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FIELD-OF-VIEW VARIATIONS AND STRIPE-TEXTURING EFFECTS ON ASSAULT LANDING PERFORMANCE IN THE C-130 WEAPON SYSTEM TRAINER

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Two experiments were conducted using the C-130 Weapon System Trainer (WST) located at Little Rock AFB, Arkansas. These experiments were the first of a series of research and development efforts designed to provide input to specification of the visual requirements for the C-17 flight simulator. Both studies assessed the effect of an experimental manipulation upon pilot performance of an assault landing. The basic experimental design for each was a randomized block repeated measures. For each study, ten experienced C-130 pilots served as subjects. The first study investigated the effect of limiting the field of view (FOV) of the WST by reducing the five-channel, six-window visual system to two channels and two windows. The second study investigated the effect of data base texturing upon pilot performance. No strongly significant FOV effects were obtained in the first study. However, the results of the second study indicated that data base texturing improved the pilots' ability to fly at lower altitudes and place the aircraft closer to the center line during landing and touchdown.

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SUMMARY

The objectives of the present effort were twofold: (a) to determine the effects of variations in window configurations on pilot performance in the C-130 Weapon System Trainer (WST) and (b) to study the differences in pilot performance as a function of the new stripe color texturing as compared to color with no texturing. These objectives were accomplished by using the existing on-board computer systems and hardware available in the C-130 WST located at Little Rock AFB, Arkansas. Much of the impetus for conducting these studies derived from the need to determine future visual system requirements for the C-17 flight simulator currently under development. The C-130 is considered a generic wide-bodied aircraft; thus, the findings from this aircraft may be considered relevant to the new C-17. It as already been determined that the C-17 will have window configurations and mission profiles nearly identical to those of the C-130. In both part (a) and part (b) of this study, experienced C-130 instructor pilots and fully qualified operational pilots served as subjects. In each case, they were required to fly standard combat assault landings and to adhere as closely as possible to the optimum flight parameters. The experimental manipulations involved two different window configurations and two texture conditions. The results showed no strongly significant differences in the two window conditions; however, there were statistically significant differences in the texture condition versus the no texture condition.

PREFACE

The work was performed in support of the Air Force Human Resources Laboratory's Technical Planning Objective 3, the thrust of which is Aircrew Tactics and Training. The general objective of this thrust is to identify and demonstrate cost-effective training strategies and training equipment capabilities for use in developing and maintaining the combat effectiveness of Air Force aircrew members. This particular study was conducted under Work Unit 1123-03-83, Flying Training Research Support, Contract No. F33615-87-C-0012, and is responsive to a need expressed by the Air Force Deputy for Simulators for empirical data that relate aircrew training effectiveness to those simulator design factors which significantly impact overall system costs. The results obtained here give some indication as to the visual system requirements in the emerging C-17 aircraft, and may apply to other aircraft as well.

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I. INTRODUCTION

The present effort examines the effects of field of view (FOV) and stripe texturing on assault landing performance in the C-130 Weapon System Trainer (WST), which can be looked upon as representative of Air Force wide-bodied aircraft. The C-130 WST located at Little Rock AFB, Arkansas, has been identified as an excellent test platform on which to carry out research and development (R&D) on simulator characteristics and training methods. This system has been used to investigate both training procedures and visual display qualities. The trainer, because it represents a state-of-the-art visual system, offers an effective tool for pursuing R&D on visual system characteristics such as FOV and stripe texturing.

The C-130 WST is especially important as a research device in that the findings from this system may be generalized to the C-17 now under development by the Air Force because the C-17 will have a mission profile which is almost identical to that of the C-130 as well as a very similar window configuration. Such research using the C-130 WST will allow determination of C-17 simulator visual system requirements to be accomplished well in advance of the aircraft's inclusion in the Air Force inventory, and also provide Air Force procurement agencies with useful design characteristics for future wide-bodied simulators.

