Touchdown Performance with a Computer Graphics Night Visual Attachment

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A computer graphics system was programmed to display to the pilot a dynamic perspective view of an airport terminal area comprised of 1200 points of light. The advantages of this system are that it has high resolution and it eliminates the camera optics and electromechanical servos of TV-model systems. The disadvantages are that it lacks fine ground texture and has a small computational delay. A brief experimental evaluation was conducted in which eight airline pilots made 50 landings each in a fixed-based simulation of a DC-8 transport. They were instructed to touch down at 0.6 m/sec. The vertical velocity of the aircraft at touchdown was displayed to the pilot at the completion of each run. Their average vertical velocity at touchdown for the last 10 landings was about 0.8 m/sec. This performance was similar to that obtained on current TV-model systems.

I. Introduction

MOST current visual flight attachments utilize the TV camera and terrain-model concept to provide the pilot with an out-the-window view of an airport terminal area. These simulators are considered to be adequate during the approach to the runway, but there appears to be near unanimous agreement that the task of height control during the flare and touchdown is unrealistically difficult. In particular, previous studies[1-5] have indicated that sink rate at touchdown is considerably higher on simulators than in flight. Pilots also require more landings in simulators to attain "acceptable" sink rates at touchdown. At present, there is considerable controversy over whether this poor performance is due to a lack of realistic visual cues or motion cues, or both. This paper reports on our initial experience in using a general-purpose computer graphics system to display the pilot's view of an airport's runway, taxiway, and approach lights at night. The system was developed to support studies on head-up displays and to help solve the controversy over poor visual simulation during the flare and touchdown. A computer graphics visual simulator completely eliminates some fundamental problems that plague TV-model systems, as well as introducing some new problems of its own. The system and its advantages and disadvantages with respect to a TV-model system will be discussed. Finally, some data on touchdown performance will be presented.

II. Display System

Figure 1 illustrates the operations required to generate a two-dimensional perspective picture of a three-dimensional object: in this case, a model of the airport and surrounding city lights. First, the model is generated by specifying the *X*, *Y*, *Z* locations of all point sources of light and the end points of all lines in a ground coordinate system. These coordinates are then stored as a list in the computer memory. Next, in real time, the position and attitude of the aircraft with respect to the ground coordinate system are used to compute a 4×4 rotational and translational matrix, which, in turn, is used to transfrom the airport model into a coordinate system centered at the nominal viewing position of the pilot and aligned with the axis system of the aircraft. The transformed coordinates are tested to see if they are within the pilot's field of view. Lights outside the field of view are eliminated, and that portion of lines outside the field of view is clipped off. Finally, a perspective transformation is applied to the remaining visible elements to form a two-dimensional image drawn on a 53.3-cm (21-in.) cathode ray tube (CRT). (Hidden lines are not removed by this system.) The pilot views the CRT through a standard set of collimating lenses. The horizontal and vertical field of view was 28°, the magnification was one-to-one, and the image distance was set to infinity. The preceding calculations are straightforward. The problem has been to perform the calculations fast enough to generate perspective pictures with reasonable detail in real time. Our past attempts at dynamic perspective displays of a runway were limited to about 60 point sources of light when computed with software algorithms.[4,6] Our current display system, an Evans & Sutherland Line Drawing System-2, implements the matrix multiplication, clipping, and perspective algorithms in special-purpose hardware. It performs all computations digitally and is fast enough to permit a monochrome image consisting of 1000 to 2000 points and lines to be processed 30 times/sec. This gives the impression of continuous motion.

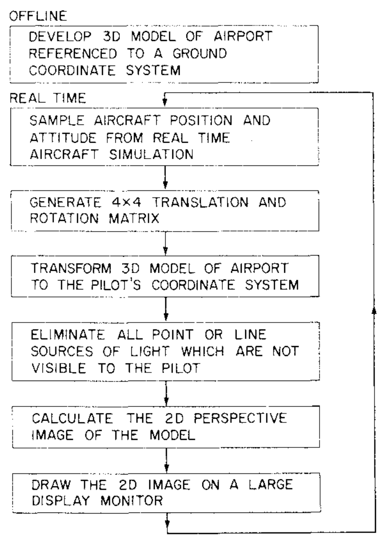

Fig. 1 Operations required to generate a two-dimensional perspective picture of a three-dimensional object.

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Figures 2-5 show examples of night views of various conventional airports and STOLports that we have generated with this system.

