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NIGHT VISUAL APPROACHES – PILOT PERFORMANCE WITH AND WITHOUT A HEAD-UP DISPLAY

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ABSTRACT

Simulated night visual approaches were flown into two airports with and without a head up display in a transport aircraft. The HUD featured pitch stabilized vertical scales which displayed the glide slope angle to the runway aim point and a horizontal bar which aided the pilot in his control of the aircraft flight path angle. One airport was located on flat terrain with numerous foreground lights, the second airport had no foreground lights and the terrain sloped up behind the airport.

With the HUD glide slope tracking precision was equally good for either runway. With no HUD glide slope tracking was about three times worse with the flat airport and about eight times worse with the airport with no foreground lights and up-sloping terrain beyond the runway.

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INTRODUCTION

Eighty two of the two hundred and thirty four civil aircraft accidents prior to 1968 occurred during the approach and landing. Thirty eight of these eighty two accidents occurred at night over dark terrain or water toward lighted cities and airports. Meterological conditions in all cases were such that the flight crew could have employed visual reference to ground light patterns (ref. 1).

To properly comprehend the night visual approach problem it is necessary to understand what visual cues the pilot can use to determine whether he is on the desired glide slope. Figure 1 shows a side view of an aircraft and the pilot's forward view. If the desired runway aim point is kept 3° below the true horizon, the aircraft will stay on a 3° glide slope. In the forward view this angle appears as the vertical distance between the runway aim point and the horizon. This distance has been called the H-distance. It is the only dimension in the external visual scene which remains constant as the aircraft descends along a constant glide slope. If the aircraft deviates above the desired glide slope, the H-distance increases. Deviation below glide slope reduces the H-distance (ref. 2).

The H-distance for a standard glide slope is only 3° and has been shown to be difficult to estimate (ref. 3). The Boeing Company has conducted research in a simulator to measure a pilot's ability to visually estimate his glide slope when terrain and runway variables

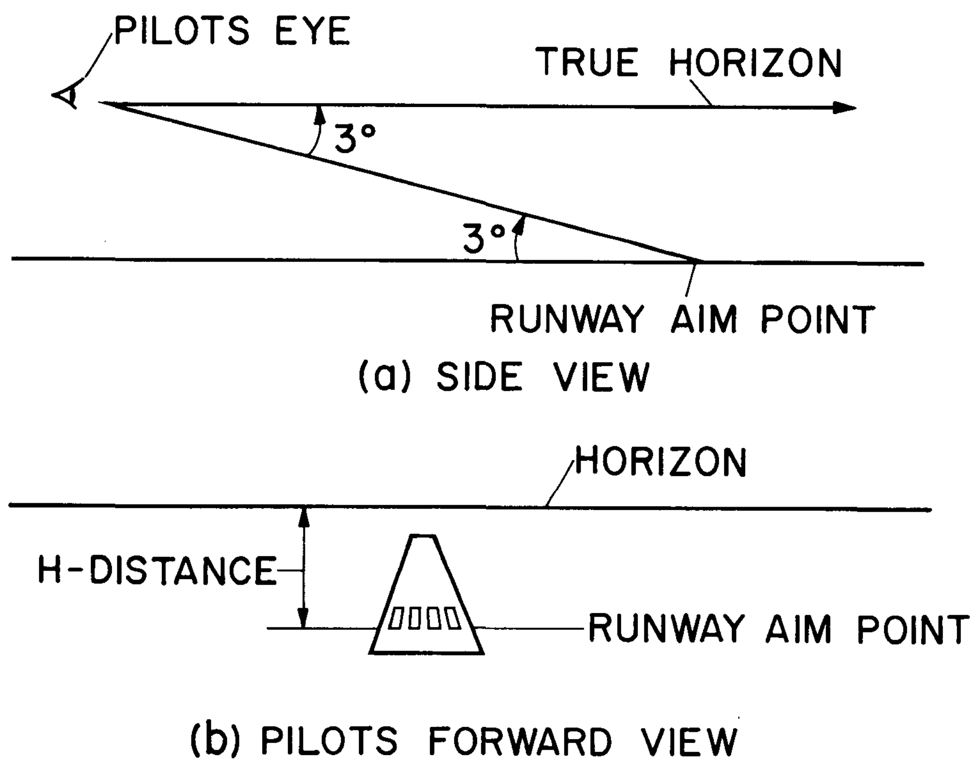


FIGURE 1. APPROACH GEOMETRY

such as light patterns, terrain slope, dark foreground, different runway widths to length ratios are varied. When the H-distance was distorted by city lights on hills behind the airport, pilots flew dangerously low (ref. 4).

A number of ground and airborne displays have been designed to aid the pilot in accurately perceiving his glide slope angle or H-distance during a visual approach. The ground Visual Approach System Indicator (VASI) provides visual guidance to aid the pilot in staying on the proper glide slope. Another aid, studied in this report and in reference 5 is a simple pitch stabilized head up display (HUD) that indicates the glide slope angle to the runway aim point. One advantage of the HUD over the VASI is that the magnitude of glide slope error and the rate of change of glide slope error can be determined with the HUD whereas the VASI only tells the pilot if he is high, low or on. In addition other information can be easily added to the HUD to aid the pilot.

In conjunction with a larger simulation program (ref. 5) to evaluate a head up display for providing vertical guidance for standard visual approaches and high capture noise abatement, a number of approaches were flown with and without a head up display to airports with two types of ground terrain. One airport/city model, San Jose Municipal Airport, was located on flat terrain with numerous foreground lights. In the second airport/city model all city foreground lights and runway were removed and the terrain up-sloped behind the airport. The objectives of this part of the study were to (1) determine the effect of the HUD on glide slope tracking precision during visual approaches and to (2) determine the feasibility of using computer graphics techniques to generate night views of airports in which the pattern of city lights may cause the pilot to incorrectly perceive his glide slope angle.

EQUIPMENT

A research simulator cockpit configured like a STOL transport was used for this evaluation. The column, wheel, and rudder pedals were spring loaded. The throttle levers were mounted on an overhead panel. Standard cockpit instruments displayed sink rate, airspeed, altitude and power. Digital readouts of distance to a Distance Measuring Equipment (DME) transmitter located 4000 ft down the runway from the threshold and radar altitude were also displayed.

