European Rotorcraft Forum 2011 Paper Number 79

A Comparison of Linear and Logarithmic Scale Display Designs for Rotorcraft Landing in Brownout

Zoltan Szoboszlay
US Army Aviation and Missile Research, Development and Engineering Center (AMRDEC)
Aeroflightdynamics Directorate
Moffett Field, California
z.szoboszlay@us.army.mil

Gregory Neiswander
San Jose State University
Ames Research Center, Moffett Field, CA
gneiswander@merlin.arc.nasa.gov

ABSTRACT

The purpose of this study was to compare two scaling methods for rotorcraft display symbology. Linear scaling and logarithmic scaling were tested for the horizontal velocity and position symbols in the BrownOut Symbology System, 2nd Generation (BOSS2), which uses a single display page from cruise speeds to landing. The symbology was presented on both a panel-mounted display and a head-mounted display. The conventional linear scale of the velocity vector changed sensitivity during the approach to provide enough range (150 knots) at the beginning of the approach, and enough sensitivity at the end of the approach. The unconventional logarithmic scale did not change sensitivity, but still provided enough range at the beginning of the approach (160 knots) and the same sensitivity at the end of the approach as the linear scale. Results showed that the average pilot performance was within desired criteria for both scale types. Pilots indicated a strong preference for the logarithmic scale on the questionnaire. There was also little difference in pilot performance between the panel-mounted and head-mounted displays. Finally, brownout landings were also performed without knowledge of the landing point coordinates and without guidance to test the robustness of the design. The distance from the intended landing point degraded to two rotor diameters on average when the landing point coordinate was unknown, but all other performance parameters were still within the desired criteria.

PURPOSE

The purpose of this study was to compare two symbology scaling methods: conventional linear scaling and unconventional logarithmic scaling for horizontal velocity and position symbology within the second generation BrownOut Symbology System (BOSS2). This system was developed by the US Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) and the Air Force Research Laboratory (AFRL). The symbology is used for helicopter approaches into dust (brownout) or snow conditions (Refs. 1-5).

Unlike the previous generation, BOSS2 was designed to use a single page display from cruise speeds to hover and landing. For a conventional linear velocity vector to be used during the entire approach, the velocity scale must be changed from a less sensitive scale at the beginning of the approach (which provides enough range) to a more sensitive scale with reduced range at the end of the approach. The more sensitive scale is needed to control the aircraft at low speeds. The unconventional logarithmic scale can provide the same range at the beginning of the approach as the linear scale and the same sensitivity at the end of the approach as the linear scale, without a scale change.

If the logarithmic scale does not degrade performance compared to the linear scale, and is acceptable to pilots, then a single display page is possible without any scale changes from cruise speeds to hover and landing. This feature would be a substantial improvement to current rotorcraft display design.

BACKGROUND

Figure 1 details the linear horizontal velocity vector and acceleration cue symbols used on many of the current generation US military rotorcraft. Typically only one end of the acceleration vector is shown, and is used as a predictor of aircraft velocity. The pilot controls the position of the acceleration cue symbol with cyclic inputs. The acceleration cue symbol mitigates the adverse effects of the lag between a cyclic input and the corresponding steady-state change in aircraft velocity. This lag may cause the pilot to over-control in cases where the display shows only the velocity vector (AVS-7 NVG-HUD).

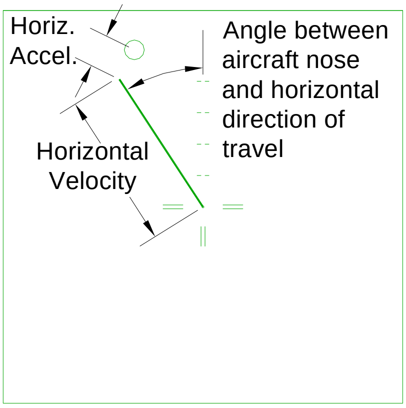

Figure 1. Definition of velocity vector and acceleration cue symbols.

Figure 2 shows the velocity vector and acceleration cue symbols on the head-mounted display of the AH-64D aircraft (Ref. 6). The linear scale of the velocity vector is 60 knots to the vector length limit on the transition page and 6 knots on the hover and bob-up pages. The position symbol moves +/- 40 ft longitudinally or laterally on a linear scale and is only visible on the bob-up page.

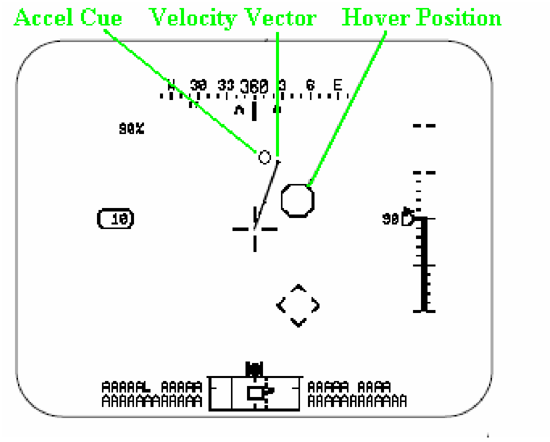

Figure 2. AH-64D hover display.

Figure 3 shows the hover display for the CH-47F aircraft (Ref. 7). The linear scaling of the velocity vector changes from 120 knots to 60 knots to 20 knots from the ownship symbol to the compass. The hover position symbol changes scale from 1 Nm to 200 ft to 40 ft to the compass.

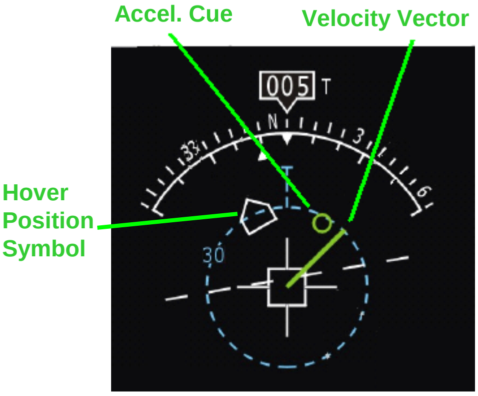

Figure 3. CH-47F hover display.

Figure 4 shows the hover page of the UH-60M (Ref. 8). The linear velocity vector scale is 40 knots to the compass, and does not extend past the compass. The velocity vector turns off below 4 knots. In addition to the velocity vector, two velocity bars are also shown, which move directly opposite the velocity vector. The pilot must move the cyclic in the direction of the intersection of the bars to come to a hover. The velocity bars are scaled the same as the velocity vector and limit at 40 knots and turn off above 60 knots. The scale of the hover position symbol is 0.2, 1.0, or 3.0 km to the compass rose.

Figure 5 shows the hover display of the OH-58D aircraft (Ref. 9). The linear scale of the velocity vector is 7 knots to the edge of the attitude indicator. The linear scale of the position symbol is either 44 or 88 ft to the edge of the attitude indicator, depending on the page displayed.

