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FLIGHT SIMULATOR RUNWAY VISUAL TEXTURAL CUES FOR LANDING

By

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August 1980
Interim Report for Period November 1976 — August 1979

LABORATORY

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The effects of seven different runway types were investigated on pilot performance during landings in a T-37 flight simulator. Data were also gathered on 6 of the same 12 pilots during actual T-37 aircraft landings at the Air Force Flight Test Center, at Edwards AFB. The seven simulated runways consisted of one night runway and six day runways with varying amounts of textural information cues on the runway touchdown zone area. The night runway was also tested with and without touchdown zone landing lights (TD-Zone lights), and the day runways were tested with and without the runway overruns. The simulated aircraft average vertical velocity at touchdown decreased systematically from 201 ft/min for the night runway without the TD-Zone lights to 136 ft/min for the day runway with 4-foot texture patterns. The day runways

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alone, without the overrun, varied from 195 ft/min for the Bare Bones runway to 136 ft/min for the 4-foot texture pattern. Although these average vertical velocities were still much higher than those recorded in the actual aircraft (32 ft/min), the texture patterns did influence the pilot flare and touchdown in a systematic manner. Additional visual cues might have reduced the vertical velocities even more, but the limited edge capacity of the Computer Image Generation (CIG) scene did not permit the study of other visual cues while investigating texture patterns. The presence of the TD-Zone lights in the night scene also reduced the average vertical velocity at touchdown (190 ft/min), but this difference was not statistically significant. The presence of the runway overruns on the daytime runways limited the overall range of touchdown vertical velocities to a smaller range spanning from 176 ft/min for the "Willie" runway to 158 ft/min for the 4-foot textured runway. When the overrun was present, apparently the pilots used the overrun visual cues, the chevron texture patterns and other related cues, in addition to the runway texture patterns in order to perform the flare and touchdown. This resulted in reduced overall touchdown vertical velocities, but apparently the more uniform pilot performance (restricted range) did not involve an optimum use of the 4-foot texture patterns. Several other data parameters also varied across runway types; however, there were no consistent differences related to runway texture patterns. The significant effects with the other data parameters were most often related to differences between the night and the day runway scenes.

PREFACE

This report covers research conducted by the Flying Training Division of the Air Force Human Resources Laboratory between November 1976 and August 1979. Full support of this project was provided by the 82d Flying Training Wing, Williams AFB, Arizona 85224. The Air Force Flight Test Center, Edwards AFB, California, also provided full support for the collection and reduction of the cine-theodolite aircraft data. The research project was conducted in support of Project 1123, Flying Training Development, Mr. James F. Smith, Project Scientist; Task 112303, Exploitation of Flight Simulation in Undergraduate Pilot Training (UPT), Mr. Robert R. Woodruff, Task Scientist; Work Unit 11230332, Terrain Visual Cue Requirements for Flight Simulation, Capt George H. Buckland, Principal Investigator and Eric G. Monroe, Associate Investigator.

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FLIGHT SIMULATOR RUNWAY VISUAL TEXTURAL CUES FOR LANDING

I. INTRODUCTION

The lack of adequate flare and final touchdown visual information cues has been a longstanding criticism of flight simulators in general (Armstrong, 1968, 1970; Bray, 1973; Chase, 1971; Crane, 1962; Dyda & Lew, 1963; Sorum & Fister, 1974; Valverde, 1968; Wempe & Palmer, 1970). A typical fault often mentioned is the lack of adequate textural information (Armstrong, 1968) in the visual scene. Improvements in this area might provide better cues for depth perception. It is not clear what the best cues for depth perception are; however, textural information may be such a cue. The flexibility of computer image generation (CIG), which permits rapid variation of visual scene content, appeared ideal for testing the utility of textural patterns as landing cues.

One major difficulty in assessing the adequacy of a flight simulator visual scene is the problem of specifying the different aspects of the visual environment. Figure 1 shows the Williams AFB runway from a T-37 cockpit at three different points on the glideslope. Note the runway tire tracks which appear in the last photo. Although this visual textural cue is not readily apparent from a distance, it appears to become a powerful cue for judging depth and motion as the pilot approaches it. Many of the textural cues in the runway touchdown zone are of an irregular nature, such as the tire tracks on the runway, and they are therefore difficult to vary or specify in an orderly parametric fashion. However, unless pilot performance or training effectiveness can somehow be shown to vary along some dimension of textural detail, it is difficult to convincingly demonstrate that simulated runway texture has actually contributed to improved pilot performance. Also, some generalizable definition of textural requirements for flight simulation in general is needed for decisions on cost-effective designs of future flight simulators. Binary judgements, such as "our simulated tire tracks did or did not help," are not as useful in this regard. Ultimately, simulated tire tracks may be used, but only after they have been related to a more general dimension of visual texture. Also, there may be less costly ways to simulate runway textures than the edge-consuming simulated tire tracks. A grid pattern superimposed on the touchdown zone area appeared to be a simple way to vary runway texture along a dimension of coarseness, given the present visual image generation capabilities of the Advanced Simulator for Pilot Training (ASPT) at the Air Force Human Resources Laboratory/Operation Training Division (AFHRL/OT).

Assessing a flight simulation visual scene in terms of its adequacy for touchdown and landing can be pursued in a number of ways, ranging from student training effectiveness to experienced pilot performance. The criticism of touchdown visual information has often been stated by experienced pilots and demonstrated by their simulated aircraft vertical velocity being excessive at touchdown (Armstrong, 1968; Chase, 1971). Thus, it was decided to initially investigate this phenomenon (i.e., excessive velocity) in the ASPT by using experienced pilots who could be assumed to have reached a stable level of performance in the T-37. This approach permitted assessment of the relative differences in pilot performance in response to the different runway texture patterns; the performance of the experienced pilots served as a stable basis for comparing the relative efficacy of the different runways. Additional data collected on six of the pilots during actual T-37 landings were used to compare pilot landing performance in the simulator to pilot performance during actual aircraft landings.

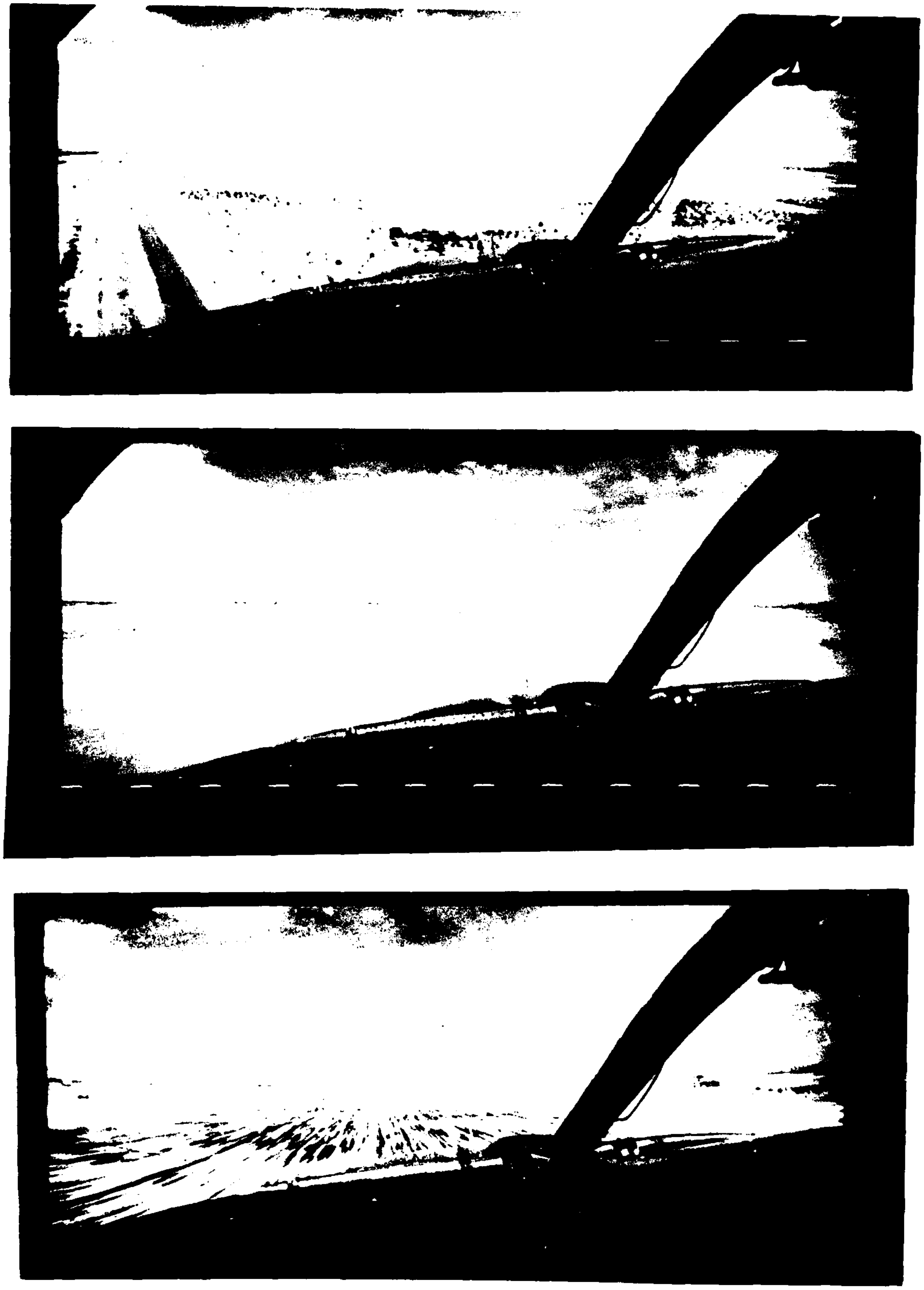

Figure 1. **Williams AFB Runway.**

II. METHOD

Experimental Design

The basic simulator experimental design was a two-factor, repeated measures design with all pilots being tested under all seven levels of the first factor and both levels of the second factor. The first factor consisted of six different daytime runway types plus one night runway. The second factor was whether there was a 1000-foot runway overrun marked with chevrons prior to the runway threshold for the daytime scene and whether there were touchdown zone landing lights (TD-Zone lights) for the night scene. The two independent variables of runway type and runway overrun/TD-Zone lights were presented in a limited random order, with each pilot landing on each runway type five times with the overrun/lights and five times without the overrun/lights. The experimental sessions were divided into five missions with each mission consisting of 14 landings in which each runway type occurred once with the threshold/TD-Zone lights and once without. The runway types were presented in a random order for each mission of 14 landings.

Aircraft Data

The T-37 aircraft flare and touchdown data were gathered at the Air Force Flight Test Center (AFFTC) at Edwards AFB. The AFFTC facility includes cine-theodolite tracking devices for determining aircraft time, space, and position data during touchdown or takeoff. Using these data, it was possible to gather information on the aircraft path during the flare and landing, as well as such touchdown data as the aircraft vertical velocity and groundspeed at touchdown. During this exercise, each pilot performed at least 10 touch-and-go landings using a closed pattern at Edwards AFB.