III. Comparison with TV-Model System

Table 1 lists a number of advantages and disadvantages of a computer graphics visual flight attachment when compared to a TV-model system. On the positive side, since the computer graphics system is completely digital, its resolution and positioning accuracy is inherently more precise than a system that uses analog signals and servosystems. Simulating a real-

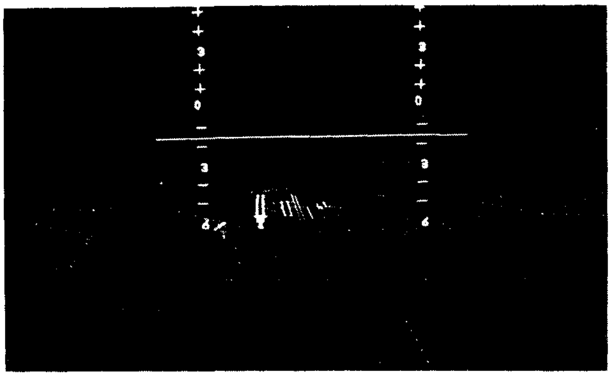

Fig. 2 San Jose Municipal Airport with a superimposed head-up display.

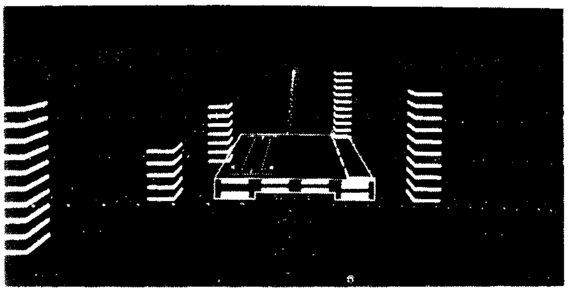

Fig. 3 Elevated STOLport using both line and point sources of light.

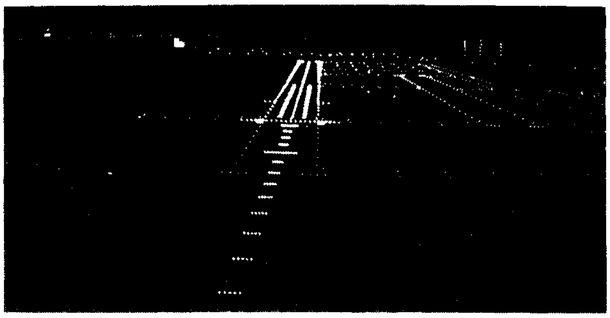

Fig. 4 San Jose Municipal Airport with zone and centerline lights; range = 305 m beyond threshold, altitude = 5m.

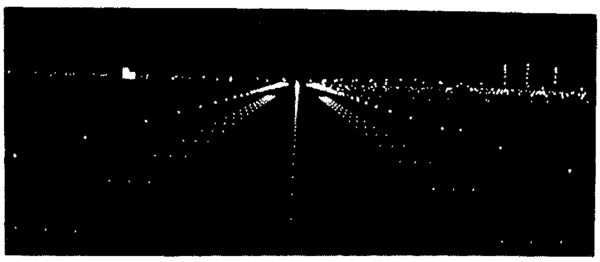

Fig. 5 San Jose Municipal Airport with zone and centerline lights at touchdown; range – 305 m beyond threshold, altitude = 5 m.

Table 1 Comparison between computer graphics and TV-model visual flight attachments

I.	Advantages of computer graphics over TV
1)	High precision and resolution (all digital).
2)	No servomechanisms (no dynamic lags on nonlineantion).
3)	No TV camera or optics (no depth-of-field problem).
4)	Easy to program new airports.
5)	Moving lights possible (other aircraft, strobe lights, surface traffic, flashing obstruction lights).
6)	Side-window scenes possible.
II.	Disadvantages of computer graphics
1)	Limited texture (no tire skid marks).
2)	Pure computational delay ($\approx$ 1/30 sec).
3)	Monochromatic color (growth possibility).
4)	No surface or hidden-line capability.
5)	Day scenes difficult because the system displays luminous dots and lines.

world area 40×40 km allows lights to be located on a 1-cm grid. The nominal viewing position of the pilot also can be positioned to this same 1-cm accuracy. Since the computer graphics system does not use a TV camera, there is no depth-of-field problem which causes objects located in front of and behind the TV camera focal plane to be out of focus. The images of all objects generated by this graphics system are equally sharp.

On the negative side, there is a pure computational delay involved in generating the perspective picture. This delay varies from almost zero, for the first part of the model to be processed, to 1/30 sec for the last element to be processed. A 1/30-sec delay results in a 12° phase lag at 1 Hz in all axes for any amplitude input. The inability of the system to generate the same amount of ground texture detail as a TV-model system is potentially a more serious disadvantage. Our system is capable of drawing a perspective image of between 1000 and 2000 point or line sources of light, which is considerably below the detail or texture possible with a model. Realistic day scenes cannot be simulated with this graphics system because it does not draw surfaces or remove hidden lines. Also, the luminous dots and lines this system generates are much more suitable for night scenes than day scenes. However, there are more complex computer graphics systems available that do draw surfaces and remove hidden lines and therefore can draw fairly realistic day scenes.

