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Flare Cue Symbology for Zero-Zero Weather Landings

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14. ABSTRACT
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Flare cue symbology for zero-zero weather landing

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ABSTRACT

When flying an airplane, landing is arguably the most difficult task a pilot can do. This applies to pilots of all skill levels particularly as the level of complexity in both the aircraft and environment increase. Current navigational aids, such as an instrument landing system (ILS), do a good job of providing safe guidance for an approach to an airfield. These aids provide data to primary flight reference (PFR) displays on-board the aircraft depicting through symbology what the pilot's eyes should be seeing. Piloting an approach under visual meteorological conditions (VMC) is relatively easy compared to the various complex instrument approaches under instrument meteorological conditions (IMC) which may include flying in zero-zero weather. Perhaps the most critical point in the approach is the transition to landing where the rate of closure between the wheels and the runway is critical to a smooth, accurate landing. Very few PFR's provide this flare cue information. In this study we will evaluate examples of flare cueing symbology for use in landing an aircraft in the most difficult conditions. This research is a part of a larger demonstration effort using sensor technology to land in zero-zero weather at airfields that offer no or unreliable approach guidance. Several problems exist when landing without visual reference to the outside world. One is landing with a force greater than desired at touchdown and another is landing on a point of the runway other than desired. We compare different flare cueing systems to one another and against a baseline for completing this complex approach task.

Keywords: Enhanced vision, flight symbology, flight guidance, situation awareness, military transport

1. INTRODUCTION

1.1 Background

This paper presents the results of the first of three studies in support of the Autonomous Approach and Landing Capability (AALC) demonstration program. The AALC program was initiated to advance the development of an enhanced vision system for safely conducting self contained approach and landing operations in poor visibility conditions. The issues addressed by this and the other studies were cited as concerns in a 1998 flight test program[1]. The two issues addressed here are: 1) excessive sink rate attributed to low quality sensor imagery, and 2) touchdowns outside of the desired touchdown zone. Each of these concerns was raised previously by pilots because of the relatively low quality images provided by the sensor and the symbology at hand.

1.2 Test Item Description

The Transport Aircraft Cockpit (TRAC) is a reconfigurable, three seat (pilot, copilot, flight engineer) transport aircraft cockpit research simulator. Wide-angle collimating windows are used for displaying out-the-window scenes. Head down instrument formats are displayed using three 21" monitors across the front of the cockpit. Active matrix liquid crystal displays are also available as head down display devices. Several aero- and feel models (e.g. C-141, C-17) are available to provide aircraft flying characteristics. The simulation also has the flexibility to switch between a center yoke, a center C-17-style stick, or a side stick controller for flight control inputs. For this evaluation, TRAC was configured with the three display configurations, a C-17 aeromodel, and the center C-17-style flight control stick.

Cockpit display formats and out-the-window scene graphics were generated by Linux-based PCs. Visual scene generation occurred at rates varying from 25Hz to 30Hz depending upon scene complexity. Graphics programming was accomplished in C/C++ and Fortran languages, with C++ being the program of choice for visual scene rendering.

The AALC system simulated in TRAC consisted of a digital light engine (DLE) head-up display (HUD) and 94 GHz active millimeter wave (MMW) radar. The HUD symbology displayed consisted of the primary flight reference as described in the C-17 "dash 1"[2]. Because TRAC does not have a HUD, the symbology was displayed on the out-the-window scene. An effects-based simulation of MMW radar imagery was written in-house with assistance from AFRL/SN and the prime contractor.

1.3 Test Objectives

a. Evaluate the ability of the candidate displays to provide the pilot with sufficient cues to touchdown within the desired landing zone.
b. Evaluate the ability of the candidate displays to provide the pilot with sufficient cues to touchdown with an acceptable sink rate.
c. Evaluate the perceived and actual situation awareness provided by the candidate displays with regard to touchdown location.
d. Evaluate the perceived workload experienced by pilots when using the candidate displays.