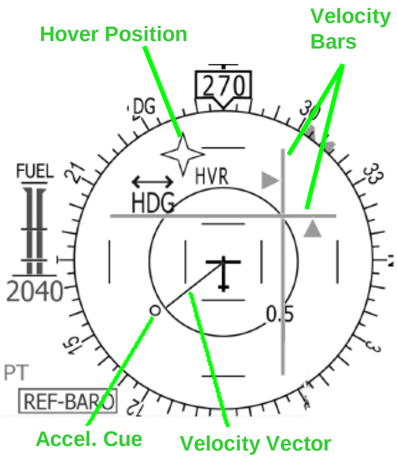

Figure 4. UH-60M Hover Display.

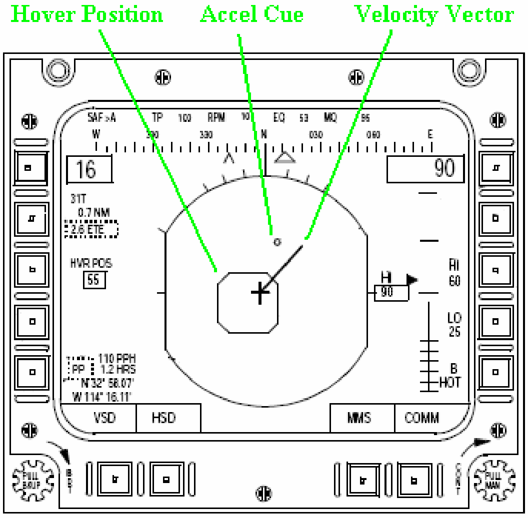

Figure 5. OH-58D hover display.

Figure 6 shows the AVS-7 Night Vision Goggle Head Up Display (NVG-HUD) (Ref. 10). The linear scale of the velocity vector extends to 15 knots. Above 15 knots, the vector is still drawn but does not extend further. Note the diamond at the end of the velocity vector does not indicate acceleration; it indicates the end of the velocity vector.

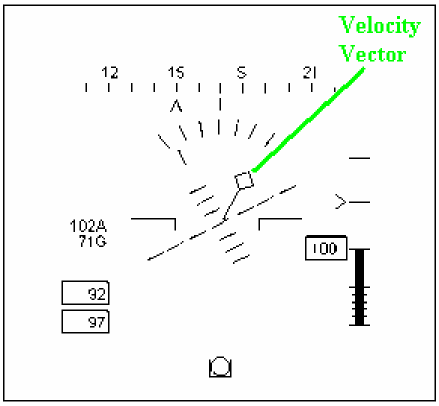

Figure 6. AVS-7 NVG-HUD display.

As illustrated in this background section, the velocity vector and hover position symbols in the current US Army inventory uses a linear scale as opposed to a logarithmic scale. Some of the scales change sensitivity (AH-64 and CH-47F) whereas others limit the legnth of the vector or turn off the vector when the scale limit is exceeded.

METHOD

The test conditions are detailed in Figure 7. For the main 2x2 matrix, both linear and logarithmic scales were flown on both head-mounted and panel-mounted displays. In each case, the landing coordinates were pre-designated and the pilots had guidance on the display during the approach. After the complete 2x2 matrix was flown, pilots then flew the 2x1 matrix of test points, without pre-designated landing point coordinates and without guidance during the approach. In this case the pilots used the out-the-window view and sensor imagery to navigate to the landing zones. For every condition, five landings were performed by each pilot as detailed in Table 1.

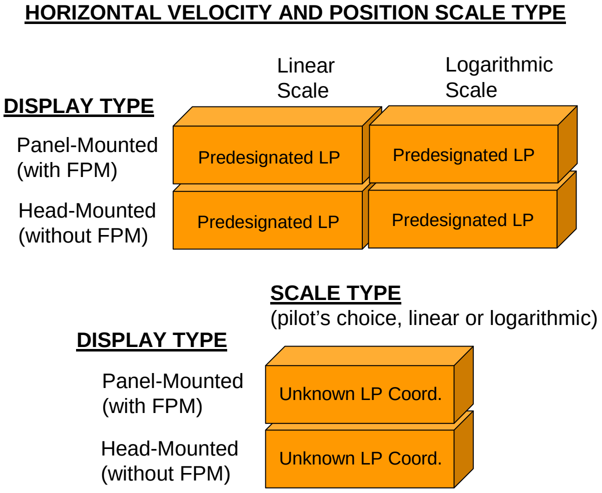

Figure 7. Text Matrix (the flight path marker symbol is abbreviated FPM, landing point is LP).

Table 1. Order of landings for each cell of the test matrix.

Order	Landing Area Type
1st	Open field in front of village
2nd	Open field behind small hill
3rd	Square wall compound
4th	Hill Top
5th	Valley over mountain pass

Performance criteria were divided into desired, adequate, and outside adequate criteria to enable the Cooper-Harper handling quality rating to be used. Criteria are detailed in Table 2. There were no criteria for heading or time to complete the maneuver. Each maneuver started at 80 knots and 200ft radar altitude, and required a turn.

Table 2. Performance criteria

	Desired	Adequate	Outside Adequate
Vertical Velocity	< 200 ft/min	200 < x < 400 ft/min	> 400 ft/min
Lateral Velocity	< 0.5 knots	0.5 < x < 1.0 knots	> 1.0 knots
Fwd Lon. Velocity	< 5 knots	5 < x < 10 knots	> 10 knots
Aft Lon. Velocity	< 0.5 knots	0.5 < x < 1.0 knots	> 1.0 knots
Position	< 50 ft	50 < x < 100 ft	> 100 ft

Two display formats were tested. The panel-mounted format can be seen in Figure 8. A simulated infrared camera provided the terrain background imagery. The simulated camera had a 60° vertical x 45° horizontal field-of-view, was fixed in position to the airframe, and aligned with the aircraft centerline. Symbology was overlaid on top of the infrared imagery using a color key video mixer. The image size was 8 inches vertical x 6 inches horizontal.

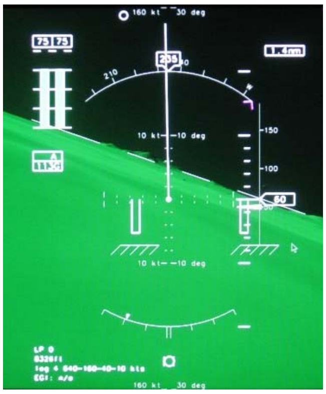

Figure 8. Panel-mounted display.

The other display format was a monochrome, monocular, head-mounted display (Rockwell-Collins EyeHUD, Figure 9). A head tracker was not used for this test. The head-mounted display provided a 20°H x 15°V field-of-view of symbology only. The pilot viewed terrain imagery on the out-the-window displays through the clear optics with one eye, and direct view with the other eye.