Subjects

Twelve T-37 instructor pilots (IPs) from Williams AFB were used as subjects for the flight simulator portion of the study. Six of these IPs also served as subjects for the touchdown data collected in the actual T-37 aircraft. Each pilot was required to be a qualified T-37 IP and to be current in the T-37 at the time of the study.

Apparatus

The ASPT was used for the simulation portion of the study (Bell, 1974). Standard Air Training Command (ATC) T-37 basic jet trainers were used for the aircraft portion of the study. The simulated T-37 was always initialized with 1000 pounds of fuel for each landing. The actual T-37 sorties began with full fuel (approximately 1800 pounds) and continued touch-and-go landings until nearly empty (approximately 300 pounds).

The ASPT consists of two fully instrumented cockpits. One cockpit is configured as a T-37 aircraft, while the other cockpit is currently used for A-10 flight simulation. The ASPT visual system uses seven 36-inch monochromatic cathode-ray tubes (CRTs) to provide a wraparound visual scene with a visual field of view of + 110 to -40 degrees vertical and ±150 degrees horizontal. The visual scenes are produced using computer-generated imagery (CGI). Almost any simulated visual scene can be produced with current ASPT hardware and software as long as it does not require more than 2000 edges to display the scene content. All of the objects and surfaces in the visual environment must be constructed of these straight line segments or edges. The visual imagery is updated at 30 times per second in response to the aircraft movement through the simulated environment.

The ASPT cockpits are mounted on six-degrees-of-freedom, hydraulically actuated motion platforms. Additional motion cues are also provided by 32-bellow pneumatic g-seats with variable tension lap belts. Neither of the motion systems, i.e., motion platform and g-seat, was active for this study.

The ASPT has the ability to record, store, and score various pilot performance parameters automatically. The measures, discussed later under dependent variables, are sampled and stored from 3.75 to 15 times per second, depending on their nature. The ASPT can be preprogrammed to vary any of the simulator configurations for a particular experimental study. Thus, it was possible to present the different runway types in quasi-random order for each pilot. Before each landing, the pilot was initialized on the glideslope approximately one mile from the runway threshold for a particular runway type. After touchdown, the aircraft was reinitialized on the glideslope for a different runway type.

Independent Variables

The major factor which was varied consisted of seven different runway types; six were daytime runways differing in the amount of textural detail in the touchdown zone area, and the seventh was a night-time visual scene. The night runway scene was used to investigate reports that night landings are typically firmer in terms of vertical velocity at touchdown. The environment for the daytime runway consisted of a monochromatic background representing the ground with a lighter shade for the sky and the horizon boundary. The daytime scenes contained no other scene detail except for the runways, and the night scene had scattered point lights only, in order to delineate the ground and horizon.

Figures 2 to 7 show the experimental simulated runways from different points on a glide slope. The glide slope used for these pictures is somewhat steeper than normal in order to enhance the visibility of the texture patterns. The pictures were taken from a black-and-white CRT monitor which had a higher contrast ratio than the monochromatic green CRTs used for the simulator cockpit. Figure 2 shows the night runway scene with and without the TD-Zone lights at three different points on the glideslope. Figures 3 and 4 show the six daytime runways from the same point just prior to the runway overrun. Figure 3 has the overrun, while Figure 4 does not have the overrun. Notice that the texture patterns are just barely distinguishable at this distance. The pilot would be making the decision to flare over the beginning of the overrun. Figures 5 and 6 show the daytime runways from a point over the overrun just prior to the runway threshold. At this point, the texture patterns are clearly distinguishable from each other, and the pilot should be executing the flare now. Figure 7 shows the daytime runways from a point just over the runway threshold, thus providing a very clear picture of the texture patterns. It is important to note that these texture patterns are never viewed from a static position during landing, and they produce a somewhat different visual sensation during motion.

The seven runways started with a very basic Bare Bones runway consisting of a rectangular runway surface which was 6000 feet long and 150 feet wide. The runway was outlined by a stripe which was the same width and intensity as the dashed centerline stripe which was also used on all runways. There was also a small dark rectangle marking 1000 feet from the threshold, on either side of all daytime runways. The night runway had dual "VASI like" lights marking the 1000-foot point. All of the runways had the same footprint and position as the Bare Bones runway. Textural detail was merely added to the Bare Bones runway to generate the more detailed runways. The second daytime runway, the "Willie" runw iy, was modeled after the Williams AFB runway. This runway

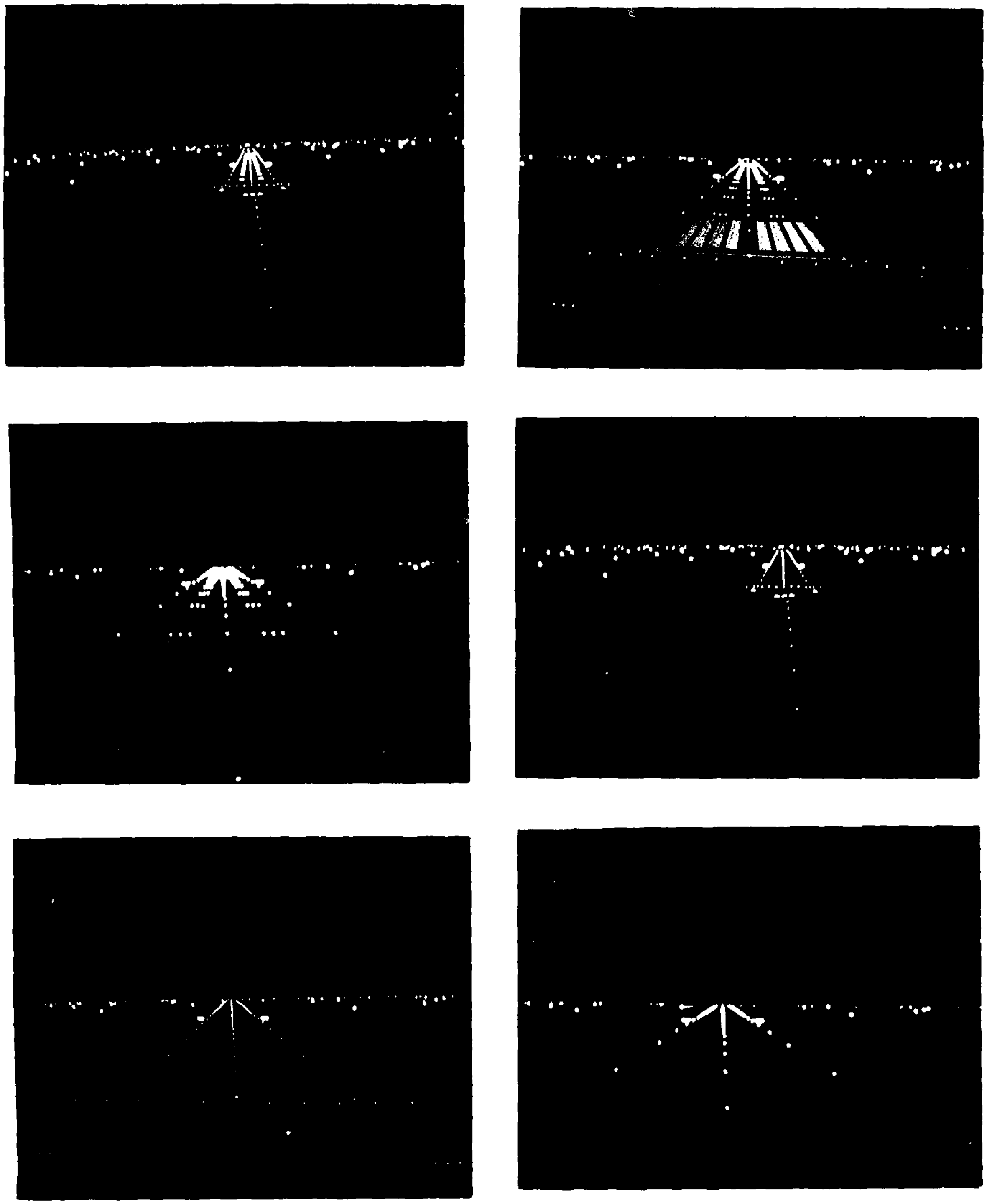

Figure 2. **Night runway scenes.**

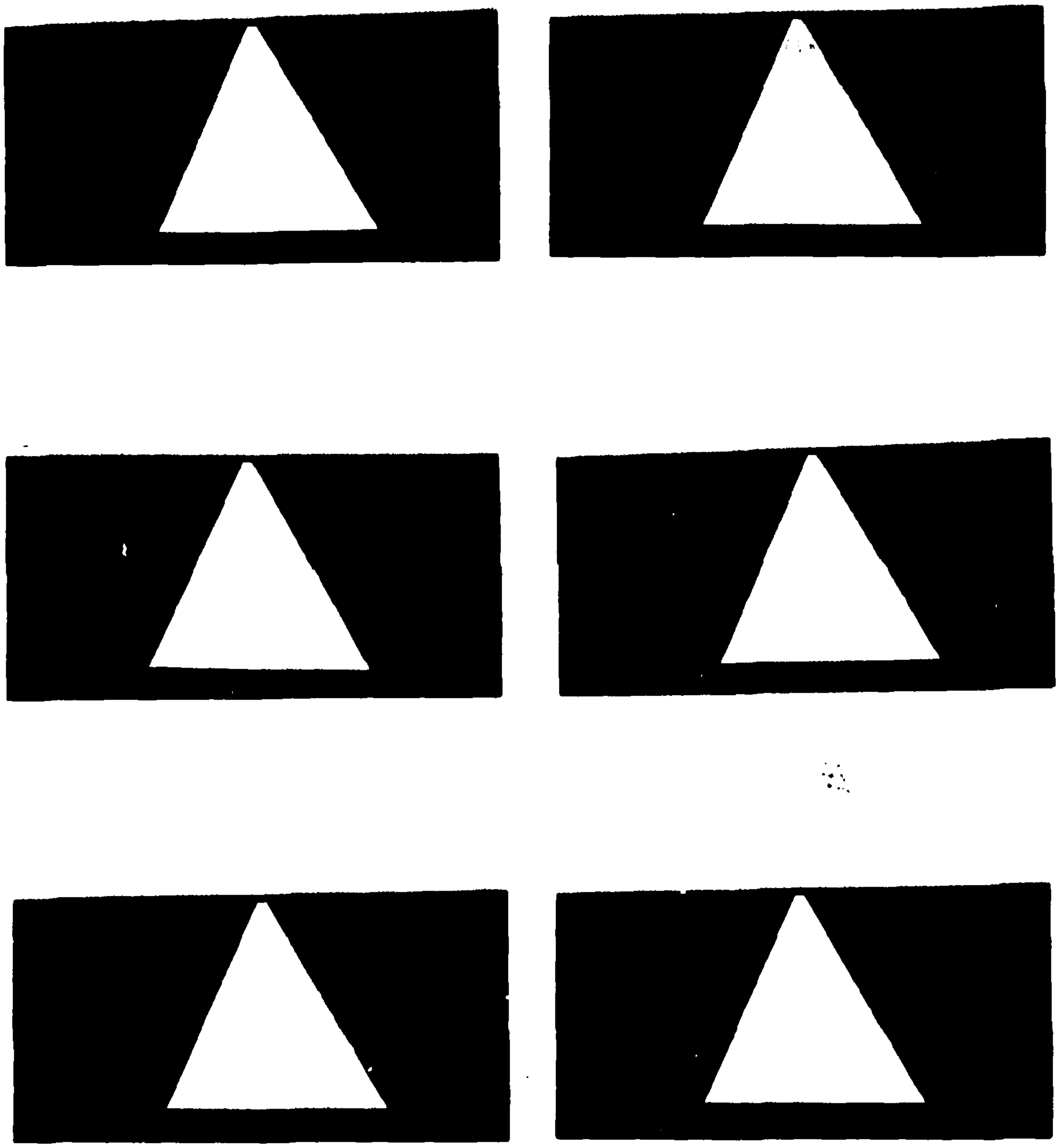

Figure 3. Daytime runways near the beginning of the overrun.