Weather conditions simulated were Visual Meteorological Conditions (VMC) – no restriction to visibility – and Instrument Meteorological Conditions (IMC) – 0′ ceiling and 0′ runway visual range.

1.4 Limitations

TRAC is a fixed-base simulator; therefore vestibular effects of conducting these operations were not controlled. Effects specific to obscuration types (e.g. rain, snow, and fog) were not simulated.

2. TEST AND EVALUATION

2.1. Participants

Twelve pilots of varying experience/qualification levels from mobility organizations participated. They came from one of three USAF C-17 wings, the C-17 SPO, AFFTC, and the Air Force Reserve.

2.2. Duration of Study

Each pilot spent one day (approximately 6 hours) completing simulator "ground school" training, simulator flying training, simulator data collection, and experiment debriefing.

2.3. Design

The experimental design for the study was a repeated measures three-factor multivariate analysis of variance. Each participant received each treatment condition, and the order of presentation for the conditions was randomized to counter order effects.

2.4. Independent variables

Three factors were controlled, two with three levels and one with two levels. The first factor was HUD configuration and its three levels were minimum impact symbology (MIS), commercially available symbology (CAS), and full outline/rising runway symbology (FORRS). The second independent factor was runway configuration and its three levels were 75′, 150′ and 300′ widths; all runways were 3000′ long. The final factor was visibility where the two levels were VMC (unrestricted ceiling and visibility) and IMC (0′ ceiling and 0′ visibility).

2.5. Dependent variables

Several measures were collected during and after the trials. Landing performance data was collected to determine landing technical error. Subjective situation awareness data were collected in post-mission and post experiment questionnaires. Finally, a subjective questionnaire was provided to solicit specific design guidance and feedback.

2.6. Procedure

Pilots flew 36 simulated landings (roughly 5 minutes each) under the various combinations of the independent variables HUD x Runway width x Visibility (3 x 3 x 2 x 2 replications). The scenario began approximately 4 miles from the runway along the extended centerline; flightpath error data collection began at the 2 mile (600′ AGL) point.

2.7. Display Configurations

As mentioned there were three configurations that combined display symbology and imagery. The three configurations are described below. Symbology was selected for its purported design characteristics. Runway outlines purport to aid aircrew in locating, lining up with, and touching down in the proper location on the runway. Flare cues are designed to give the pilot better information on when to begin making the control inputs for the transition to landing[3].

2.7.1. Configuration 1: Minimum Impact Symbology (MIS)

The first was treated as a "minimum impact" baseline configuration. This configuration consisted of the primary flight information from the C-17 HUD overlaid on the MMW RADAR image. The only additional symbology in configuration 1 was a drift angle indicator that is normally displayed on the head-down display (HDD) in the C-17. In this study it was displayed on the HUD (See figure 1).

