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TEST OF GLIDE SLOPE GUIDANCE WITH AND WITHOUT SIMPLIFIED ABBREVIATED VISUAL APPROACH SLOPE INDICATOR

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16. Abstract

In a flight test at a small airport, rectangular aiming-point markings with and without the additional use of a low-cost version of the red/white simplified abbreviated visual approach slope indicator (SAVASI) served as daytime approach guidance aids. Results showed that approaches made with the SAVASI were less variable in measured approach slope, and approaches made in the last half-mile before landing were nearer the 4° SAVASI glidepath angle. On average, approaches made either with or without the SAVASI were steeper than 4°, and tracking of itinerant aircraft not informed of the testing confirmed that the usual approach for small aircraft at this runway was in the 5° to 6° range. This indicates that future installations of SAVASI or related guidance aids should be made after measuring the normal practice at a given airport. Test pilot opinion was that the SAVASI was easy to use and provided good guidance in the vertical plane and that the rectangular aiming-point markings were beneficial.

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INTRODUCTION

PURPOSE.

The purpose of this activity was to determine the effectiveness of painted aiming-point markings as installed at Ocean City, New Jersey, and the effect of the additional use of the low-cost simplified abbreviated visual approach slope indicator (SAVASI) as a visual flight rules (VFR) approach aid. This test was intended to contribute toward the goal of establishing minimum accuracies necessary for an effective glide slope guidance aid for secondary airports.

BACKGROUND.

The Ocean City system, featuring rectangular aiming-point markings and the SAVASI glide slope guidance aid, was installed and evaluated favorably by pilot opinion in 1970, see reference 1. SAVASI, the simplified abbreviated VASI, also called the "2-Box VASI" and AVASI (abbreviated VASI) was developed as a low-cost version of the standard VASI by using two boxes with a single lamp in each.

Federal Aviation Administration (FAA) Advisory Circulars, references 2 and 3, provide further details and recommend the SAVASI for utility airports having limited power, for glide slope guidance above hazardous objects, for environments where visual reference information is lacking or deceptive, and to effect a reduction in the probability of undershoots and overshoots.

The rectangular aiming-point markings as installed at Ocean City are analogous to the 1,000-foot fixed-distance aiming-point markings used for all-weather instrument runways and short takeoff and landing (STOL) airports.

After VASI was adopted as a national standard and red/white systems were approved by the International Civil Aviation Organization (ICAO) for major airports, and while related red/white systems were recommended for secondary or utility airports, other guidance concepts not based on red/white systems were advanced. In the past, a number of flight tests have been conducted using two-color, tricolor, and flashing-color systems. The various Navy systems for aircraft carriers have been tested with civil aircraft, and specially proportioned markings and shapes of light patterns have been examined. Later paragraphs of this report will refer to reports of these tests, but first, two main points should be made. Standardization of the red/white system for glide slope guidance and international adoption of that standard came only after a major series of tests and comparisons. Variation from that widely approved standard system should not be supported unless there is demonstration of a significant advantage in safety or efficiency. A second general point to be considered is that quantitative information on the effectiveness of the red/white systems should be published. Thus, it is necessary to measure the quality of approaches made with the various recommended red/white systems so that new systems that are proposed may be compared to factual information on the standard aids. If a newly proposed and previously untested glide slope guidance aid is offered, the quality of approaches attained with its use should be compared to published performance with the red/white system most comparable in cost. In this way, it would be determined objectively whether a definite and important advantage exists.

At about the time that the red/white system was advocated by United Kingdom authorities for adoption as an international standard, two broad studies of visual cues and glide slope guidance aids were published, see references 4 and 5. Lane and Cumming examined the role of visual cues in final approach to landing and argued in 1956 that approaches should be tracked using an aiming point marked on the runway and that glidepath aids such as the Royal Air Force tricolor system and the several Navy light systems should be evaluated. Two years later, Cumming published his report describing the precision visual glidepath (PVG), also known as the double-bar ground aid or the Cumming-Lane device, see reference 6. The FAA then conducted an extensive series of tests comparing the chief candidate systems, see reference 5. A wide cross section of pilots participated, and aircraft from a Piper Tri-Pacer to a Boeing 707 were employed. The result was that the Cumming-Lane and the red/white system proposed by the Royal Aircraft Establishment emerged as the systems selected for continuing evaluation. That evaluation resulted in excellent approach performance with both systems; still a choice of a standard had to be made. Hence, it was recommended that the red/white VASI be adopted as a United States (U.S.) standard, and this was done. Later, the same system was adopted by ICAO as an international standard, and it has functioned in the United States and abroad for some years.

Special models, such as the SAVASI, were developed for small airports lacking the resources to support a full VASI, or for runways having special obstacle avoidance or noise abatement problems, or catering to classes of aircraft such as STOL aircraft with special approach characteristics. In several of these cases, there were other candidate systems in addition to a variant of the red/white VASI, see reference 7. After testing, however, the various adaptations of the red/white system proved to be recommended for adoption for small airports. The 1967 evaluation of a variety of low-cost glide slope guidance techniques produced the conclusion that except for the red/white VASI, all those systems tested could produce misleading and possibly hazardous information under certain conditions, and none had a useful daytime range, see reference 8. Further evolution of the red/white system was reported in the 1973 outline of work accomplished on the VASI for the newer long-bodied aircraft and in development of the visual approach multiple slope indicator (VAMSI) which defined two separate approach paths for terrain or other conditions requiring a multiple-angle approach path, see reference 9.

Meanwhile, two flight tests were conducted at pilot training schools with low-cost red/white systems. At Opa-Locka, Florida, a VASI was installed with a 4° aim. Instructors using the 3,500-foot runway with small, single-engine aircraft requested that the aim be raised to 5°. This was done, and the red/white system was found to be useable for student training. At Mangham Airport near Fort Worth, Texas, another low-cost VASI was installed at a 2,500-foot runway with obstacle clearance problems at both ends. That VASI was aimed at 6°, and it appeared that the VASI aided the student pilots, see reference 9.

With these studies as background, the prevailing view at the start of the present test was that a VASI for small, general aviation aircraft use should be aimed in accordance with local approach zone conditions, with 3° the most shallow alternative and an angle near 6° the maximum when required by obstructions on the approach path. Since the Ocean City Airport has an almost clear approach zone out about 1,200 or 1,300 feet, it appeared to present a situation that would be compatible with a glide slope aid aimed at, or near the shallowest extreme.

When first installed at Ocean City, the SAVASI was, in fact, aimed at 3°, and test pilots reported that this was satisfactory. Three years after publication of the report covering the SAVASI and related visual aids for secondary airports, NASA conducted the first systematic flight test on a specially proportioned diamond mark as a glide slope guidance aid. In that series of flights, a diamond configured to provide a square image to the pilot on a 3.6° approach was used (reference 11). The records of approach path did not indicate a major guidance effect resulting from use of the diamond mark, but as in the case of the earlier SAVASI test, pilot comment was favorable.

To attain a degree of comparability in conditions, the present test was made with the SAVASI aimed at approximately 4°, the same angle targeted in the NASA diamond test, but brought to a viewing angle of 3.6° by runway slope. Thus, there was an opportunity to determine whether or not the SAVASI would produce flight path data indicating a significant glide slope guidance effect, which the diamond had not produced, and to compare the SAVASI guidance with that of the previously recommended rectangular aiming points.

The second part of the purpose of this activity referred to the goal of establishing minimum accuracies necessary for an effective glide slope aid. It should be remembered that SAVASI had been reported to give adequate approach slope guidance at the shorter ranges normally associated with small, general aviation aircraft, e.g., final approaches of 1/2 to 1 1/2 miles. Measurement of the approach performance with SAVASI would then provide an initial standard of comparison for evaluating the effectiveness of other aids.