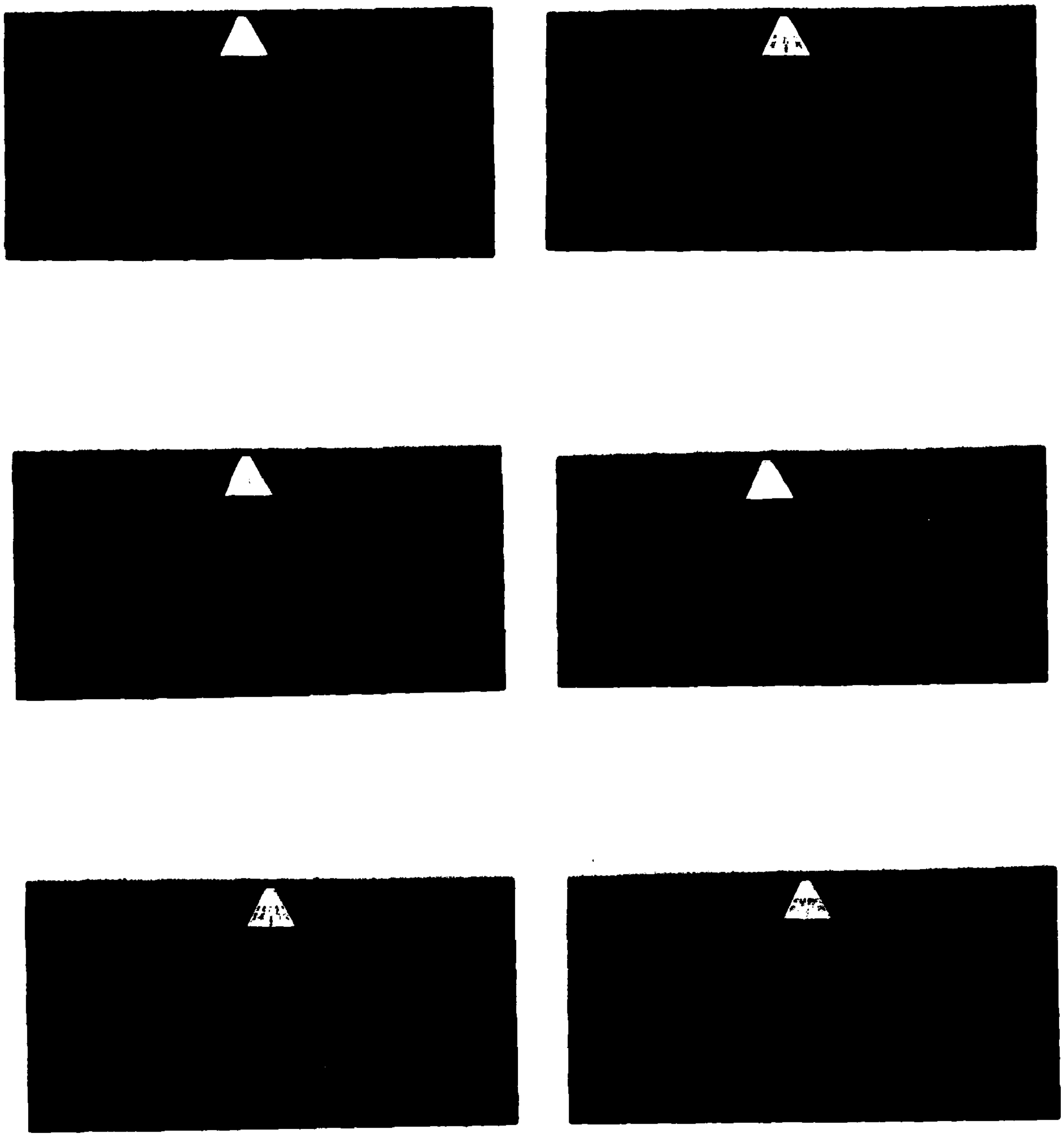

Figure 4. **Daytime runways (without the overrun) near the beginning of the overrun.**

