PILOT PERFORMANCE IN THE VISUAL CARRIER LANDING TASK – SIMULATOR VS. FLIGHT

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INTRODUCTION

At the 6th NTEC-Industry Conference, 13 November 1973, I presented a paper on "New Approach to the Evaluation of Visual Attachments to Flight Simulators".[1] Some of the bases for the approach given then will now be re-emphasized, and an application to an in-house experiment will be presented.

Present methods of measuring performance characteristics of a visual attachment do not indicate whether visual cues which a pilot uses to perform a visual flight task are adequately presented to him. Lybrand in 1958,[2] stated that the best way of assessing *a visual attachment is to have experienced* pilots fly specific flight paths,and base rating on judgments of these pilots to supplement available evidence. By 1975 it was recognized by a Working Group of the Fluid Mechanics Panel of Advisory Group for Aeronautical Research and Development (AGARD), reference 3, addressing pilot performance and learning in simulated landings, that "the landing maneuver is subject to a number of direct performance measures. Particularly sensitive are measures at the instant of ground contact... . Landing performance measures (on the other hand) appear to uniquely correlate with subjective assessments...". However, this report did not provide a list of performance measures. As a result I went back to some World War II studies to identify objective pilot performance measures. These were developed in reference 1 and are repeated here:

a. Ratio of landing distance divided by distance from a designated point (runway end)

b. Landing attitude at touchdown

c. Index 1, elevator movement

d. Index 3, aileron movement.

The measures had correlation with graduation elimination criteria or could discriminate between groups having different amounts of training. The four measures selected had high repeatability or showed significant individual pilot differences. These are defined in Appendix A.

Normal acceleration was eliminated since most simulators at that time didn't have an exact analog of their landing gear bouncing on ground impact.

Rate of descent was eliminated because other studies showed that pilots have difficulty in judging rate of descent. Figure 1 from Palmer's paper at the 1973 AIAA Visual and Motion Conference[4] shows the effect of training on touchdown vertical velocity. With this variability, the measure is not dependable.

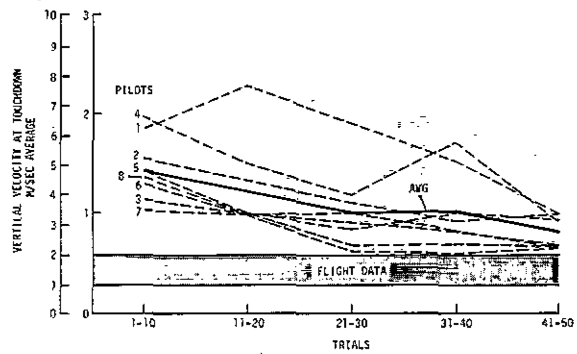

Figure 1. Effect of training on touchdown vertical velocity

Using existing flight and simulator data from Boeing 707 and KC135A test flights, the selected pilot performance parameters were used to relate to the adequacy of visual cues presented in the simulator visual attachment.

Table 1 from reference 1 shows a comparison of key parameters at a high gross weight for the Boeing 707 airplane.

The flight data is given at the top, the simulator data is given at the bottom.

For Index 1 the smallest value is 1.0 and represents no control movement.

For Index 3 the smallest value can be 0 and represents no control movement while the largest value can be 1.0 and represents the same number of movements as samples taken.

In Table 1 comparing flight test and simulator pilot performance, pilot performance in the simulator N matches pilot performance in the aircraft somewhat closer than that in simulator C.

I stated then that if I had data on later simulators and visuals for the Boeing 707 a closer correlation should have occurred.

TABLE 1
COMPARISON OF KEY PARAMETERS HIGH GROSS WEIGHT
(More than 150,000 Lbs.)