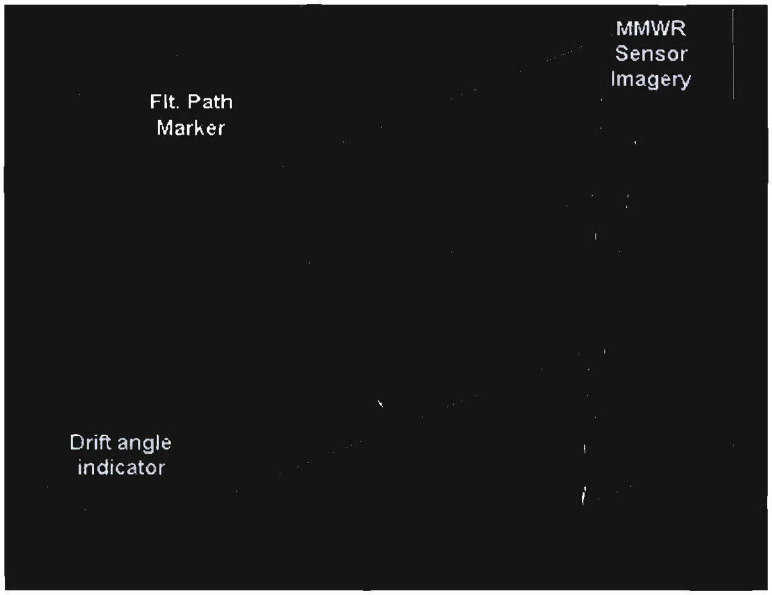

Figure 1. Configuration 1 in IMC

The task was to use the dual cue flight director and the flight path marker in conjunction with the underlying imagery to make the approach and landing. Touchdown location cues were provided via the imagery only. Vertical velocity cues were provided via imagery and the VVI in the HUD. In VMC the underlying imagery was an unobstructed daylight view of the landing zone and surround. The VMC condition also included the landing zone marking panels according to current practice. In IMC the underlying image was the MMWR image as shown above. Based on the desire of the user, no analog to the marking panels was implemented for IMC.

2.7.2. Configuration 2: Commercially Available Symbology (CAS)

The second display configuration used the same imagery as configuration 1, but made one modification to the C-17 HUD as well as two additions. The flight director was modified from the dual-cue pitch and bank steering bars to a single-cue ball. The inputs to the ball were equivalent to those provided to the steering bars. The first addition was a flare cue based on those currently available on commercial aircraft outfitted with HUDs. This cue consists of a circle (the FD) and a 'plus' sign that appears at 105′ AGL. As the aircraft descends the glideslope, the task of the pilot is to track the plus sign as it climbs higher in the display. When the plus sign centers in the circle (at 55′ AGL) the pilot should initiate the flare maneuver.

The second addition was a symbolic representation of the runway side edges. The edge lines are designed to function as cues for lining up on the runway and to reinforce the visual cues provided by the image (e.g. perspective, splay angle, optical flow). See figure 2.

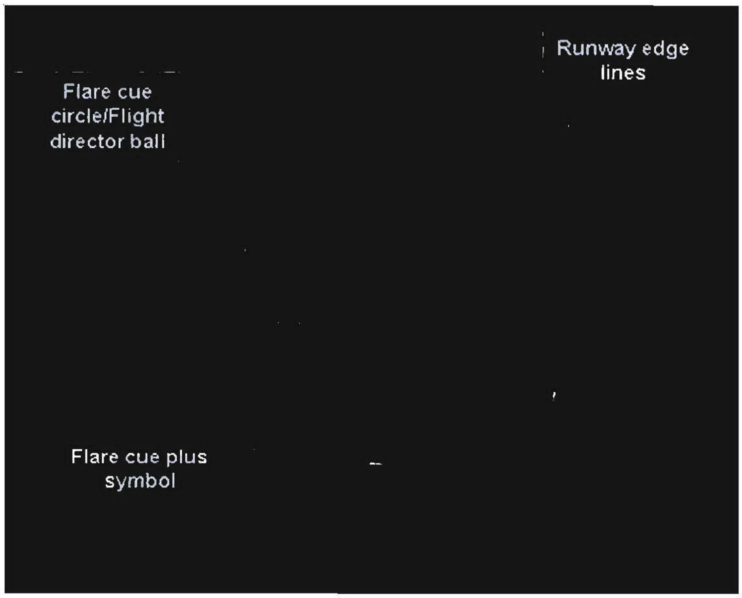

Figure 2. Configuration 2 in IMC.

2.7.3. Configuration 3: Full Outline/Rising Runway Symbology (FORRS)

Expanding on the idea of the runway edge lines from the previous configuration, a full runway outline was provided (threshold, departure and edges), plus a runway centerline and a landing zone marker. Just as the runway edge lines were expected to reinforce the underlying imagery, so, too, were the additional runway features expected to reinforce the imagery and the edge lines. See figure 3.