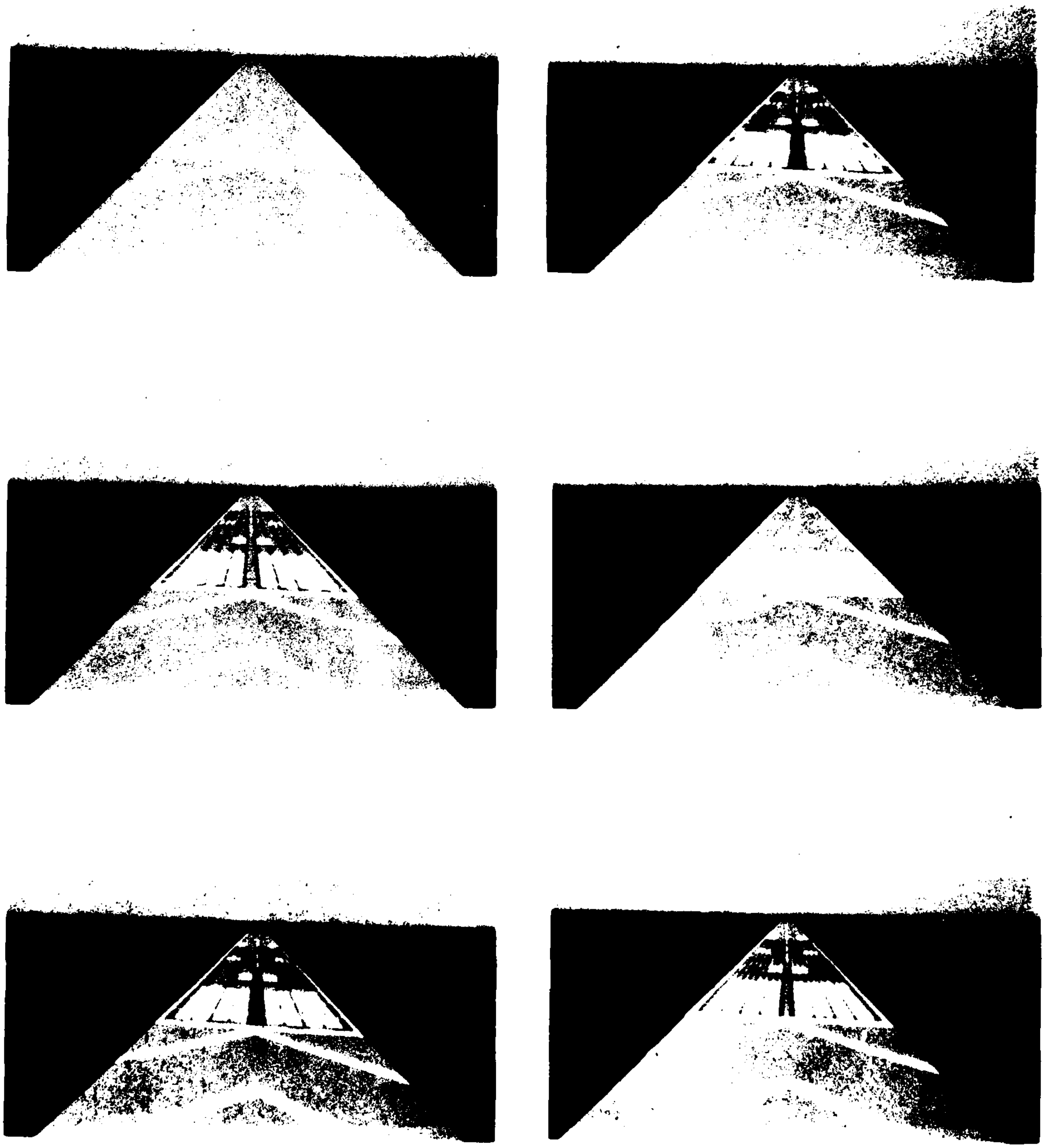

Figure 5. **Daytime runways from the mid-overrun area.**

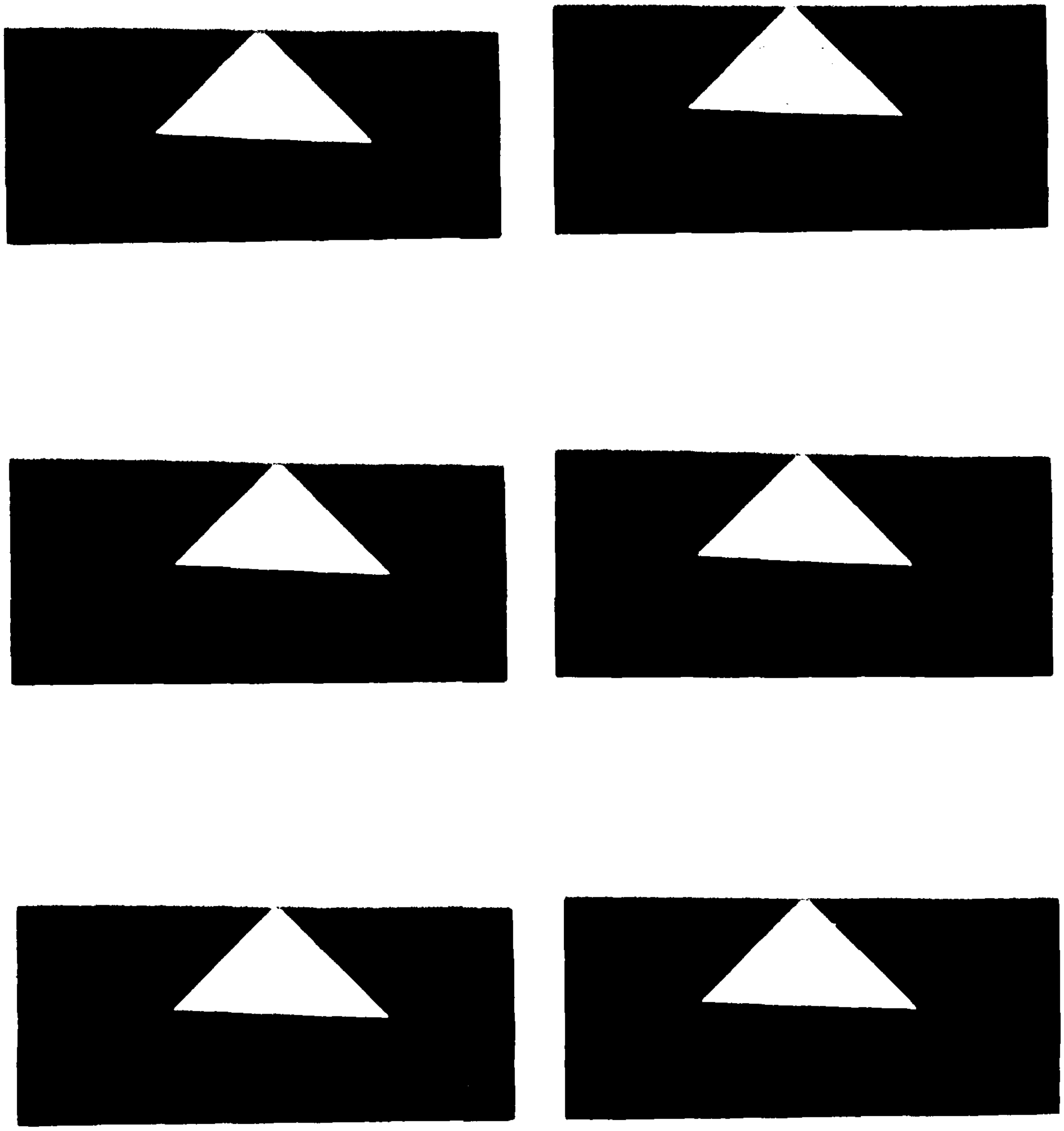

Figure 6. **Daytime runways (without the overrun) from the mid-overrun area.**

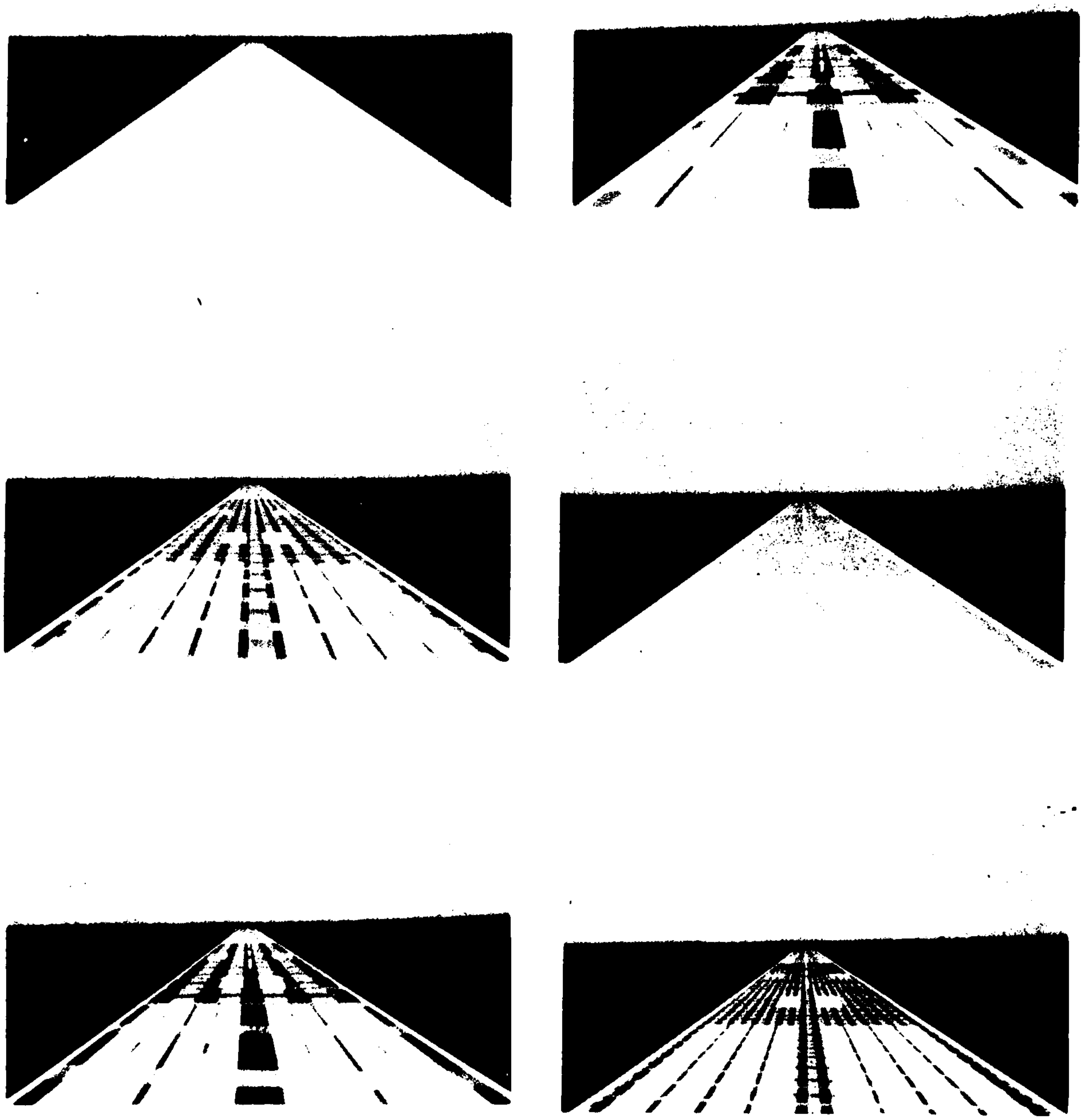

Figure 7. **Daytime runways from the runway threshold.**

had the standard Air Force runway markings and the number (30) added to the Bare Bones runway. The third through sixth runways consisted of the "Willie" runway with texture patterns underneath the runway markings. The runway markings were thus not obscured by the texture patterns. The patterns covered the width of the runway and extended 1000 feet down the runway from the threshold. The texture patterns varied in size with 25-foot spacing for runway three, 16-foot spacing for runway four, 8-foot spacing for runway five, and 4-foot spacing for runway six. Although the pattern appears to be a simple checkerboard pattern, it was specially designed to conserve more CIG edges than would a plain checkerboard. Figure 8 schematically presents the actual texture pattern which was used. The night runway scene was modeled after the Vital III (McDonnell Douglas Corporation) visual scene technology. All vertical light cues were removed; however, the point lights were retained to indicate the location of the ground plane and the horizon. The runway markings, which were visible near the ground, were the same as for the basic ASPT runway.

The second factor which was varied was the presence or absence of the runway overrun for the daytime scene and the TD-Zone lights for the night scene. The overrun was 1000 feet long. This factor was explored because the decision to flare, and much of the flare itself, occurs over the overrun. The chevron markings on the overrun also provide textural cues. Although the approach lights on the night scene are more comparable to the runway overrun, the TD-Zone lights were varied in the night scene in order to provide an effect which might be more comparable to the texture patterns on the daytime runway. Also, it was thought that the absence of approach lights on the night scene would produce too great an adverse effect on the landing performance on that runway.

Dependent Measures

The ASPT simulator has the capacity to record and store almost any variable which is generated during a flight simulation. The variables measured are accessed via performance measurement software which accesses the desired variables, computes the required parameters, and stores the data in an experimental data file. Table 1 shows the variables which were analyzed for this landing study. The derived scores (scores 1 to 4) are expressed in percentages. They were used to condense some of the more detailed measures in an effort to provide more concise measures for data analysis and to provide performance feedback to the pilots.

Four derived scores were used: the final approach score, the flare score, the touchdown score, and the total or overall score. Figure 9 shows how these scores were displayed on the in-cockpit CRT after each touchdown. Additional discrete parameters were also provided on this scoring page. The overall score is merely an arithmetic mean of the other three scores. The other scores are computed on the basis of time within tolerance bounds. These tolerance bounds are shown in Table 2. The tolerance bands are referenced to ideal aircraft flightpaths and parameters. These ideal parameters are presented as the base values in Table 2. The final approach score is thus the percentage of time that airspeed, centerline alignment, and glidepath are all kept within tolerance limits when the final approach segment was scored. The final approach segment was scored from 10 seconds after the simulator came off freeze (started landing sequence) until the flare scoring started. The tolerance limits were set during preliminary studies using expert pilot performance as the criterion for the tolerance bands. The primary purpose of the final approach score for this study was to keep the pilot on the glide path to prevent coming in low due to the lack of visual cues prior to the runway. For example, extremely low approaches have often been reported in landing over water at night. The flare score was based on airspeed, altitude, pitch, and centerline alignment from the time when the aircraft was 1000 feet from the threshold until touchdown. Since airspeed, altitude, and pitch all change during the flare, equations based on time from the start of scoring were used for computing the tolerance limits for the flare. This approach to flare scoring was experimental in nature. The touchdown score was based on airspeed, heading, and vertical velocity at the instant of touchdown.

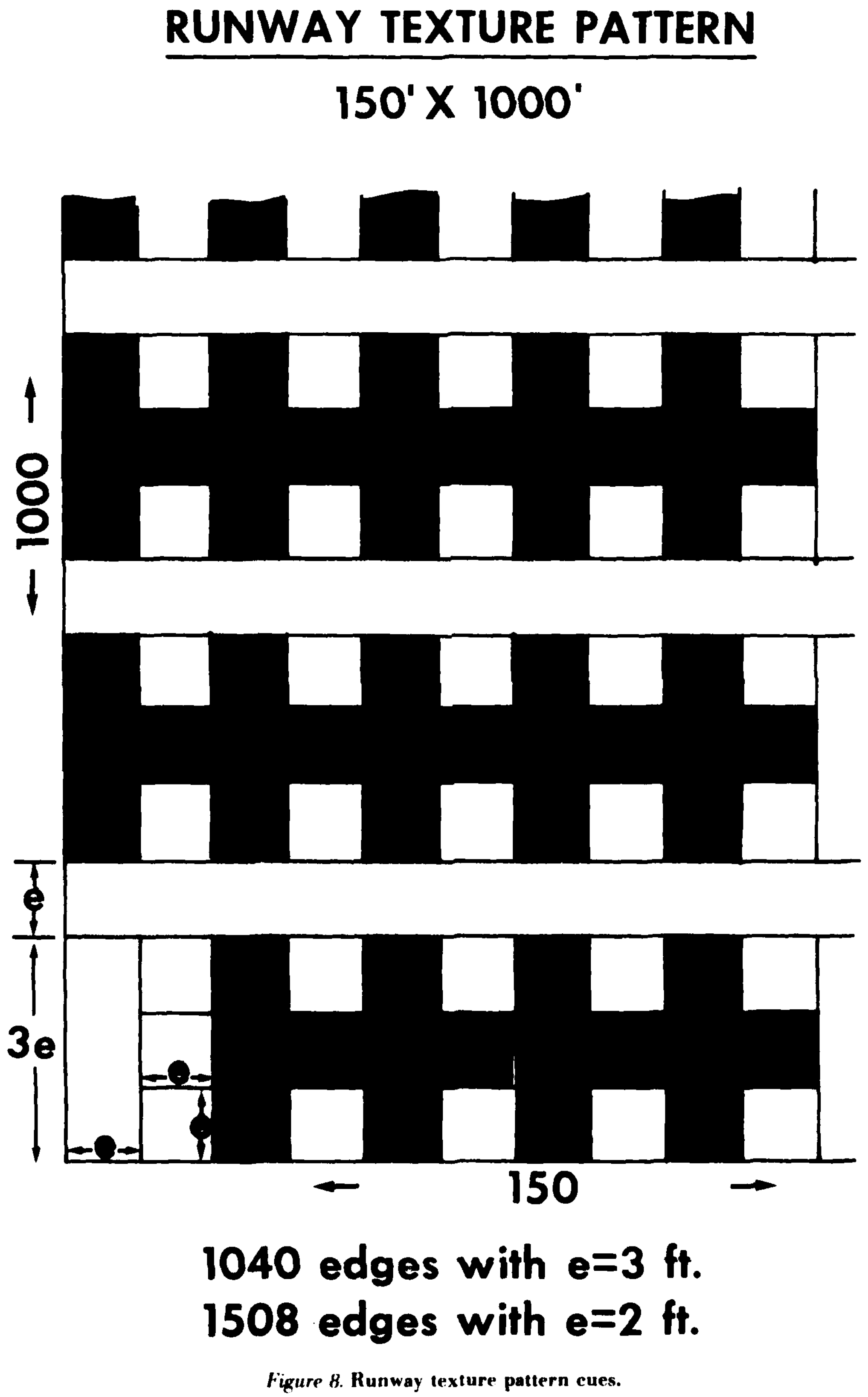

Figure 8. Runway texture pattern cues.