DISCUSSION

PROCEDURE.

Ten subject pilots flew six approaches each to runway 24 at Ocean City, New Jersey, with the SAVASI turned ON to provide glide slope guidance, and then six approaches each with the SAVASI turned OFF. Alternate pilots used the reverse order of SAVASI OFF, then SAVASI ON. The 12 data approaches were flown in a single session using a long, 2-mile final approach from an altitude of 800 feet above sea level (ASL). Although it is not representative of the normal practice at small airports, a long, 2-mile final approach is encountered at many busier airports and was considered desirable for this test. The 2-mile approach provided more time for the pilot to intercept the glidepath and stabilize his approach, making it possible to record many more data points.

The approach required a right-hand traffic pattern maintaining 800 feet ASL until inbound on the final approach path at the 2-mile checkpoint. From this point, the pilots were instructed to intercept and fly the red/white on-glidepath signal for the approaches with the SAVASI turned ON. Without the SAVASI, the pilots were instructed to fly the same pattern, but to start their descent at the 2-mile point and 800 feet altitude using the markings as an aiming point, and to fly a stable approach. Touch-and-go landings were made from all approaches with the exception of the last for each pilot.

An altitude of 800 feet ASL at range 2 miles from the runway threshold created a 4 1/4° approach to the glide slope intercept point on the runway midway between the SAVASI lamp boxes and the rectangular aiming-point markings. After completion of the 2-mile approaches, small samples of shorter, or "normal", approaches were tracked and recorded. Six of the pilots flew a second session (four in day and two at night) with the same blocks of six approaches with and without SAVASI. Additional "normal" approach data were obtained by tracking local and itinerant traffic not informed of the test, or that they were being recorded. On these approaches, the SAVASI was turned ON, but it was not known if the pilots used it in any way.

VISUAL AIDS.

The visual guidance system of runway 24 at Ocean City is summarized in figures 1, 2, and 3, and is more completely described in the appendix. Rectangular aiming-point markings were painted on each side of the runway and located midway between the SAVASI boxes (figure 4). Each rectangle was 15 by 200 feet, which left a clear area, except for the runway centerline stripe, of 20 feet between rectangles (figure 1). The SAVASI was aimed for a 4° approach path. The red/white oncourse guidance signal range was about $\pm 1/4°$ in the vertical plane, extending from about 3 3/4° to 4 1/4°. In the transition zone between white and red, there was a narrow pink zone that indicated transitioning between the upper or lower limits.

The runway itself was paved with blacktop and was 50 feet wide by 2,900 feet long. A 500-foot gravel underrun preceeded the threshold, and was interspersed with ankle-high weeds that did not obscure the level surface. Hence, the daytime visual approach situation at Ocean City was that of a clearly defined runway with a clear near approach zone. A rather level golf course preceeded the runway for 700 feet, and prior to this, out about 1,300 feet from the runway threshold, a residential area with two-story houses extended out to about 1 1/4 miles. The 2-mile approach path, then, covered more-or-less typical small city buildings for the first 1 3/4 miles, and essentially level ground for the last 1/4 mile (figure 5).