The night scenes of the two airports were generated on an Evans and Sutherland computer graphics system. This system employs special purpose matrix multiplier and perspective hardware to permit the real time calculation and display of perspective views of airports with up to 1200 lights.

The scene was a night view of either San Jose Municipal Airport referred to as SJC or the other airport referred to as NFL for "no foreground lights." Planar views of these airports are shown in figures 2 and 3.

The two dimensional perspective view of these airports was displayed on a 21" cathode ray tube and viewed by the pilot through a set of collimating lens. The field was 30° vertically and

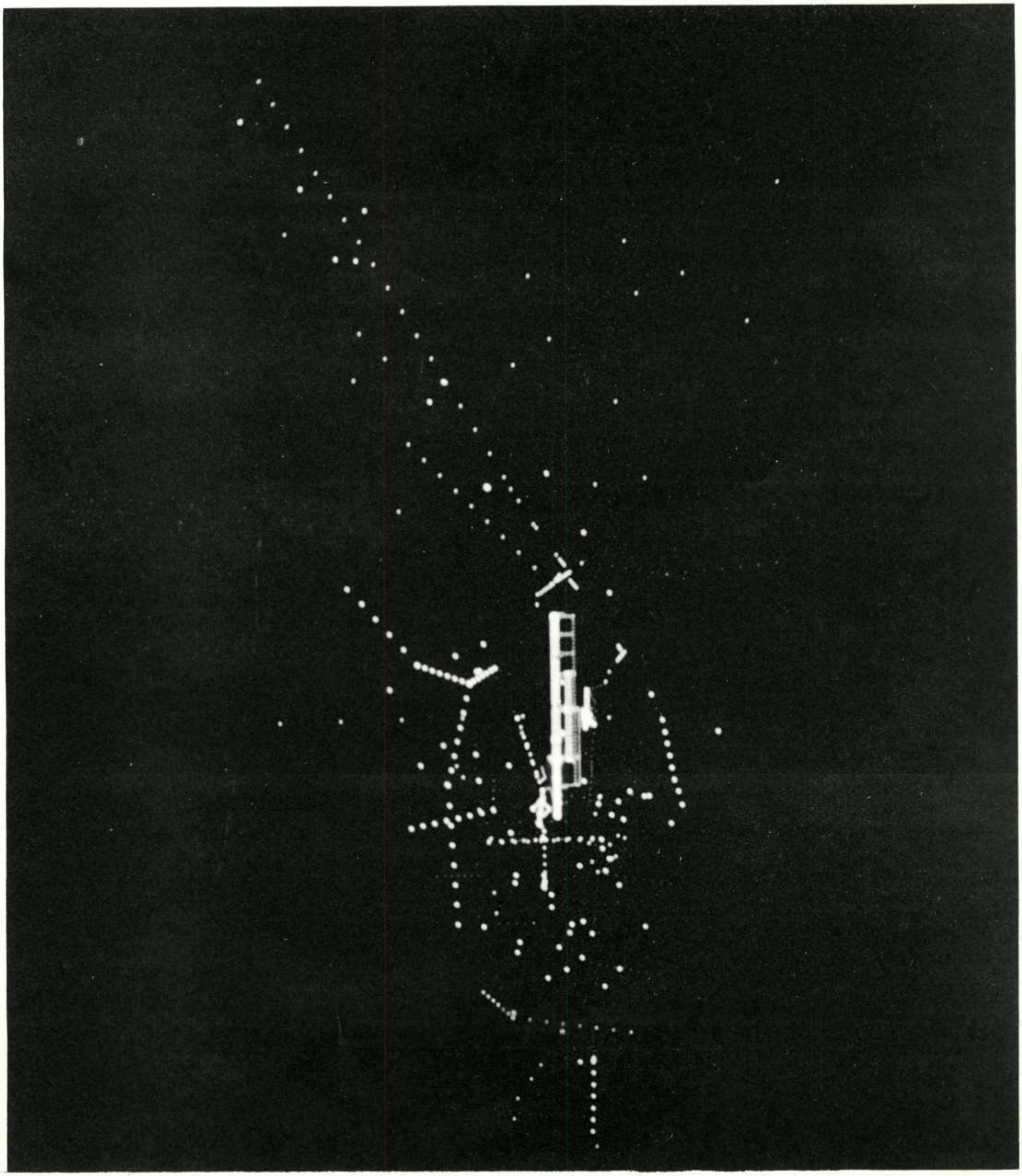


FIGURE 2. PLANAR VIEW OF SAN JOSE MUNICIPAL AIRPORT (SJC)