IV. System Applications

The computer graphics system has been used as a visual flight attachment for evaluating a number of head-up displays for STOL and conventional aircraft during non-ILS visual approaches.[7,8] Figure 2 shows a simulation of San Jose Municipal Airport with a superimposed head-up display that was evaluated as an aid in making visual noise-abatement approaches. Since both the night scene and head-up display shown in Fig. 2 were generated by the same graphics system, it is possible to achieve perfect alignment and registration, an achievement which is difficult and time-consuming when a head-up display is overlaid on a TV-model system. Figure 3 shows an elevated STOLport that uses both line and point sources of light.

The pilots that participated in the head-up display studies were enthusiastic about the realism of the night scene simulation. However, in the studies using the display in Fig. 2, pilots complained that the lack of runway texture caused difficulty in executing a precise flare and touchdown. To help remedy this deficiency, the touchdown zone and centerline lighting systems shown in Figs. 4 and 5 were added.

V. Evaluation of Touchdown Performance

At this point, it was decided to conduct a brief experiment to determine how well pilots could learn to flare and touchdown using this night visual attachment.

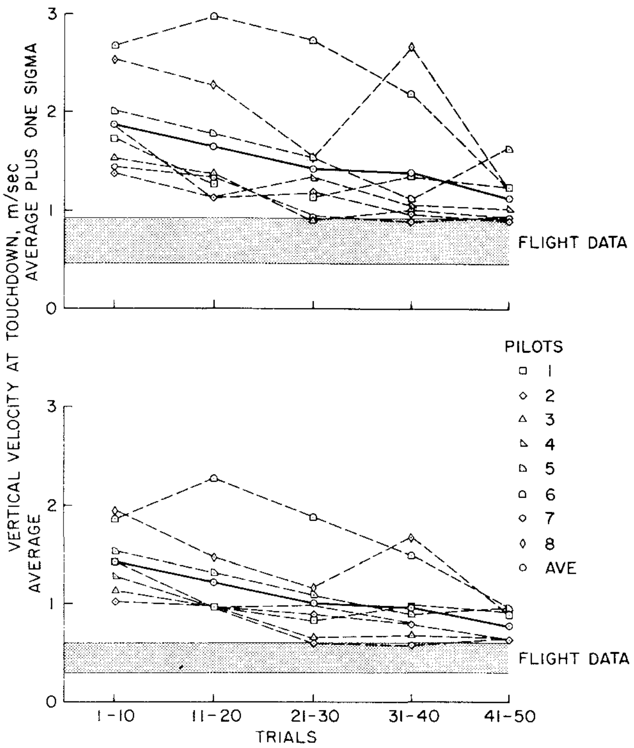

Fig. 6 Effect of training on touchdown vertical velocity for a computer-generated night visual flight attachment.

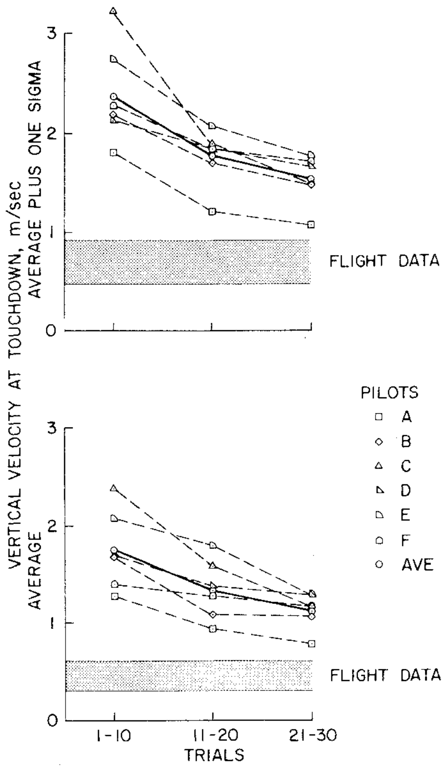

Fig. 7 Effect of training on touchdown vertical velocity for a TV-model visual flight attachment.