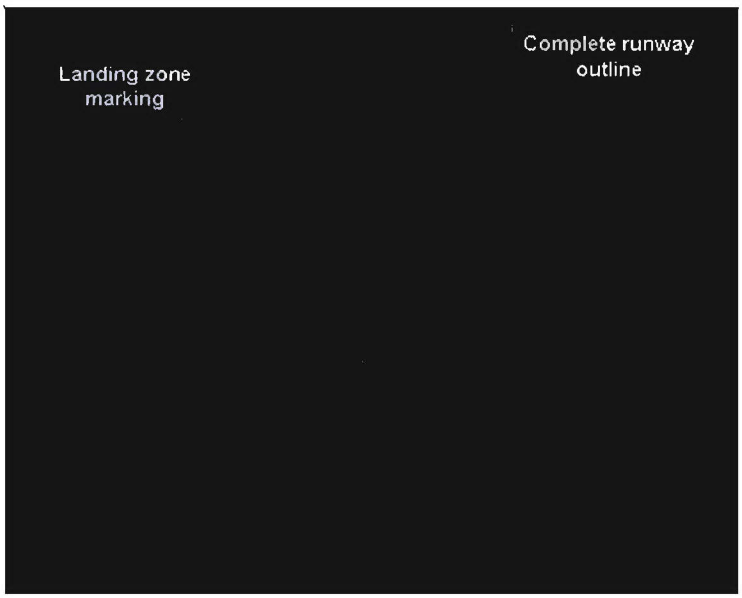

Figure 3. Configuration 3 in IMC with Flight Director (RA > 105').

Configuration three reverted to the dual-cue flight director of the C-17 except that at 105′ AGL a mode change was effected converting the pitch steering bar into a rising runway cue. Referenced to the aircraft waterline symbol the rising runway (nee pitch steering bar) centered under the waterline and rose at a rate proportional to the sink rate. The bottom portions of the waterline symbol represented the main gear so that when the rising runway contacted the bottom 'points' of the waterline symbol the main gear were simultaneously contacting the ground. In this configuration the Flight Path Marker (FPM) was reduced to one quarter size at 105′. This was done to reduce the clutter in the center of the display. Configuration three again used the same underlying imagery as the other two configurations. See figure 4.

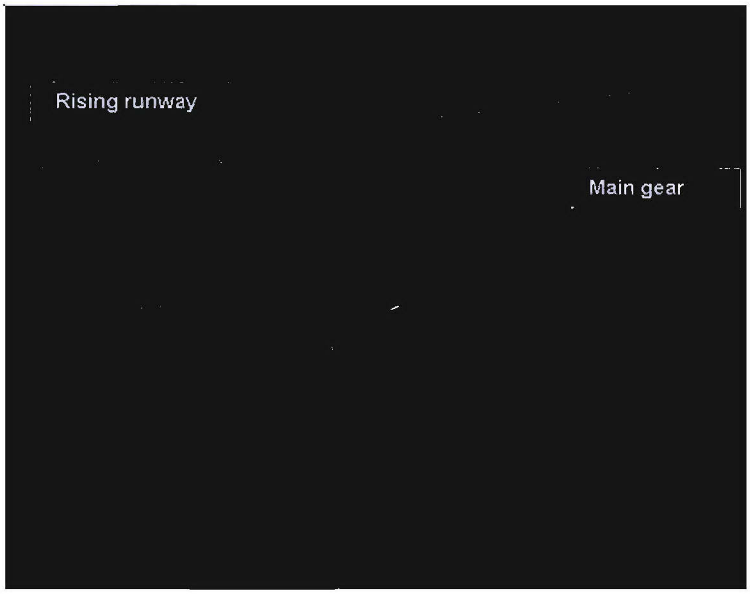

Figure 4. Configuration 3 in IMC with Rising Runway (RA<105′).

2.8. Measures

To determine the effect of the different display configurations several parameters were measured.

2.8.1. Touchdown location

The nominal touchdown location was established as the center of the landing zone. Deviations, both laterally and longitudinally, were measured from the center of the touchdown box. These data were also used to score the landings as pass/fail; 'pass' if they were in the box and 'fail' if out. Additionally, lateral and longitudinal errors (in feet) from the center of the touchdown zone were measured.

