overwhelmed by the presence of the cones used as course markers.

In order to identify the effect of degraded NVG on flight performance, tasks were developed which relied on naturally occurring cues to conduct the maneuver. A series of four flight test manoeuvres were developed that would require the pilot to use ground and trees to accurately position the rotorcraft.

This paper details two flight tests which examined the functionality of flight test manoeuvres that could be used to identify objective performance differences when pilots use different NVGs. The flight tests used a variation of the standard VCR scale methodology and a texture rating developed for this trial. Vertical and horizontal position errors were recorded and used to determine if there were performance differences in the manoeuvres based on the NVG that the pilot was wearing.

Methods

Subjects

Four test pilots participated in the first and second flight tests. An additional pilot participated in the first round of flight tests but was unavailable for the second set of tests. The pilots ranged in age from 48 to 51 years. The pilots had an average of 5200 hours of rotorcraft flight time and just over 120 hours of NVG flight time.

Equipment

The NRC Bell 206 helicopter was used for the current experiment (see Figure 1). The NRC Bell 206 is a single engine, teetering rotor, light utility helicopter with dual flight controls and provisions for two research crew in the back. The Bell 206 is equipped with a data system capable of providing high precision attitude, rate, position and air-data at high data rates. The Bell 206 has been equipped with NVG compatible cockpit and exterior lighting.

Figure 1: NRC Bell 206 Jetranger Helicopter

The evaluator used two sets of NVGs for the flight tests. Both sets of goggles were made by ITT Corporation and were standard F4949 NVGs with roughly equivalent performance (see Table 1). One set of these goggles was equipped with a set of broad-spectrum, neutral density filters to partially limit the amount of light entry (see Figure 2). The neutral density filters were placed in front of the objective lens of the NVG. The optical density of the filters was 0.4 from 350 nanometers (nm) to 2000 nm. That is, approximately 40% of the light between 350 and 2000 nm was blocked from entering the goggles. The gain and the resolution of the goggles were measured on a Hoffman Engineering ANV-126A calibration unit.

Goggle	Tube	Gain (0.1 mFl)	Resolution (0.1 mFl)
A (Unfiltered)[1]	Left	7467	20/40
	Right	7668	20/40
A (Filtered)	Left	3245	20/45
	Right	3271	20/45
B (Unfiltered)	Left	7792	20/40
	Right	8435	20/40

Table 1: NVG gain and resolution data.

Figure 2: NVG with neutral density filter on right-eye tube; left-eye tube filter holder shown in lower right corner

Procedures

Four manoeuvres were developed for this flight test which would cause the pilot to use ground and or tree-line textures to maintain maneuver performance. The manoeuvres consisted of a hover task, a shallow, run-on landing task, a vertical remask (bob-up) maneuver and a precision turn about the tail. The hover, landing and bob-up tasks were conducted with respect to the corner of a tree-line found off the runway at the Rideau Valley Airpark (CPL3) near Kars, Ontario, Canada (see Figure 3).

The hover task consisted of moving the aircraft into a hover at 10 feet above ground (AGL), with the aircraft positioned 1.5 rotor-diameters away (50 feet) from each side of the tree-line and maintain the position for 30 seconds. The landing task began with the helicopter positioned 150 feet aft of the landing site. The hover position was used as the spot at which the pilot would land the aircraft. The pilot began the maneuver at 10 feet AGL and was instructed to perform a continuous descent to land 1.5 rotor-diameters away from each side of the tree-line. The bob-up began in the hover position (10 feet AGL and 1.5 rotor diameters away from the tree-lines). The pilot was asked to maintain a constant horizontal position and climb to tree-top height (approximately 75 feet AGL) and descend to 10 feet AGL. Finally, for the turn about the tail (or tail turn) the pilot began at 10 feet AGL and approximately 10 ft aft of a reference marker[2]. The pilot would translate forward to position the tail rotor directly over the reference marker. The pilot then yawed the aircraft 90° right, 180° left and 90° right while maintaining the positioning of the tail rotor over the marker. In the first set of flights, the pilots flew each maneuver once, provided VCR [13] and a rating of texture cues using a rating scale similar to those used for the VCR. The pilot then repeated this process with the second set of NVGs. In the second set of flight tests, the pilots flew each maneuver twice before providing subjective ratings. Half of the pilots flew the manoeuvres with the filtered goggles first, while the other half flew with the unfiltered goggles first.