II. FIELD-OF-VIEW STUDY

The WST visual system provides computer-generated imagery of out-of-the-window visual cues. The system can provide day, dusk, and night scenes and presents imagery using a six-window, five-channel, color cathode-ray tube (CRT) display system with infinity optics. The visual data base currently contains more than 300,000 square miles of real-world terrain and cultural features, with over 80 hand-modeled airfields, airdrop/assault landing zones, and low-altitude parachute extraction zones throughout the world. The image generator is capable of generating 8,000 visible edges and 4,000 point lights simultaneously. Other features include surface (stripe) texturing and the capability to generate several moving models (aircraft, missiles, or land vehicles) simultaneously. With this visual system, simulator training has been expanded to include: visual approaches and landings; engine-out go-arounds; low-level navigation; visual slowdown, run in, airdrop, and escape; visual formation flying; night vision goggles procedures; hostile environment training; and special operations training.

Any combination of the six visual windows may be used for research purposes, allowing great flexibility in experimental design. In addition, the system has the capacity to record and document various flight parameters which may be needed for the development of performance measures. In short, the C-130 WST is an excellent test bed for wide-bodied simulator research. For a more detailed description of this system, see the C-130 Flight Simulator Operating Instructions (1982 & 1983).

Method

Subjects. The 10 subjects for this phase of the study were experienced C-130 operational and instructor pilots.

Approach. Each subject performed a series of 16 assault landings using two alternative window configurations (i.e., FOV conditions). Figure 1 shows a top-view diagram of the windows and crew positions in the C-130 WST. The six windows receive five channels of visual information with the two forward windows, A and A', sharing the same visual channel. The two FOV conditions used were: condition 1, all windows operational; condition 2, only windows A and B operational. The only crew position occupied was that of the pilot. The experimenter was seated at the aft console and monitored the data results on each run.

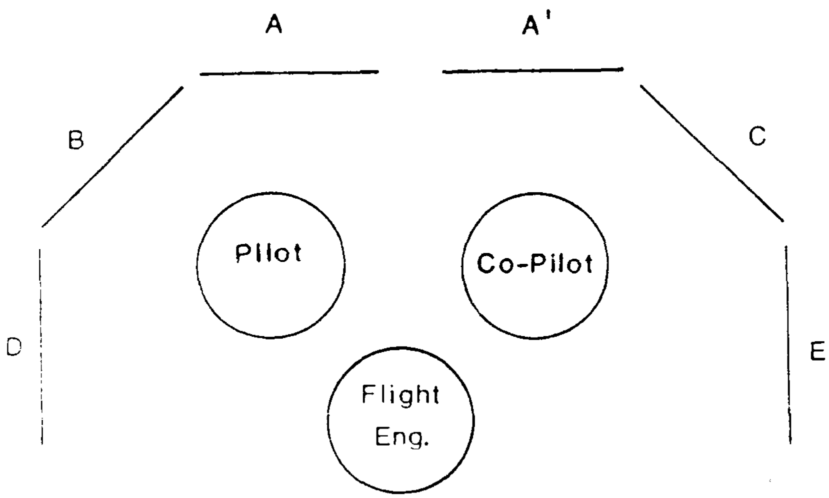


Figure 1. C-130 WST Window Configuration.

Figure 2 shows a top view of the total horizontal FOV that is available to the pilot in the WST. The forward window, window A, has a horizontal width of 43°, with a 2.5° blank space separating it from window B. Window B and window D are each 47°, and they are separated by a 3° blank space. The height of each window is 35 feet. The pilot's FOV is quite limited on the right side due to the optical effects produced by the arrangement of the windows: To the right of window A, there is a 33° blank space, followed by an 11.3° window of visibility, followed by an 11.3° blank space and finally an 11.3° far-side view.