Point of Landing Touchdown Dist. / Runway Length	Landing Attitude Degrees	Index 1 Elevator	Index 3 Aileron	Simulator Designation
A. FLIGHT DATA				
.29	9.3	1.23	.815	
--	8.5	1.42	.89	
Max. .34				
Min. .03				
Mean .13	-	-	-	
S.F.				
Max. .27				
Min. .11				
Mean .19	-	-	-	
Chicago				
Max. .22				
Min. .11				
Mean .16	-	-	-	
B. SIMULATOR DATA				
Max. .35	5.3	4.50	.567	}
Min. .10	0.9	2.00	.467	} N
Mean .19	3.8	2.95	.507	}
.17	3.0	1.50	-	D
.17	0	1.06	.944	C

THE IN-HOUSE EXPERIMENT

It appeared since 1973 that data on later simulators was not available and therefore I would have to collect my own data. There existed at the NAVTRAEQUIPCEN in 1973 an in-house flight simulator with a visual system which could be used to conduct the validation experiment. The experimental facility arrangement is shown in Figure 2. A description and the performance of the sub systems follows:

The gantry, optical probe and the T-28 flight simulation were described in the 11th NTEC-Industry Conference Proceedings[5] and will not be repeated. The model for the image pickup was a three dimensional model of the CV-59, U.S.S. Forrestal, at a scale of 250:1, complete with the Fresnel Lens Optical Landing System (FLOLS) display unit, and illuminated by a number of high intensity lights. These were used previously in Device 2H87, Aircraft Carrier Landing Trainer. The details are shown in Figure 3. The carrier image was projected in front of the pilot by means of a G.E. color TV Projector, Model PJ500 onto a standard movie screen located so as to provide a 60° horizontal field of view picture directly in front of the pilot seated in the simulator cockpit. The television picture was generated by a Cohu color TV camera model coupled to the optical probe. The FLOLS activation simulation is based on the model described in reference 6. The subjects were six pilots assigned to NAS Cecil Field, Jacksonville, Florida, qualified in A-7 aircraft.

RESULTS

The premise as stated in reference 1 is that the proper method for evaluating the adequacy of a visual attachment to a flight simulator is to measure the pilots' effort in performing a specific task in the simulator and compare it with the effort expended doing the same task in the real world. Any large difference would indicate, provided the flight simulator characteristics are represented adequately, that the amount of visual information presented to the pilot external to his cockpit is different between that shown in the simulator and that shown in the real world flight.

The subject pilots flew 2 practice flights and 5 test flights for daytime conditions and 5 for night conditions. Only the daytime flights will be discussed as only daytime results are available from actual carrier landings. This performance in the simulator would be compared to that of pilots' performance obtained in landings on board carriers.

Flight test data was obtained from two cruises reported in references 7 and 8. The CVT-16, U.S.S. Lexington, in the Gulf of Mexico in 1968 and the CV-42, U.S.S. F. D. Roosevelt, in the Atlantic off the coast of Florida in 1965. Earlier data from the Naval Air Test Center (NATC) landings on