Figure 9. Helmet mounted display.

A brownout cloud was simulated by changing the transparency of the entire out-the-window view and the simulated infrared sensor imagery. The brownout effect started reducing the transparency of the terrain image when the aircraft was both below 100 ft altitude and below 20 knots. The out-the-window view and infrared view of the terrain became completely opaque when the aircraft was both below 50 ft altitude and below 10 knots. A linear transparency function was used between the transparent and opaque limits.

Training and data collection runs were conducted in the same day. One hour of classroom training was followed by 2-3 hours of simulator training during which the entire test matrix was flown for practice in the same order as the data collection runs. Data collection runs were conducted in the afternoon and lasted for 2-3 hours. Display conditions were counterbalanced as much as possible. The 2x2 matrix was flown first followed by the 2x1 matrix.

Six military-trained pilots participated in the simulation. All were male and five were on current flight status while one was on temporary non-flight status. A summary of pilot experience is listed in Table 3. Five of the pilots were graduates of test pilot school. All pilots had prior helmet-mounted display experience. Five of the pilots also had prior experience using panel-mounted displays with a velocity vector and acceleration cue. One pilot (7th) did not achieve an adequate level of proficiency in the training time allocated and was not used for data runs.

The same BOSS2 symbology set was used with both the linear and logarithmic scales as detailed in Figure 10 and Figure 11. The only difference between the two symbol sets was the scaling of the plan-view symbols, and the lack of a flight path marker symbol on the head-mounted display (indicating current direction of travel).

Table 3. Pilot experience.

	Exp Rating	Heli Hrs	HUD Hrs	PMD Experience	Brown out Occurances (estimates)
P01	Yes	1500	30	Yes	200
P02	Yes	6200	50	Yes	5
P03	No	2300	500	No	180
P04	Yes	1500	250	Yes	30
P05	Yes	2200	600	Yes	1000
P06	Yes	1300	5	No	30

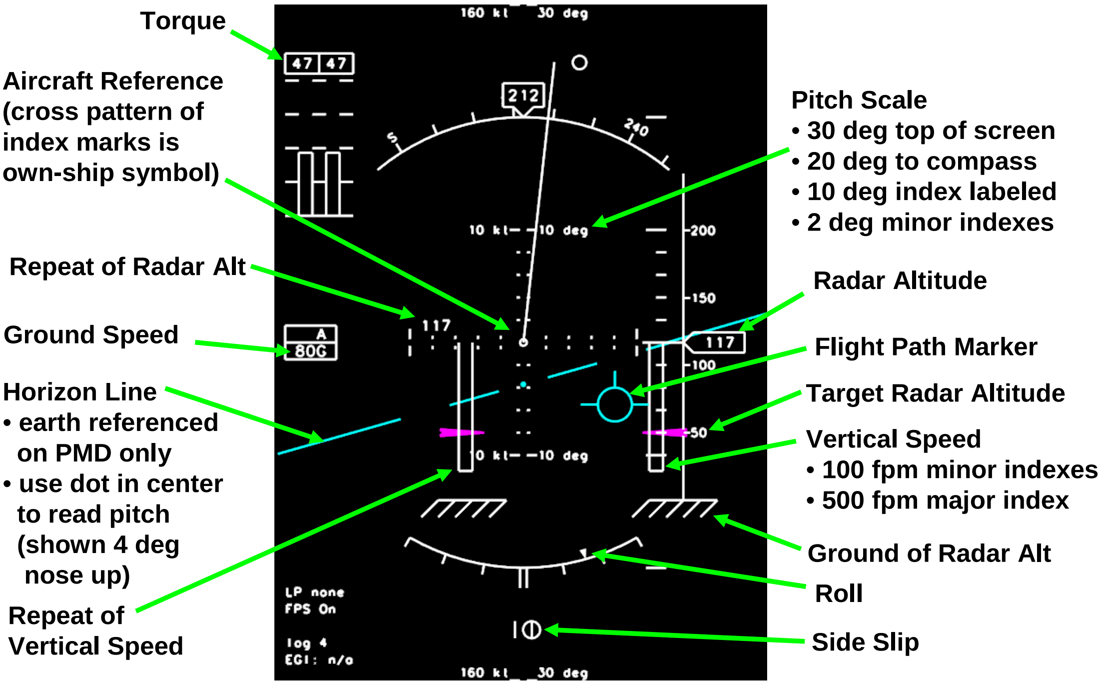

Figure 10. Description of BOSS2 symbols (not including plan-view symbols).

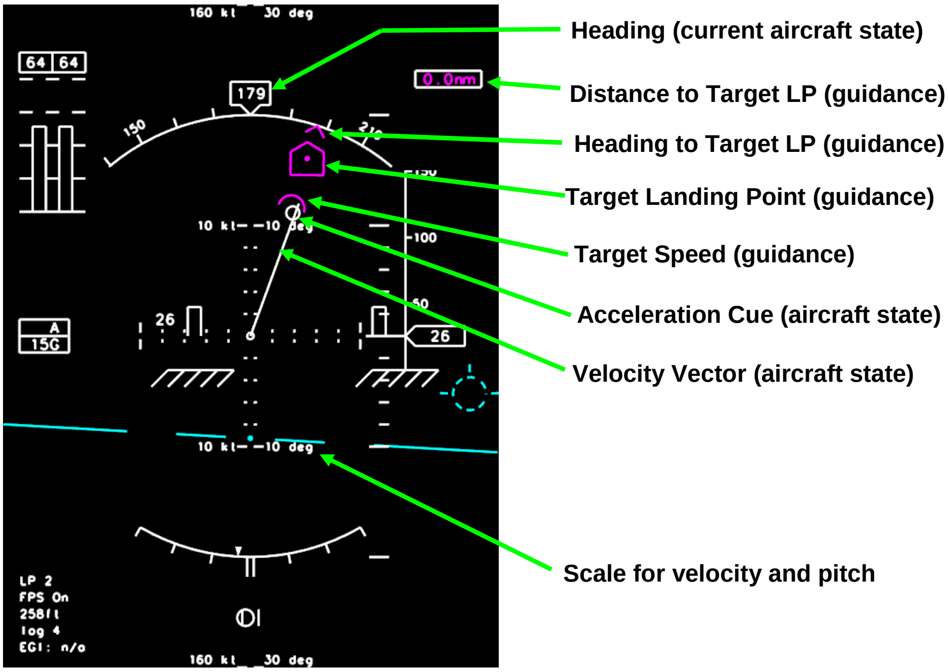

Figure 11. Description of BOSS2 plan view symbols.

Figure 12 details how the display was divided into 3 major segments above and 3 major segments below the ownship symbol. Table 4 lists the velocity values for each of the major indexes. During the approach the linear scale would change sensitivity twice as the aircraft reduced speed. The switching occurred when the velocity vector reached the 1st major index. When the linear scale changed, the velocity vector would immediately increase in length, and the acceleration cue, target speed symbol, and target position symbols would immediately move farther from the ownship symbol. In contrast, the logarithmic scale did not change sensitivity during the approach.