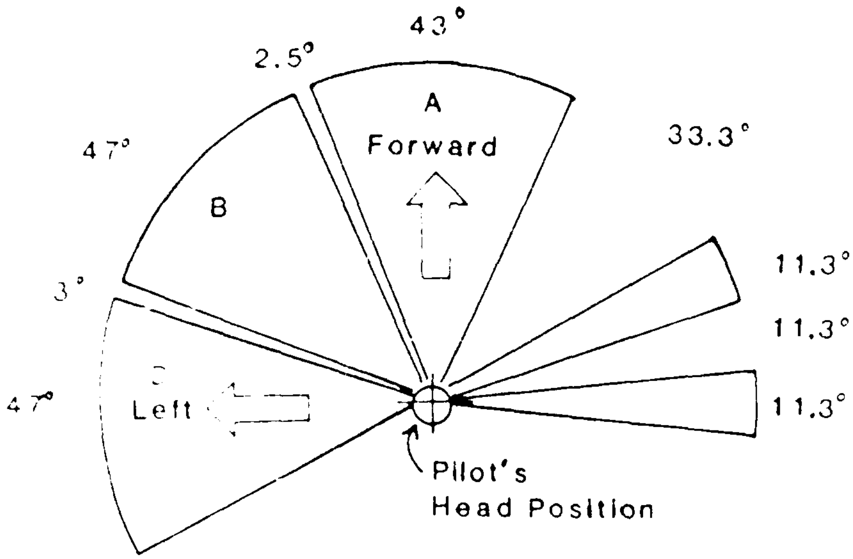
The assault landing was chosen as the experimental task because it represents a high workload, high performance demand procedure for even the most experienced pilots. The pilot must successfully land the aircraft on a short, usually rugged runway while maintaining very precise flight parameters (see C-130 Flight Simulator Operating Instructions 1982 & 1983).

The experimental procedure was to initialize the simulation at 2.2 nautical miles on a final approach to the assault landing. The pilot was instructed to fly the aircraft and attempt at all times to approach as closely as possible the optimum flight parameters for the landing. On each successive run, the window configuration was changed. Half of the subjects began in FOV condition 1, and the other half began with FOV condition 2. The subjects alternated between the two conditions for a total of 16 trials (8 in each condition). Each run was conducted under unobscured daylight conditions, with no crosswinds, no turbulence, and no aircraft system malfunctions.

For each run, the C-130 WST on-board system was programmed by the experimenter to reset the aircraft at 2.2 miles, change window conditions and release the system for the next run. The on-board computer automatically recorded and printed out a hard copy of performance data for the following critical flight parameters at 1/2 nautical mile out, at threshold, and at touchdown: (a) airspeed, (b) rate of descent, (c) angle of attack (AOA), (d) altitude above ground level (AGL), (e) distance from runway threshold, and (f) distance to right or left of runway center line.

The 6-degree-of-freedom motion system was operative on each experimental run so that the pilot received proprioceptive, kinesthetic and vestibular cues during the assault landings. In addition, each pilot wore a headset which supplied realistic auditory cues during experimental runs.

The full set of experimental runs for each pilot took approximately 1 hour, including stops, resets, and reconfiguration of the system at the on-board console.



Vertical FOV = 35 Feet

Figure 2. Top View of Pilot's Total Horizontal Field of View.

Results

A separate analysis was conducted on the data at each of the three points of the course: 1/2 mile out, threshold, and touchdown (see Tables 1 through 5). Of the six parameters recorded, five were analyzed at each location. Airspeed, rate of descent, AOA, center line deviation, and altitude AGL were analyzed at 1/2 mile out and at threshold. At touchdown, distance from threshold replaced the AGL parameter for analysis purposes.

The data were analyzed using a split-plot analysis of variance approach. Subjects were grouped according to the FOV each received first. The two FOV conditions were compared within subjects. A multivariate analysis of variance (MANOVA) was performed first, followed by a univariate analysis of variance (ANOVA) on each of the five performance variables.

The FOV by subjects-within-groups interaction term (the split-plot error term used to test FOV and FOV-by-group effects) was first tested by the replication error term with MANOVA and ANOVA analyses to determine whether or not it would be appropriate to pool these terms into a single error term for the split-plot effects. These tests were not significant; so, the pooled error term was formed to test for FOV effects. No significant FOV effects were discovered with the MANOVA or ANOVA tests for 1/2 mile out or threshold. A significant univariate group-by-FOV interaction was found for descent rate, as well as a significant

Table 1. FOV Multivariate Tests (MANOVA)