FIGURE 1. OCEAN CITY, NEW JERSEY, AIRPORT

FIGURE 2. AIMING-POINT MARKINGS

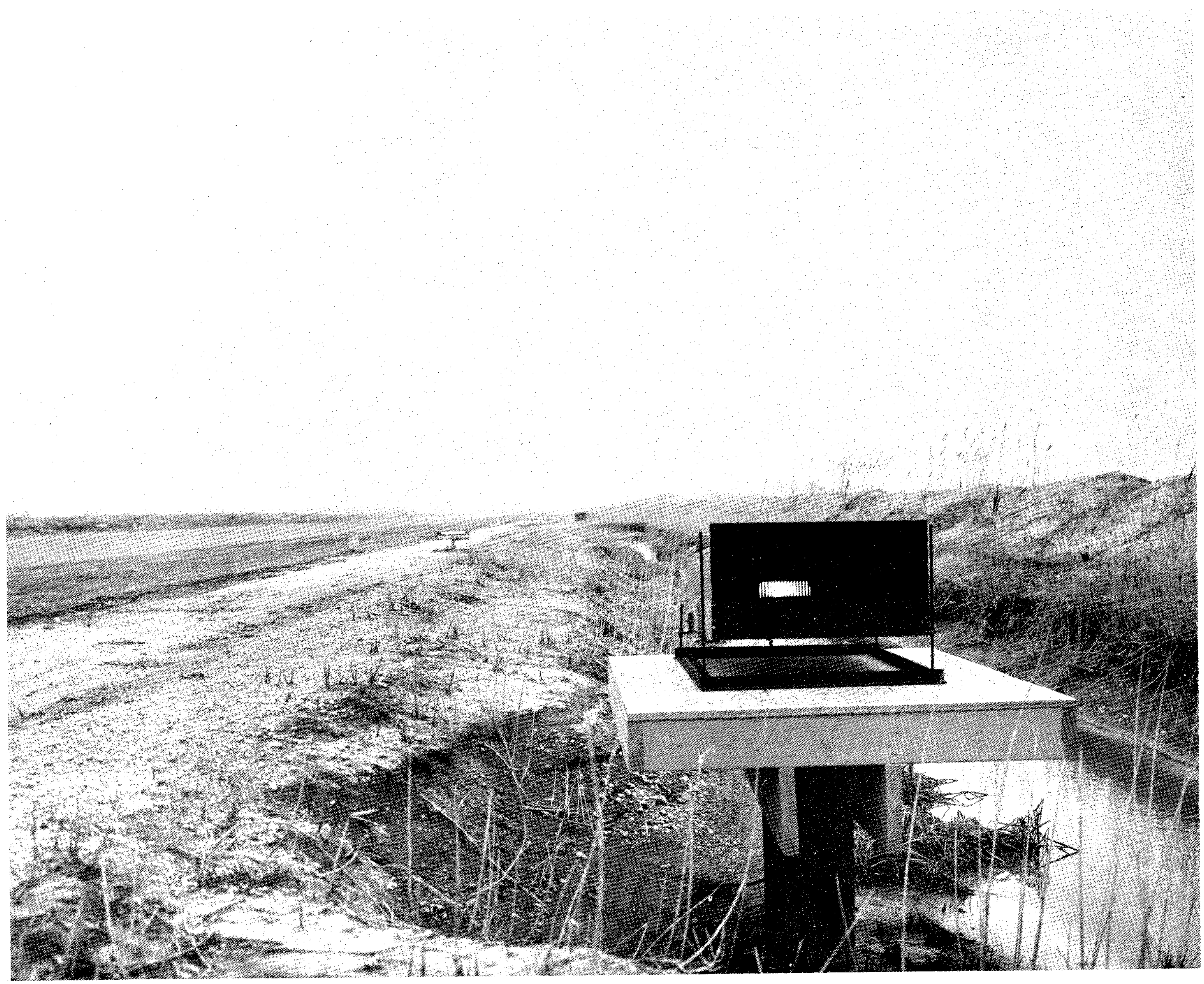

FIGURE 3. SAVASI LAMP BOXES

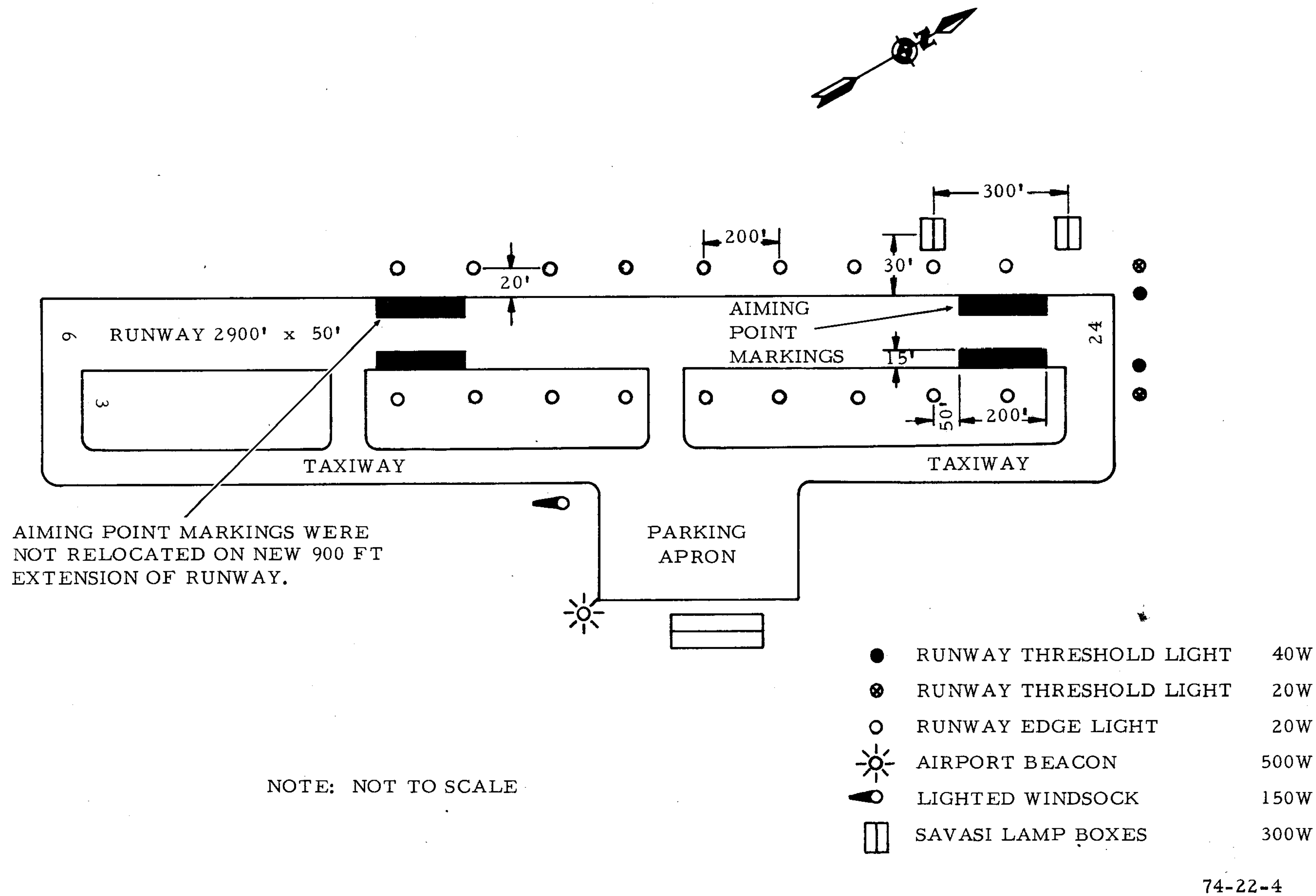

FIGURE 4. OCEAN CITY, NEW JERSEY, AIRPORT LAYOUT

FIGURE 5. APPROACH ZONE, RUNWAY 24, OCEAN CITY, NEW JERSEY

SUBJECT PILOTS AND AIRCRAFT.

The 10 pilots who participated in the basic series varied over a substantial range in age, total flying experience, and FAA ratings (table 1). Other than students and airline transport ratings (ATR's) at the extremes of the pilot population, this sample panel was reasonably representative of general aviation pilots. All were employed at the National Aviation Facilities Experimental Center (NAFEC), either by the FAA or by contractors, but none were employed as professional pilots.

TABLE 1. PILOT INFORMATION

FAA Pilot Certification	Number of Pilots	FAA Ratings	Number of Pilots
Private	6	Airplane, single engine land	10
		Airplane, single engine sea	2
Commercial	4	Airplane multiengine land	1
		Instrument	2
		Instructor	2

Total Flying Hours	Number of Pilots	Pilot Age	Number of Pilots
101-200	4	26-30	2
201-300	2	31-35	3
301-400	0	36-40	1
401-500	1	41-45	2
901-1000	1	46-50	1
1001-1100	1	51-55	1
over 1200	1		

A Piper PA-28 Cherokee, representative of modern, four-seat, single-engine light aircraft, was used as the test aircraft. Eight of the 10 subject pilots were already current and qualified in this type aircraft, and the other two were qualified with a flight instructor. A test pilot from the Flight Operations Branch, NAFEC, rode in the right seat and served as a safety pilot during each flight as required for NAFEC test flights. This member of the test team also reported distance checkpoints by radio and recorded certain inflight data.

The pilots were instructed to use an approach speed of "about 80 to 85 mi/h," and to use their own discretion on flap settings and threshold speeds. It was emphasized to the pilots that this was not a "check ride" and that the objective was to obtain approach guidance from the visual aids.

EXPERIMENTAL DESIGN.

A treatment-by-subjects experimental design was employed with 10 subject pilots flying six 2-mile approaches with each of the visual guidance conditions, SAVASI OFF and SAVASI ON in alternating order. Six of the pilots flew a second session using a "normal" approach pattern, four in the daytime and two at night, with the same blocks of six approaches and visual guidance conditions. The number of pilots making normal approaches was reduced when it was found that pilots seldom tracked the 4° SAVASI oncourse signal. Since the turn onto the normal final approach is usually made well above the red/white oncourse signal, it appeared probable that the normal approaches of 1/2 to 1 mile did not allow sufficient time to intercept the 4° glidepath. Rather than continue with the remaining subjects flying above the red/white oncourse, it was decided to compare these small samples with normal approach data obtained from local and itinerant pilots not instructed to use the visual guidance.

DATA COLLECTION.

Data were recorded as a continuous plot for the entire 2-mile approach path. Visual observation was made to determine the point of touchdown. Also recorded were wind direction and velocity and pilot questionnaire data.

APPROACH PATH DATA. The final approach path was tracked by a manually operated optical tracking device (figure 6). The device, formerly a photogunsight, was adapted to provide electrical voltage signals for continuous recording of approach path elevation and azimuth angles (figure 7). A separate recorder pen operated by a pushbutton switch was used as an event marker to record 2-mile and 1-mile distances reported from the aircraft by the safety pilot. The tracking device was located on the left side of the runway, 125 feet from runway centerline, and toward the approach path for alignment with the 4° SAVASI glide slope.

LANDING TOUCHDOWN DATA. The approximate touchdown distance from threshold was estimated and recorded by an observer using flag markers and runway edge lights as distance markers.

PILOT QUESTIONNAIRE DATA. Qualitative data were obtained from questionnaires completed by each subject on completion of the series of approaches.

EVALUATION CRITERIA.

To decide that a given glide slope guidance aid is or is not adequate, three aspects of its use must be studied: (1) mean descent angle, (2) variability of the approach path above and below average during the approach, and (3) pilot subjective evaluation. An ideal glide slope system would support approaches with a measured mean angle approximating the SAVASI design angle, e.g., a 4° glide slope, on average, when the SAVASI is aimed at 4°. Obviously, variations around the mean angle should not be extreme, although air mass movements and chance fluctuations in performance insure that few approaches will ever follow the design path exactly, and it is known that pilots have a normal tendency to be on or above the glidepath signal rather than below.