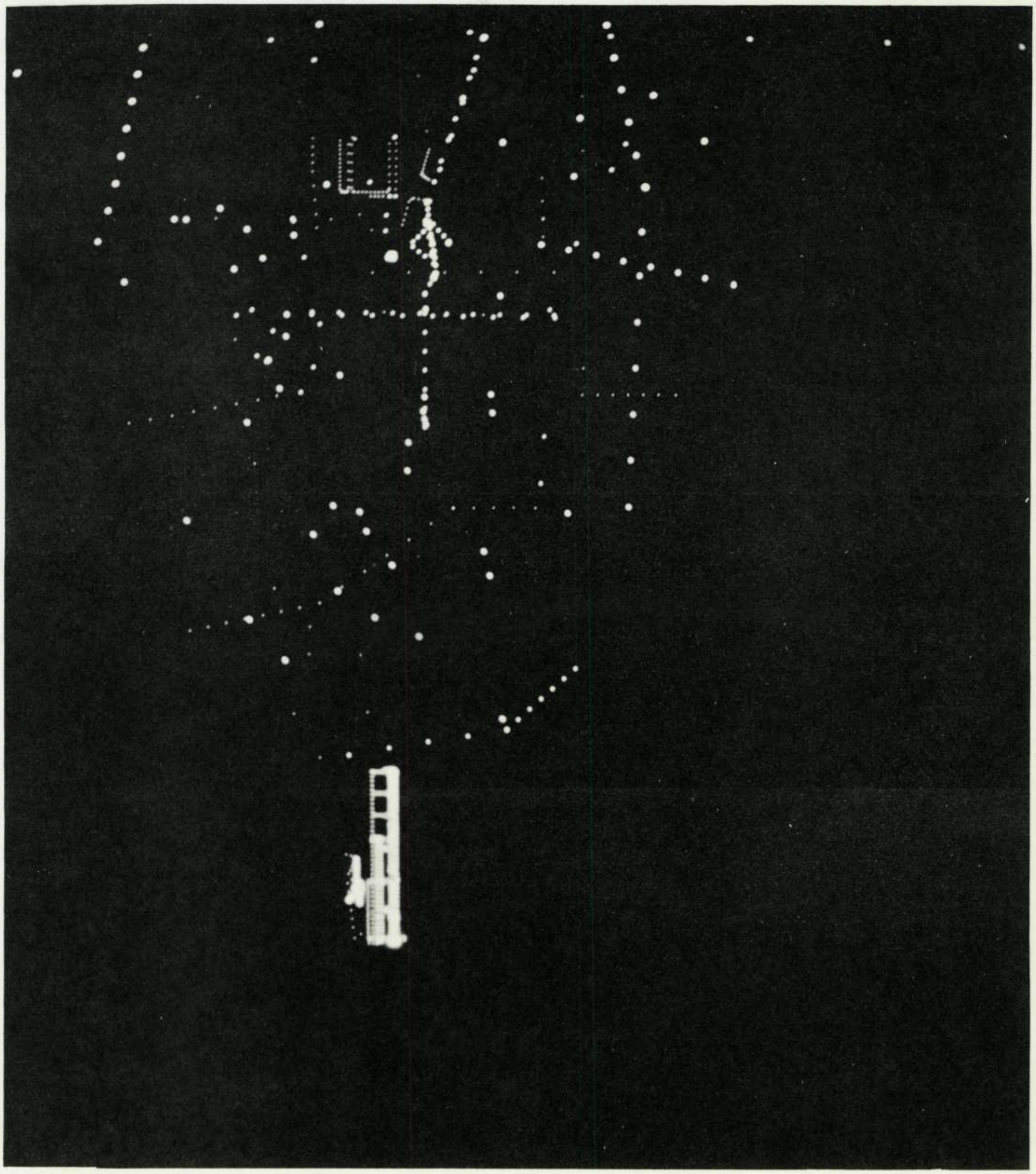


FIGURE 3. PLANAR VIEW OF NFL AIRPORT WITH NO FOREGROUND LIGHTS AND UP SLOPED TERRAIN BEHIND THE RUNWAY

horizontally, and gave unity magnification. Figure 4 shows the pilots' view of the NFL airport and HUD display during an approach.

The head up display was a simulation of a HUD manufactured by Sundstrand Data Control, Inc. The display is collimated so that the display symbology shown and described in figure 5 appears at infinity. The HUD symbology consists of two vertical approach angle scales and a horizontal flight path bar. The approach angle scales are driven by the aircraft's pitch attitude so that the zero on the scale is always on the true horizon. The approach angle scales indicate the depression angle below the horizon, or in other words the glide slope angle to any point on the ground.

The horizontal flight path bar displays ground referenced flight path angle multiplied by a gain and biased to the reference three degree glide slope angle. This bar provided flight director like commands. If the pilot made the proper corrections to the aircraft's flight path angle required to overlay the bar on the desired runway aim point, the aircraft would capture and then track a three degree glide slope to the aim point.

The simulated HUD display was programmed to function the same as the one manufactured by Sundstrand except that perfect signals were used for altitude rate, ground velocity and pitch. The display symbols were drawn directly on the CRT by the computer graphics system and the actual computer and displays were not used.

