EVALUATION OF THE MALCOLM HORIZON IN A MOVING-BASE FLIGHT SIMULATOR

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The Malcolm horizon (MH) provides a pilot with pitch and bank orientation information by projecting an artificial horizon across the instrument panel of his aircraft (1) (Fig. 1). This mode of presentation theoretically allows orientation information to be processed by peripheral (ambient) vision in the natural fashion, thus reducing the likelihood of spatial disorientation and sparing foveal (focal) vision for other tasks, thereby reducing workload and improving performance (2). It was our objective to demonstrate the efficacy of the MH in a controlled, simulated, instrument flight environment.

METHOD A Garrett/Varian Model B laser MH was installed in a Singer/Link GAT-3 (USAF T-40) flight simulator, with the MH projector located in the ceiling directly above the pilot's head (Fig. 2). The GAT-3 simulates the North American Sabreliner (USAF T-39) business jet, and has a two degree-of-freedom (pitch and roll) motion system that employs washout, washback, and scaling to create a fairly realistic feeling of instrument flight. Fourteen pilots, 7 USAF and 7 civilian with instrument rating, served as subjects. Although the pilots in this group could generally be classified as inactive or flying infrequently, they had a mean of 1700 hr of pilot time with 330 hr of instrument flying and 130 hr of simulator time. The subjects were allowed to practice ad lib the TACAN RWY 33 approach to Kelly AFB; after about two hours of practice in each mode they felt they were "ready for the check ride" and were tested on the VOR RWY 33 approach, which was similar to the TACAN approach.

To balance the potential order effect, 7 subjects were tested first using the MH plus the conventional instruments (experimental condition) and then tested with conventional instruments only (control condition); the other 7 were tested in the reverse order. Mean squared error (MSE) and mean absolute error (MAE) measurements of deviation from desired values for each of 8 flight parameters were used to compare performance during the experimental condition with that during the control condition. These parameters were: pitch attitude (PA), roll attitude (RA), turn rate (TR), airspeed (AS), vertical velocity (VV), heading (HE), altitude (AL), and course deviation (CD). One-tailed paired t-tests were employed in the preliminary statistical analysis, reported here. When each subject had completed testing under both the experimental and control conditions, his solicited comments on the positive and negative aspects of the MH were recorded.

In addition to the 14 subjects described, a NASA test pilot was subjected to the test protocol, first in the experimental and then in the control condition. As his flying was frequent and regular, and his level of sophistication was presumably greater than that of the other subjects, we felt it appropriate and instructive to present his results separately.

<u>RESULTS</u> Data from two portions of the instrument approach have been analyzed. The first portion is the approximately 6-min segment from completion of the procedure turn to the missed-approach point. The second is a 1-min segment between final approach fix and missed-approach point during which task loading was increased markedly by having the subject change communications transceiver frequency and transponder code. These tasks required the subject to abandon his instrument scan temporarily, as the transceiver was to the right of the flight instruments and the transponder was on a pedestal below his right thigh. During the 6-min segment of the approach (Table I) the

subjects exerted much better control over vertical velocity when using the MH than when using conventional instruments only, and pitch attitude deviations were significantly less at the $p<0.10$ level. (Airspeed deviation comparisons are not presented in Table I because subjects reduced airspeed at their discretion during the middle portion of the 6-min segment. Moreover, the altitude deviation measurements are to be read with caution, as digitization errors account for a substantial portion of these data and have necessitated additional analysis.) The subjects' performance on the 1-min segment with high task loading (Table II) was again characterized by better control over pitch attitude when the MH was used, but vertical velocity control was not significantly better with the MH on this segment. In addition, control of course deviation was worse, although heading was significantly more stable at the $p<0.10$ level.

The test pilot's performance on the 6-min and 1-min segments are presented in Tables III and IV, respectively. His control of pitch attitude and vertical velocity was consistently better with the MH than without (Fig. 3). On the other hand, his heading deviations were greater with the MH, and his airspeed control on the 1-min segment was worse with the MH.

