TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-AM-72-9		

4. Title and Subtitle	5. Report Date
PILOT TRACKING PERFORMANCE DURING SUCCESSIVE IN-FLIGHT SIMULATED INSTRUMENT APPROACHES	February 1972
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Paul G. Rasmussen and A. Howard Hasbrook	
9. Performing Organization Name and Address	10. Work Unit No.
FAA Civil Aeromedical Institute P. O. Box 25082 Oklahoma City, Oklahoma 73125	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	OAM Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Eight instrument rated pilots with flying experience ranging from 600 to 12,271 hours each flew 10 simulated ILS instrument approaches in a single engine, general aviation aircraft equipped with a primary flight display arranged in a conventional "T" configuration. Continuous glide slope and localizer tracking performance were recorded during each approach. Approaches were flown consecutively at approximately ten-minute intervals, with a one-minute in-flight rest period prior to each approach.

The principal finding was that there were no statistically significant changes in glide slope tracking with respect to accuracy of tracking or consistency of performance as a result of the practice afforded by the ten approaches. Some performance measures did yield statistically significant changes in localizer tracking performance, but these changes were of a small order of magnitude. Results are discussed in terms of the factors operating to limit the precision with which the glide slope and localizer can be tracked.

17. Key Words	18. Distribution Statement
Aviation safety, Instrument flight, Flight training	Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	14	$3.00

Form DOT F 1700.7 (8-69)

Acknowledgment

The authors wish to extend their thanks to Mr. Richard Speck for his design and technical support on the data acquisition system.

PILOT TRACKING PERFORMANCE DURING SUCCESSIVE IN-FLIGHT SIMULATED INSTRUMENT APPROACHES

I. Introduction.

Making an instrument approach is a complex, multi-element task that requires extensive and rapid information acquisition and processing, decision making, and highly skilled psychomotor inputs to maneuver the aircraft within the constantly narrowing electronic "beam" of the Instrument Landing System (ILS) approach.[1,5] It is generally accepted that such a task requires a high degree of instrument flying proficiency and that practice and currency of experience are important factors in achieving the necessary flying skills. In spite of the critical requirements on human capability for making an ILS approach, there appears to be a paucity of quantitative data defining the limits of human performance in relation to individual components of the total system requirement.

Most evaluations of pilot performance during actual or simulated instrument approaches (e.g., pilot proficiency check flights) are generally subjective and summary in nature. Except for extreme cases, it is practically impossible to rate one performance against another, or against an absolute standard, with the degree of precision or discrimination necessary to characterize subtle but real differences among individual performances. This is not to say that observational judgments are necessarily inadequate for the purpose of determining if a performance meets certain established criteria. In fact, specified flight maneuvers can be rated with a high degree of reliability between independent observers.[4] However, such subjective judgments frequently fail to identify the extent to which the component tasks contribute to, or subtract from, the performance of the overall task. Quantitative data, such as is obtained by continuous, automated recording of selected elements of pilot performance or of flight parameters, are required for most of the research work on pilot performance, whether it is for the purpose of evaluating training techniques or designing a more effective man-machine interface.[2,7]

The Control group from an earlier study[4] provided an opportunity to study the glide slope and localizer tracking behavior of a group of instrument rated pilots and to investigate the effects of practice afforded by an extended series of successive approaches.

The data to be reported here are not presented as being definitive since they cover only a limited number of performance parameters in one type of aircraft and for a relatively small number of subjects. It is believed, however, that the data suggest several potentially productive lines of investigation which could lead to the establishment of objective performance criteria with special reference to training, proficiency, and currency requirements, compatible control-display relationships, and the composition and structuring of complex, multi-element flying tasks.

II. Equipment and Methodology

Research Device. A four-place, single engine general aviation aircraft was used for the study. Figure 1 shows the aircraft instrument panel. It is representative of the "T" configuration frequently found in this type of aircraft except that the position of the vertical speed indicator has been moved to the right to provide a more centrally located space for the glide slope/localizer indicator. Quick-removal slats installed in the windshield area, and to the left of the subject, were used to simulate an instrument environment without obstructing the outside view of the safety pilot.