The other dependent measures consisted of aircraft state parameters which either represented the actual aircraft position and/or travel through space versus the ideal path used for the derived scores (RMS deviation) or else represented the pilot inputs to control the aircraft. The pilot inputs were monitored in order to look at the smoothness of pilot control. These scores are referred to as smoothness profile scores (number 18 to 22) and are computed over time at a 15-Hz rate. They measure either the amount (degrees) and force (pounds) of control movement, i.e., power, or the amount of aircraft change over time, i.e., Roll and Pitch RMS Rate. The smoothness profile scoring began with the final approach scoring and continued until touchdown.

All scoring was stopped when the aircraft touched down with greater than 50 pounds weight on wheels. The touchdown values of airspeed, heading, distance from threshold, and distance from centerline were also taken at the point of weight on wheels greater than 50 pounds. However, the vertical velocity at touchdown was taken from the sample (at 15 Hz) just before weight on wheels greater than 50 pounds was detected, since the vertical velocity rapidly approaches zero after the wheels touch the pavement. The vertical velocity figures from the actual aircraft landings were also taken from the sample just before the aircraft wheels touched the pavement. This was readily determined from the cine-theodolite photographic data.

Table 1. **Performance Measurement Data Items**

1.	Final Approach Score, %
2.	Flare Score, %
3.	Touchdown Score, %
4.	Total (Overall) Score, %
5.	Final Aproach Airspeed, Knots, RMS Deviation
6.	Final Approach Centerline, Feet, RMS Deviation
7.	Final Approach Glidepath, Degrees, RMS Deviation
8.	Flare Airspeed, Knots, RMS Deviation
9.	Flare Altitude, Feet, RMS Deviation
10.	Flare Pitch, Degrees, RMS Deviation
11.	Flare Centerline, Feet, RMS Deviation
12.	Flare Altitude, Feet, MSL at start of Flare scoring
13.	Touchdown Position from Centerline, Feet
14.	Touchdown Position from Threshold, Feet
15.	Touchdown Airspeed, Knots
16.	Touchdown Heading, Degrees
17.	Touchdown Vertical Velocity, Ft/Min
	Smoothness Profile, processed at 15 Hz:
18.	Aileron Power, Lb-Degrees/Second
19.	Roll RMS Rate, Degrees/Second
20.	Elevator Power, Lb-Degrees/Second
21.	Pitch RMS Rate, Degrees/Second
22.	Rudder Power, Lb-Degrees/Second

Overall Score 43.68

	AIRSPEED	CENTERLINE	GLIDE Path	FINAL SCORE
% HI	000000000	000000000	000000000	
% ON	000000000	100.0	41.81	000000000
% LOW	100.0	000000000	58.18	

	AIRSPEED	ALTITUDE	PITCH	CENTERLINE	FLARE SCORE
% HI	000000000	000000000	25.71	000000000	
% ON	88.57	100.0	742.8	65.71	40.00
% LOW	11.42	000000000	000000000	34.28	

	KIAS	ALT	PITCH	FINAL ERRORS	PARAMETER SET
START VALUES	95.82	1436.	.6488	000000000	.12

	KIAS	HEADING	VERT VEL	TD SCORE	TOUCHDOWN ERRORS
TOUCHDOWN VALUES	77.42	301.6	-210.3	91.06	000000000

CENTERLINE	DISTANCE
-10.04	523.6

	CENTERLINE		DISTANCE	
PRESENT VALUES	1.194	-=LEFT + =RIGHT	1805	-=SHORT OF THRESHOLD + = DISTANCE DOWN RUNWAY

Figure 9. **In-Cockpit CRT display for pilot feedback.**

Table 2. **Tolerance Values for Derived Scores**

	Base	Lower	Upper	Units
Final Approach				
Indicated Airspeed	100.0	-3.0	5.0	Knots
Centerline	0.0	-50.0	-50.0	Feet
Glidepath	3.863	-5.5	+ .55	Degrees
Flare				
Airspeed	BV[a]	-3	+ 3	Knots
Altitude	BV[b]	-13.0	13.0	Feet
Pitch	BV[c]	-3	+ 3	Degrees
Centerline	0.0	-15.0	15.0	Feet
Touchdown				
Airspeed	77.5[d]			Knots
Vertical Velocity	0.0[d]			Feet/Sec
Heading	30.2[d]			Degrees

[a]Flare Airspeed was scored as follows: BV (Airspeed) =(-1.96*t) + 98.0
t is time in seconds.
[b]Flare Altitude is scored as follows: BV (Altitude =(-5.489*t) + 1435.3
[c]Flare Pitch is scored as follows: t from 0 to 8.5 seconds, BV (Pitch) =(.78*t) - .59 and t after 8.5 seconds, BV (Pitch) = 5.5
[d]Touchdown is scored as: 100% - (2*ASD) + (.04*VV) - HD

ASD = airspeed deviation from 77.5 knots.
VV = vertical velocity at touchdown.
HD = heading absolute deviation from 302 degrees.

Procedures

The pilots were initially exposed to the simulator by giving them 15 minutes of familiarization flying in a simulated Williams AFB environment, during which time they performed a takeoff and closed pattern landing, aerobatic maneuvers, and a landing attitude stall in order to familarize themselves with the handling characteristics of the simulator. Each pilot was also given an initial training mission of 14 landings, which required landing once on each runway type with and without the overrun/TD-Zone lights. During the training mission, the pilots were instructed to execute typical landings, based upon their own judgement as instructor pilots. They were also encouraged to try to touchdown at about 500 feet from the runway threshold, without distorting their normal flare and landing. This touchdown point was in the middle of the texture pattern area. During training, the pilots were also instructed on how to use an in-cockpit CRT screen which presented a simplified version of the performance measures used for scoring the landing. Figure 9 presents a typical example of the feedback scoring for one such landing. The basic purpose of this feedback scoring was to maintain the motivation of the pilots during the 70 landings required for the experimental missions in order to encourage a consistent level of pilot performance.

Each landing required approximately 1.5 minutes from prior initialization to reinitialization after touchdown. The pilots were allowed to proceed at their own pace with rest breaks as they were required. Most of the pilots required about two 2-hour sessions on separate days in order to complete the initial training and the experimental missions in the ASPT.

Analysis

Table 1 lists the performance measures which were analyzed for this study. The basic design was a repeated measures design on all subjects. The data items were first analyzed using multivariate analysis of variance techniques (MANOVA) (Bock, 1975). A modified version of BMDX69 (Dixon, 1970) was used to perform the analyses. The multivariate analyses were selected as the appropriate omnibus test due to the intercorrelation and interdependencies of the variables measured. Stepdown univariate analysis of variance (ANOVA) (Myers, 1966) tests were then computed in order to ascertain the location of the statistically significant differences within the measurement set. Tukey tests were finally performed for investigating significant differences within specific variables between the different runway types. The criterion of a .05 probability level was used for determining statistically significant differences for the multivariate, univariate, and Tukey tests.

III. RESULTS AND DISCUSSION

The results of the MANOVAs and ANOVAs are presented in Tables 3, 4, 5, and 6. The four different MANOVA and related ANOVAs were performed in order to illustrate possible differences in the statistical results which might have been due to the particular subset of data analyzed; that is, whether the night runways were included with the daytime runways as in Table 3 or the two data sets were analyzed separately as in Tables 5 and 6. Table 4 presents the data separately analyzed either with or without the overrun/TD-Zone lights. The MANOVA for the entire data set showed statistically significant differences with probabilities of chance occurrence less than .0001 for all three independent variables: the runways, overrun/TD-Zone lights, and subjects. The ANOVAs also demonstrated significant differences for many of the data items. The pilots were significantly different on almost all data items. Typically, such differences are found between pilots due to individual style differences (Irish & Buckland, 1978). Some of the univariate differences for runway types are much easier to interpret than others.

Touchdown Segment

The most striking result, shown in Table 7, concerned aircraft vertical velocity at touchdown. Aircraft vertical velocity at touchdown is directly related to the firmness of the landing, and pilots usually try to minimize the firmness of the touchdown bump. Although the firmness of a touchdown is only one aspect of a number of parameters which are related to the quality of a particular touchdown, a major purpose of the flare is to reduce aircraft vertical velocity in a smooth fashion so that aircraft vertical velocity approaches the minimum practical level for a particular aircraft at touchdown. The optimum touchdown vertical velocity is typically much less for a small aircraft than for a large one. Thus, studies of average vertical velocities at touchdown for commercial turbojet air transports (707-type aircraft) found that the average values ranged from 96 to 114 ft/min (Stickle, 1961, 1962; Stickle & Silsby, 1960). Vertical velocity data collected on T-37 aircraft in this study resulted in an average touchdown value of 32 ft/min.