All of the subjects praised the MH for its ability to provide rapid indication of pitch deviations; its ability to provide rapid bank information was mentioned less frequently. A number of subjects felt a heading reference on the projected horizon would make the MH considerably more useful. Negative comments were to the effect that the horizon is too narrow; a sky pointer is needed; the flicker and specular reflections are irritating; and that pitch sensitivity is too great, even though the MH used in this study was set at the lowest of three pitch sensitivity levels. All subjects felt that the MH functions as a large, sensitive, attitude indicator, rather than as a provider of primary orientation cues through peripheral vision. Some thought that making the projected horizon longer and adding heading reference lines might promote the latter function, however.

DISCUSSION The subjects felt the MH gave them better control over pitch attitude, and their performance bore this out. The highly significant improvement in vertical velocity control associated with use of the MH in the 6-min approach segment is a manifestation of their better control of pitch attitude. Why the improved pitch attitude control did not result in improved vertical velocity control in the 1-min segment is perhaps explicable: the forced disruption of the instrument crosscheck during this segment prevented the subjects from using pitch control inputs to effect vertical velocity control responses, and they merely stabilized pitch attitude with the MH. The reasons for the inconsistent results relating to heading and course deviation are not readily apparent.

The MH concept is sound. Testing of a commercial realization of this concept in a flight simulator has revealed certain strengths and weaknesses of the currently available MH hardware. Further statistical analyses of the data acquired in the present study, as well as additional studies in different flight environments, are required to ensure a complete understanding of the potential utility of the MH as an aid to flying.

REFERENCES

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2. Money, K.E. Theory underlying the Peripheral Vision Horizon Device. DCIEM Technical Communication 82-C-57, Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, Canada, Dec 1982.

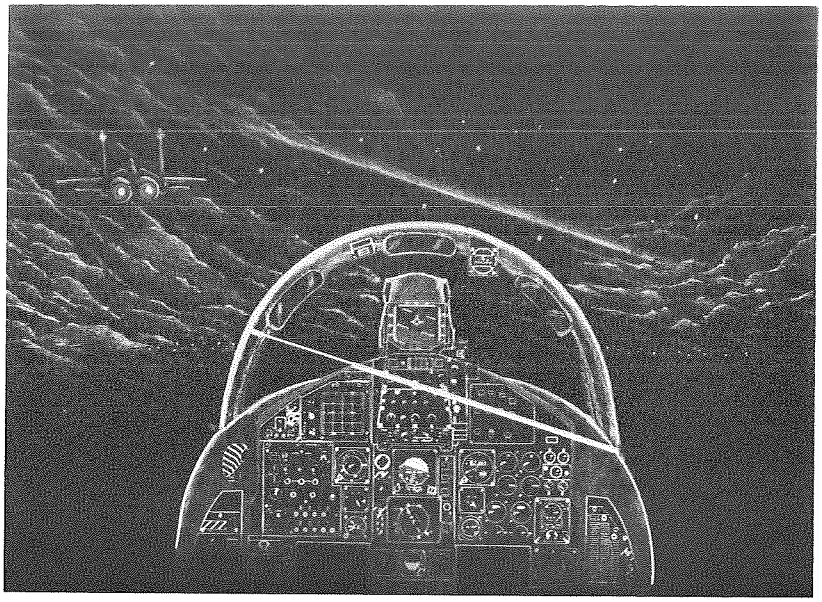

Figure 1. The Malcolm horizon, projected on the instrument panel, indicating a nose-down left bank.

Figure 2. The MH projector in the simulator (above the subject's head).