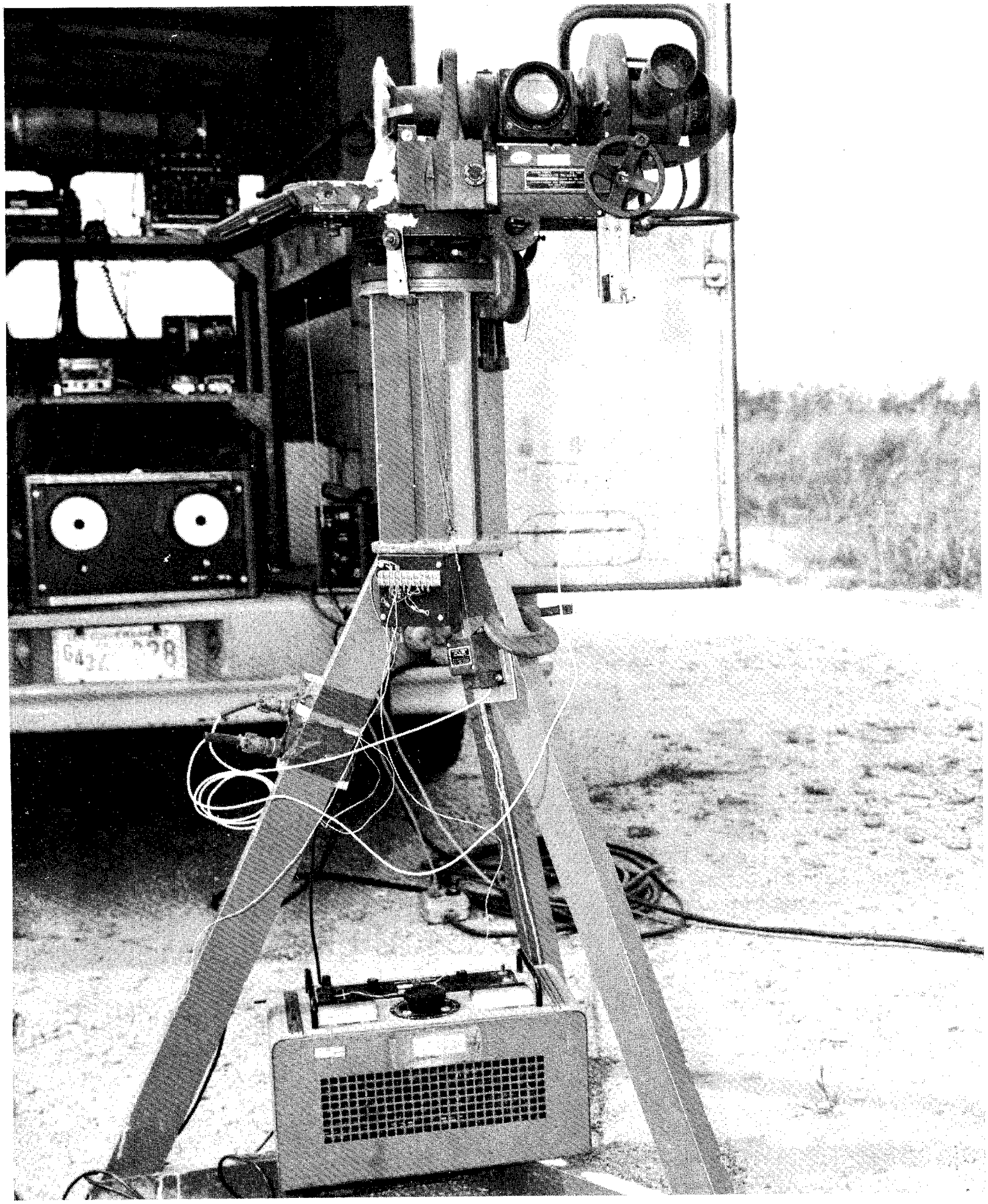

FIGURE 6. OPTICAL TRACKING DEVICE

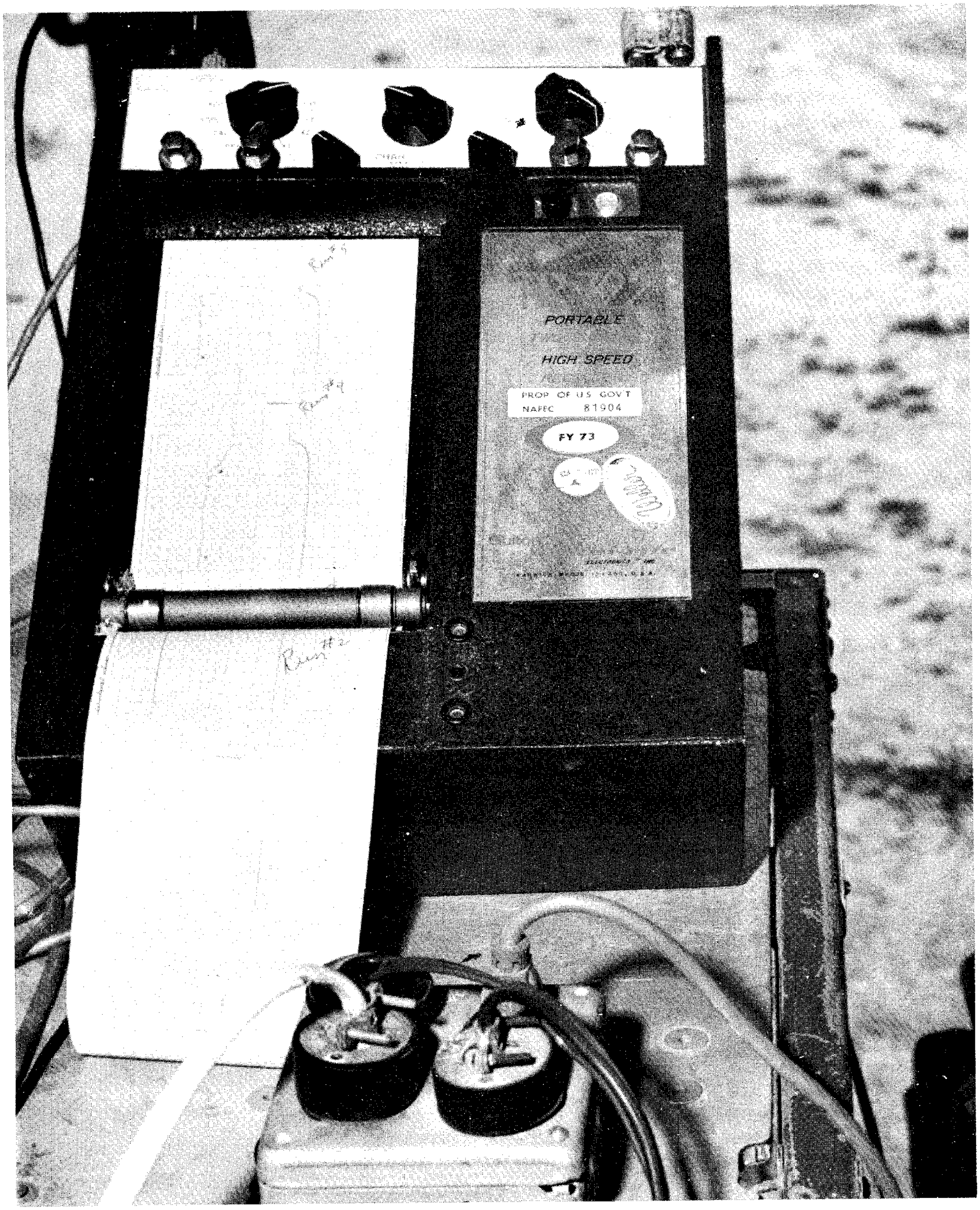

FIGURE 7. PORTABLE RECORDING DEVICE

It would be reasonable to conclude that one aid was more sensitive or more precise than another if variability was less, even though differences in average elevation angle might be small. The subjective evaluation of representative pilots constitutes a valid standard for choosing one system over another. This is because the pilot must be able to employ the guidance aid without undue workload that might reduce the safety margin in ancillary performances, and the pilot must accept the system and be willing to use it and follow it when in need. Finally, most important is the pilots' ability, easily and precisely, to detect signals that warn him he is low, high, or unsafe.