While the simulated vertical velocity was much greater than the actual aircraft vertical velocity measured at Edwards AFB, the texture patterns did produce an effect. The average vertical velocities at touchdown decreased systematically from 195 ft/min for the night runway to 147 ft/min for the 4-foot texture pattern. These values were also somewhat less than the touchdown vertical velocities reported for large aircraft simulations. Various average touchdown vertical velocities have been

Table 3. **Results of MANOVA and ANOVA Analyses**

Data Item	Runway Probability	Overrun/ TD-Zone Lights Probability	Subject Probability
Overall MANOVA (All 22 variables)	.0001[a]	.0000[a]	.0000[a]
Final Approach Score	.1046	.0004[a]	.0000[a]
Flare Score	.2361	.0460	.0000[a]
Touchdown Score	.0000[a]	.6155	.0000[a]
Total Score	.4163	.4652	.0000[a]
Final Approach			
Airspeed RMS Deviation	.1213	.8282	.0000[a]
Centerline RMS Deviation	.0417[a]	.0001[a]	.0000[a]
Glidepath RMS Deviation	.0046[a]	.0000[a]	.0000[a]
Flare Portion			
Airspeed RMS Deviation	.0206[a]	.0973	.0000[a]
Altitude RMS Deviation	.0000[a]	.4836	.0000[a]
Pitch RMS Deviation	.0000[a]	.1591	.0000[a]
Centerline RMS Deviation	.2531	.0023[a]	.0000[a]
Start of Flare Altitude	.0000[a]	.0000[a]	.0000[a]
Touchdown			
Centerline Position	.0057[a]	.0000[a]	.0000[a]
Distance from Threshold	.0000[a]	.0976	.0000[a]
Airspeed	.0000[a]	.0658	.0000[a]
Heading	.0119[a]	.8221	.0000[a]
Vertical Velocity	.0000[a]	.2814	.0000[a]
Smoothness Profile			
Aileron Power	.1216	.6440	.0000[a]
Roll RMS Rate	.0086[a]	.2401	.0000[a]
Elevator Power	.0170[a]	.1276	.0000[a]
Pitch RMS Rate	.2732	.0000[a]	.0000[a]
Rudder Power	.2171	.0481[a]	.0000[a]

[a]All variables with probabilities less than .05 are considered to have statistically significant differences within that variable for that particular data item.

Table 4. **Results of MANOVA and ANOVA Analyses with or without Overrun/TD-Zone Lights**

Variable	Runway Probability Without Overrun/ TD-Zone Lights	Runway Probability With Overrun TD-Zone Lights
Overall MANOVA (all 22 variables)	.0001[a]	.0001[a]
Final Approach Score	.2744	.0861
Flare Score	.0275[a]	.6180
Touchdown Score	.0216[a]	.0005[a]
Total Score	.0857	.2691
Final Approach		
Airspeed RMS Deviation	.7014	.0232[a]
Centerline RMS Deviation	.3396	.0005[a]
Glidepath RMS Deviation	.0262[a]	.0454[a]
Flare Portion		
Airspeed RMS Deviation	.0012[a]	.7868
Altitude RMS Deviation	.2631	.0000[a]
Pitch RMS Deviation	.0000[a]	.0000[a]
Centerline RMS Deviation	.4006	.4768
Start of Flare Altitude	.0714	.0000[a]
Touchdown		
Centerline Position	.0936	.0342[a]
Distance from Threshold	.0002	.0000[a]
Airspeed	.0000[a]	.0000[a]
Heading	.0222[a]	.1052
Vertical Velocity	.0000[a]	.0873
Smoothness Profile		
Aileron Power	.2538	.3999
Roll RMS Rate	.3099	.0026[a]
Elevator Power	.1313	.0770
Pitch RMS Rate	.3694	.8790
Rudder Power	.3787	.4985

Note. — All subject probabilities were $p < .0004$ or less. Most were $p < .0000$.

[a] All variables with probabilities less than .05 are considered to have statistically significant differences within that variable for that particular data item.

Table 5. **Results of MANOVA and ANOVA Analyses on Daytime Runways Only**

Variable	Runway Probability	Overrun Probability	Subject Probability
Overall MANOVA (All 22 variables)	.0000[a]	.0000[a]	.0000[a]
Final Approach Score	.3204	.0035[a]	.0000[a]
Flare Score	.3794	.0042[a]	.0000[a]
Touchdown Score	.0000[a]	.7464	.0000[a]
Total Score	.3035	.7968	.0000[a]
Final Approach			
Airspeed RMS Deviation	.2059	.8550	.0000[a]
Centerline RMS Deviation	.1383	.0000[a]	.0000[a]
Glidepath RMS Deviation	.0491[a]	.0003[a]	.0000[a]
Flare Portion			
Airspeed RMS Deviation	.5823	.0200[a]	.0000[a]
Altitude RMS Deviation	.1314	.1361	.0000[a]
Pitch RMS Deviation	.0000[a]	.0219[a]	.0000[a]
Centerline RMS Deviation	.2302	.0163[a]	.0000[a]
Start of Flare Altitude	.2062	.0000[a]	.0000[a]
Touchdown			
Centerline Position	.0310[a]	.0000[a]	.0000[a]
Distance from Threshold	.0000[a]	.0167[a]	.0000[a]
Airspeed	.0001[a]	.1921	.0000[a]
Heading	.0176[a]	.4611	.0000[a]
Vertical Velocity	.0000[a]	.1170	.0000[a]
Smoothness Profile			
Aileron Power	.2891	.7434	.0000[a]
Roll RMS Rate	.2620	.0993	.0000[a]
Elevator Power	.0261[a]	.0654	.0000[a]
Pitch RMS Rate	.4083	.0000[a]	.0000[a]
Rudder Power	.2349	.0310[a]	.0000[a]

[a]All variables with probabilities less than .05 are considered to have statistically significant differences within that variable for that particular data item.

Table 6. **Results of MANOVA and ANOVA Analyses for Nighttime Runway Only**

Variable	TD-Zone Lights Probability	Subjects
Overall MANOVA (all 22 variables)	.0001[a]	.0000[a]
Final Approach Score	.0284[a]	.0000[a]
Flare Score	.0395[a]	.0000[a]
Touchdown Score	.5208	.0398[a]
Total Score	.0113[a]	.0000[a]
Final Approach		
Airspeed RMS Deviation	.2997	.0000[a]
Centerline RMS Deviation	.1468	.0000[a]
Glidepath RMS Deviation	.0219[a]	.0000[a]
Flare Portion		
Airspeed RMS Deviation	.1382	.0061[a]
Altitude RMS Deviation	.2934	.0007[a]
Pitch RMS Deviation	.0154[a]	.0000[a]
Centerline RMS Deviation	.0266[a]	.0011[a]
Start of Flare Altitude	.7715	.0004[a]
Touchdown		
Centerline Position	.0024[a]	.0002[a]
Distance from Threshold	.0643	.0001[a]
Airspeed	.0924	.0000[a]
Heading	.0086[a]	.0218[a]
Vertical Velocity	.1685	.5052
Smoothness Profile		
Aileron Power	.6999	.0002[a]
Roll RMS Rate	.3193	.0001[a]
Elevator Power	.7835	.0309[a]
Pitch RMS Rate	.1056	.0012[a]
Rudder Power	.5763	.1206

[a]All variables with probabilities less than .05 are considered to have statistically significant differences within that variable for that particular data item.

Table 7. **Vertical Velocity (Ft/Min, a Negative Value) at Touchdown**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	201	190	195
Bare Bones	195	171	183
Willie	172	179	175
25 Ft Texture	168	168	168
16 Ft Texture	158	173	165
8 Ft Texture	151	170	161
4 Ft Texture	136	158	147

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	*	*	*	*
Bare Bones		NS	NS	NS	*	*
Willie			NS	NS	NS	*
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

Note. — Averaged Vertical Velocity of actual aircraft at touchdown was 32 ft/min, based on Edwards Flight Test Center Cine-Theodolite Tracking of T-37 (74 landings)

* — Statistically significantly different at .05 level.

NS — Not significantly different.

reported for transport visual flight simulators, ranging from 216 to 258 ft/min (Chase, 1971) to 510 to 960 ft/min (Crane, 1962).

The second variable of the overrun/TD-Zone lights appeared to disrupt the linear decrease in touchdown vertical velocity. Without the overrun, the linear trend in decreasing vertical velocity at touchdown was apparent. With the overrun present, the range of touchdown vertical velocities was reduced, and the linear decrease in vertical velocity was disrupted. There was no readily apparent statistical interaction between the runway overrun and texture patterns. The presence of the overrun appeared to make performance on all the runways more similar, apparently somewhat offsetting the influence of the texture patterns on the runway.

However, the separate analyses performed on the data with or without the overrun/TD-Zone light variable still showed several significant differences under both conditions. Table 4 shows the results of these analyses. Although there are some differences in the pattern of significant differences between the two conditions, all but two differences fall within the overall pattern of statistically significant differences shown in Table 3 for the combined data. The two additional significant differences are the flare score without the overrun/TD-Zone lights ($p < 0275$) and the final approach airspeed RMS deviation with the overrun/TD-Zone lights.

Tukey tests were performed at the .05 level to compare statistical differences between individual runways for the touchdown vertical velocity. Table 7 also displays the pattern of Tukey test differences which was found for vertical velocity at touchdown. In general, if a runway is compared to the next most similar runway, as they are arranged in Table 7, it was not statistically significantly different. However, runway types which were two or three types removed from each other were significantly different. Thus, the average performance differences from one level of texture to another were not sufficient to be significantly different, due to the variability of the data. However, there was a readily apparent trend in the decreasing vertical velocity at touchdown from the night runway to the most highly textured (4-foot) daytime runway.

While there were significant differences for several of the other data parameters, the interpretation of the differences is not as clear as it is for the aircraft vertical velocity at touchdown. Consistent trends which varied along an apparent dimension of runway texturing did not appear. For example, the touchdown score, which was a composite or derived score based upon touchdown vertical velocity, airspeed, and heading, showed statistically significant differences across runway types ($p < .0000$). However, the Tukey tests of touchdown vertical velocity indicated that only the score from the Bare Bones runway was significantly different from those of other runway types. Table 8 shows the touchdown scores for the different runway conditions. The score on the Bare Bones runway was lower than the scores for the other runways. Apparently the combination of high airspeed and vertical velocity at touchdown significantly lowered the touchdown scores for the Bare Bones runway versus the other runways. Table 9 shows the airspeed values at touchdown for the various experimental conditions. While the night runway produced the highest vertical velocities at touchdown, the airspeeds were significantly lower at touchdown. Table 10 presents the data on heading at touchdown. Both the night and the Bare Bones runways produced touchdown headings closer to the ideal heading of 302 degrees; however, this effect was apparently not large enough to greatly influence the touchdown scores for the two runway types.

The position of the aircraft relative to the centerline at touchdown also showed significant differences across runway types. This effect is shown in Table 11. In general, the pilots were more accurate in positioning the aircraft on the runway centerline of the more textured runways. The distance from the runway threshold to aircraft touchdown also showed significant differences across runway types. Table 12 shows the average values for the runway types and illustrates the pattern of significant differences from the Tukey tests. There was a tendency to touch down sooner, i.e., closer to the runway threshold, for the Bare Bones runway, and farther from the threshold for the night runway.

Flare Segment

Although the night runway landings were slightly farther down the runway than the day landings, the start of flare altitude (1000 feet from runway threshold) was slightly higher. Table 13 shows the average start of flare altitudes. The primary difference found by the Tukey tests was between the night and the day runways.

Three of the four measures on the flare segment were statistically significantly different for the average scores; the RMS deviation scores for airspeed ($p < .0206$), altitude ($p < .0000$), and pitch ($p < .0000$). Tables 14, 15, and 16 show the average values and Tukey test results for these RMS measures. The flare section centerline RMS deviation was not statistically significantly different across runway types.