Figure 3: Treeline used for hover, bob-up and landing manoeuvres

The average deviation from the ideal position for the hover, landing and bob-up tasks (horizontal and/or vertical bias) was measured as well as the standard deviation for the average position error (horizontal and/or vertical drift) using the onboard GPS/inertial measurement unit. For the tail-turn, the deviations were calculated based on the position of the tail-rotor with respect to position of the reference marker. Finally, for the landing, the linearity of the descent profile was also measured and analyzed.

All the flight tests were conducted during nights where there was no moonlight and little or no cloud cover. This was done to have the goggles performing at near maximum gain levels as this is typically where the performance differences between NVG arise.

[1] NVG A was only used with the filter in place; the normal performance for that NVG is given for comparison.

[2] Small (1 ft^3) overturned baskets that lined the runway were used as the markers for this maneuver.

Results

It should be noted that the first set of flights was conducted with grass texture for all pilots. Due to time constraints, the second set of flights was conducted with snow and ice on the ground for two pilots and broken snow and grass patches on the ground for the other two pilots. As well, due to time and funding constraints, only 4-5 pilots were able to participate in the flight trials. As such, the statistical power of the analyses reported in this paper was lower than desirable, meaning that there was a greater likelihood of not detecting a difference when one actually existed.

The results from the subjective rating data are presented initially, followed by the objective data.

Subjective Rating Data

First Flight Test: Visual cue ratings and texture ratings tended to be between 2 and 3 (1=good, 3=fair & 5=poor). A two-way repeated measures analysis of variance (ANOVA) was run on the attitude VCR data, and repeated for horizontal translational rate cues, vertical translational rate cues and on the texture rating data. The independent variables in the analyses were NVG type (NVG A or B) and maneuver (hover, landing, bob-up or tail-turn). The analyses indicated that there were no statistically significant differences in ratings between the manoeuvres. Similarly, there were no significant differences for the attitude VCR. However, there were significant differences between NVG for horizontal translational rate ratings [$F(1,4)=13.241$, $p<0.022$], vertical translational rate ratings [$F(1,4)=20.179$, $p<0.011$] and texture ratings [F(1,4)=10.894, p<0.030]. In all cases the ratings were poorer for the filtered goggle (NVG A) than for the unfiltered goggle (NVG B). The average ratings for each goggle are presented in the upper half of Table 2.

Flight test	NVG	Attitude VCR	Horizontal VCR	Vertical VCR	Texture
1	A	2.1	3.3	3.1	3.5
	B	1.9	2.7	2.5	2.7
2	A	3.1	3.5	3.5	3.3
	B	2.4	2.8	2.8	2.8

Table 2: Average ratings for filtered and unfiltered goggles for each rating type (Note: higher ratings indicate poorer cueing).

Second Flight Test: Averaged visual cue and texture ratings for these tests tended to be between 2.5 and 3.5. A two-way repeated-measures ANOVA was run on the rating data with NVG type and maneuver as the two independent variables. There were no statistically significant effects for attitude VCR or for the texture cue ratings. There was a marginally significant difference for NVG type from the horizontal VCR ratings [$F(1,3)=10.000$, $p<0.051$] and a significant effect of NVG type in the vertical VCR data [$F(1,3)=14.520$, $p<0.032$]. Again, the ratings were poorer for the filtered goggle than for the unfiltered goggle (see bottom half of Table 2). There was also a significant effect of maneuver on horizontal VCR [$F(3,9)=10.862$, $p<0.002$]. Post-hoc analysis indicated that the average ratings for the bob-up (3.7) were significantly worse than for any of the other manoeuvres (hover=3.1, landing=2.9 & tail-turn=2.9).

Objective Data

First Flight Test: The average and standard deviation of the aircraft position error data was collected and analyzed using a one-way, repeated-measures ANOVA with goggle type as the independent variable. For the hover task both the plan position and height data were analyzed. None of the measures showed a statistically significant effect of NVG type. Similarly, the landing and bob-up showed no statistical differences between NVG A and NVG B. For the tail-turn, plan position errors were calculated with respect to the position of the tail rotor. Height offsets and drifts were also subjected to the analyses. Of these dependent measures, only position standard deviation showed a significant effect of goggle type [$F(1,4)=10.517$, $p<0.048$]. That is, pilots tended to drift more (15ft) with NVG A than with NVG B (10ft).