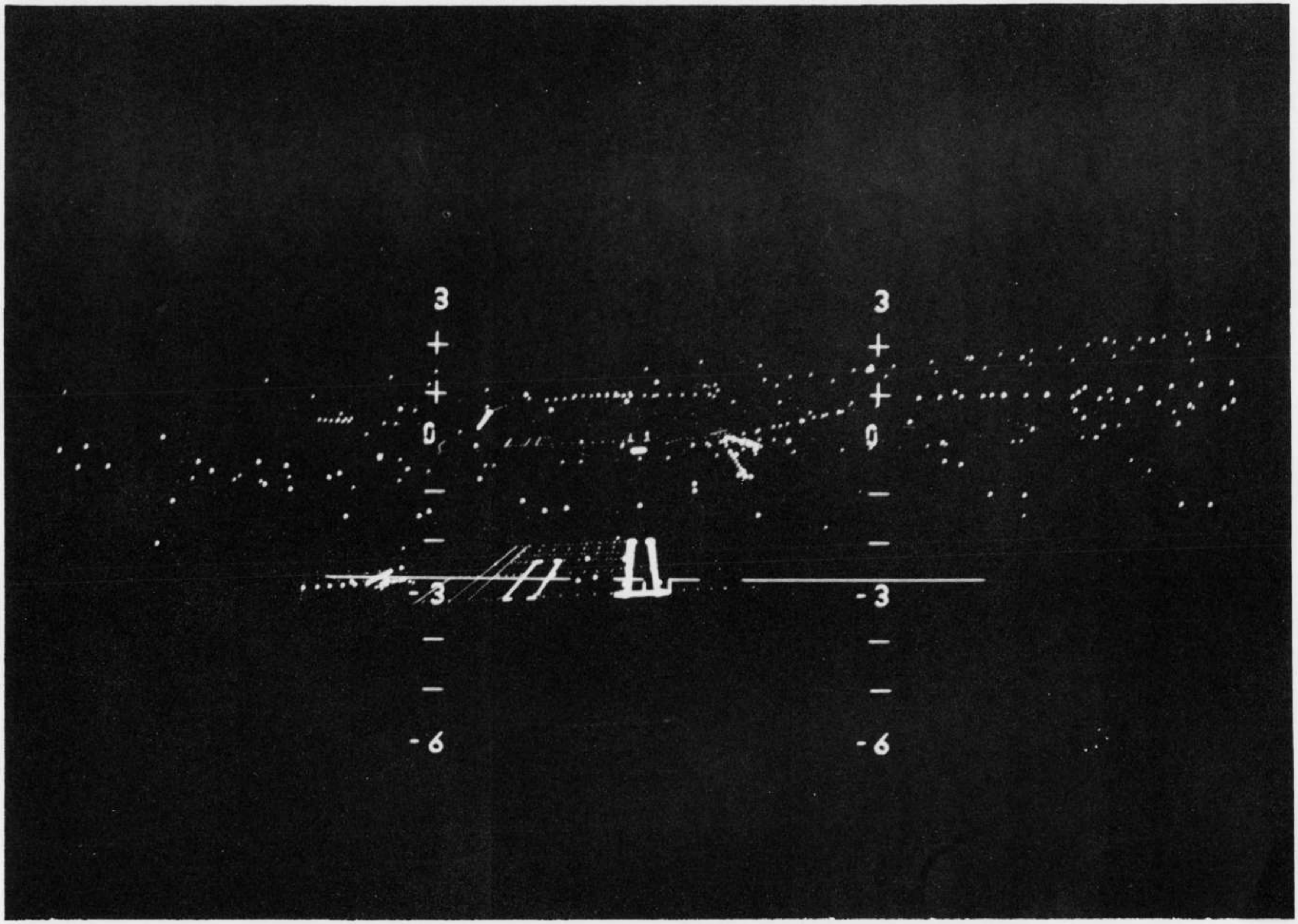


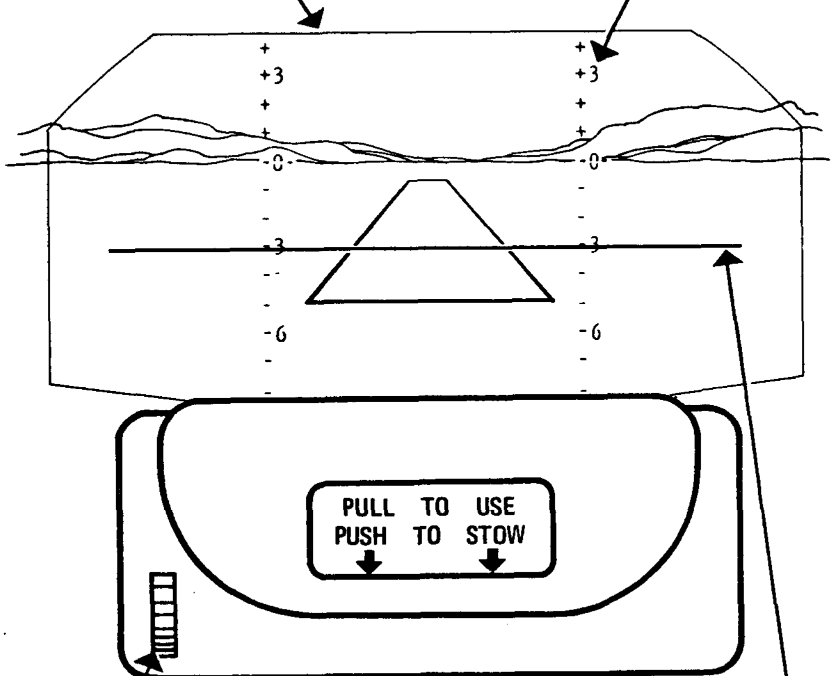
FIGURE 4. PILOT'S VIEW OF NFL AIRPORT AND THE HEAD-UP DISPLAY

Viewing Lens

Fabricated of optically ground and coated acrylic plastic — folds down automatically when the unit is stowed, extinguishing the display lighting. The display is self-calibrating.

Approach Angle Scales

Displayed vertically — one on each side of the lens. Numbers on the scale above zero are in plus (+) degrees, those below zero are in minus (−) degrees. Slope angle to the runway aiming point is read off directly.



Intensity Control

Adjusts the intensity of the image from low to full bright depending on background light level. Once set, an automatic contrast feature maintains readability throughout a wide range of ambient lighting.

Horizontal Bar

Extends horizontally across the width of the lens. In use, it is aligned between the pilot's eyes and the runway. Maneuvering the aircraft to hold the bar on the runway aiming point will cause the aircraft to intercept and maintain a −3° flight path to the TDZ.

Image

Consists of two displayed cues — approach angle scales and a flight path bar. Image intensity is pilot adjustable. Parallax is zero when seated in the aircraft eye reference position.

Failure Modes

No self-test is required. Continuous internal monitoring automatically extinguishes the display illumination in the event of system failures or loss of validity signals.

FIGURE 5. VISUAL APPROACH MONITOR DISPLAY SYMBOLS

The dynamics of a four engine transport in the DC-8 size range were programmed on a digital computer. Flaps and gear were always down. An autothrottle system was used to control power and speed. At the beginning of each run, the simulated aircraft was positioned 12,000 m (39,300 ft) from the runway aim point at an altitude of 458 m (1500 ft). Simulated turbulence consisted of random gusts and a headwind profile shown in figure 6. Aircraft altitude was recorded every 200 meters from 12,000 meters to touchdown.

PROCEDURE

In the main experiment described in reference 5 the pilots flew a number of approaches for training and familiarization with the HUD display and the SJC airport and then one or more sets of eight approaches in which display and task variables were changed. The two approaches of present interest were normal three degree approaches with and without the HUD display. After flying these approaches five of the pilots each made two additional approaches to NFL airport without the HUD and then a final approach with the HUD. Turbulence was present on all of the approaches.

The pilot task for all conditions was to maintain the initial altitude of 458 m (1500 ft) until the DME readout flashed indicating the pushover point for the three degree glide slope. The pilot then flew down a three degree glide slope to the runway aim point 1000 ft beyond the threshold.