Table 8. **Touchdown Score (%)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	86.6	87.2	86.9
Bare Bones	83.4	82.4	82.9
Willie	84.9	85.9	85.4
25 Ft Texture	86.1	86.1	86.1
16 Ft Texture	87.3	86.4	86.8
8 Ft Texture	85.3	86.1	85.7
4 Ft Texture	85.0	86.0	85.5

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	*	NS	NS	NS	NS	NS
Bare Bones		*	*	*	*	*
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 9. **Touchdown Airspeed (Knots)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	78.4	77.5	78.0
Bare Bones	81.3	82.0	81.7
Willie	80.8	79.8	80.3
25 Ft Texture	79.5	80.1	79.8
16 Ft Texture	79.9	79.7	79.8
8 Ft Texture	81.0	80.3	80.6
4 Ft Texture	81.4	80.3	80.9

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	*	*	*	*	*	*
Bare Bones		*	*	*	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 10. **Heading at Touchdown**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	302.0	301.7	301.9
Bare Bones	301.9	302.0	301.9
Willie	301.7	301.6	301.7
25 Ft Texture	301.8	301.8	301.8
16 Ft Texture	301.8	301.9	301.8
8 Ft Texture	301.7	301.8	301.8
4 Ft Texture	301.6	301.7	301.7

[a]ANOVA $p < .119$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	NS	NS	NS	NS
Bare Bones		NS	NS	NS	NS	*
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 11. **Centerline Position (Feet) at Touchdown**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	-3.63	-5.27	-4.45
Bare Bones	-3.45	-5.41	-4.43
Willie	-3.40	-3.20	-3.30
25 Ft Texture	-2.94	-4.96	-3.95
16 Ft Texture	-3.16	-4.39	-3.77
8 Ft Texture	-2.12	-4.00	-3.06
4 Ft Texture	-1.89	-3.68	-2.79

[a]ANOVA $p < .0057$. for Average Data. negative values are to the left of runway centerline.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	NS	NS	NS	*
Bare Bones		NS	NS	NS	NS	*
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 12. Distance from Threshold (Feet) at Touchdown

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	573.2	619.5	596.3
Bare Bones	476.4	419.7	448.0
Willie	534.8	536.3	535.6
25 Ft Texture	604.2	558.3	581.3
16 Ft Texture	575.3	547.4	561.4
8 Ft Texture	498.1	505.9	502.0
4 Ft Texture	549.8	498.8	524.3

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	*	*	NS	NS	*	*
Bare Bones		*	*	*	NS	*
Willie			NS	NS	NS	NS
			NS			
25 Ft Texture				NS	*	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 13. **Start of Flare Altitude (Feet)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	1449.2	1448.5	1448.8
Bare Bones	1446.8	1439.7	1443.2
Willie	1448.3	1440.1	1444.2
25 Ft Texture	1447.2	1440.0	1443.6
16 Ft Texture	1449.2	1441.1	1445.2
8 Ft Texture	1444.9	1440.5	1442.7
4 Ft Texture	1445.0	1440.0	1442.5

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	*	*	*	NS	*	*
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 14. **Flare Airspeed RMS Deviation**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	2.16	2.59	2.37
Bare Bones	2.74	2.88	2.81
Willie	3.00	2.85	2.92
25 Ft Texture	3.18	3.00	3.09
16 Ft Texture	3.12	2.76	2.94
8 Ft Texture	2.92	2.64	2.78
4 Ft Texture	3.61	2.61	3.11

[a]ANOVA $p < .0206$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	*	NS	NS	*
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 15. **Flare Altitude RMS Deviation (Feet)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	9.20	10.20	9.72
Bare Bones	8.1[illegible]	8.90	8.55
Willie	[illegible].31	7.8[illegible]	8.10
25 Ft Texture	7.85	7.38	7.62
16 Ft Texture	8.60	7.65	8.12
8 Ft Texture	7.99	7.80	7.89
4 Ft Texture	8.75	8.14	8.44

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	*	*	*	*	*
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.

NS Not significantly different.

Table 16. **Flare Pitch RMS Deviation**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	4.28	4.84	4.56
Bare Bones	3.07	2.58	2.82
Willie	3.64	3.50	3.57
25 Ft Texture	4.24	3.69	3.97
16 Ft Texture	3.96	3.89	3.93
8 Ft Texture	3.22	3.34	3.28
4 Ft Texture	3.70	3.26	3.48

[a]ANOVA $p < .0000$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	*	*	*	*	*	*
Bare Bones		*	*	*	NS	*
Willie			NS	NS	NS	NS
25 Ft Texture				NS	*	NS
16 Ft Texture					*	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

The main differences for the flare airspeed RMS deviation seem to lie between performance on the night runway versus the other runways, with the RMS deviation being lower for the night runway. Apparently the pilots maintained airspeeds for the night runways which were closer to the "ideal" flare airspeed profile. This findings is in agreement with the lower airspeeds for aircraft touchdown at night shown in Table 9. The night runway touchdown airspeeds were significantly lower than those for the other runways, while the Bare Bones touchdown airspeeds were statistically significantly higher at touchdown.

Table 15 shows that the RMS deviation from the "ideal" flare altitude profile was greater for the night runway. The Tukey tests results indicate that this was the primary significant difference for this variable. This result is in agreement with the data for the start of flare altitude (see Table 14) which indicated that the pilots were higher at the start of flare for the night runway scene.

The results for flare pitch RMS deviation are presented in Table 16. Apparently the flare pitch RMS deviation from the "ideal" flare pitch profile was larger for the night runway and smaller for the Bare Bones runway versus the other daytime runways. The results of the Tukey tests indicate that both the night and the Bare Bones runways were statistically significantly different from each other and from the other runways in this regard.

The derived flare score was not significantly different across runway types on the average; however, it was significantly different when the scores were analyzed for only the data without the overrun/TD-Zone lights. Table 17 shows the average values for these data. Apparently the flare scoring was influenced by the runway types without the presence of the overrun, but the presence of the overrun/TD-Zone lights produced more homogeneous scores, in a fashion which was similar to the influence of the overrun on vertical velocity at touchdown. The only significant difference for the landings without the overrun/TD-Zone lights, which was demonstrated by the Tukey tests, was between the night and the 1-foot texture patterns. In this no-lights condition, the texture patterns apparently produced poorer flare scores. Most of the pilots indicated dissatisfaction with the flare scoring. Consequently, they were instructed to execute their flares and landings according to their own best judgement and ignore the flare scoring, because it was only an initial attempt at scoring flare performance.

Final Approach Segment

Performance differences were also found in the final approach segment for the centerline ($p <$ .0474) and glidepath ($p <$.0040) RMS deviations. The average scores and Tukey test results for the centerline RMS deviations are shown in Table 18. There appears to be slightly greater centerline deviation for the night runway, especially when the night runway was compared to the Bare Bones, Willie, and 8-foot textured runways. None of the Tukey test results were significantly different, apparently because the Tukey test is more statistically conservative than the overall ANOVA. The average values and Tukey test results for the final approach glidepath RMS deviation are shown in Table 19. Again, the main differences appeared to be between the night runway and the daytime runways. Average values for the final approach airspeed RMS deviation were only statistically significantly different ($p <$.0232) for the runways with the overrun/TD-Zone lights. The average values and Tukey test results are shown in Table 20.

Only two of five smoothness profile measures, roll RMS rate and elevator power, differed significantly across runway types. The roll RMS rate data are shown in Table 21. The primary difference was between the night runway and the daytime visual scenes. The elevator power data, shown in Table 22, also indicate a slight increase in control activity for the night runway. Like the

Table 17. **Flare Scores (%)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	52.4	42.1	47.3
Bare Bones	43.8	47.7	45.8
Willie	42.3	45.0	43.6
25 Ft Texture	38.6	40.5	39.6
16 Ft Texture	36.0	44.7	40.4
8 Ft Texture	41.3	50.1	45.7
4 Ft Texture	33.3	46.7	40.0

[a]ANOVA $p < .0275$ for data Without Overrun/TD-Zone lights.

Results of Tukey Tests — (Without Overrun/TD-Zone lights)

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	NS	NS	NS	*
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 18. **Final Approach Centerline RMS Deviation (Feet)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	18.0	20.4	19.2
Bare Bones	18.2	14.1	16.1
Willie	18.3	14.8	16.6
25 Ft Texture	19.4	16.7	18.1
16 Ft Texture	21.5	15.7	18.6
8 Ft Texture	18.0	15.4	16.7
4 Ft Texture	18.6	17.5	18.1

[a]ANOVA $p < .0417$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	NS	NS	NS	NS
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 19. **Final Approach Glide Path RMS Deviation (Degrees)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	.354	.477	.416
Bare Bones	.316	.432	.374
Willie	.297	.371	.334
25 Ft Texture	.306	.338	.322
16 Ft Texture	.252	.379	.315
8 Ft Texture	.334	.339	.337
4 Ft Texture	.383	.407	.395

[a] ANOVA $p < .0046$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	*	*	NS	NS
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 20. **Final Approach Airspeed (Knots) RMS Deviation**

ASPT Simulated Visual Scene	*Without* Overrun/ TD-Zone Lights	*With* Overrun/ TD-Zone Lights	Average[a]
Night	1.43	1.63	1.53
Bare Bones	1.35	1.62	1.49
Willie	1.50	1.40	1.45
25 Ft Texture	1.34	1.04	1.19
16 Ft Texture	1.27	1.41	1.34
8 Ft Texture	1.19	1.29	1.24
4 Ft Texture	1.49	1.29	1.39

[a] ANOVA $p < .0232$ for data with the Overrun/TD-Zone Lights.

Results of Tukey Tests - (With Overrun/TD-Zone Lights)

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	NS	NS	NS	NS	NS
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 21. **Roll RMS Rate (Degrees/Second)**

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	1.46	1.54	1.50
Bare Bones	1.37	1.32	1.34
Willie	1.32	1.31	1.32
25 Ft Texture	1.31	1.40	1.36
16 Ft Texture	1.50	1.36	1.43
8 Ft Texture	1.38	1.36	1.37
4 Ft Texture	1.39	1.18	1.28

[a]ANOVA $p < .0086$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	*	NS	NS	NS	*
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

Table 22. Elevator Power (Pounds-Degrees/Second)

ASPT Simulated Visual Scene	Without Overrun/ TD-Zone Lights	With Overrun/ TD-Zone Lights	Average[a]
Night	1.12	1.01	1.07
Bare Bones	.70	.57	.64
Willie	.56	.56	.56
25 Ft Texture	1.23	.67	.95
16 Ft Texture	.77	.78	.78
8 Ft Texture	.87	.69	.78
4 Ft Texture	1 .60	.66	.63

[a]ANOVA $p < .0170$.