Effect	Wilks' Lambda	F	df	p
		1/2 Mile Out		
Group	.492	0.83	(5,4)	.590
FOV	.982	0.53	(5,144)	.750
Group by FOV	.984	0.16	(5,144)	.803
		Threshold		
Group	.242	2.50	(5,4)	.197
FOV	.975	0.74	(5,144)	.592
Group by FOV	.972	0.82	(5,144)	.536
		Touchdown		
Group	.343	1.53	(5,4)	.350
FOV	.967	0.98	(5,144)	.434
Group by FOV	.934	2.05	(5,144)	.076

Table 2. FOV Univariate Tests--1/2 Mile Out

Effect	F	df	p
Group		(1,8)	
Airspeed	0.01		.932
Descent Rate	1.12		.320
AOA	0.40		.543
AGL	0.65		.444
Center Line Deviation	1.41		.269
FOV		(1,148)	
Airspeed	1.48		.226
Descent Rate	1.04		.310
AOA	0.44		.509
AGL	1.49		.225
Center Line Deviation	0.25		.616
Group by FOV		(1,148)	
Airspeed	0.09		.770
Descent Rate	0.54		.464
AOA	0.86		.355
AGL	0.35		.557
Center Line Deviation	1.06		.305

Table 3. FOV Univariate Tests--Threshold

Effect	F	df	p
Group		(1,8)	
Airspeed	2.96		.124
Descent Rate	0.04		.843
AOA	3.72		.090
AGL	0.24		.638
Center Line Deviation	3.78		.088
FOV		(1,148)	
Airspeed	0.01		.925
Descent Rate	0.99		.321
AOA	1.52		.220
AGL	1.45		.230
Center Line Deviation	0.74		.392
Group by FOV		(1,148)	
Airspeed	1.06		.304
Descent Rate	3.71		.056
AOA	0.03		.860
AGL	0.66		.418
Center Line Deviation	0.02		.880

Table 4. FOV Univariate Tests--*Touchdown*

Effect	F	df	p
Group		(1,8)	
Airspeed	3.11		.116
Descent Rate	0.48		.507
AOA	0.65		.443
Distance From Threshold	0.01		.921
Center Line Deviation	3.61		.094
FOV		(1,148)	
Airspeed	0.17		.682
Descent Rate	1.05		.306
AOA	3.79		.053
Distance From Threshold	2.29		.132
Center Line Deviation	0.27		.604
Group by FOV		(1,148)	
Airspeed	3.16		.078
Descent Rate	6.55		.012
AOA	1.61		.206
Distance From Threshold	2.06		.153
Center Line Deviation	0.48		.489

Table 5. FOV Means

Variable	Criterion	Narrow FOV	Wide FOV	Standard error
1/2 Mile Out				
Airspeed	115	117.4	117.0	0.2
Rate of Descent	800	779.3	755.7	16.3
AOA	2.5	3.39	3.45	0.07
AGL	150	178.5	174.8	2.1
Center Line Dev.	0.0	-11.2	-12.2	1.4

Threshold

Variable	Criterion	Narrow FOV	Wide FOV	Standard error
Airspeed	115	112.0	112.0	0.2
Rate of Descent	400	502.8	480.9	15.6
AOA	2.5	4.49	4.31	0.10
AGL	17.5	9.4	10.0	0.4
Center Line Dev.	0.0	-5.4	-6.0	0.5

Touchdown

Variable	Criterion	Narrow FOV	Wide FOV	Standard error
Airspeed	105	110.6	110.5	0.2
Rate of Descent	250	422.5	398.7	16.4
AOA *	4.5	4.9	4.6	0.1
Dist. from Thres.	250	230.7	256.1	11.8
Center Line Dev.	0	-5.6	-6.0	0.5

* Significant univariate difference in the absence of a multivariate effect

FOV effect for AOA. However, since none of the MANOVAs were significant, these results are considered tentative at best. If there is any FOV effect at all, it is that the mean AOA at touchdown is closer to the ideal of 4.5 with the wide FOV than it is with the narrow FOV (see Table 5).