The data analysis employed in this test was aimed at summarizing the flight performances in statistics related to these standards for each of the main test conditions; i.e., approaches using SAVASI and approaches without SAVASI, together with painted aiming-point markings and long, 2-mile approaches. Also, covering small samples of "normal" approaches, additional comparisons were made to summarize day versus night conditions and describe approaches made by itinerant pilots using the test runway but not informed of the test measures.

RESULTS

TEST RESULTS FOR 2-MILE APPROACHES.

The mean approach angle over the extended 2-mile approach path was 4.3° with SAVASI and 4.6° without SAVASI, as shown in table 2. This small mean difference, about 1/3°, was tested for statistical significance using the "t" test on paired means. The result was a failure to reject the null hypothesis, $t = 1.7$, $p > .05$. The 10 pairs of mean approach angles did not show sufficiently large and consistent differences with SAVASI versus without SAVASI to attain conventional requirements for a decision that the two conditions produced samples drawn from different populations.

The accompanying histograms illustrate the distribution of recorded data points at 5-second intervals throughout the approach with the exception of the last 10 seconds prior to threshold, where duck-under is prominent. Histograms for the 2-mile approaches are shown in figures 8 and 9.

Examination of the individual approaches provides a clearer picture of the similarities and differences in mean approach angles. In table 3, the 2 miles of approach are partitioned into four segments of 1/2 mile each. Hence, there were four pairs of grand means which, when combined, generated the grand means in table 2, 4.3° and 4.6°.

TABLE 2. MEAN APPROACH ANGLES FOR 2-MILE APPROACHES. EACH PILOT MADE SIX APPROACHES WITH SAVASI AND SIX APPROACHES WITHOUT SAVASI

	Mean Approach Angle	
Pilot	With SAVASI (Degrees)	Without SAVASI (Degrees)
1	4.2	4.4
2	4.6	4.7
3	4.0	4.4
4	4.5	4.2
5	4.1	4.0
6	4.4	4.8
7	4.7	4.5
8	4.1	5.4
9	4.0	4.1
10	4.7	5.6
Grand Mean	4.3	4.6

TABLE 3. MEAN APPROACH ANGLES FOR 1/2-MILE SEGMENTS OF 2-MILE APPROACHES WITH SAVASI AND WITHOUT SAVASI

	Mean Approach Angle	
Distance Segments From Threshold	With SAVASI (Degrees)	Without SAVASI (Degrees)
2 to 1 1/2 miles	4.0	4.0
1 1/2 to 1 mile	4.4	4.5
1 to 1/2 mile	4.5	4.6
1/2 to ≈ 1/4 mile*	4.4	4.9
Overall Mean	4.3	4.5**

*The final 1/2-mile segment was truncated by the cut-off of tracking data 10 seconds before runway threshold, resulting in data in this segment from approximately 1/2 mile to more or less 1/4 mile.

**Absence of a few measures on certain approaches accounts for the difference from 4.6°, which is a mean of 10 individual pilot means and is reported in table 2.