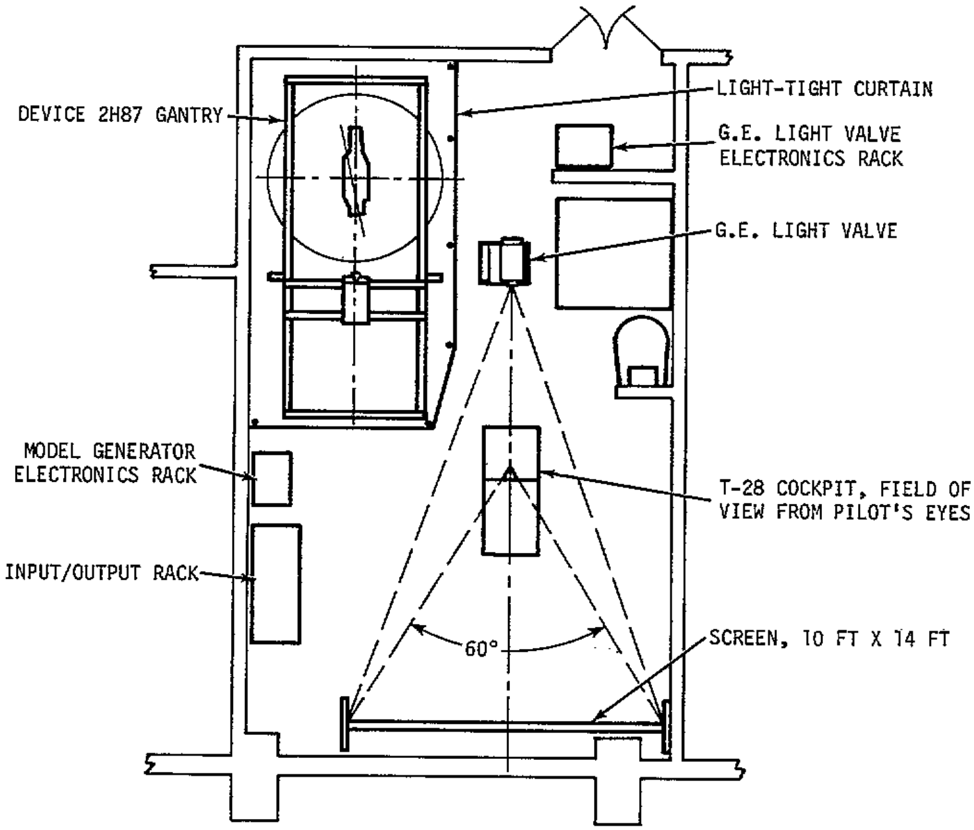

Figure 2. Experimental Facility Arrangement

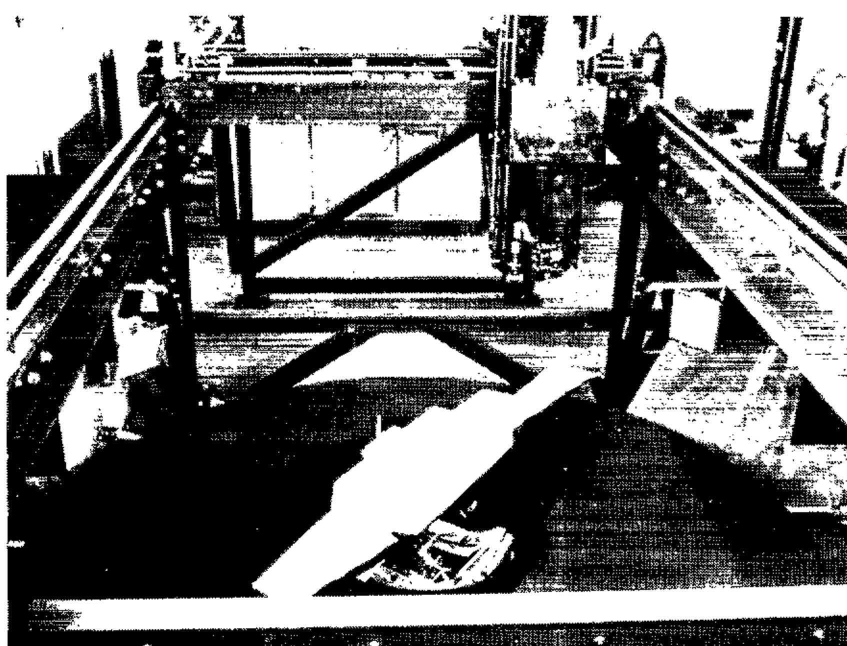

Figure 3. Camera and optic probe gantry system with the optic probe just above and behind the carrier

CVS-40, U.S.S. Tarawa, in 1955 without FLOLS, reference 9, were also available.

Of the 30 landings the pilots made for recording, 20 were considered successful. The data was recorded on strip chart recorders and extracted manually. The comparison of simulator and actual pilots' performance was performed and plotted graphically as probability curves; however, only one of these will be presented. Figure 4 shows the ramp to first main wheel touchdown distance. For the simulator the