A portable, battery-powered tape recorder automatically recorded the deviations from glide slope and localizer centerlines by taking its input directly from the ILS receiver output. Event information such as passage over geographical "fixes", calibration checks, and narrative comments were supplied to the recorder by the observer who operated the equipment.

safety pilot placed the aircraft on the centerline of the glide slope/localizer "beam" at a fixed geographical point. Speed, power, gear, and flaps were set in "approach configuration" before turning control of the aircraft over to the subject. In this manner all subjects started their approaches in identical approach geometry from the same point in space. Upon completion of each approach at the middle marker, the safety pilot raised the landing gear and flaps, and instructed the subject to "go-around". After go-around, the subject climbed back to initial approach altitude. He was then given a one-minute rest period while the safety pilot made a 180° turn in-bound to the glide slope/localizer centerline. The same procedure was repeated for each approach and the flight was terminated after the tenth approach.

III. Results.

The performance data were evaluated by several criteria that emphasize different aspects of the ILS tracking task. Only quantitative data are presented. No specific claims are made that any performance measure, or combination of measures, accurately reflect the overall "quality" of an ILS approach. The practical relevance of any given measure must be judged on the basis of how well the criteria for the individual measures reflect actual demands of the tracking task portion of the ILS approach.

All values are given in terms of the number of "dots" of deviation from the centerlines of the glide slope and localizer paths as indicated on the crosspointer instrument, except for the composite weighted scores which are expressed as percentages. Angular deviation (expressed in "dots" of instrument indication) is used, rather than linear distance, because this is the information that is displayed to the pilot and on which he must act without translation into linear distances. The relationship of indicated "dot" deviations to linear distances is also a changing ratio as a function of the distance between the aircraft and point of origin of the two signals. This makes it impractical to attempt to use linear deviation as a means of comparing performance at varying distances along the approach.

Position of Aircraft at the Middle Marker

This measure considers only the position of the aircraft with respect to the glide slope and localizer centerlines at the time the aircraft passed over the middle marker. It does not reflect performance prior to that point and gives no indication as to how well the pilot handled the aircraft with respect to such things as attitude, or rate of change with respect to the glide slope and localizer centerlines.

(1) *Glide Slope Data.* Figure 3 presents the arithmetic means of the deviations from glide slope centerline at the middle marker for each of the ten approaches. These values express only the magnitude of the deviations, not the direction above or below centerline. The means range from 0.76 to 2.36 "dots". Individual performances range from 'on centerline" to "off scale" (more than 5.0 "dots"). Eight of the 80 individual approaches resulted in deviations at the middle marker of more than 3.0 "dots". Two of these larger deviations occurred as late as approach #9 in the sequence of ten approaches.

The algebraic means for the same glide slop data all fell within one dot of the centerline Individual deviations range from 3.4 "dots" below, to off scale (more than 5.0 "dots") above centerline. There are no significant difference among the means for the ten approaches as teste by analyses of variance.

Consistency of performance was examined b comparing the arithmetic differences betwee deviations on successive approaches for each sub ject, i.e., between approaches 1 and 2, 2 and etc. The means of the differences between su cessive approaches range from 0.98 to 1.73 "dots and differences by individual subjects range fro zero to 4.6 "dots". There are no significant di ferences among the difference values for th successive approaches as tested by analysis variance.

(2) *Localizer Data.* The results for localiz deviations from centerline are presented Figure 4. The arithmetic means range from 0. to 1.49 "dots" and individual deviations ran from zero to 4.6 "dots" for the ten approache There are no significant differences among a proaches as tested by analysis of variance.

Consistency of performance was examined the same method as for the glide slope da The means of the differences range from 0.59 1.09 "dots" and differences by individual su jects range from zero to 4.1 "dots". There a no significant differences among the differen values for the successive approaches as test by analysis of variance.