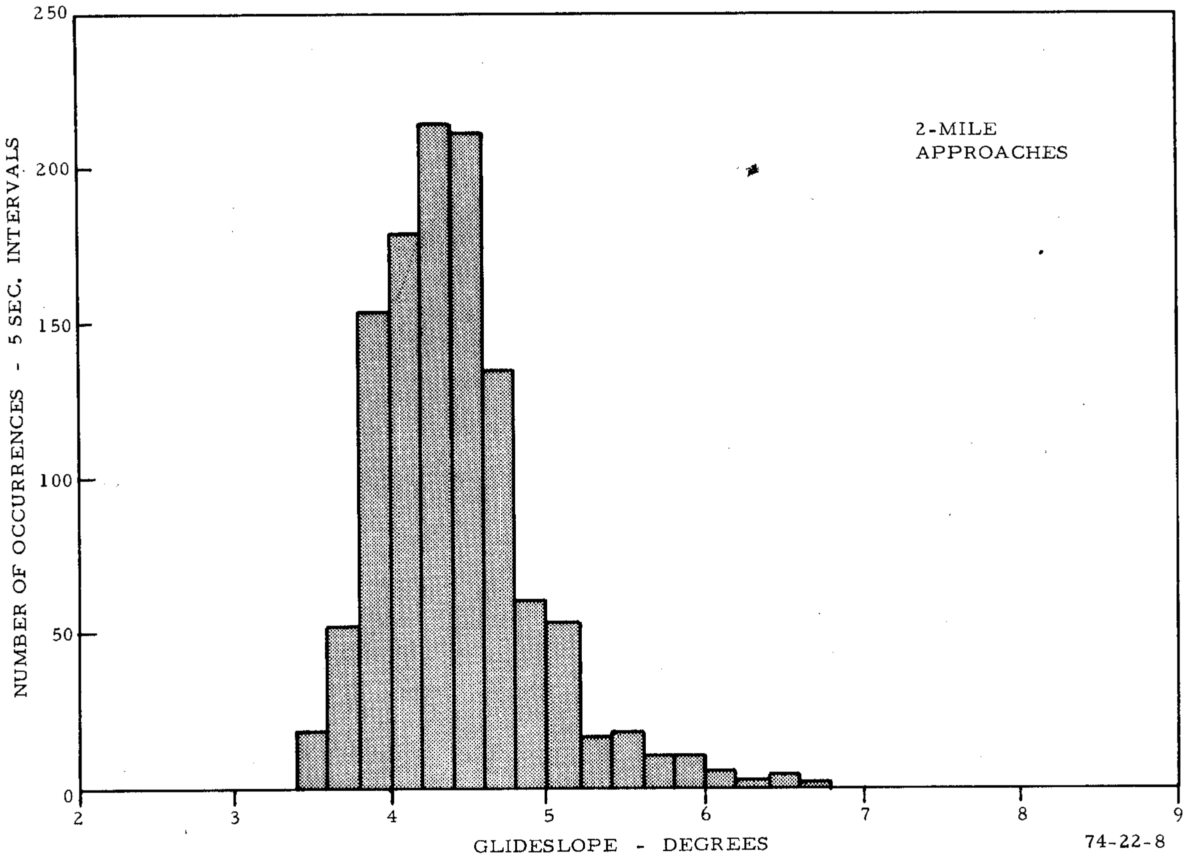

FIGURE 8. HISTOGRAM OF GLIDEPATH POSITION WITH SAVASI GUIDANCE

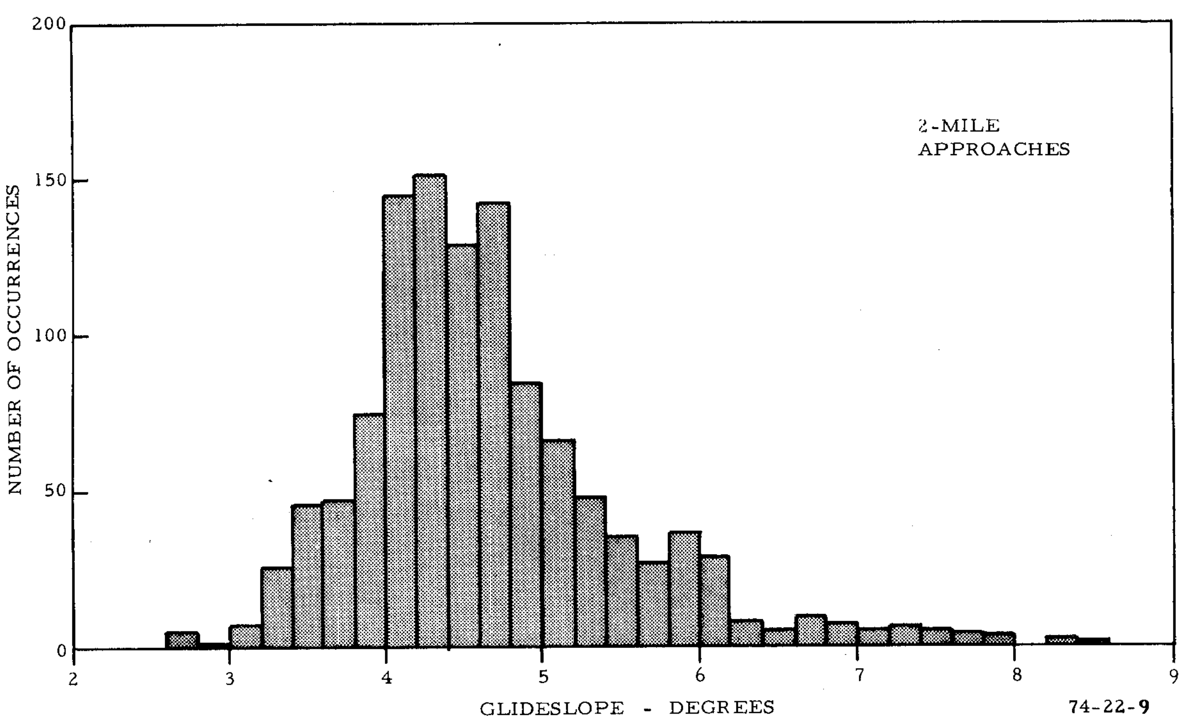

FIGURE 9. HISTOGRAM OF GLIDEPATH POSITION WITHOUT SAVASI GUIDANCE

The mean angle during the initial 1/2 mile was 4.0° with and without SAVASI. This was expected since the pilots were instructed to turn on final at 2 miles at an altitude of 800 feet, which produces approximately a 4.0° angle measured from the glidepath intercept point midway between the SAVASI lamp boxes. As the approaches progressed, the angles became more variable both during an individual approach and between pilots and guidance conditions. This variability was expected, since after passing through the 4.0° window at 2 miles and 800 feet, each pilot was on his own to control the approach. From the 2-mile point, the approaches, on the average, rose above a 4° elevation. For the bulk of the 2-mile distance, the group averages were parallel, but at some point after the half-way point, the mean angle without SAVASI increased about 1/2° over that produced with SAVASI. It was this higher mean angle without SAVASI in the late part of the approaches that constituted the bulk of the small difference in the overall means.

Another summary fact that may be gleaned from table 2 is that the means for segments were less variable with SAVASI, showing a range of 4.0° to 4.5° compared with a range of 4.0° to 4.9° without SAVASI. This is a crude indication that the variability of the angles measured during the approaches without SAVASI may have been greater, i.e., the operating guidance may have been slightly less precise than that functioning during runs with SAVASI, as could be expected since the aiming-point markings did not provide specific glidepath guidance.

Analysis of variance for general, balanced designs was applied to both the standard deviations (sd) and the root mean square (rms) errors for the two guidance conditions. If the distributions of errors from the mean angles had been "normal" (had conformed to the curve of the bell-shaped normal distribution), both analyses would have produced equivalent "F" ratios and levels of statistical significance. As the case proved to be, variations from the mean glide slope deviated from the normal distribution to a sufficient extent to make reference to both sd and rms necessary.

The sd for approaches without SAVASI was, as expected, larger than that with SAVASI (.178 versus .163). Analysis of variance produced the small "F" of 1.295, however, and this yields a probability of 28 percent of obtaining a similar difference in sd when, in fact, only chance and sampling factors are operating, far short of usual statistical conventions for rejecting the null hypothesis.

Abandoning the assumption of normality in the distribution of deviations from the mean angle, another analysis of variance was run on the rms errors. Here the means were .188 for approaches without SAVASI versus .161 for SAVASI approaches. The between-conditions mean square proved to be larger than that based on sd, while the error term, variance within guidance groups, shrank. The result was a large "F" ratio of 8.38 which gives a probability of attaining so large a difference through chance of only .02, using a two-tailed distribution. This outcome justifies rejection of the null hypothesis (no difference between error distributions) and supports the conclusion that approach performance was more variable without SAVASI.

The pilot questionnaire that obtained subject-pilot evaluations contained 20 items on the basic series of 2-mile approaches in daylight conditions. Nine of these items provided an opportunity to state that the SAVASI did or did not possess some feature or capability that contributed to an effective glide slope aid. Pilot responses were generally very favorable to SAVASI for day operations and included the following:

1. Seven out of 10 pilots said the range of SAVASI was sufficient for day operations for the 2-mile approach.

2. Nine out of 10 said SAVASI provided a light intensity adequate for the operations conducted (2-mile approach).

3. Ten out of 10 said the SAVASI provided an oncourse signal that was easily and accurately flown to a height near threshold.

4. Ten out of 10 said the SAVASI glide slope oncourse signal area was about right, as opposed to the vertical beam being too wide or too narrow.

5. Nine out of 10 said the system provided an adequate oncourse signal from a distance of 1 mile; seven out of 10 gave the same response for 1 1/2 miles; and five out of 10 okayed the signal from a distance of 2 miles.

6. Ten out of 10 said the SAVASI pink signal provided guidance or warning of starting to enter or leave the oncourse glidepath.

7. Ten out of 10 said the pink transition area was about right, as opposed to too narrow or too wide.

8. In a complex question asking whether the SAVASI provided, at 1/2-mile distances, distinctive information that was easily recognized for guidance below glidepath, on glidepath, or above glidepath, 84 total entries were favorable to SAVASI out of a possible 90. Hence, the pilots voted heavily in favor of statements that the guidance lights were adequate for above, on, or below glidepath guidance from 1 1/2 miles to near threshold.

9. Eight out of 10 said the SAVASI brought the aircraft over the threshold about right, as opposed to too high or too low.

According to the binomial test, a vote of 8 to 2 in the expected direction generates a probability of .055 of repeating that split or a wider one, when there is no real preference. Nine to one, in contrast, is likely to occur through chance only 11 times in a thousand ($p = .011$). Hence, the responses to the nine questions on SAVASI either attain or approach statistical significance except for queries about effective range that mention or include the initial portion of the 2-mile approach path. This can be expected since previous tests indicate the daytime nominal SAVASI range to be 1 to 1 1/2 miles.

The remaining 11 questions were pointed toward evaluation of the painted aiming-point markings during daytime operations.

10. Seven out of 10 said the markings helped identify the runway.

11. Six out of 10 said they were able to see the markings from 2 miles at 800 feet.

12. Eight out of 10 said the markings were sufficiently distinctive.

13. Eight out of 10 said they found the markings useful as an aiming point.

14. Six out of 10 said they did use the markings as an aiming point most of the time.

15. Two out of 10 said they used the markings for the entire approach.

16. Seven out of 10 felt that the markings were beneficial in judging a constant glidepath angle.

17. Five out of 10 said the markings provided useful guidance for runway alignment on final approach.

18. Nine out of 10 said they would use the markings if they were present on the runway in use.

19. Eight out of 10 said the markings would provide useful guidance for all runways.

20. Nine out of 10 said they found no disadvantage or unsafe condition with the markings.

The above responses revealed general pilot satisfaction with the aiming-point markings. As with the SAVASI lights, the markings were not believed by all to have an effective range extending out to the most distant segment of the long approaches used in this test. Also, the markings did not receive overwhelming endorsement for aid in runway alignment, runway identification, or judgment of a constant glidepath angle - all tasks somewhat peripheral to the main purpose of the markings in establishing a strikingly visible aiming point. Observation from a higher altitude and elevation angle would probably produce better response in identification of the runway and possibly alignment.

TEST RESULTS FOR NORMAL APPROACHES.