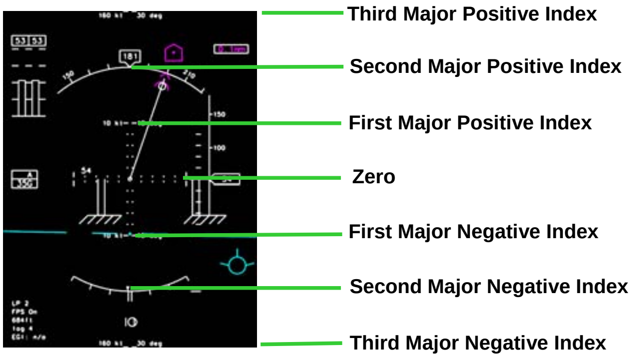

Figure 12. Major scales indexes.

Table 4. Velocity scales.

	3rd Major Index	2nd Major Index	1st Major Index
Least Sensitive Linear	150 knots	100 knots	50 knots
Mid Sensitive Linear	75 knots	50 knots	25 knots
Most Sensitive Linear	30 knots	20 knots	10 knots
Log Scale	160 knots	40 knots	10 knots

What is called the logarithmic scale in this paper is actually a hybrid of linear between 0-10 knots, and logarithmic base four between 10-160 knots. Therefore, below 10 knots both the logarithmic and linear scales were identical.

Equation 1 details the formula used to convert magnitude of the linear velocity vector to the logarithmic scale before the vector was displayed on the linear screen. The conversion was done only above 10 knots. The angle of the velocity vector was left unchanged below or above 10 knots.

$$\text{Log scale velocity magnitude} = 10 * \text{LOG}_4\,(4 * v/10)$$

where v = linear magnitude of velocity vector

(Equation 1)

For the acceleration cue with the logarithmic scale, a screen distance between the ownship symbol to the first major index corresponded to an acceleration of 16.7 ft/sec^2. This scale was used between 0 and 10 knots. Above 10 knots ground speed, the acceleration cue vector magnitude was reduced by the same factor as the velocity vector, to make the movement of the acceleration cue less sensitive to pilot cyclic input at higher speeds, and more sensitive to pilot input at lower speeds. Similarly, the sensitivity of the acceleration cue symbol was reduced for the linear scale at higher speeds, and scale changes occurred in increments when the velocity vector changed scales.

Table 5 lists the distance scales used for the Landing Point (LP) symbol. Equation 2 details the formula used for the logarithmic distance scale beyond 100 feet. Within 100 ft, the two scales were identical, and linear.

Table 5. Distance scales.

	3rd Major Index	2nd Major Index	1st Major Index
Least Sensitive Linear	1500 feet	1000 feet	500 feet
Mid Sensitive Linear	750 feet	500 feet	250 feet
Most Sensitive Linear	300 feet	200 feet	100 feet
Log Scale	1600 feet	400 feet	100 feet

$$\text{Log scale position magnitude} = 100 * \text{LOG}_4\,(4 * d/100)$$

where d = linear magnitude of position vector

(Equation 2)

The logarithmic scale for velocity and position had undesirable artifacts compared to the pure linear scale. For example, if the pilot were to fly over the LP at constant speed, the landing position symbol would appear to speed up until the aircraft was within 100 ft of the LP, and then appear to slow down once beyond 100 ft of the LP. However, the aircraft was not flown at constant speed over the LP; rather the aircraft was decelerating making the LP symbol appear to slow down on the screen. The later effect dominated as long as the pilot followed the guidance and performed a moderate deceleration to land or hover.

Another undesirable artifact of the logarithmic scale was that if the pilot were to fly in a straight line offset from the LP, then the LP would take a curved path on the screen. However, if the pilot followed the guidance, then the aircraft would not be offset from the LP, and the pilot would not see this effect.

The pitch scale was identical for all display conditions. The unconventional pitch scale indexes were fixed on the screen instead of being attached to the moving horizon line as typically implemented. The horizon line was scaled to the simulated infrared imagery. Therefore, the horizon line was earth-referenced, and was the projection of the horizontal plane onto the terrain imagery from the aircraft position.

The GENHEL UH-60A helicopter model was used with Flight Path Stabilization (FPS) turned on. Heading-hold engaged below 60 knots. Pilots used a right side-stick with spring-to-center for the cyclic and a conventional collective on the left side of the seat. Pedals were available, but typically not necessary with the heading hold. The heading hold allowed small changes in heading with large pedal inputs. A sum of sinusoids was added into each control to simulate light turbulent winds. The simulation intentionally froze upon first ground contact, and pilots could read the aircraft state at first contact on the displays.

RESULTS

Objective Data

One-way Analysis of Variances (ANOVAs) were performed to test for significant differences in the mean performance between display conditions of the pilot group. Prior to analyses, the performance parameters were averaged for the five landings each pilot performed for each display condition. In a few cases (3%), only 3 to 4 landings were averaged instead of five due to missing data. The six display conditions were tested first as a 1x6 ANOVA. Pairwise comparisons (Tukey's method) were then completed if display condition was a significant effect. Additional two-way ANOVAs were also performed on the 2x2 data subgroup (for known LP coordinates). All analysis used $\alpha = 0.05$ corresponding to a 95% confidence that the effects were not due to randomness of the data.

Vertical Speed at Touchdown. Figure 13 shows the average vertical speed at touchdown, where the performance values for the five landings each pilot made were averaged first before averages and standard errors were computed across pilots. Table 6 lists the color code for Figure 14 which shows the percentage of landings in the desired, adequate, and outside adequate categories. For Figure 14, the five landing performance numbers were not averaged and represent true percentages of landings.

Results of the 1x6 ANOVA found no significant effect across the display conditions (Figure 13). Average vertical speed was significantly less with the logarithmic scale as compared to the linear scale using the 2x2 ANOVA (F(1, 20)=6.20, $p < 0.05$), Figure 15. On average, all conditions were well within the desired criteria for vertical speed. There were no significant effects for panel-mounted display vs. head-mounted display, the interaction between the scaling and the display formats, or having LP coordinates vs. not having LP coordinates.