2.8.2. Vertical Velocity

A continuous measure of the vertical velocity indicator was collected, but the value at touchdown was used for these analyses.

2.8.3. Situation Awareness

Three methods were used to collect SA data. The first was the China Lake SA[4]. After each trial the pilot would refer to the China Lake SA card and provide a rating for the just completed run. Available ratings ranged from 1 (*very good*) to 5 (*very poor*). Each rating was accompanied by a set of content descriptors to help verbally anchor the ratings (see figure 5).

SA SCALE VALUE	CONTENT
VERY GOOD 1	• Full knowledge of aircraft energy state/tactical environment/mission • Full ability to anticipate/accommodate trends
GOOD 2	• Full knowledge of aircraft energy state/tactical environment/mission • Partial ability to anticipate/accommodate trends • No task shedding
ADEQUATE 3	• Full knowledge of aircraft energy state/tactical environment/mission • Saturated ability to anticipate/accommodate trends • Some shedding of minor tasks
POOR 4	• Fair knowledge of aircraft energy state/tactical environment/mission • Saturated ability to anticipate/accommodate trends • Shedding of all minor tasks as well as many not essential to flight safety/mission effectiveness tasks
VERY POOR 5	• Minimal knowledge of aircraft energy state/tactical environment/mission • Oversaturated ability to anticipate/accommodate trends • Shedding of all tasks not absolutely essential to flight safety/mission effectiveness

Figure 5. China Lake Situation Awareness rating card

The second measure was also collected at the end of each trial. Here, the pilot was asked to place a pencil mark on graph paper where the touchdown zone was represented (see figure 6). In this way we could compare a pilot's perception of the touchdown point to what we measured in the simulation.

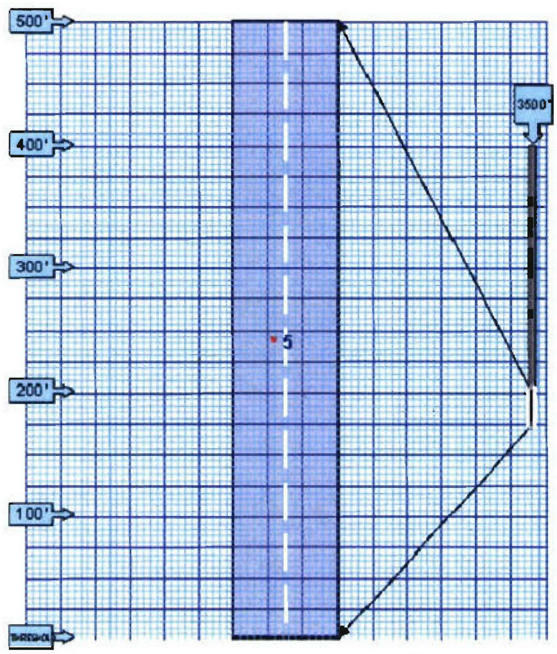

Figure 6. Touchdown Card

Finally, at the end of all of the trials the pilots were asked to rank order the three display configurations, with the configuration allowing the best SA ranked as '1'. Pilots were asked to provide rankings for two phases of the approach and landing: 1) descent point to transition to landing (600′ to 150′ AGL), and 2) transition to landing to touchdown (105′ to 0′).

2.8.4. Workload

Three measures of workload were collected. NASA Task Load Index (TLX)[5] and the USAFSAM Workload Scale were administered after each trial (see figure 7).