Second Flight Test: The average and standard deviation of the aircraft position error data was collected and analyzed using a one-way, repeated-measures ANOVA with goggle type as the independent variable. As with the data from the first flight test, there was only a difference in the tail turn maneuver. Of the position measures recorded for the tail turn, only the average position error showed a significant effect of NVG type [$F(1,3)=12.583$, $p<0.038$]. Figure 4 shows the track(s) of the Bell 206 for one of the pilots for tail-turns done with NVG A and NVG B. The average distance from the ideal position with NVG A was 32 feet, while the average distance from the ideal position with NVG B was 26 feet.

Figure 4: Bell 206 position data for tail-turns done with NVG A (yellow) and NVG B (blue).

Discussion

Data from the two flight tests indicated that the horizontal and vertical translational rate VCR's were fairly effective way to differentiate the performance of the high and low gain NVG. This is possible when the cues for the manoeuvres do not overwhelm the terrain textures. The bob-up was rated as the poorest cued maneuver because the cues that the pilot referenced changed during the maneuver. As the pilot gained height, the texture of the ground became less distinct and they needed to use the coarser texture of the trees as their reference. The texture ratings only showed differences between goggles in the first flight test and so the utility of that rating scale is somewhat questionable.

Of the four manoeuvres chosen to highlight the differences in performance with the unfiltered versus the filtered goggles, only the tail-turn was effective. A past experiment comparing standard NVG to a hyperstereo helmet mounted display (HMD) of night vision imagery showed a trend for the tail-turn to differentiate these displays [18]. Although every pilot showed greater drift with the HMD than with the NVG, due to a low number of participants the effect was not statistically significant. It also must be noted that the hyperstereo effect and the see-through HMD likely also contributed to the maneuver performance difference between the NVG and the HMD. However, the presence of the performance differences for the tail-turn maneuver suggests that the maneuver can effectively differentiate NVG performance differences.

One factor that distinguishes the tail-turn from the other manoeuvres is that the cues for the maneuver are much more dynamic. Hover and landing task performance is largely unaffected by the lack of head movements, despite the small field of view. The bob-up does require occasional head movements to confirm fore/aft positioning but the majority of the time is spent looking forward. In the tail-turn, the pilots are often switching between looking forward and looking into the turn. Further, regardless of which direction the pilot looks, the cues are constantly changing. In these conditions an NVG with better contrast representation would more readily allow the pilot to discern texture cues indicative of drift.

Another common aspect to the hover, bob-up and landing manoeuvres is that they all have a forward limit. Examination of the data indicated that there was a tendency for pilots to drift forward during the hover and the bob-up. This drift was typically reversed as soon as the pilot became aware of it. The landing task required the pilot to transition forward and land at the hover task location. However, once at or near this position, there is little room for additional forward translation. This forward limit for the test area is consistent with a confined area task and pilots are often instructed to hover close to the forward obstacle(s) to maintain tail-rotor clearance [19]. However this confined area strategy limits the extent to which the pilot can drift forward which in turn limits the size of the position error.

Drift, height and speed information have been linked to contrast and/or texture cues [14, 15, 16, 17]. Based on the work by Mason [6], one would expect a low-gain set of goggles would be unable to detect the contrast required to allow the pilot to see these texture cues. Salazar, Temme and Antonio [20] noted that using only visual acuity and/or resolution to describe NVG performance omitted relevant factors such as contrast, noting that the ability to discriminate contrast changed as illumination decreased whereas visual acuity did not change. Indeed, given that NVGs are monochrome, the contrast of a target against the background is nearly the only cue available to detect ground texture, targets and obstacles. Yet NVG specifications do not typically include data on the ability of the NVG to resolve contrast. Although several manufacturers report the MTF of the image intensifiers (i.e., the ratio of the contrast of the input vs. contrast of the output) the MTF is based on high contrast stimuli. Similarly, RTCA DO-275 does not specify the minimum resolvable contrast for an NVG system. Most North American regulations [21, 22], indicate that NVGs must meet the minimum standards listed in DO-275 [1]. Given the importance of contrast resolution to NVG performance and the number of agencies referring to DO-275, the absence of a specification for contrast is critical. While the specifications in DO-275 represented the state of the art at the time it was written, NVG technology has improved, as have the tools available to assess NVGs. An additional test of the image intensifiers during the MTF measurements, using the same spatial frequencies at a lower contrast, would enhance the characterization of NVG performance.

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