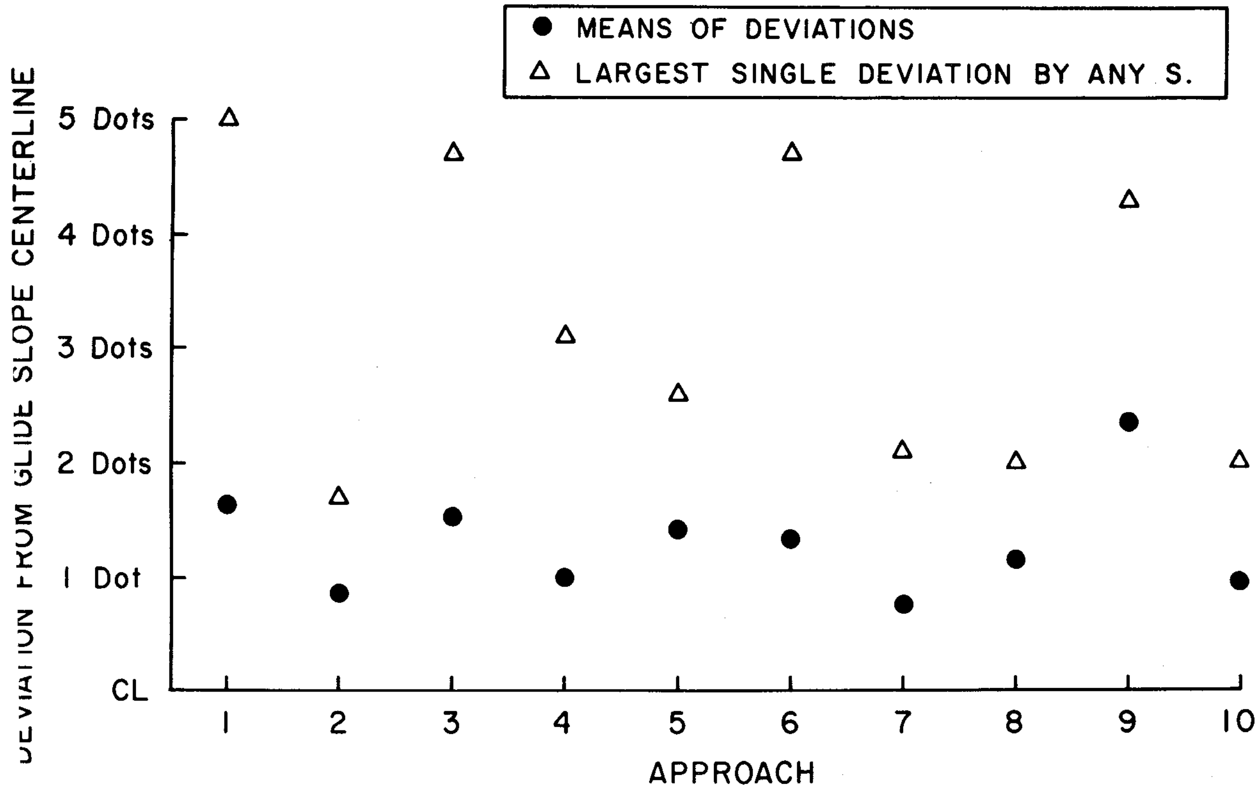


FIGURE 3. Arithmetic means and maximum deviations from glide slope centerline at the middle marker.