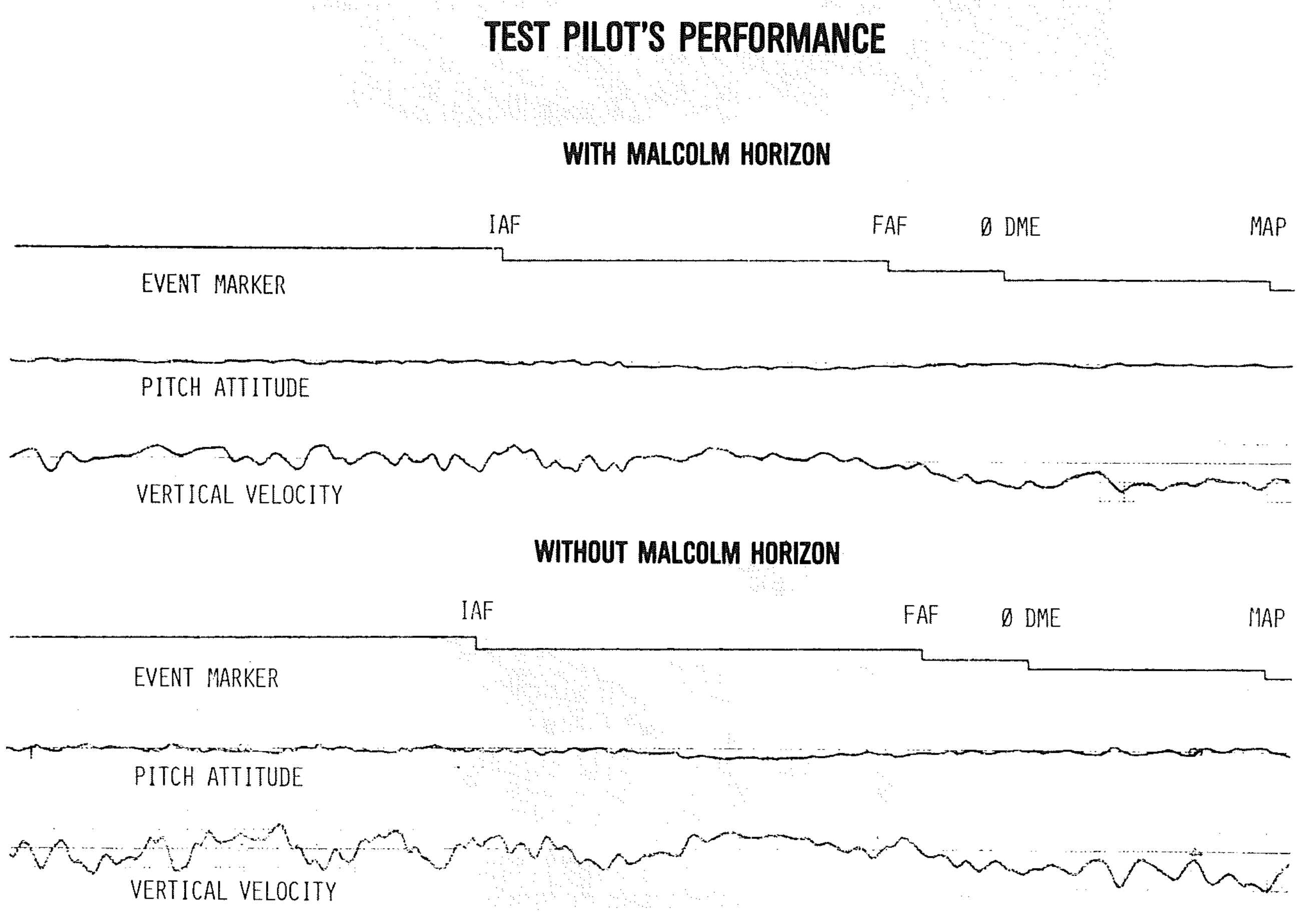

Figure 3. Test pilot's pitch-attitude and vertical-velocity performance, using the Malcolm horizon plus conventional instruments (above) and using conventional instruments only (below).