III. TEXTURE STUDY

Previous research on texturing has indicated that surface texture patterns provide pilots with altitude maintenance information (Edwards, Pohlman, Buckland, & Stephens, 1981; McCormick, Smith, Lewandowski, Preskar, & Martin, 1983) and runway alignment information (Kraft, Anderson, & Elworth, 1982). Kraft and his associates studied two levels of scene complexity, which were designated as "simple" and "complex." The simple scene was a blue/black runway in a homogeneous surround. There were no markings on the runway for either level of complexity; however, in the complex scene, the surrounding area contained the details normally available in the Moses Lake, Washington, computer data base for flight crew training. Several performance measures were used in this study. Kraft found that the greater scene complexity significantly improved the quality of flight performance in that the pilot was able to achieve a much better lineup with the runway center line. He concluded that if cues such as those in the complex scene constitute an important aid to training and consequently result in shorter training time, the increased computer capacity needed to provide greater detail could well be worth the cost.

Sieverding (1984) described in detail the texturing capacity of the C-130 WST. He pointed out that texturing allows for a high density accumulation of individually discernible, two-dimensional, co-planar details without excessive computational overhead; this feature is especially valuable in edge- or face-limited systems. The C-130 visual system has 10 levels of detail, and as an observer moves toward a textured face, the texture pattern can become increasingly complex as it transitions to finer levels of detail. Texture can be applied to sloped or horizontally inclined faces and is specifically designed to give consistent cues at all levels of detail. Also, light and dark bands can be rotated about each other to yield texture patterns ranging from tartan plaid to pseudo-random. All face edges are straight lines; all texture patterns are composed of straight bands, although they may not be perceived as such. The C-130 WST system has the capability of being shifted rapidly from texture to non-texture presentation and vice-versa while maintaining full-color presentation.

Method

Subjects. As in the FOV study, the 10 subjects (different from the original 10) in this phase were fully qualified C-130 operational and instructor pilots.

Approach. The experimental approach was identical to that used in the FOV study, except that instead of alternating C-130 window configurations, there was an alternation of texture and non-texture. The texture condition consisted of surface texture applied in and around the landing site. All windows were operative on all experimental runs. The total number of trials per subject varied from six to eight for each condition. Variations were due to occasional equipment malfunctions.

Results

A separate analysis was conducted on the data at each of the three points of the course: 1/2 mile out, threshold, and touchdown (see Tables 6 through 10). As in the FOV study, five parameters were recorded and analyzed at each location: Airspeed, rate of descent, AOA, center line deviation, and AGL were analyzed at 1/2 mile out and at threshold; at touchdown, distance from threshold replaced AGL.

The data were analyzed using a split-plot analysis of variance approach. Subjects were grouped according to the texture condition in which they began the sequence. The two texture conditions were compared within subjects. The various trials were treated as replications. Again, analysis consisted of a MANOVA, followed by a univariate ANOVA for each of the five performance variables.

The texture by subjects-within-groups interaction term (the split-plot error term used to test texture and texture-by-group effects) was first tested to determine whether or not it would be appropriate to pool these terms into a single error term for the split-plot effects. Since these tests were not significant, the pooled error term was formed to test for texture effects.

At 1/2 mile out, there were no significant multivariate effects. There was, however, a significant univariate effect for texture in terms of center line deviation; that is, pilots flying in the texture condition, came closer to the center than when in the no texture condition.

At threshold, there was a significant multivariate effect for texture. There were also significant univariate effects for texture in terms of AGL and center line deviation. In both conditions, the pilots tended to fly lower than the target AGL;

Table 6. Texture Multivariate Tests

Effect	Wilks' Lambda	F	df	p
1/2 Mile Out				
Group	.146	4.68	(5,4)	.080
Texture	.941	1.54	(5,123)	.183
Group by Texture	.960	1.03	(5,123)	.403
Threshold				
Group	.647	0.44	(5,4)	.806
Texture	.916	2.25	(5,122)	.054
Group by Texture	.975	0.62	(5,122)	.682
Touchdown				
Group	.741	0.28	(5,4)	.903
Texture	.885	3.19	(5,123)	.010
Group by Texture	.977	0.59	(5,123)	.709

Table 7. Texture Univariate Tests--1/2 Mile Out

Effect	F	df	p
Group		(1,8)	
Airspeed	0.59		.466
Descent Rate	0.16		.703
AOA	0.15		.711
AGL	0.01		.918
Center Line Deviation	0.21		.660
Texture		(1,127)	
Airspeed	1.54		.217
Descent Rate	1.83		.179
AOA	0.91		.342
AGL	0.06		.803
Center Line Deviation	4.94		.028
Group by Texture		(1,127)	
Airspeed	2.78		.098
Descent Rate	0.41		.522
AOA	0.01		.999
AGL	1.10		.297
Center Line Deviation	0.01		.947