Experimental Design and Task

Eight airline pilots with no previous experience with visual simulators each made 30 landings. After participating in another study to evaluate a head-up display, they each made an additional 20 landings. The aircraft was fairly complete six-degree-of-freedom simulation of a DC-8 transport including a simulation of ground effect. A fixed-base simulator was used. All approaches started at a range of 2595 m from the runway threshold. The aircraft was trimmed at an airspeed of 145 knots and positioned on a 3° glide slope to the runway aim point (305 m or 100 ft beyond the threshold). Figures 4 and 5 show the pilot's view at the beginning of the approach lights and at touchdown. The pilots were instructed to make a "normal" visual approach and attempt to touchdown with a vertical velocity of 0.6 m/sec (120 ft/min). The vertical velocity at touchdown was displayed to the pilot after completion of each approach. This performance feedback was provided in an attempt to replace the normal motion cue feedback at touchdown which lets the pilot know if he has made a smooth landing. This experimental design and landing task is very similar to an experiment conducted by Bray[9] to evaluate a side-window display with a TV-model visual flight attachment.

Experimental Results

The only performance measure discussed in this paper is vertical velocity at touchdown, a parameter shown to be sensitive to simulator fidelity and the simulator experience of the pilot.[3] Figure 6 shows the mean vertical velocity at touchdown for each pilot averaged over blocks of 10 trials. In addition, the mean plus one standard deviation are shown to indicate consistency of performance. Shown for comparison in Fig. 7 are data taken by Bray[9] in a similar experiment with a TV-model visual flight attachment and a fixed-based simulator. Other touchdown and approach performance data are summarized in Table 2.

The most striking fact about the data from the two experiments is how similar the average learning curves are for the first 30 landings. The average vertical velocity at touchdown for the computer graphics system is 10 to 20% lower than the average data for the TV-model system, but, considering the large pilot variability, this difference would not be statistically significant. The average vertical velocity at touchdown for trials 21-30 is about twice that measured in actual flight with this class of aircraft.[5,9,10] Both sets of data also show relatively slow continuous learning. Performance

Table 2 Touchdown and approach performance measures with a computer graphics night visual flight attachment[a]

Trials	Touchdown performance: Vertical velocity, m/sec		Lateral velocity, m/sec		Forward velocity, m/sec		Lateral offset from runway centerline, m		Approach performance: Range from runway aim point 305 m down runway, m		Altitude at a range of 400 m, m		Altitude at a range of 1800 m, m	
	Mean	α	Mean	α	Mean	α	Mean	α	Mean	α	Mean	α	Mean	α
1-10	1.42	0.57	−0.2	0.7	69.4	2.3	−0.4	5.5	287	204	19.7	7.4	93.2	11.3
11-20	1.24	0.62	−0.3	0.8	70.0	2.9	−1.5	4.0	343	304	20.4	13.0	93.2	11.9
21-30	1.01	0.56	−0.2	0.6	70.0	3.2	−1.4	3.6	355	254	18.9	10.5	90.4	12.9
31-40	0.98	0.60	−0.3	0.8	72.0	2.3	−0.8	5.2	252	194	17.1	6.3	90.8	14.0
41-50	0.77	0.38	−0.1	0.6	71.3	3.1	0.5	3.0	294	293	14.1	3.8	84.6	14.3

[a] Data averaged over eight pilots.

continued to improve throughout the entire set of runs. It has been estimated that when a pilot transitions to a new aircraft, he requires only a few familiarization landings to produce average vertical velocities at touchdown of 0.3 to 0.6 m/sec (1 to 2 fps). This type of performance is not apparent in either Fig. 6 or 7. After participating in another study to evaluate a head-up display and after an additional 20 landings on the computer graphics display, all pilots were below 1 m/sec, and four were landing with an average vertical velocity of 0.6 m/sec, about the upper limit for flight data.

VI. Conclusions

Fairly complex night scenes have been generated with computer graphics techniques. These displays have received enthusiastic pilot comments as to their degree of realism. In a short study focusing on touchdown performance, eight pilots showed learning curves for vertical velocity at touchdown which were slightly better than those measured in another study using a TV-model simulator. Valid comparisons are difficult to make, but performance with a computer graphics system appeared to be at least as good as pilot performance with a TV-model simulator but still not good enough.

Our future work in this area will follow two approaches. The first approach will continue the elusive search for the missing and false visual cues in visual simulation. Small lines will be used for the runway lights instead of point sources so that the lights will appear to get larger an brighter as the aircraft approaches touchdown. A full color display will be used to simulate the actual color of the runway lights. A prediction circuit wil be used to compensate for computation delays in generating the picture. The second approach will attempt to use psychophysical methods to measure a pilot's errors and delays in estimating altitude, altitude rate, and altitude acceleration during the final stages of the flare in a manner similar to that used by Barnes.[2] These data then will be used in a pilot model to predict vertical velocity at touchdown as a function of these estimation errors and delays.

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