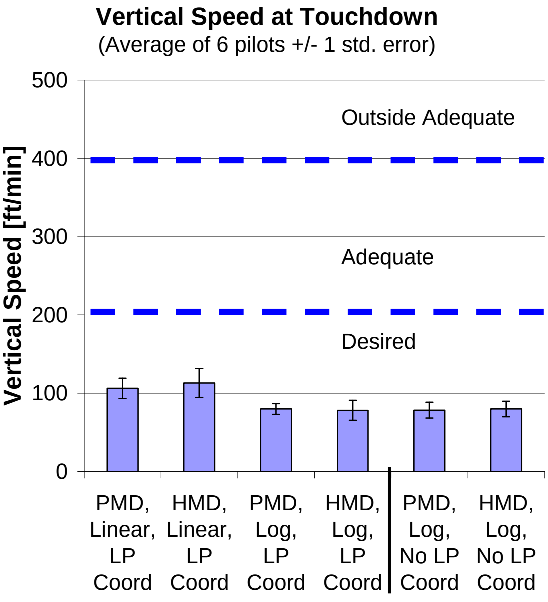

Figure 13. Average touchdown vertical speed.

Table 6. Key for percentage graphs.

🟥	Red	Outside Adequate Criteria
🟨	Yellow	Adequate Criteria Met
🟩	Green	Desired Criteria Met

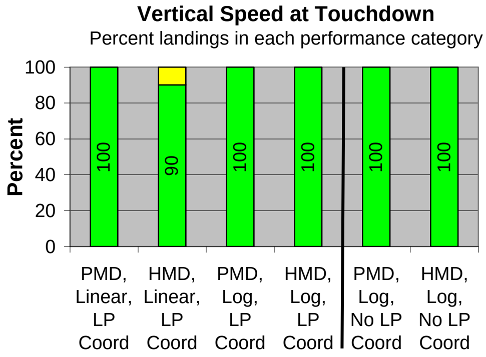

Figure 14. Percentage of touchdowns that met vertical speed criteria.

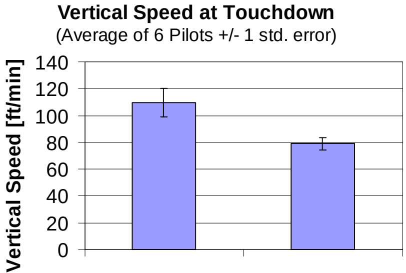

Figure 15. Average touchdown vertical speeds vs. scaling for 2x2 matrix.

Lateral Speed at Touchdown. Figure 16 shows the average lateral speed at touchdown. Figure 17 shows the percentage of landings in each performance category. Note the very narrow tolerances for lateral speed in order to prevent aircraft roll-over. Results revealed no significant differences between the six display conditions using the 1x6 ANOVA. From inspection of the charts, it can be seen that the majority of the landings were within the desired performance criteria. However, up to 10% of the landings were in the adequate category. There were no significant differences between the linear vs. logarithmic, the interaction between the scaling and the display formats, or having vs. not having LP coordinates. There was a significant but very small increase in average lateral speed at touchdown for the head-mounted display compared to the panel-mounted display (F(1, 20)=6.12, $p < 0.05$) as shown in Figure 18. On average, performed was well within the desired criteria.

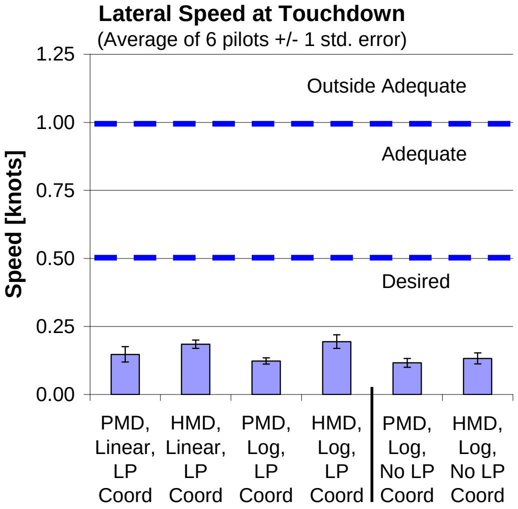

Figure 16. Average touchdown lateral speed.

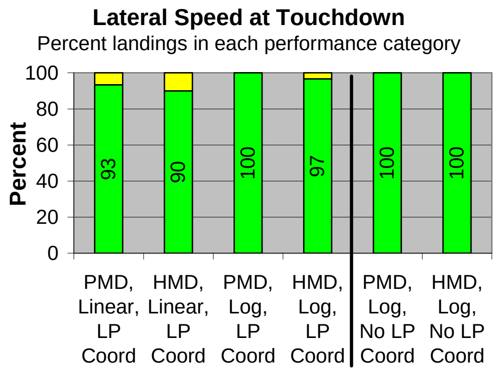

Figure 17. Percentage of touchdowns that met lateral speed criteria.

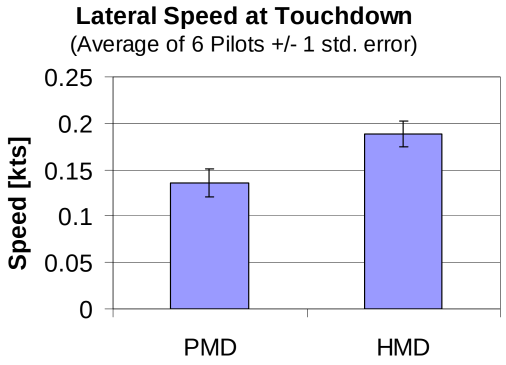

Figure 18. Lateral speed at touchdown vs. display format for 2x2 matrix.

Forward Speed at Touchdown. Figure 19 shows the average forward speed at touchdown. Figure 20 shows the percentage of landings in each performance category. If the velocity was aft, then a zero was used for forward speed in computing the average speed. No ANOVAs were performed for forward speed because this filtering produced uneven distribution of data. Figure 19 and Figure 20 both clearly show that the majority of landings were within desired criteria, with up to 10% in the adequate category.

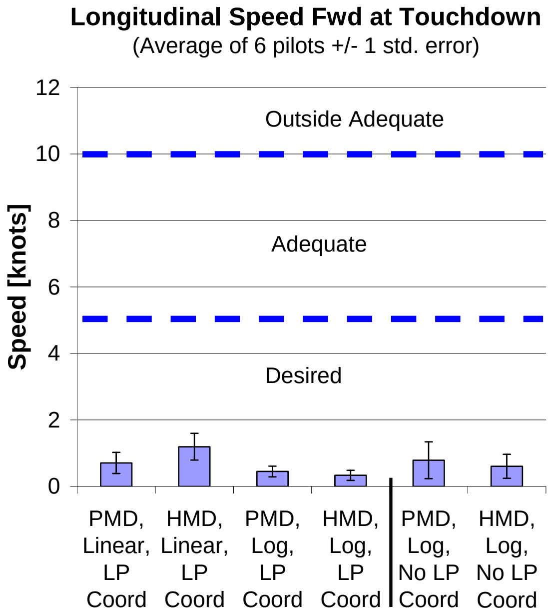

Figure 19. Average touchdown forward speed.