The major portion of the test was conducted by pilots flying long, 2-mile approaches starting from an altitude that comprised a 4° or 4 1/4° window. This, however, was not a normal approach condition and was justified only by the test requirement to standardize the procedure and insure equivalent measurement from one condition to another. A normal approach is usually shorter.

The possibility exists that a guidance aid tested under a set of other-than-normal conditions, such as these, might fail to pass the test in actual general aviation operations. Similarly, it is thinkable that a guidance aid might prove its mettle in actual use, even though it had not produced superior approaches in controlled test series.

With these considerations in mind, two small samples of "normal" approaches were run. Observation of the normal or uncontrolled operations at the test airfield suggested that it is a common practice to turn on final at a distance from threshold of 1/2 to 1 mile. Hence, four pilots were instructed to fly the same sequence of approaches as used in the major series, but to proceed around the airfield in a normal pattern, turning on final approach at a point that they considered a normal approach. This resulted in final approaches in the actual range of 1/2 to 1 mile from threshold.

Mean approach angles for each of four pilots making the normal length approaches in daytime are summarized in table 4. It is evident that the pilots remained above the oncourse SAVASI signal (4°), and those without SAVASI produced an equivalent grand mean.

TEST RESULTS FOR LOCAL AND ITINERANT TRAFFIC.

A total of 46 aircraft were tracked as they approached runway 24 without any special instructions and without being informed that tracking was underway. Classified as local traffic, three single engine aircraft made 13 approaches, and the other 33 approaches were made by a wide variety of single and twin engine aircraft making one approach each. The length of these final approaches varied from about 1 mile to a little less than 1/2 mile. In time, the tracked segments ranged from 60 seconds to 25 seconds, with a mean of 40 seconds. From this, it may be seen that the aircraft operating independently of our test executed final approaches roughly comparable in length to those of our test pilots making "normal" approaches.

The mean glide slope angle obtained from the 46 independent aircraft approaches was 5.2° for the portion of the approaches from 55 seconds to 15 seconds to threshold. A typical duck-under was shown in a mean of 4.0° at 10 seconds prior to threshold and a measured angle of 2.5° at threshold. The mean glide slope angle in the most distant segment of the approaches was 5.4°, in the mid-segment, 5.2°, and in the inner one-third, 4.7°. The standard deviation was large at each segment measuring 1.3° overall. This high degree of variability, compared to that found for the test aircraft, indicates a wide variation in approach performance for the disparate aircraft types and for the various pilots operating under independent decision processes.

Since the mean glide slope angle of the local and itinerant approaches was above 5° while the SAVASI was aimed at 4°, it is unlikely that the red/white guidance signal from the SAVASI could have had any major influence in determining the glide slope or in reducing variability of performance. As suggested in the discussion of the "normal" approaches, the short final segment represented by a tracking plot of 55 seconds or less may not give the pilot sufficient time to intercept and adjust his control to the guidance of the SAVASI. Had the guidance aid been aimed at 5°, i.e., somewhere near the mean path adopted by the independent aircraft, glide slope intercept might have occurred earlier and more easily. In that case, the red/white signal might have been more effective. This point may call for future testing.

TABLE 4. MEAN APPROACH PATHS FOR FOUR PILOTS MAKING DAYTIME NORMAL-LENGTH APPROACHES

	Mean Approach Angle (Day)	
Pilot	With SAVASI (Degrees)	Without SAVASI (Degrees)
1	4.7	4.7
2	5.1	4.5
3	5.0	6.0
4	4.6	4.4
Grand Mean	4.8	4.8*

*Not a simple average of the individual entries because of slightly different length of approaches.

Next, two pilots flew nighttime approaches with a normal pattern to provide a brief test of the hypothesis that the 4° SAVASI oncourse signal would be more appropriate at night. These approaches proved to be even steeper than the daytime normal approaches. The mean with SAVASI was about 5 1/3°, almost the same as without SAVASI, see table 5. Since the approach paths rarely came near the oncourse signal of the guidance system, there appeared to be no real difference between the two conditions.

TABLE 5. MEAN APPROACH PATHS FOR TWO PILOTS MAKING NIGHTTIME NORMAL-LENGTH APPROACHES

	Mean Approach Angle (Night)	
Pilot	With SAVASI (Degrees)	Without SAVASI (Degrees)
1	5.7	6.1
2	5.0	4.7
Grand Mean	5.3	5.4

INTERPRETATION OF THE RESULTS.

Examination of the tracking data compels recognition of two facts. First, the small general aviation aircraft were flown with steeper approach paths than had been expected. From this it is inferred that the 4° aim of the SAVASI was too low. Second, the subject pilots did not make so-called stabilized approaches, even though they were started through an approach window 2 miles from threshold, at an altitude of 800 feet. Individual tracks showed stair-step descents in several cases, and approach zone features and wind conditions appeared to combine to produce a characteristic performance described below.

From the 2-mile turn-on point, the initial 3/4 mile of approach was generally along the island shoreline and parallel to rows of city buildings close by, on the left. From about 1 1/4 miles to 1/4 mile from the threshold, the approach path crossed a residential area with many two-story houses. The final 1/4 mile was over a nearly level golf course and weed-covered gravel underrun area. Tracking data, however, for the last 10 seconds prior to threshold were not used in calculating the mean approach angles since it was expected that the pilots would duck-under his projected flight path in an attempt to land closer to the threshold.

The sort of approach path condition created by the residential area tended to induce the pilot to stay on the high side because of normal reluctance to descend when nearing the city buildings close by, on the left, and when approaching or crossing over the two-story housing area. Turbulence and lifting action in this area was common with onshore winds (easterly to southerly that prevailed about half the time. These factors, along with the pilot's normal tendency to fly on, or above the glidepath signal, together with the fact that the 4° slope was lower than he would normally make, probably account for much of the increase in the mean approach angle for both visual aid conditions.

Once past the houses, a tendency to duck-under would be expected, and this was supported by the data within the last 10 seconds and by the experimenter's observations. The duck-under maneuver appeared to change the aiming point to the runway threshold or the runway numbers, and with the flare, the painted aiming points appeared to become a point for touchdown. Excess speed over the threshold and during the initial flare caused some floating, usually beyond the paint markings.

The bulk of the difference between performance with the SAVASI and either the no SAVASI or the normal approach pattern conditions appeared to be the more constant path achieved in the final 1/2 mile of the approach and the lower elevation angle, closer to the SAVASI guidance signal, near the airport boundary. These results make it appear that the SAVASI was an aid to reducing the variation of approach paths, even though most approaches were above the 4° glidepath. It must be remembered that the 4° glidepath was not precise, since the red/white oncourse signal itself covered about 1/2° and most of the approaches were probably in the top segment of the red/white signal and some in the pink/white area.

If the SAVASI had been aimed more steeply and, hence, more in line with what the itinerant pilots apparently found to be a normal or comfortable angle of descent, its effectiveness in steadying the approach and reducing extreme excursions might have been even greater.

The present results do not provide a definite answer to the question of what minimum accuracy is required for an approach aid. The SAVASI appeared to be an addition to the natural cues and guidance value of the painted runway markings. How precise the approaches would have been had the SAVASI been aimed higher cannot, however, be estimated.

CONCLUSIONS AND RECOMMENDATIONS

Based on a series of 120 tracked approaches using a long, 2-mile approach and on smaller samples of "normal" approaches to a small airport providing painted aiming-point markings with and without a low-cost version of the red/white VASI, it is concluded that:

1. The SAVASI is effective in aiding the pilots to maintain an average descent nearer the red/white oncourse signal and in reducing variability along the approach path.

2. Under all guidance conditions, the approaches flown tend to be higher than expected. It is recommended that approach aids for this runway be aimed at about 5°.