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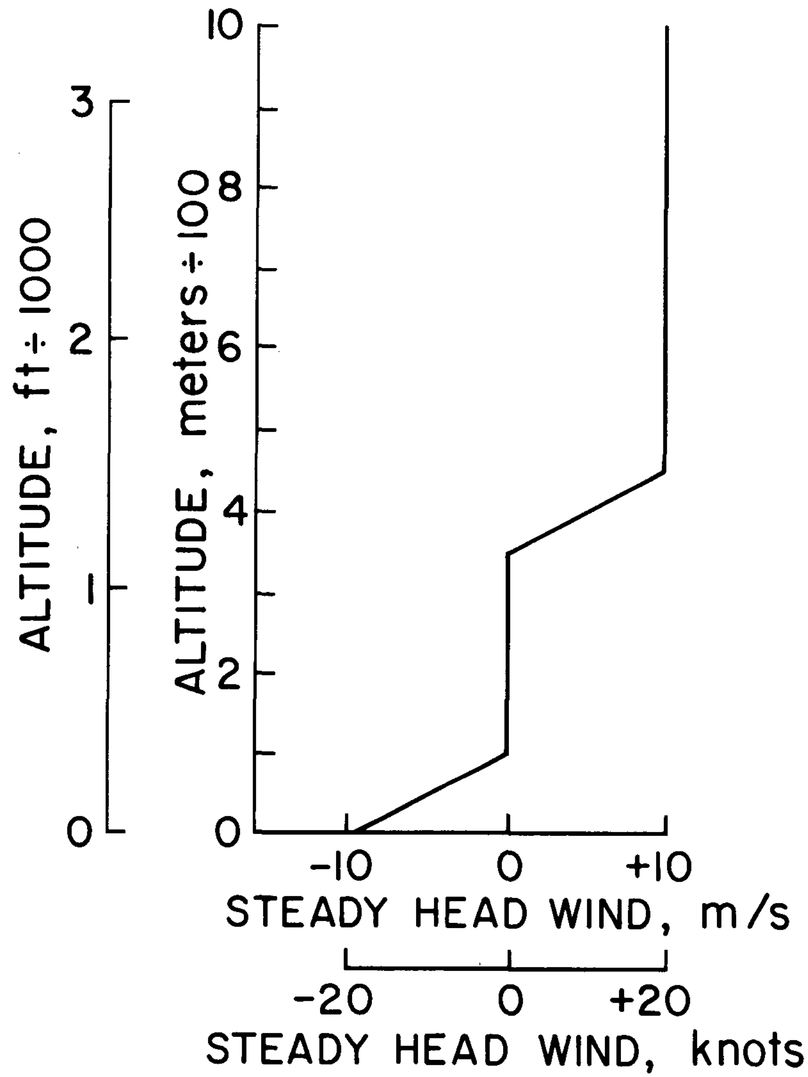

FIGURE 6. HEADWIND PROFILE

RESULTS AND DISCUSSION

Overlays of the vertical profiles for each of the four experimental conditions are shown in figures 7, 8, 9, and 10. The root mean square (RMS) deviation of the altitude errors from the reference three degree slide slope for each condition was calculated and is shown in figure 11. Figure 12 is a plot of the ratio of the RMS glide slope error with no HUD to the RMS error with the HUD for approaches into each airport.

The vertical profiles in figure 8 flown without HUD into SJC airport show a large decrease in glide slope tracking precision as compared to the vertical profiles in figure 7 flown with the HUD. Figure 11 and 12 show that the RMS glide slope error increased by a factor of about three for ranges of 6000 meters to a range of 200 m from the runway aim point for approaches flown without the HUD. The data indicate that the use of a HUD that aids the pilot in estimating his glide slope angle to the runway aim point or H distance results in considerable improvement in glide slope tracking precision.

The pilots then flew two approaches with no HUD into NFL aircraft which they had not seen before. The vertical profiles in figures 8 and 9 and the RMS data in figure 11 show the large decrease in glide slope tracking precision with this airport as compared to SJC airport (figure 8). This degradation in performance resulted from just changing the city lighting pattern by removing the foreground light and placing lights on a hill behind the runway.

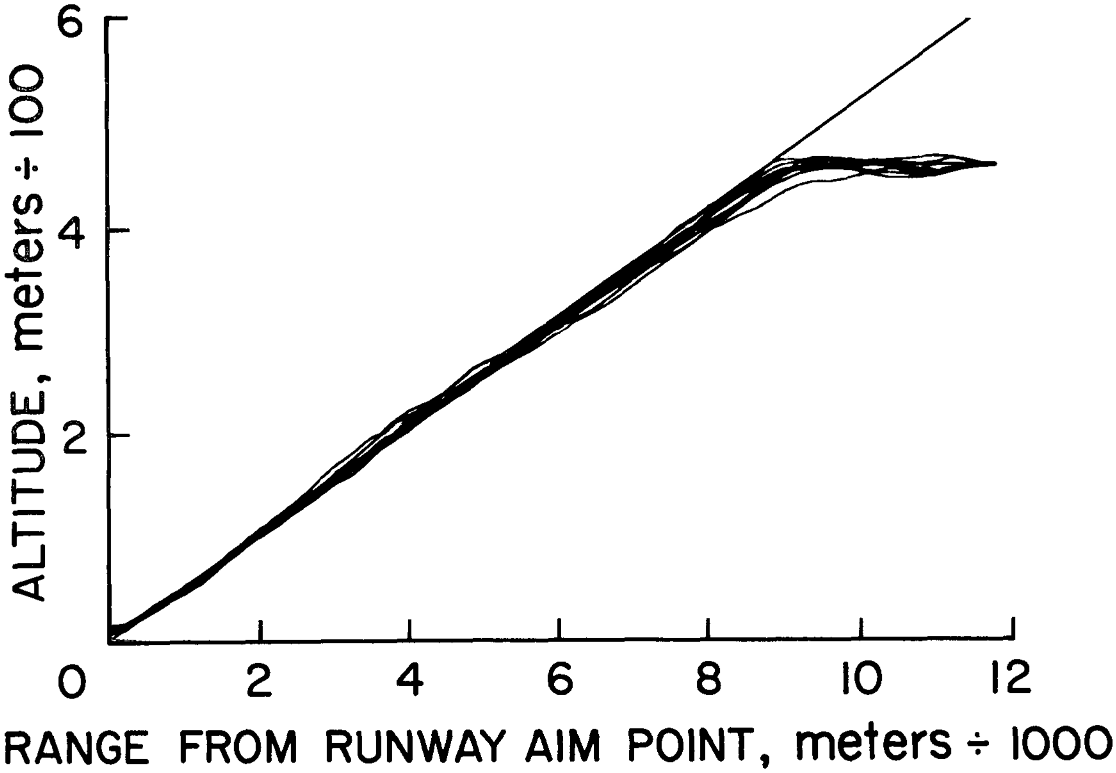

FIGURE 7. VERTICAL PROFILES OF APPROACHES INTO SJC AIRPORT WITH THE HEAD-UP DISPLAY (N=10)