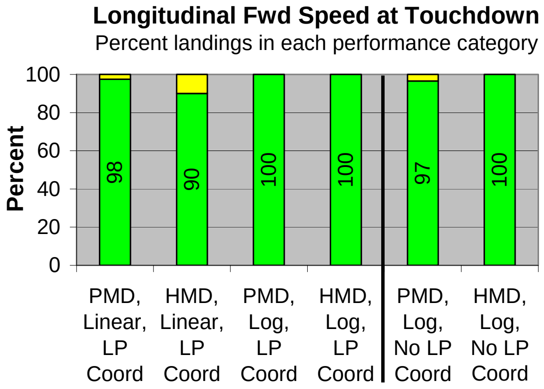

Figure 20. Percentage of touchdowns that met forward speed criteria.

Aft Speed at Touchdown. Figure 21 shows the average aft speed at touchdown. Figure 22 shows the percentage of landings in each performance category. If the speed was forward, then a zero was used for aft speed in computing the average speed. No ANOVAs were performed for aft speed because of this filtering. Note that the aft speed tolerance was much lower than forward speed tolerance. The graphs show that the majority of the landings were within the desired performance criteria, with one landing in the adequate range.

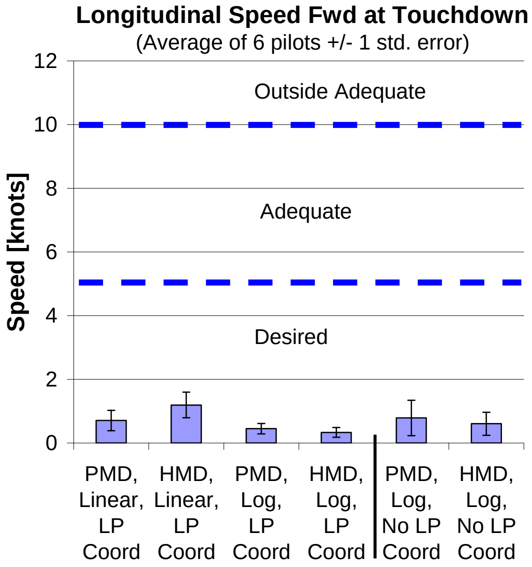

Figure 21. Average touchdown aft speed.

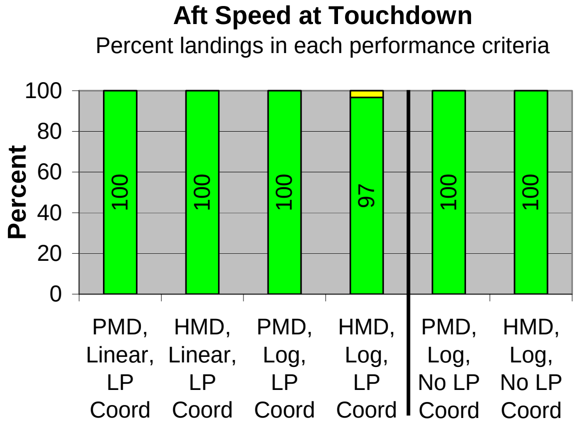

Figure 22. Percentage of touchdowns that met aft speed criteria.

Position Error. Figure 23 shows the average distance at touchdown from the intended landing point. As a distance reference, the main rotor diameter of the UH-60 is 54 feet. Figure 24 shows the percentage of landings in each performance category. For conditions with guidance, the majority of the landings were within desired criteria, and up to 7% were within adequate criteria (HMD, Linear only). The two conditions with an unknown landing point (guidance off) resulted in larger distances from the landing point and much more variability (SD = 67 ft for PMD and SD=110 ft for HMD). The ANOVA results reflected these findings, as there was a significant effect for display condition ($F(5, 30)=11.60$, $p < 0.001$). The pairwise comparisons revealed that both the unknown landing point conditions were associated with significantly higher position error in comparison to the four other conditions (Table 7 lists the respective p-values). There was no significant difference for the panel-mounted vs. head-mounted displays or the interaction between the scaling and display formats in the 2x2 ANOVA. There was a significant difference between the linear vs. log scaling ($F(1, 20)=5.20$, $p < 0.05$). Figure 25 shows that the linear scaling was associated with 5 ft more position error on average in comparison to the log scaling.

Table 7. Pairwise comparison p-values.

	PMD, Log, No LP Coordinates	HMD, Log, No LP Coordinates
PMD, Linear, LP Coordinates	$t(30) = 3.81$ $p < 0.01$	$t(30) = 5.28$ $p < 0.001$
HMD, Linear, LP Coordinates	$t(30) = 3.55$ $p < 0.05$	$t(30) = 5.03$ $p < 0.001$
PMD, Log, LP Coordinates	$t(30) = 3.98$ $p < 0.01$	$t(30) = 5.45$ $p < 0.001$
HMD, Log, LP Coordinates	$t(30) = 3.98$ $p < 0.01$	$t(30) = 5.45$ $p < 0.001$

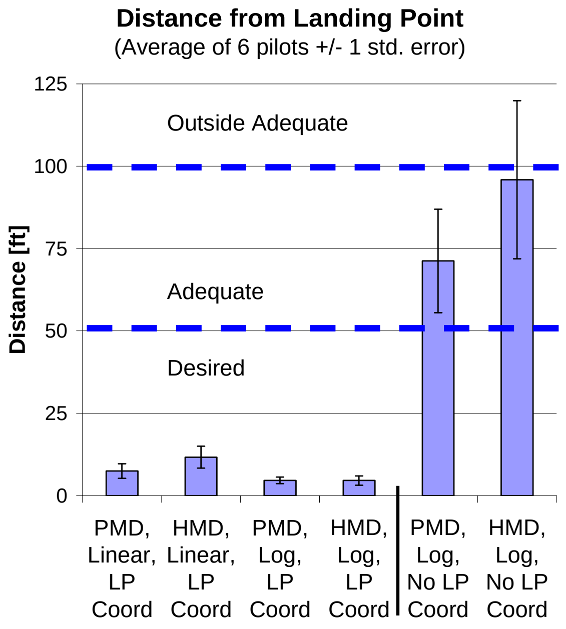

Figure 23. Average touchdown distance.

None of the landings were considered crashes. There were three go-around maneuvers executed 3 out of 183 attempts (2%) where the pilot aborted the landing. All three were with the logarithmic scale, two with no landing point coordinate.

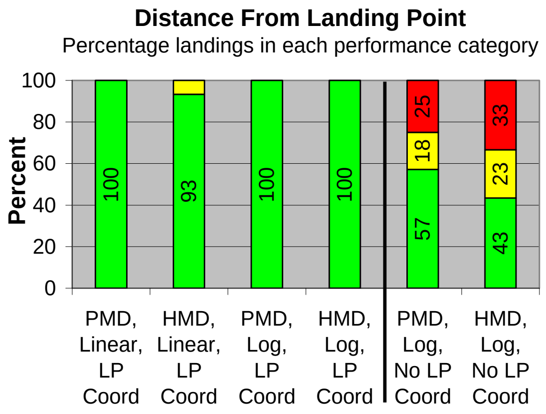

Figure 24. Percentage of touchdowns that met distance criteria.