NASA Task Load Index

WORKLOAD DEMAND	RATING SCALE
MENTAL DEMAND (mental + perceptual activity)	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Low … High
PHYSICAL DEMAND (activate levers, knobs, aircraft control)	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Low … High
TEMPORAL DEMAND (time pressure, pace of tasks)	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Low … High
EFFORT (combined mental and physical workload)	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Low … High
PERFORMANCE (success of performing the task)	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Good … Poor
FRUSTRATION (level of stress and annoyance)	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Low … High

	USAFSAM Workload Scale
1	NOTHING TO DO; No system demands
2	LIGHT ACTIVITY; Minimum system demands
3	MODERATE ACTIVITY; Easily managed; Considerable spare time
4	BUSY; Challenging but manageable; Adequate time available
5	VERY BUSY; Demanding to manage; Barely enough time
6	EXTREMELY BUSY; Very difficult; Nonessential tasks postponed
7	OVERLOADED; System unmanageable; Essential tasks undone; Unsafe

Figure 7. NASA TLX (*top*) and USAFSAM Workload Scale (*bottom*) cards

Finally, as with SA, at the end of all trials, pilots were asked to rank order the three configurations with respect to workload. In this case, '1' was to indicate the highest workload.

3. RESULTS AND ANALYSES

3.1. Landing performance

The first objective of successfully touching down in the 500′ assault landing zone with a 90% success rate was not met. As table 1 below indicates, the success rate for assault zone landings ranged from 16.7% to 79.2%. No condition resulted in a 90% success rate. Further analysis of the touchdown data using a chi-square procedure show that the variables are not associated with each other.

		VMC				IMC				
	Runway width	**75′**	**150′**	**300′**	**Avg$_{VMC}$**	**75′**	**150′**	**300′**	**Avg$_{IMC}$**	**Avg**
HUD	**MIS**	79.2%	62.5%	20.8%	54.2%	58.3%	66.7%	54.2%	59.7%	57.0%
HUD	**CAS**	79.2%	37.5%	16.7%	44.5%	62.5%	62.5%	50.0%	58.3%	51.4%
HUD	**FORRS**	70.8%	62.5%	58.3%	63.9%	45.8%	50.0%	70.8%	55.5%	59.7%

Table 1. Percentage of landings in the 500′ box

However, looking at the error scores for lateral touchdown, the main effects for runway width and HUD configuration, and the interaction of HUD and weather were statistically significant. The FORRS was significantly better than the MIS or the CAS in terms of lower errors. The 75′ runway had significantly lower mean errors than either of the other two runway widths, and the mean error on the 150′ wide runway was significantly lower than mean error on the 300′ wide runway. See figures 8 and 9.

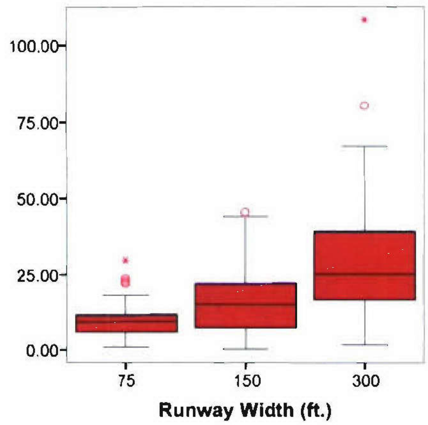

Figure 8. Main effect for runway width lateral —rmse (ft)

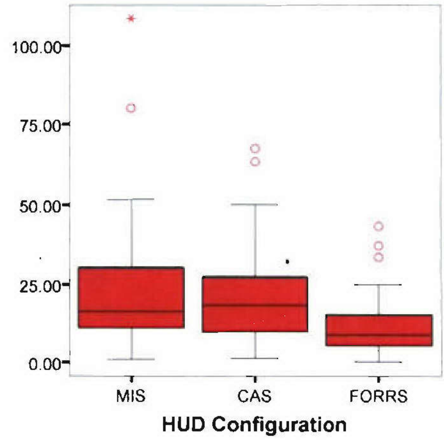

Figure 9. Main effect for HUD configuration — rmse (ft)

In the HUD by weather interaction, lateral error was different between FORRS and MIS depending on the weather condition. For MIS, lateral error was slightly better in VMC than IMC, but for FORRS, the error was lower for IMC than VMC. However, FORRS was still better than MIS overall (see figure 10).