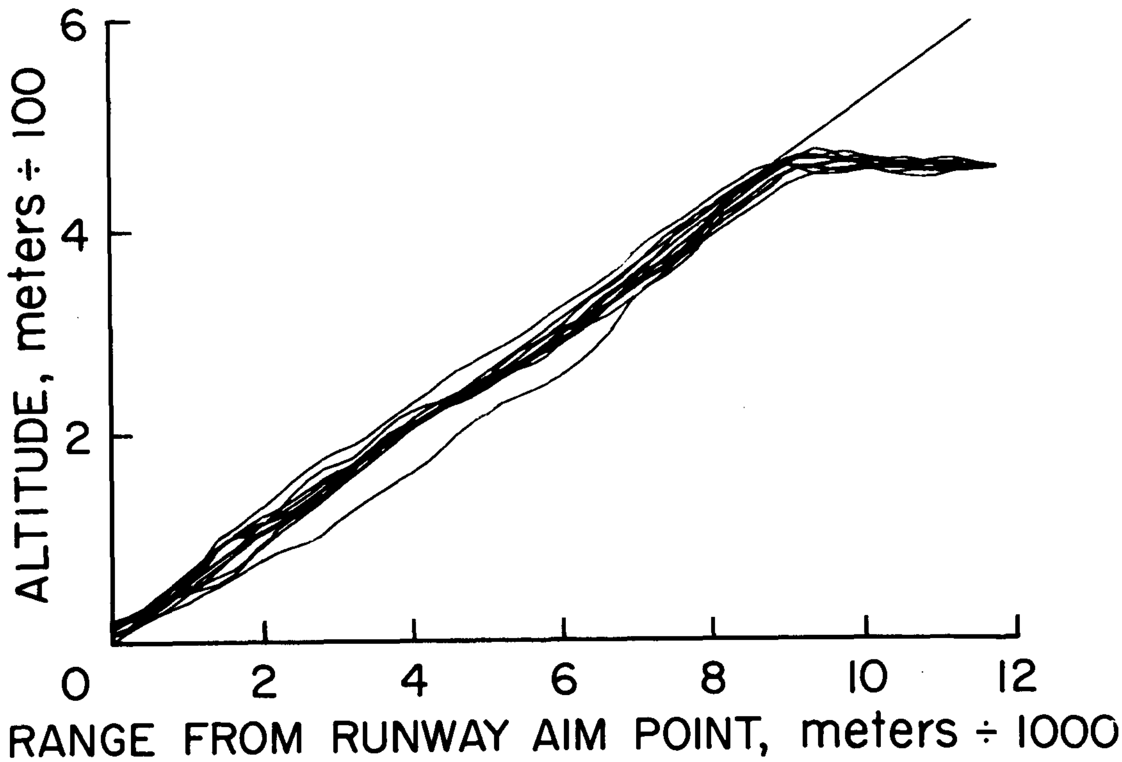

FIGURE 8. VERTICAL PROFILES OF APPROACHES INTO SJC AIRPORT WITHOUT THE HEAD-UP DISPLAY (N=10)

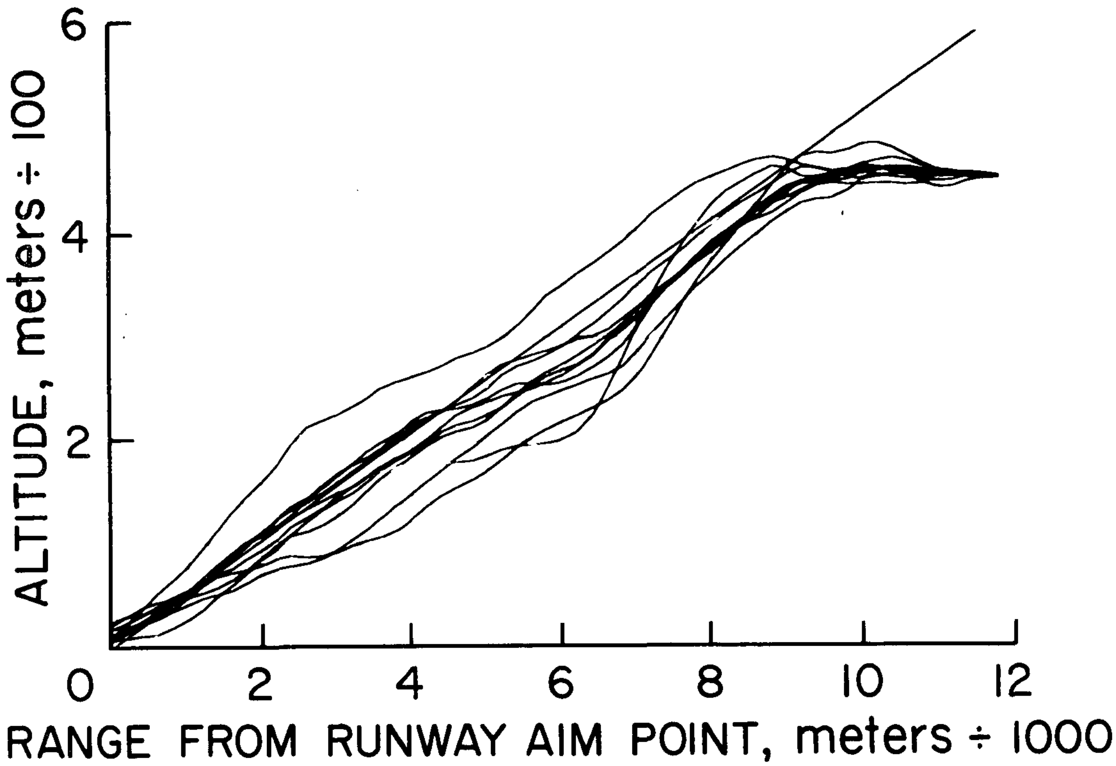

FIGURE 9. VERTICAL PROFILES OF APPROACHES INTO NFL AIRPORT WITHOUT THE HEAD-UP DISPLAY (N=10)