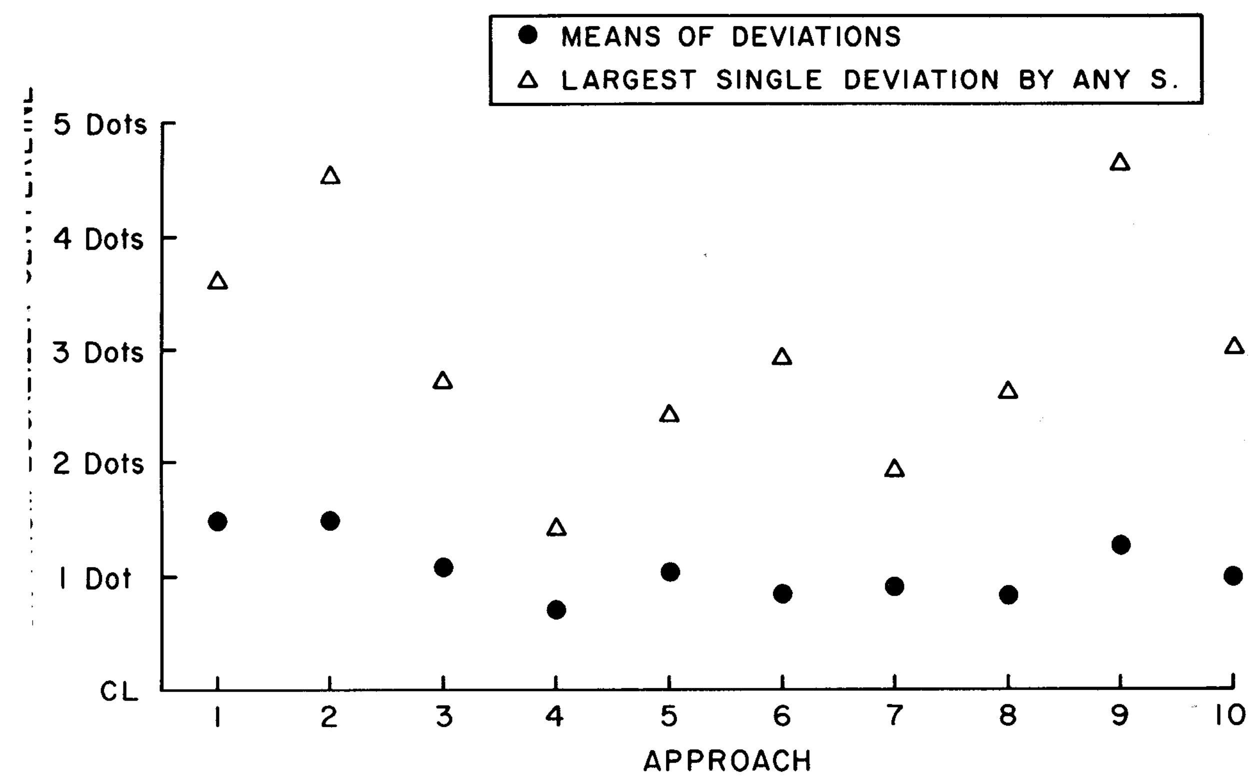


FIGURE 4. Arithmetic means and maximum deviations from localizer centerline at the middle marker.

Range of Glide Slope Deviation Changes During the Last Thirty Seconds of Approach

This measure is a numerical expression of the range of the aircraft's vertical excursions relative to the glide slope centerline during the last half-minute of the approach prior to reaching the middle marker. It is derived by determining the number of equivalent "dots" between the highest and lowest position of the aircraft relative to the glide slope centerline during the specified period. The resulting value can be interpreted as a simple indication of the vertical stability of the aircraft's track. The score does not reflect accuracy in tracking the glide slope centerline because a small value can indicate both large and small, but relatively constant deviations from centerline. The frequency and appropriateness of the indicated changes in deviations do not enter into the resulting values.

The means and maximum values of these changes in glide slope deviations during the last thirty seconds of the approach are given in Figure 5. With the exception of one approach, the means of the changes all fall between two and three "dots". Individual values range from 0.7 to 7.4 "dots". There are no significant differences among approaches with respect to this performance measure as tested by analysis of variance.

Consistency of performance was examined by taking the differences in magnitude of the range of glide slope deviation on successive approaches by the same subject. The means of the differences tend to be slightly more than the equivalent of one "dot". The range of individual values falls between zero and 4.7 "dots". There are no significant differences among the difference values for successive comparisons as tested by analysis of variance.