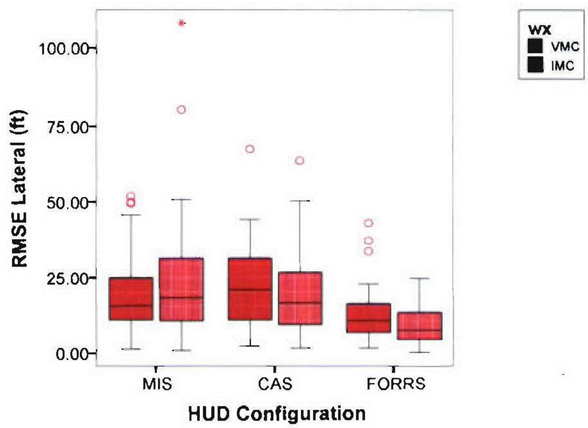

Figure 10. HUD configuration by weather interaction — rmse (ft)

In the longitudinal direction, there was a significant interaction between HUD configuration and weather (see figure 11). Looking at the contrasts, the difference occurred between the FORRS and the CAS. CAS in IMC had slightly better error than it did in VMC, while FORRS in VMC outperformed itself in IMC. While the interaction was significant, the FORRS absolute means were better under both weather conditions than CAS.

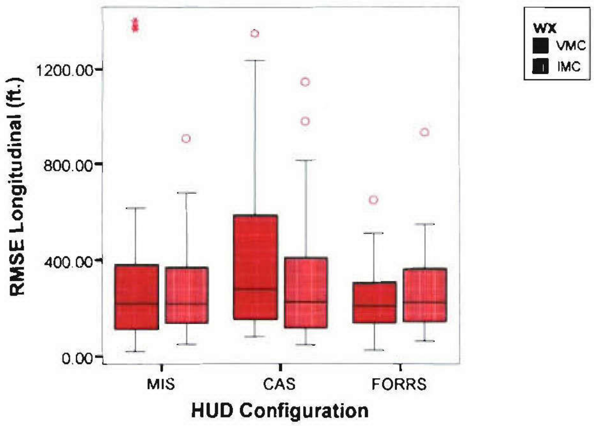

Figure 11: HUD configuration by weather — rmse longitudinal (ft)

There were no significant main effects or interactions for vertical velocity.

3.2. Situation Awareness

The China Lake SA scale results revealed a significant interaction for runway width and weather only. There were no significant display configuration effects. The overall mean was 2.28 with a standard deviation of .832. Across all 18 conditions, the conditional means ranged from 2.00 to 2.75, indicating that SA was rated on average between 'Adequate' and 'Good' in all conditions.

In terms of touchdown location situation awareness, the percent correct scores for the various conditions are shown below in table 2. If a pilot touched down in the box and indicated so, their response was scored as correct. Likewise, if they touched down outside the box and indicated so, their response was scored as correct. Only when their responses did not match the touchdown location were the responses scored as incorrect.

		VMC				IMC				
	Runway width	75′	150′	300′	Avg_{VMC}	75′	150′	300′	Avg_{IMC}	Avg
HUD	MIS	83%	67%	42%	64%	79%	71%	71%	74%	69%
	CAS	75%	46%	37%	53%	63%	63%	50.0%	59%	56%
	FORRS	71%	79%	71%	74%	58%	67%	96%	74%	74%

Table 2: Percent correct for touchdown SA

For the configuration rankings for SA provided by the pilots, the Friedman test for rank order data was used for the two phases of flight. For each phase, the ranks from highest (FORRS) to lowest (MIS) SA were significant. For the *descent to transition* phase the average ranks were 1.50, 2.00, and 2.50 for FORRS, CAS, and MIS, respectively ($\chi^2 = 6.0$, df = 2, p = .05). For the *transition to touchdown* phase, the average ranks were 1.17, 1.83, and 3.00 in the same order ($\chi^2 = 20.7$, df = 2, p < .01).