TABLE I. PERFORMANCE OF 14 SUBJECTS ON 6-MINUTE SEGMENT OF INSTRUMENT APPROACH

Flight Parameter	MSE			MAE		
	MH + Conventional $\bar{X}$ ± SEM	Conventional $\bar{X}$ ± SEM	p	MH + Conventional $\bar{X}$ ± SEM	Conventional X ± SEM	p
PA	2.22 ± 0.21	4.27 ± 1.34	<0.10	1.17 ± 0.07	1.55 ± 0.24	<0.10
RA	153 ± 8	146 ± 19	NS	10.7 ± 0.3	10.0 ± 0.9	NS
TR	1.79 ± 0.05	1.85 ± 0.12	NS	1.21 ± 0.01	1.23 ± 0.02	NS
AS	---	---	--	---	---	--
VV	53,800 ± 6,300	78,200 ± 10,100	<0.005	176 ± 8	209 ± 10	<0.0025
HE	49.9 ± 9.2	56.5 ± 9.0	NS	5.5 ± 0.5	5.9 ± 0.4	NS
AL	(79,600 ± 16,100)	(93,800 ± 31,500)	(NS)	(243 ± 28)	(262 ± 39)	(NS)
CD	147 ± 9	132 ± 13	NS	11.9 ± 0.4	11.2 ± 0.6	NS

TABLE II. PERFORMANCE OF 14 SUBJECTS ON 1-MINUTE SEGMENT WITH HIGH TASK LOADING

Flight Parameter	MSE: MH + Conventional $\overline{X} \pm$ SEM	MSE: Conventional $\overline{X} \pm$ SEM	MSE: p	MAE: MH + Conventional $\overline{X} \pm$ SEM	MAE: Conventional $\overline{X} \pm$ SEM	MAE: p
PA	1.93 ± 0.48	5.11 ± 1.76	<0.05	1.05 ± 0.15	1.65 ± 0.31	<0.05
RA	141 ± 9	138 ± 20	NS	10.5 ± 0.3	9.8 ± 0.9	NS
TR	1.75 ± 0.10	1.90 ± 0.16	NS	1.20 ± 0.03	1.24 ± 0.04	NS
AS	890 ± 92	898 ± 84	NS	28.8 ± 1.6	29.3 ± 1.3	NS
VV	68,500 ± 11,500	71,000 ± 10,100	NS	209 ± 72	222 ± 71	NS
HE	46.8 ± 13.6	97.3 ± 31.7	<0.10	5.3 ± 0.8	7.6 ± 1.3	<0.10
AL	(110,200 ± 39,100)	(113,000 ± 48,200)	(NS)	(287 ± 45)	(269 ± 55)	(NS)
CD	156 ± 9	131 ± 15	<-0.05	12.4 ± 0.4	11.2 ± 0.7	<-0.05

TABLE III. PERFORMANCE OF TEST PILOT ON 6-MINUTE SEGMENT OF INSTRUMENT APROACH

Flight Parameter	MSE			MAE		
	MH + Conventional	Conventional	% Diff	MH + Conventional	Conventional	% Diff
PA	1.62	3.55	-54	1.10	1.45	-24
RA	177	177	0	11.4	11.8	-3
TR	1.72	1.87	-8	1.19	1.20	-1
AS	---	---	---	----	----	---
VV	37,300	79,100	-53	158	237	-33
HE	349	183	91	15.0	10.5	43
AL	(123,000)	(180,700)	(-32)	(342)	(413)	(-17)
CD	133	178	-25	10.5	12.3	-15

TABLE IV. PERFORMANCE OF TEST PILOT ON 1-MINUTE SEGMENT WITH HIGH TASK LOADING

Flight Parameter	MSE			MAE		
	MH + Conventional	Conventional	% Diff	MH + Conventional	Conventional	% Diff
PA	1.46	2.26	-35	1.07	1.15	-7
RA	150	264	-43	11.2	12.7	-12
TR	1.61	2.70	-40	1.16	1.35	-14
AS	1194	785	52	34.4	27.9	23
VV	26,600	40,300	-34	143	162	-12
HE	146	56	161	10.8	7.1	52
AL	(126,900)	(132,600)	(-4)	(354)	(363)	(-2)
CD	227	218	4	14.9	14.7	1