3. Both the painted aiming-point markings and the SAVASI are well accepted by pilots.

4. The present results indicate that the SAVASI may serve as an interim approach guidance standard for comparison with other systems. It is recommended that the minimum quantitative accuracy that should be attained before an approach aid is determined to be effective should wait until another flight test can be conducted with a planned guidance signal higher than the present 4° and closer to the "comfortable" angle of descent for this class of aircraft.

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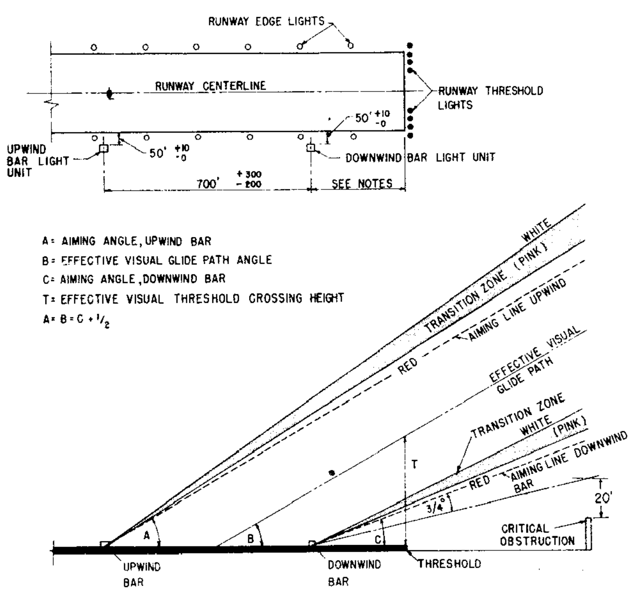
APPENDIX

TWO-BOX VASI LAYOUT, INSTALLATION AND AIMING CRITERIA



A= AIMING ANGLE, UPWIND BAR
B= EFFECTIVE VISUAL GLIDE PATH ANGLE
C= AIMING ANGLE, DOWNWIND BAR
T= EFFECTIVE VISUAL THRESHOLD CROSSING HEIGHT
$A = B = C + 1/2$

NOTES:

1. INSTALL THE UPWIND AND DOWNWIND BAR LIGHT UNITS AN EQUAL DISTANCE FROM THE RUNWAY EDGE.

2. LOCATE THE CENTER OF THE OPTICAL APERTURE OF THE INSTALLED UPWIND AND DOWNWIND BAR LIGHT UNITS WITHIN PLUS OR MINUS ONE FOOT OF THE RUNWAY CROWN.

3. LOCATE THE LIGHT UNIT IN EACH BAR ON A LINE PERPENDICULAR TO THE RUNWAY CENTERLINE. PLACE THE FRONT FACE OF EACH LIGHT UNIT WITHIN A TOLERANCE OF ±6 INCHES FROM THIS LINE.

4. ALIGN EACH LIGHT UNIT OUTWARD INTO THE APPROACH ZONE ON A LINE PARALLEL TO THE RUNWAY CENTERLINE WITHIN A TOLERANCE OF PLUS OR MINUS ½ DEGREE.

5. AIM THE DOWNWIND AND UPWIND LIGHT UNITS IN ACCORDANCE WITH THE EQUIPMENT MANUFACTURER'S INSTRUCTIONS WITHIN ±2 MINUTES OF THE RESPECTIVE ANGLE FORMED BY LINE A AND THE RUNWAY SURFACE, AND LINE C AND THE RUNWAY SURFACE.

6. DETERMINE THE EFFECTIVE VISUAL GLIDE PATH OF THE SYSTEM BY THE STEPS LISTED BELOW.
   a. MAKE A PLOT OF THE APPROACH AREA SHOWING THE LOCATION AND HEIGHTS OF ALL OBSTRUCTIONS.
   b. DRAW A LINE FROM THE DOWNWIND BAR LOCATION TO 20 FEET ABOVE THE MOST CRITICAL OBSTRUCTION IN THE AREA SEE ABOVE FIGURE.
   c. AIM THE DOWNWIND BAR AT AN ANGLE EQUAL TO THAT OBTAINED IN NOTE b ABOVE PLUS ¾ DEGREE.
   d. AIM THE UPWIND BAR IN ACCORDANCE WITH THE EQUIPMENT MANUFACTURER'S INSTRUCTIONS ½ DEGREE ABOVE THE DOWNWIND BAR.
   e. THE EFFECTIVE GLIDE PATH OF THE SYSTEM (ANGLE B) IS EQUAL TO THE AIMING OF THE UPWIND BAR.

7. LOCATE THE DOWNWIND BAR 125 FEET TO 800 FEET FROM THE RUNWAY APPROACH THRESHOLD.

8. WHERE TERRAIN DROPS OFF RAPIDLY NEAR THE APPROACH THRESHOLD AND SEVERE TURBULENCE MAY BE EXPERIENCED, ESTABLISHED THE EFFECTIVE GLIDE PATH AT ITS MAXIMUM ELEVATION AND DOWNWIND BAR LOCATED ITS MAXIMUM DISTANCE FROM THE LANDING THRESHOLD IN ORDER TO KEEP AIRCRAFT AS HIGH AS FEASIBLE OVER THE LANDING THRESHOLD.

9. THE MINIMUM EFFECTIVE VISUAL GLIDE PATH IS 2.5 DEGREES. THE MAXIMUM EFFECTIVE VISUAL GLIDE PATH IS 4° FOR PROPELLER DRIVEN AIRCRAFT.

10. LIGHT AND MARK ALL OBSTRUCTIONS AS REQUIRED (FAR PART 77).

11. AT LOCATIONS WHERE SNOWFALL IS LIKELY TO OBSCURE THE LIGHTS, THE LIGHT UNITS MAY BE INSTALLED UP TO A MAXIMUM HEIGHT OF 6 FEET ABOVE GROUND LEVEL. SINCE RAISING THE LIGHT UNITS ALSO RAISES THE EFFECTIVE VISUAL GLIDE PATH, THE UPWIND AND DOWNWIND BARS SHOULD BE RELOCATED DOWNWIND A DISTANCE SUFFICIENT TO COMPENSATE FOR THIS. THE DISTANCE THE BARS SHALL BE MOVED IS DETERMINED FROM THE FOLLOWING FORMULA: $d = \frac{h}{\tan\theta}$ WHERE

    d = DISTANCE IN FEET BOTH BARS SHOULD BE MOVED TOWARD THRESHOLD.
    θ = VISUAL GLIDE PATH ANGLE
    h = THE DIFFERENCE BETWEEN THE AVERAGE ELEVATION OF THE UPWIND AND DOWNWIND BARS FROM THE ELEVATION OF A POINT ON THE RUNWAY CENTERLINE MIDWAY BETWEEN THE UPWIND AND DOWNWIND BARS.

12. AT LOCATION WHERE 2-BOX VASI INSTALLATIONS CAN NOT BE ON THE LEFT SIDE, INSTALL THE LIGHT UNITS ON THE RIGHT SIDE OF THE RUNWAY AND PUBLISH THIS FACT IN THE AIRMAN'S INFORMATION MANUAL.

13. THE MINIMUM AND MAXIMUM THRESHOLD CLEARANCE OF THE EFFECTIVE VISUAL GLIDE PATH IS 25 FEET AND 60 FEET RESPECTIVELY. WHERE THE DISTANCE BETWEEN PILOT'S EYE AND THE LOWEST PORTION OF THE AIRCRAFT IN LANDING ATTITUDE EXCEEDS 10 FEET, THE MINIMUM THRESHOLD CROSSING HEIGHT IS INCREASED BY AN AMOUNT EQUAL TO THAT IN EXCESS OF THE 10 FEET.

TWO-BOX VASI LAYOUT, INSTALLATION AND AIMING CRITERIA