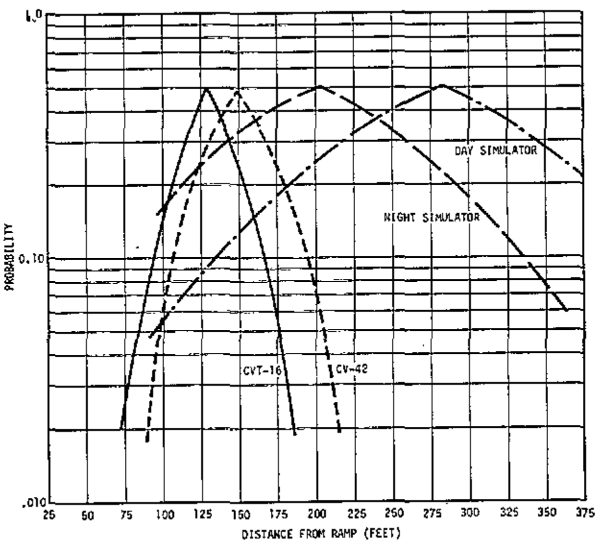

Figure 4. Probability of exceeding or not exceeding ramp to 1st wheel touchdown distance (main)

touchdown distance was determined by freezing the optical probe at an altitude of 65 feet above the water (the pilot's eye position in the aircraft on deck) and finding the proper distance along the deck corresponding to the freeze time point on the strip chart. The flight test results were obtained by analysis of calibrated photographic films of the landings.

Pitch angle was either derived from the photographic analysis (flight test) or from the measured value on the simulator recorder. The angle of attack and the indicated air speed for flight tests are derived from recorded data while those for the simulator are computer outputs. The lateral position along the deck is developed as described for touchdown distance.

Landing parameters as proposed in reference 1 are presented in Tables 2 and 3. Table 3 also presents a comparison of carrier dimensions from reference 10 and other published sources which will be used to discuss the results.

DISCUSSION

The touchdown and ramp parameters shown in Tables 2 and 3 will be discussed.

a. Pitch angle at touchdown was considered in reference 1 a key reference parameter. Both flight test and simulator pilot performance gave similar values.

b. Touchdown point - Since the aircraft carriers are of different size it was necessary to normalize this parameter. Normalized touchdown points for simulated landings are not consistent with those from operational landings.

c. Indicated air speed at touchdown - If the relationship across CVT-16 and CVA-42 is any indication, as the wind over deck increases the engaging speed decreases, and the indicated air speed (calibrated value) at touchdown should continue to decrease as we get to the simulated CV-59 landings.

Two questions are raised here:

(1) Should the mean distance to touchdown be the same or different for the different size carriers?

(2) Should the indicated airspeed at touchdown be the same or different for the different size carriers?

To answer these questions, I reviewed Brictson's analysis of carrier landings. According to Brictson in reference 11 and his earlier reports, there should be no difference in landing difficulty between FLOLS settings of 3.5° and 4° on large carriers. Landings on the large size carriers should be slightly better than on the medium size carriers. While on day landings, pilots approach above the glide slope path, they land short of the target wire (#3). If a pilot maintains a high approach (above the normal glide slope) he will land long on the deck (#4 wire or a bolter). On the other hand reference 12 states that the shallower the glide slope becomes, that is from 4° to 3°, the greater the dispersion in touchdown point with pilot glide slope error due to the simple trigonometric relationship. This is shown in Figure 4 as a greater spread in the simulator curves. The actual aircraft glide angles for the CVT-16 and CVA-42 landings exceed the on glide slope glide angle by about 2° (steeper), while for the CV-59 landings the actual glide angle is about $.7^{\circ}$ lower than theoretical (shallower).

TABLE 2
COMPARISON OF T-28C LANDINGS
(MEAN VALUES)

	CVT-16	CVA-42	SIMULATED CV-59
PITCH ANGLE AT T/D (Degrees)	6.24	5.51	6.7
AIRCRAFT GLIDE ANGLE AT T/D (Degrees)	4.4	4.39	.3
ANGLE OF ATTACK AT T/D (Degrees)	10.64	9.9	7.0
ENGAGING SPEED (KTS)	65.10	62.10	58
WIND OVER THE DECK (KTS)	19.5	21.2	30
INDICATED AIR SPEED @ T/D (KTS)	84.6	83.28	88
LATERAL POSITION AT T/D (Feet) (+ is port)	- 4.05	3.39	7.0
DISTANCE RAMP TO 1st WHEEL CONTACT (Feet)	129.57	148.8	283
PRINCIPAL WIRE ENGAGED	2	2	4
OPTICAL GLIDE PATH (Degrees)	4	4	3
NUMBER OF LANDINGS	42	100	20
PITCH ANGLE AT RAMP (Degrees)	3.45	3.34	
HOOK HEIGHT ABOVE RAMP (Feet)	9.65	10.37	-
MAIN WHEEL HEIGHT ABOVE RAMP (Feet)	12.29	13.39	-
PILOT HISTORY	UPT CARQUAL Min. of 150 Flight Hours	REPL. SQ. CARQUAL	FLEET A-7 Pilots