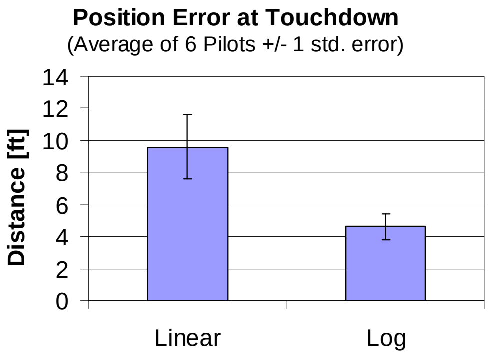

Figure 25. Average position error vs. scaling for 2x2 matrix.

Subjective Data

Handling Qualities. The Cooper-Harper Handling Qualities rating (Ref. 11) were collected from all test pilots, but not the single operational pilot, as this pilot did not have experience using the scale. Pilots were directed not to include distance from the LP in the decision tree of the rating as distance was not a safety concern in the simulation. The average ratings can be seen in Figure 26. These results show all display conditions were borderline Level 1 / Level 2 handling qualities. Level 1 is defined as desired performance with tolerable workload and satisfactory without improvement. Level 2 is defined as adequate performance with tolerable workload but with deficiencies that warrant improvement.

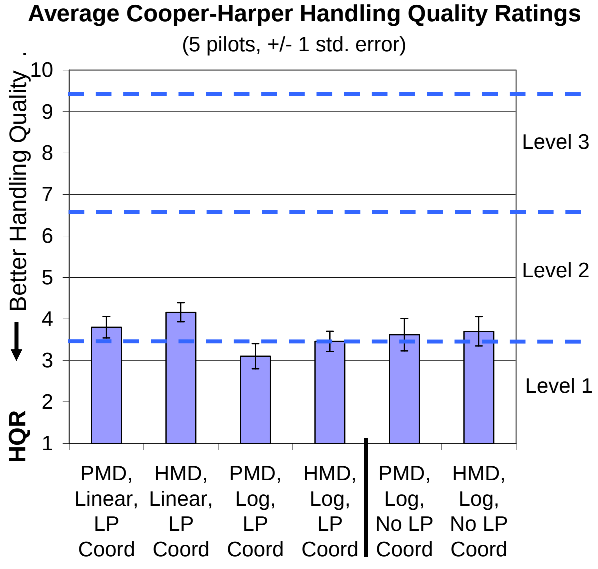

Figure 26. Cooper-Harper HQR ratings.

Scale Type Preference. Figure 27 shows the results of the post-simulation questionnaire for the question, "Do you prefer the linear or the logarithmic scale for the velocity vector and landing position symbols?" The choices were: "Prefer linear" and "Prefer logarithmic". Results show that the pilots unanimously preferred the logarithmic scale.

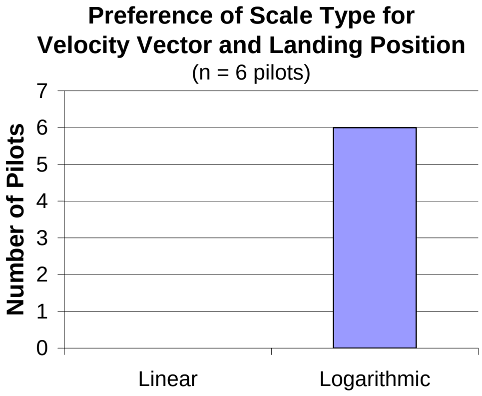

Figure 27. Pilot preference of scale type.

Altitude Symbol Location Preference. Figure 28 shows the results of the post-simulation question, "Where on the screen do you prefer the altitude information." The choices were: "Left of ownship symbol", "Right of ownship symbol", and "Both". Note that each pilot flew only the "both" condition for the test. Most pilots preferred left only, and none preferred right only.

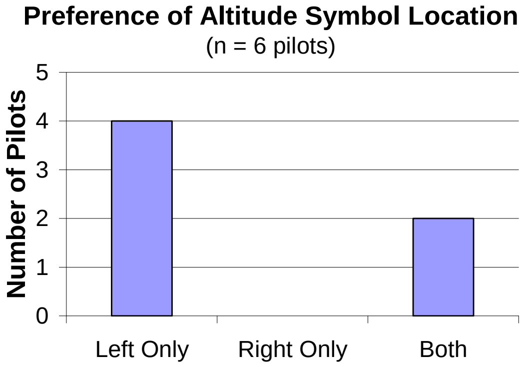

Figure 28. Pilot preference of altitude symbol location.

Display Location Preference. Figure 29 shows the results of the post-simulation question, "Please Rank Order your preference for where the information is to be displayed in the real aircraft. (1 = most preferred, 3 = least preferred). Four pilots chose "Both" as their first choice, while two chose "Panel Only" as their first choice.

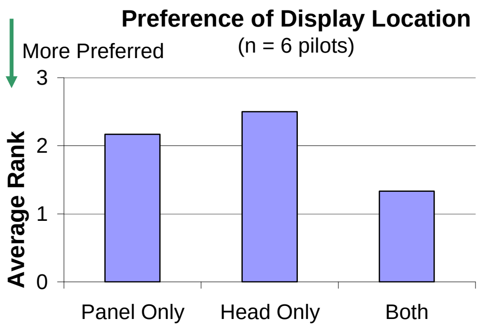

Figure 29. Pilot preference of display location

INTERPRETATION OF RESULTS

2X2 Test Matrix. One dimension of the 2x2 test matrix was a comparison of linear vs. logarithmic scaling for velocity and position, with guidance to known LP coordinates. Overall, pilot performance data showed little difference between the linear and logarithmic scales. The log scaling was associated with significantly lower amounts of vertical speed and less position error at touchdown. However, these findings were deemed not operationally relevant since all conditions, on average, were well within the desired performance criteria. The subjective data shows a unanimous (n=6) preference for the logarithmic scale over the linear, changing scale. Pilot HQR ratings showed borderline Level 1 / Level 2 handling qualities for both scales, with slightly better average HQR ratings for the logarithmic scale. Except for a small number of aborted landings (3/183), there seemed to be no issues with using the logarithmic scale.

The other dimension of the main test matrix was a comparison of panel-mounted versus head-mounted displays. The advantage of the panel-mounted display was that it included an earth referenced flight path marker symbol and earth-referenced horizon line. The flight path marker symbol indicated the current direction of travel with respect to the background terrain imagery. Therefore, the symbol could be used for vertical guidance on the panel-mounted display. The objective data showed little difference in pilot performance between the head and panel-mounted displays for all performance parameters, which is consistent with a previous NASA-Ames simulation (Ref. 2). The panel-mounted format was associated with significantly less lateral speed at touchdown, but it was determined not to be operationally relevant since the differences were small and on average all conditions were well within desired performance. In the post-simulation questionnaire, four out of six pilots indicated that they wanted both display types (head and panel-mounted) in the cockpit, and the remaining two preferred panel-mounted only.