Results of Tukey Tests

	Bare Bones	Willie	25 Ft Texture	16 Ft Texture	8 Ft Texture	4 Ft Texture
Night	NS	*	NS	NS	NS	NS
Bare Bones		NS	NS	NS	NS	NS
Willie			NS	NS	NS	NS
25 Ft Texture				NS	NS	NS
16 Ft Texture					NS	NS
8 Ft Texture						NS

* Statistically significantly different at .05 level.
NS Not significantly different.

roll RMS rate data, the primary differences in the elevator power data are between the night and the daytime runways. These night versus daytime differences are in agreement with the similar differences found for the final approach centerline and glidepath deviations. The night visual scene was more panoramic in terms of the point lights on the ground and most of the pilots expressed a preference for the night scene because of the more distributed visual scene. Possibly the night scene provided better cues for initial manual course corrections than the day scenes, resulting in more control activity and greater centerline and glidepath RMS deviations.

The presence or absence of the TD-Zone lights produced some effects on the night runway performance; however, these effects were not in the expected direction. The data items which were statistically significantly different are shown in Table 6. The average for these data items are shown in Table 23. Tukey tests were not employed because there were only two levels for this variable. In comparing the average differences for the eight significantly different variables, the performance was consistently better for the night runway without the TD-Zone lights. The final approach, flare, and total scores were higher without the TD-Zone lights. The RMS deviations for the final approach glidepath, flare pitch, and flare centerline were smaller, and thus better, for the night scene without the TD-Zone lights. The average distance from the centerline at touchdown was smaller or better for the scene without the TD-Zone lights. The aircraft heading at touchdown was also closer to the ideal of 302 degrees for the scene without TD-Zone lights. It was anticipated that the TD-Zone lights would provide additional runway texturing and thereby produce effects similar to the texturing of the day runways. However, although this variable did produce lower average vertical velocity at touchdown, the effect was not statistically significantly different. The only statistically significant effects indicated poorer performance during the final approach, flare, and landing when the TD-Zone lights were present.

Table 23. **Significantly Different Variable Averages for Night Runway with and without TD-Zone Lights**

Variable	Without TD-Zone Lights	With TD-Zone Lights
Final Approach Score (%)	80.1	69.2
Flare Score (%)	52.4	42.1
Total Score (%)	73.0	66.2
Final Approach		
Glidepath RMS Deviation (Degrees)	.354	.477
Flare Portion		
Pitch RMS Deviation (Degrees)	4.28	4.84
Centerline RMS Deviation (Feet)	6.39	8.26
Touchdown		
Centerline Position (Feet)	-3.63	-5.27
Heading (Degrees)	302.0	301.7

The presence or absence of the runway overrun produced many statistically significant effects on the daytime runways, as shown in Table 5. Table 24 contains the average values for the statistically significant data items. There is no clear pattern in the significant differences which were found. For example, the final approach score was better without the overrun, but the flare score was better with the overrun. The final approach centerline RMS deviation was better with the overrun, but the glidepath RMS deviation was better without the overrun. The flare RMS deviations for airspeed and pitch were better with the overrun, but the centerline RMS deviation was better without the overrun. The touchdown centerline position was better without the overrun, but the distance from the threshold was closer to the requested touchdown point with the overrun. The pitch RMS rate was slightly better with the overrun, but the rudder power was slightly better without the overrun. Thus, the individual effects produced by the overrun variable were equivocal at best. However, while the overrun did not produce a statistically significant effect on the vertical velocity at touchdown, it did influence the range of the vertical velocities that were produced by the different runway textures. Table 7 shows this effect. Apparently the presence of the overrun restricted the range of vertical velocities produced by the texture patterns. Possibly the pilots did not use the visual texture pattern information as much when an overrun was present.

Table 24. **Significantly Different Variable Averages for Daytime Runways with and without Runway Overrun**

Variable	Without Overrun	With Overrun
Final Approach Score (%)	83.3	77.4
Flare Score (%)	39.2	45.8
Final Approach		
Centerline RMS Deviation (Feet)	19.0	15.7
Glidepath RMS Deviation (Degrees)	.32	.38
Flare Portion		
Airspeed RMS Deviation (Knots)	3.10	2.79
Pitch RMS Deviation (Degrees)	3.64	3.38
Centerline RMS Deviation (Feet)	7.33	8.17
Start of Flare Altitude (Feet)	1,446.9	1,440.2
Touchdown		
Centerline Position (Feet)	-2.83	-4.27
Distance from Threshold (Feet)	539.8	511.1
Smoothness Profile		
Pitch RMS Rate (Degrees/Second)	.74	.70
Rudder Power (Lb-Degrees/Second)	.006	.010

IV. CONCLUSIONS

The primary effect of the runway texture patterns was observed on the aircraft vertical velocity at touchdown. This parameter is the primary indicator of touchdown firmness, and pilots typically try to minimize the firmness of the touchdown bump. Thus, vertical velocity is a good indicator of the pilots' ability to detect and thus control their rate of closure with the runway. Although the runway texture patterns did not produce vertical velocities as low as those in the actual aircraft, they did influence the touchdown vertical velocities in a consistent manner. The addition of the texture patterns did systematically reduce the simulated aircraft vertical velocity at touchdown from 201 ft/min for the night runway to 136 ft/min for the 4-foot texture pattern. The presence of the TD-Zone lights in the night runway reduced the vertical velocity at touchdown, in a fashion similar to the texture patterns on the daytime runways. However, this effect was not statistically significant.

The overrun with its chevron markings also provided a visual textural cue, which appeared to provide an alternate textural cue to the runway patterns. The presence of the overrun compressed the range of the touchdown vertical velocities across runway types, reducing the size of the differences between runways. Apparently there was a tendency for the pilots to use primarily the overrun visual cues when they were present and not to use the runway texture patterns. Thus, average touchdown vertical velocities for the Bare Bones runway were lower when the overrun was used; whereas, the average touchdown vertical velocities for the 4-foot textured runway were higher when the overrun was used.

All of the simulated landings produced vertical velocities which were much higher than those measured for the actual T-37 aircraft, using the same pilots, at the Air Force Flight Test Center. Thus, the visual texture cues, the texture patterns and the runway overrun, which were used for this study did not eliminate the problem of excessive vertical velocity at touchdown in flight simulators. While these visual texture cues did influence and systematically reduce simulated aircraft vertical velocity at touchdown, it appears that other visual cues were still missing, possibly including other textural cues. One cue which was eliminated on purpose was vertical object cues near the runway. This was done in order to control for this possible conflicting variable. That is, the pilots might have used such vertical object cues for some runway types, but not for other runways. Pilots typically use the best cues available for any particular flying task, with the use of particular environmental information cues varying according to which cues are available. Further studies of visual cue requirements for landing simulators should definitely test the efficacy of vertical object cues.

An additional area for visual textural cues might be along the sides of the runway. Pilots typically report that they do not look at the runway immediately in front of them during the landing; rather, they look at the end of the runway and the horizon. Harris, Waller, and Salmirs (1978) reported in a study using the Langley Research Center occulometer that when pilots were using a heads-down cathode ray tube approach and landing display, they generally did look close to the horizon during the flare. Thus, it is possible that pilots are using peripheral vision cues to monitor forward motion and vertical motion (vertical velocity) during the aircraft flare. Harris et al. (1978) also used checkerboard patterns either on the runway or external to the runway. These patterns were either 38 (124.7 ft), 76 (249.3 ft), or 152 (498.7 ft) meters on a side on the runway or 228 (748 ft) meters on a side external to the runway. These checkerboard patterns were thus much larger than the textural patterns used in the current study. Harris et al. (1978) reported that the checkerboard patterns on the runway produced a slight improvement in touchdown performance and an increase in the number of column control inputs. The checkerboard patterns external to the runway did not improve performance. In fact, the "touchdown performance vertical speed and airspeed without the fields was somewhat more indicative of a flare," and Harris et al. (1978)

concluded that "the addition of external fields are not conducive to good flare and landing performance with this display." Thus, based upon Harris' use of relatively large external checkerboard patterns, questions regarding the utility of visual textural cues external to the runway itself are still open to further research. Perhaps smaller checkerboard patterns would be more useful than the large patterns used by Harris.

The influence of the different runway types on the other data parameters which were analyzed was not as obvious. The most wide-spread differences occurred between the night runway scene and the daytime runways. The widespread and somewhat pervasive differences found between the night and the daytime runways provide some factual data to support the concept that pilots do employ somewhat different techniques for landing at night. This possible difference between pilot landing techniques for night versus day scenes should be investigated further since many flight simulators are now starting to use night-only visual simulation systems for pilot training. This day/night difference may be difficult to find in pilot training now, due to the general inadequacy of visual flight simulators for training flare and touchdown. However, it may be more important for future flying training as the visual scenes are improved, and they are actively used for training the flare and landing.

The use of simulated texture patterns on the runway touchdown zone area did improve pilot performance in terms of vertical velocity (sink rate) at touchdown. This variable alone was not sufficient to produce touchdown vertical velocities in the range of actual aircraft performance, and the edge capacity of our current system did not permit us to study other visual cues at the same time. It will probably be necessary to improve the visual texture cues as well as the other typical visual cues, which are used in flight simulators, in order to solve the general problem of excessive vertical velocity at touchdown. Such other visual cues, which will be investigated in later studies, concern vertical object cues near the runway, textural cues adjacent to the runway and depth cues related to collimated image techniques.

V. SUMMARY

The effects of seven different runway types were investigated on pilot performance during landings in a T-37 flight simulator. Data were also gathered on six of the same 12 pilots during actual T-37 aircraft landings at the Air Force Flight Test Center. The seven simulated runways consisted of one night runway and six day runways with varying amounts of textural information cues on the runway touchdown zone area. The night runway was also tested with and without TD-Zone landing lights and the day runways were tested with and without the runway overrun. The simulated aircraft average vertical velocity at touchdown decreased systematically from 201 ft/min for the night runway without the TD-Zone lights to 136 ft/min for the day runway with 4-foot texture patterns. The day runways alone without the overrun, varied from 195 ft/min for the Bare Bones runway to 136 ft/min for the 4-foot texture pattern. Although these average vertical velocities were still much higher than those recorded in the actual aircraft (32 ft/min), the texture patterns did influence the pilot flare and touchdown in a systematic manner. Additional visual cues probably would have reduced the vertical velocities even more, but the limited edge capacity of the CIG scene used here did not permit a study of other visual cues while investigating texture patterns. The presence of the TD-Zone lights in the night scene also reduced the average vertical velocity at touchdown (190 ft/min), but this difference was not statistically significant. The presence of the runway overruns on the daytime runways limited the overall range of touchdown vertical velocities to a smaller range, spanning from 176 ft/min for the Willie runway to 158 ft/min for the 4-foot textured runway. When the overrun was present, apparently, the pilots used the overrun visual cues, the chevron texture patterns and other related cues, in addition to the runway texture patterns in order to perform the flare and touchdown. This resulted in reduced overall touchdown vertical velocities, but apparently the more uniform pilot performances (restricted range) did not involve an optimum use of the 4-foot texture patterns. Several other data parameters also varied across runway types; however there were no consistent differences related to runway texture patterns. The significant effects with the other data parameters were most often related to differences between the night and the day runway scenes.

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SUPPLEMENTARY

INFORMATION

AD-A089434

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Errata

16 JAN 1981

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Wendell L Anderson

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