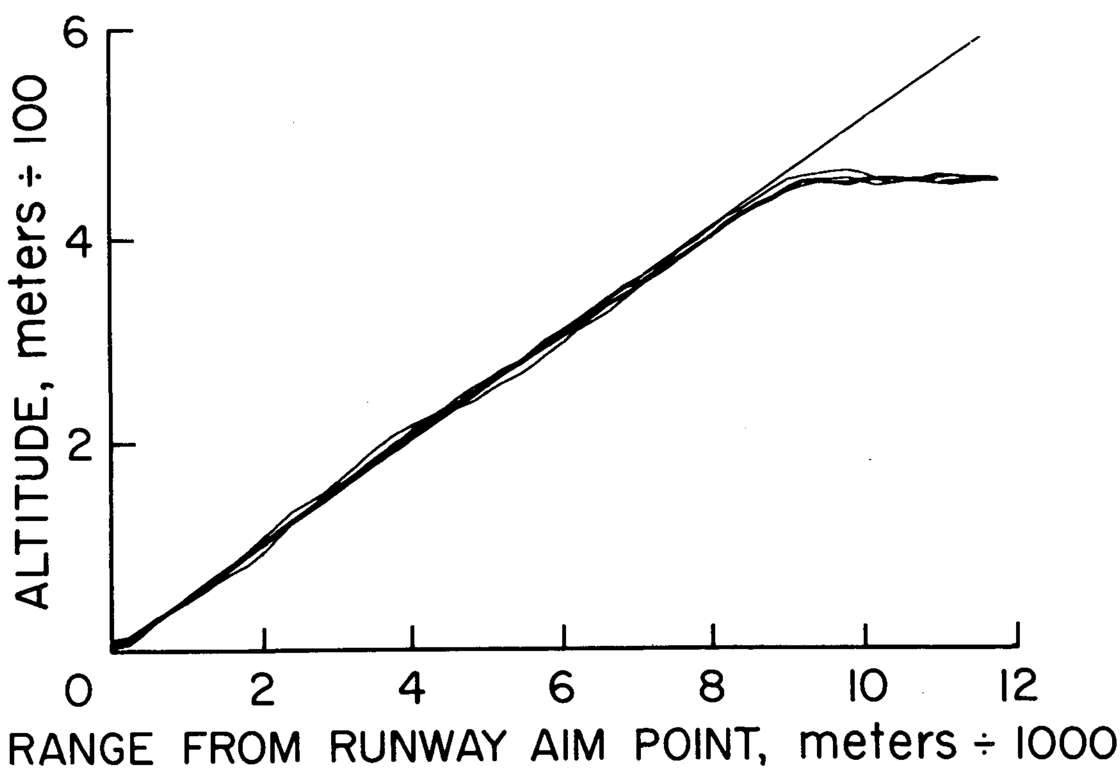

FIGURE 10. VERTICAL PROFILES OF APPROACHES INTO NFL AIRPORT WITH THE HEAD-UP DISPLAY (N=5)