2x1 Matrix. In order to test the robustness of the display design, six pilots flew landings to the same five LPs, but without guidance because LP coordinates were intentionally not entered. The scenario required the pilot to visually find the LP before brownout and to make a successful landing to that point in brownout. Each pilot was given the choice of linear or logarithmic scale, and all six chose the logarithmic scaling. Objective data showed that average performance was within desired criteria for all measures except for the distance to the LP. The average touchdown distances (1.5 to 2 rotor diameters) for the two display types were in the adequate range as opposed to desired, with 25-33% of the landings in the outside adequate range (>2 rotor diameters). Error was primarily in the longitudinal axis. This metric is believed to be highly dependent on aircraft proximity to the LP prior to complete loss of the out-the-window view of the ground. The task was expected to be more difficult without the guidance. Unexpectedly, the average HQR values were nearly the same without the guidance as with the guidance. Both panel-mounted and head-mounted displays were compared for this scenario of no guidance. The display type was not a significant effect.

CONCLUSIONS

The purpose of this test was to compare two scaling methods (linear scaling and logarithmic scaling) for horizontal velocity and position symbols on the BrownOut Symbology System, 2nd Generation (BOSS2). This display was designed to have a single page from cruise speeds to landing. The scaling methods were tested using both a panel-mounted display and a head-mounted display.

Pilot performance data and handling qualities rating showed minimal differences between using the BOSS2 symbol set with the linear scale and the BOSS2 symbol set with the logarithmic scale. Pilots indicated a strong preference for the logarithmic scale over the linear scale on the post simulation questionnaire. Pilots did not comment on the artifacts of the logarithmic scale, which are not prominent when the aircraft is decelerating directly toward the intended landing point. Future training should include conditions outside normal approaches to demonstrate logarithmic scale artifacts.

Performance data and handling quality ratings showed minimal differences between panel-mounted displays and head-mounted displays even though the panel-mounted display had additional vertical guidance with the flight path marker symbol. As a group, pilots indicated that they preferred to have both types in the cockpit.

This simulation also demonstrated that pilots could use the BOSS2 symbology set to make safe landings even without a pre-designated landing point as long as landing point distance was not a safety factor up to four rotor diameters. Distance from the intended landing point suffered primarily in the longitudinal axis, and the data spread for one standard deviation was up to four rotor diameters away. This number is believed to be highly dependent on how close the aircraft gets to the landing point before complete loss of the out-the-window ground view.

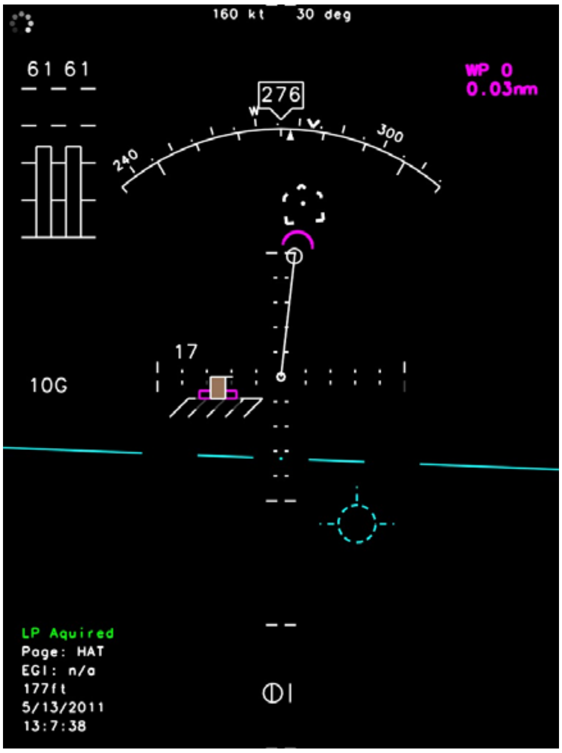

Figure 30. Hover-Approach-Takeoff Page of BOSS2.

FUTURE DIRECTIONS

Figure 30 shows the current version of BOSS2 symbology, de-cluttered from the version flown in this simulation. Altitude information is presented on the left only. BOSS2 has an enroute page, and a Hover-Approach-Takeoff (HAT) page. The HAT page is intended for the entire approach from 160 knots to landing. The pitch ladder is fixed on both pages; pitch can be read accurately at all speeds, even hover. The display shown in Figure 30 was first flown on the AFDD EH-60L aircraft July 12, 2011, with the logarithmic scales and improved horizontal and vertical guidance algorithms. Further tests are planned.

REFERENCES

[1] Keller, M., Neiswander, G., Schnell, T., Szoboszlay, Z., “Rotorcraft Hover Symbology Study for Operation in Poor Visibility Conditions,” The University of Iowa, February 15, 2008.

[2] Szoboszlay, Z., Albery, W., Turpin, T., Neiswander, G., “Brown-Out Symbology Simulation (BOSS) on the NASA Ames Vertical Motion Simulator,” American Helicopter Society 64th Annual Forum, 2008.

[3] Szoboszlay, Z., McKinley, R., Turpin, T., “Symbology for Brown-Out Landings: The First Simulation for the 3D-LZ Program,” American Helicopter Society 65th Annual Forum, 2009.

[4] Szoboszlay, Z.P., McKinley, R.A., Braddom, S.R., Harrington, W.W., Burns, H.N., Savage, J.C., “Landing an H-60 Helicopter in Brownout Conditions Using 3D-LZ Displays,” American Helicopter Society 66th Annual Forum, Phoenix, AZ, May 2010.

[5] Neiswander, G.M., “Improving Deceleration Guidance for Rotorcraft Brownout Landing,” American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 2011.

[6] “Operator’s Manual for Helicopter, Attack, AH-64D Longbow Apache, TM 1-1520-251-10; Department of the Army: Washington DC, March 2002.

[7] “Operator’s Manual for Army CH-47F Helicopter, TM 1-1520-271-10; Department of the Army: Washington DC, July 2007.

[8] “Operator’s Manual for Army UH-60M Helicopter, TM 1-1520-280-10; Department of the Army: Washington DC, November 2007.

[9] “Operator’s Manual for Army OH-58D Helicopter, TM 1-1520-248-10; Department of the Army: Washington DC, July 2007.

[10] “Operator’s Manual For Heads Up Display AN/AVS-7,” TM 11-5855-300-10, NAVAIR 16-35HUD-2, Departments of the Army and Navy, 1997.

[11] Cooper G., Harper R., “The Use of Pilot Ratings in the Evaluation of Aircraft Handling Qualities,” NASA Technical Note TN D-5153, 1969.