3.3. Workload

While the main effects for weather and runway width were significant, and HUD configuration was not, the interesting result was that the three-way interaction was significant ($F_{8, 86} = 2.198.$, p = .035). The contrasts showed that the significant differences in TLX and USAFSAM scores occurred between the FORRS and the MIS. The overall trend was for perceived workload to decline for all three configurations with increasing runway width and greater visibility. However, in IMC for the 150′ and 300′ runway widths, the FORRS provided workload scores equal to or better than the MIS and CAS in VMC. Only in the 75′ runway condition were all three HUD configurations equal regardless of visibility.

The rank ordering of the three configurations according to perceived workload yielded no significant rater agreement for either the *descent to transition* or *transition to touchdown* phases.

4. DISCUSSION

4.1. Test Objective 1

As the results show, the goal of 90% in the box performance was not reached with any of the display configurations. While there was no difference for in the box performance among the displays, there were some differences in the lateral and longitudinal errors of each configuration within the box.

4.2. Test Objective 2

There were no instances of exceeding the 600′/min sink rate at touchdown. Thus, there were no hard landings that would have resulted in a maintenance event. The concerns raised in the 1998 study were not replicated in this study under the baseline configuration (MIS). Neither the commercial (CAS), nor the experimental (FORRS) configurations provided any improvement in the maximum sink rate at touchdown. This may indicate that the concerns about hard landings using a millimeter wave image were unfounded.

4.3. Test Objective 3

The results for SA show that the FORRS configuration provided the greatest amount of situation awareness about where the aircraft touched down. However, if one puts it in grade school terms, FORRS only earned a grade of 'C'. Additionally, MIS and CAS scored even lower overall.

4.4. Test Objective 4

The results for TLX and USAFSAM indicate that while the greater amount of information provided by both the CAS and FORRS reduced perceived workload, the reduction was mediated somewhat by the runway width. No additional size cues were provided by the more complex display, the runway edges were just made more salient.

Clearly we have more work ahead to improve the 'in the box' performance for aircraft attempting an assault landing using only sensor imagery and symbology. While the display configurations performed only slightly better than flipping a coin for landing in the box, both the minimum impact and the experimental configurations were much better at letting the pilots know they were missing the box almost half the time. One possibility is to provide a standard size object/symbol in the scene that affords pilots the opportunity to visually compare the true (sensed) runway size with a known standard. Thus, a not only could the runway outlines help with locating and lining up, but the standard sized object could give an indication that the runway is narrower or wider than is typical.

As far as the flare cue symbology, results indicate that the sink rate may not be so problematic, but that completing the touchdown maneuver is still an issue. Several pilots commented that they, despite being instructed to use the flare cue symbology, tended to ignore the symbology and "go visual" using the sensor image. Indeed, the flare cue symbology is probably most often used during instrument maneuvers when there is little scene to by which to "go visual." This may indicate that a flare cue, when used with an image, needs to be integrated with the scene, rather than forcing the pilot to split attention between the symbology and the image.

As of this writing, a follow-up study is underway to address the issues raised in this report.

REFERENCES

1. D.J. Miller and M.A. Hoobler, *C-130 autonomous landing guidance (ALG) system* (AFFTC-TR-99-16), Limited distribution, Edwards AFB, CA: Air Force Flight Test Center, 1999.
2. McDonnell Douglas Corporation, Flight Manual (TO 1C-17A-1), Wright-Patterson AFB, OH: Aeronautical Systems Center (ASC/GR), 1998.
3. E.J. Martin and S.M. Cone, *A Head-up display symbology evaluation for an autonomous landing guidance system* (WL-TR-96-3104), Wright-Patterson AFB, OH: Wright Laboratory, Flight Dynamics Directorate, 1996.
4. S. Adams, "Practical considerations for measuring situation awareness," *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment*, pp. 157-164, 1998.
5. S.G. Hart and L.E. Staveland, "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research," P.A. Hancock and N. Meshkati (Eds.) *Human mental workload*, pp.139-183, Amsterdam: North-Holland, 1988.