Table 8. Texture Univariate Tests--*Threshold*

Effect	F	df	*p*
Group		(1,8)	
Airspeed	0.04		.847
Descent Rate	0.11		.750
AOA	0.05		.821
AGL	1.00		.347
Center Line Deviation	0.30		.596
Texture		(1,126)	
Airspeed	0.29		.593
Descent Rate	0.56		.456
AOA	0.56		.458
AGL	3.88		.051
Center Line Deviation	4.37		.039
Group by Texture		(1,126)	
Airspeed	0.46		.498
Descent Rate	0.44		.506
AOA	1.34		.250
AGL	0.39		.532
Center Line Deviation	0.90		.345

Table 9. Texture Univariate Tests--Touchdown

Effect	F	df	p
Group		(1,8)	
Airspeed	0.45		.521
Descent Rate	0.06		.815
AOA	0.02		.905
Distance From Threshold	0.73		.417
Center Line Deviation	0.01		.960
Texture		(1,127)	
Airspeed	0.63		.428
Descent Rate	2.33		.129
AOA	0.01		.936
Distance From Threshold	1.43		.233
Center Line Deviation	9.89		.002
Group by Texture		(1,127)	
Airspeed	0.21		.648
Descent Rate	0.79		.375
AOA	0.11		.741
Distance From Threshold	0.06		.812
Center Line Deviation	0.79		.376

Table 10. Texture Means

Variable	Criterion	No texture	Texture	Standard error
		1/2 Mile Out		
Airspeed	115	116.6	117.1	0.3
Rate of Descent	800	733.7	762.3	14.9
AOA	2.5	3.41	3.30	0.08
AGL	150	188.6	187.6	2.8
Center Line Dev.[a]	0.0	-14.0	-10.0	1.3
		Threshold		
Airspeed	115	112.6	112.8	0.[illegible]
Rate of Descent	400	569.9	550.1	18.8
AOA	2.5	4.09	4.22	0.12
AGL	17.5	14.5	12.7	0.6
Center Line Dev.[b]	0.0	-7.6	-5.3	0.8
		Touchdown		
Airspeed	105	110.5	110.7	0.2
Rate of Descent	250	497.8	450.5	21.9
AOA	4.5	5.18	5.16	0.16
Dist. from Thres.	250	309.2	283.5	15.1
Center Line Dev.[b]	0	-8.5	-6.0	0.6

[a] Significant univariate difference in the absence of a multivariate effect.
[b] Significant univariate difference in the presence of a multivariate effect.

in the texture condition, they tended to fly lower than in the no texture condition. Though the pilots tended to fly to the left of center line (as indicated by the negative mean center line deviations), they flew closer to the center line when in the texture condition than when in the no texture condition.

At touchdown, there was a significant multivariate effect for texture (see Table 10). The only significant univariate effect was center line deviation for the texture condition. Again, all pilots tended to fly to the left of center but flew closer to the center line when in the texture condition as compared to when they were in the no texture condition.

IV. DISCUSSION

Though the results of the FOV study provide no strong evidence that a wide field of view is essential for the performance of the assault landing, it would be a mistake to conclude, based on these results, that the wide FOV is not needed. Given the experience level of the subjects, and the fact that in the simulation they were initially aligned with the landing area, these results are not too surprising. The significant finding that subjects maintained a slightly higher angle of attack at touchdown in the narrow-FOV condition as compared to the wide-FOV condition (see bottom section of Table 5) could represent a compensation for the limited visual area in the narrow-FOV condition. In the absence of eye position data, it is impossible to tell what other types of compensation the subjects may have used.

The results from the texture study reinforce those obtained from previous studies (e.g., Kraft et al., 1982). Texture patterns around the landing area aid the pilot in the maintenance of center line positioning and altitude control. In the presence of texture patterns, pilots are able to detect the ground surface and thus are willing to fly at lower altitudes.

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