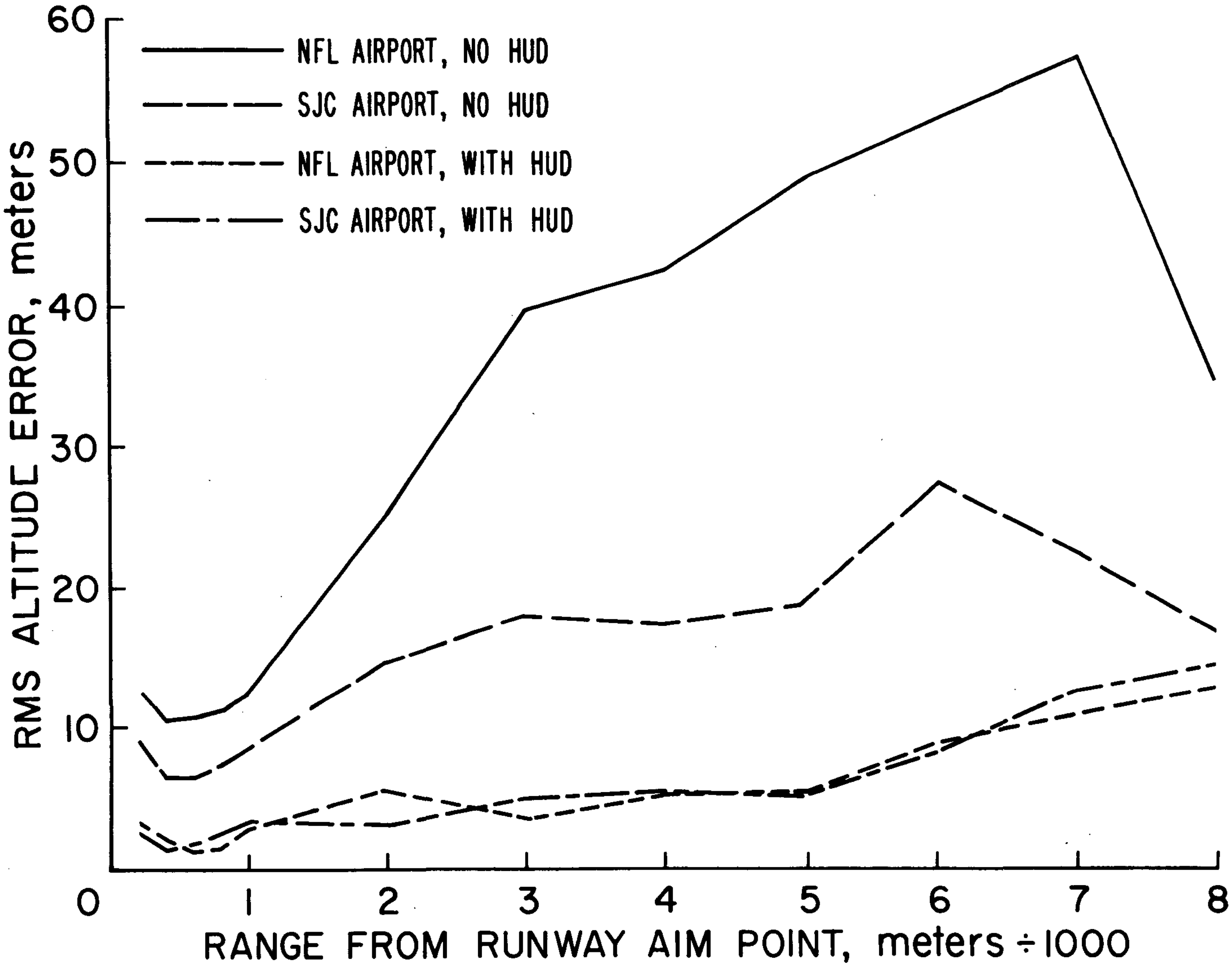

FIGURE 11. ROOT MEAN SQUARE (RMS) ALTITUDE ERROR FROM THE 3° GLIDE SLOPE

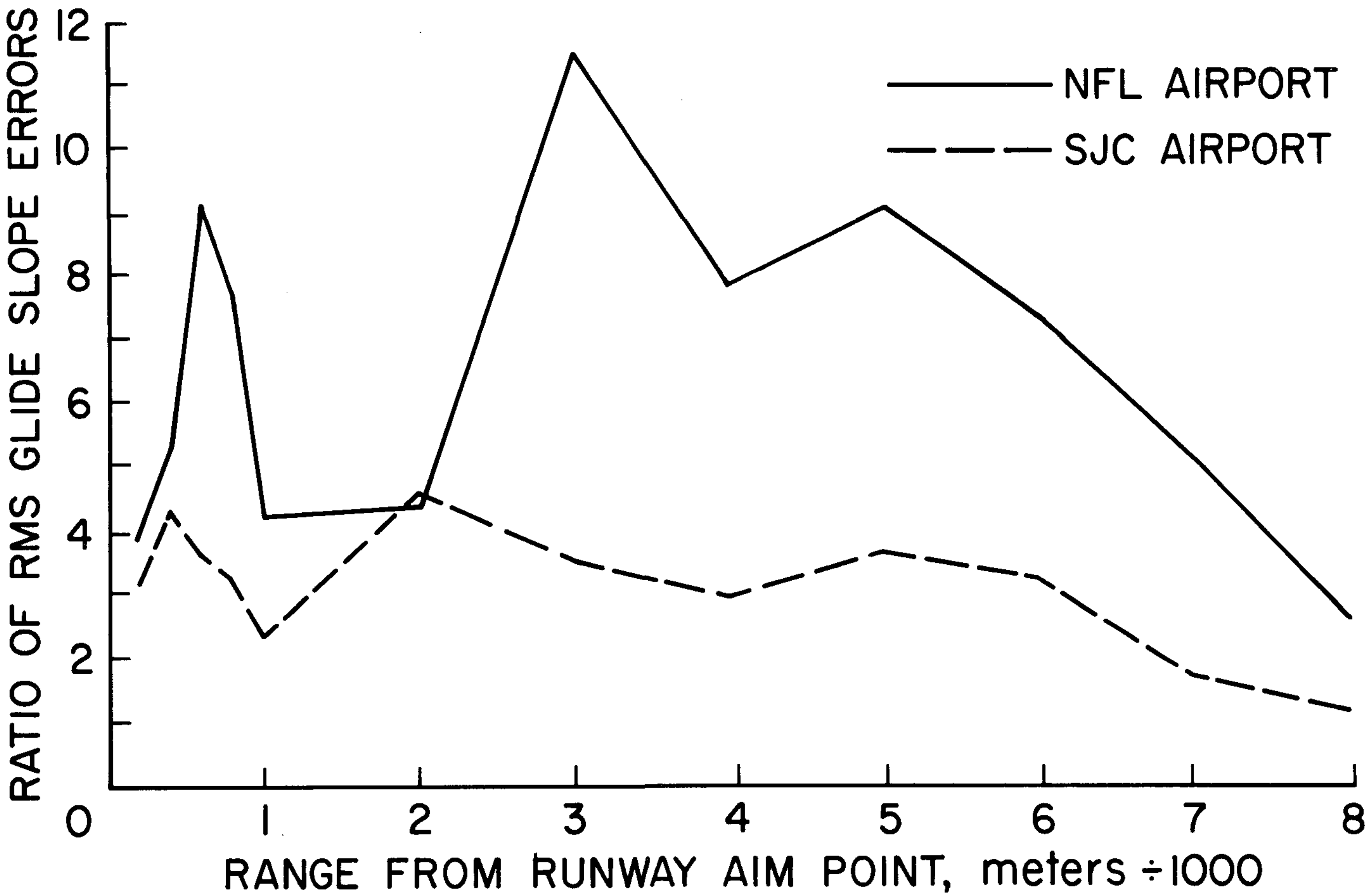

FIGURE 12. RATIO OF RMS GLIDE SLOPE ERROR WITH NO HUD TO THE RMS GLIDE SLOPE ERROR WITH A HUD FOR APPROACHES INTO EACH AIRPORT

Where the HUD was used on approaches into NFL airport, glide slope tracking was equivalent to the pilot's previous performance with the HUD and SJC airport. This can be seen by comparing figures 10 and 7 and figure 11. These data indicate that the HUD should be particularly helpful when the city light pattern causes the normal visual cues to be less reliable.

CONCLUDING REMARKS

- The simulator data showed a three fold increase in glide slope tracking when the VAM was used on the SJC airport.
- The VAM display aids the pilot especially when the city lighting patterns makes the normal visual cues less reliable.
- The computer graphics technique used to generate the night scenes appears promising as a technique to simulate various types of visual illusions during night landings and evaluate their effects on pilot performance.

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