TABLE 3
COMPARISON OF NORMALIZED LANDING AND CARRIER PARAMETERS

	CVT-16	CVA-42	CVA-59	RUNWAY
RATIO: MEAN TOUCHDOWN DISTANCE TO CANTED DECK LENGTH	.24	.28	.41	.40
ELEVATOR CONTROL INDEX NUMBER 1	-	-	1.026	1.38
AILERON CONTROL INDEX NUMBER 3	-	-	.276	.34
RATIO: 2nd WIRE DISTANCE TO CANTED DECK LENGTH	.24	.28	.24	
RATIO: 3rd WIRE DISTANCE TO CANTED DECK LENGTH	.30	.32	.29	
RATIO: RAMP TO FLOLS DISTANCE BY CANTED DECK LENGTH	.73	.80	.62	
CANTED FLIGHT DECK LENGTH RELATIVE TO CVT-16	1.00	1.00	1.27	
OVERALL FLIGHT DECK LENGTH RELATIVE TO CVT-16	1.00	1.09	1.17	

No discussion in the literature addresses the variation in touchdown airspeed; however, since the glide angle is lower the airspeed should be higher. Another factor probably contributing to the higher speed is that the simulated landing scene did not provide any texture, such as waves, to the blue water as projected on the screen. This omission on other visual simulations has been reported as a negative cue to judging speed over the water on approaching the carrier. However, airspeed is not a key parameter.

The discrepancy in touchdown distance leads to a re-examination of the visual cues. The computation of the FLOLS setting may be seen from the details in Figure 5. The apparent lens location was set by placing the optical probe at the #3 wire touchdown point and extending the glide slope line at 3^o. The display of the glide slope in the simulation was with a three lens display, instead of the normal five lens display, located at a full scale height of 40 feet above the deck vice being flush with the deck level as in the operational situation. That is, Δh instead of being 10 feet below deck level was actually 30 feet above deck level. If the pilot followed the FLOLS indications, he would probably land at the correct wire at night because of minimum ship-shape cues, but in the daytime landing the on-glide-slope as presented would place the aircraft meat ball 40 feet higher over the ramp than normally. The pilots' prior experience in carrier landings would cause them to expect to see more of the carrier deck above the aircraft forward cockpit cowling than was visible as projected on the screen. The conflict in cues between the simulated situation (following the FLOLS) and the actual (60 feet above the ramp), would become apparent.

A comparison of pitch angle over the ramp for the actual landings and the simulated landings showed that for 10 of the 20 successful simulator landings the pilots were diving for the deck ($-.5^o$ versus 3.4^o). This would seem to indicate that the pilots were trying to correct the discrepancy in height at the ramp. Table 3 also shows touchdown distances *obtained by a NASA test pilot landing the T-28* aircraft on a 5000 ft. runway. This touchdown point compares well with the landings on the CV-59, thus again confirming shallow glide path.

d. Lateral position at touchdown appears to be consistent in magnitude between actual landings and the simulated ones. The interpretation here is that steering or lateral aligning information was adequate in the simulation.

e. Elevator Control Index Number 1 and Aileron Control Index Number 3 were again difficult to obtain from the flight test. The flight test data available was from stalls and runway landings and was a substitute for data for carrier landings. For both indices the simulated landings required less control movement. The differences between the T-28 data is less than the differences shown in

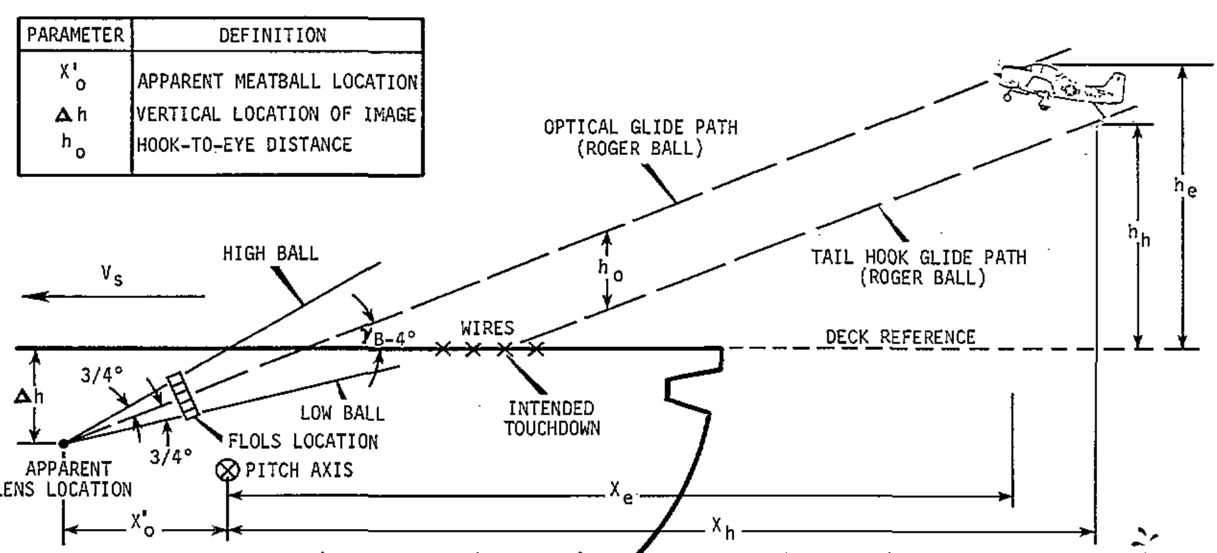

Figure 5. FLOLS relationships

Table 1 for the Boeing 707 data. Pilots flying the simulator did not complain about its flying characteristics. It was also used and was acceptable for the experiment reported in reference 5.

f. Normalized carrier dimensions show individual carrier differences which are not consistent with change in size and probably contribute to the variations in landing distance.

CONCLUSIONS

The results of this experiment tentatively support the hypotheses by showing that errors in the simulation do contribute to differences in pilot performance. The differences in landing distances can be explained by the consistent variation in other parameters such as glide path, pitch angle at the ramp, and landing speed.

The principal errors in simulation were the vertical location of the FLOLS and the lack of texture in the water. Steering alignment was satisfactory. If the computational and physical differences account for most of the differences, then the original hypothesis that the comparison in pilot performance can identify the visual cues differences in the visual attachment is valid. It is again recommended that another comparison be performed with better simulation so that this hypothesis can be adequately tested.

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APPENDIX A

Definition of Parameter Terms:

Point of Landing - Distance from approach threshold of runway to point of first wheel contact; made non-dimensionsal by dividing by runway length. If pilots recall their training, they were taught to land within the first third of the runway. Since aim point is selected by proportion then absolute distance is immaterial.

Landing Attitude - Inclination of Fuselage Reference Line to Runway At First Wheel Contact:

Index 1, Total Amount of Elevator Control Movement - calculated by running a "Map Measure" along the graphed line plotted to show wheel column (or stick) movement (affecting elevator adjustment). This provides a measure of the total length of the line representing movement (i.e. successive positions) of the control. In order to compensate for differences in total time of the maneuver as carried through by various pilots, the obtained measure was divided by the length of the straight line across the graph, which would be obtained in plotting if the control was held in a constant position, without movement, throughout the maneuver.

Index 3, Number of Aileron Control Movements - Provides a quantitative statement of the total number of discrete control movements (aileron) during the maneuver. These movements are of four types: Left to Right, Right to Left, Stationary to Left and Stationary to Right. The index is obtained by dividing the total number of control movements by the total number of readings for the maneuver.

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