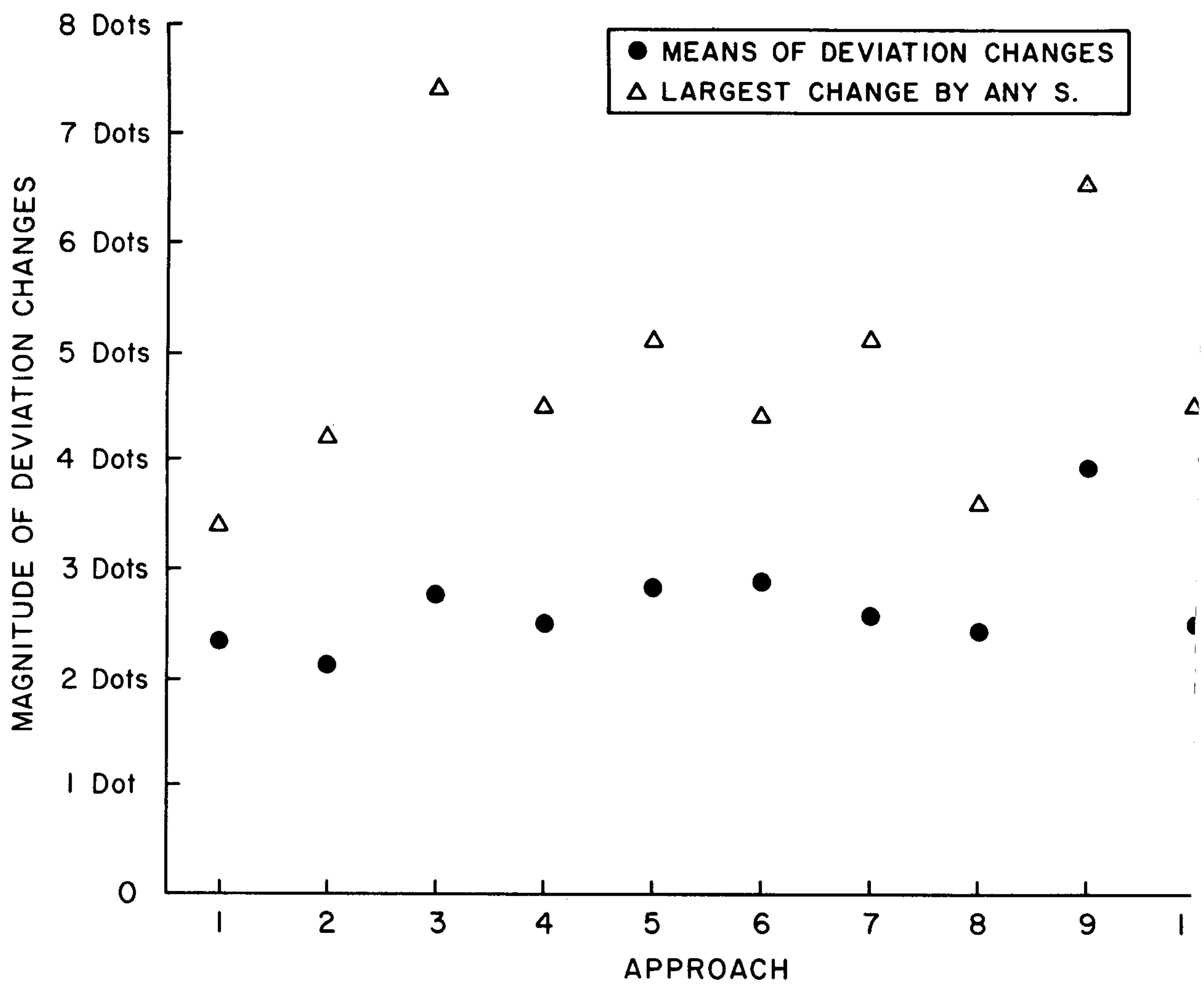


FIGURE 5. Means and maximum glide slope deviation changes during the last 30 seconds of the approaches.

Composite Weighted Tracking Scores

A composite weighted score was developed to ›rovide a single overall tracking score for each f the two elements of the ILS system. These cores express the level of tracking performance or the whole approach between the outer and ɿiddle markers. The scores were derived by ssigning an arbitrary value of 16 to deviations qual to, or less than, one "dot" (equivalent to taying within the "bulls-eye" or "donut"), and ɪccessively smaller values to larger deviations ccording to a fixed ratio as follows:

Range of Deviations From Centerline	*Point Value*
ne "dot" or less	16
reater than 1 but not more than 2 "dots"	8
reater than 2 but not more than 3 "dots"	4
reater than 3 but not more than 4 "dots"	2
reater than 4 but not more than 5 "dots"	1
ore than 5 "dots"	(−16)

These values were then multiplied by the numər of seconds the indicated deviations fell within the respective ranges. The sum of these products was the raw score. The raw score was converted to a percentage of the maximum possible score for that approach based on the lapsed time between the outer and middle markers. Maximum performance is represented by 100% and is achieved by keeping the needle within the "bullseye" continuously between the outer and middle markers.

(1) *Glide Slope Data.* The means and ranges of the composite glide slope tracking scores are presented in Figure 6. The means range from 77.6% to 89.5%. The range of individual scores is from 49.7% to 100.0%.

There are no significant differences among approaches on the basis of this criterion as tested by analysis of variance. The slight upward trend of scores during the first few approaches is significant only at a low level of confidence ($p<.10$).

Consistency of performance was examined by taking the difference between scores on successive

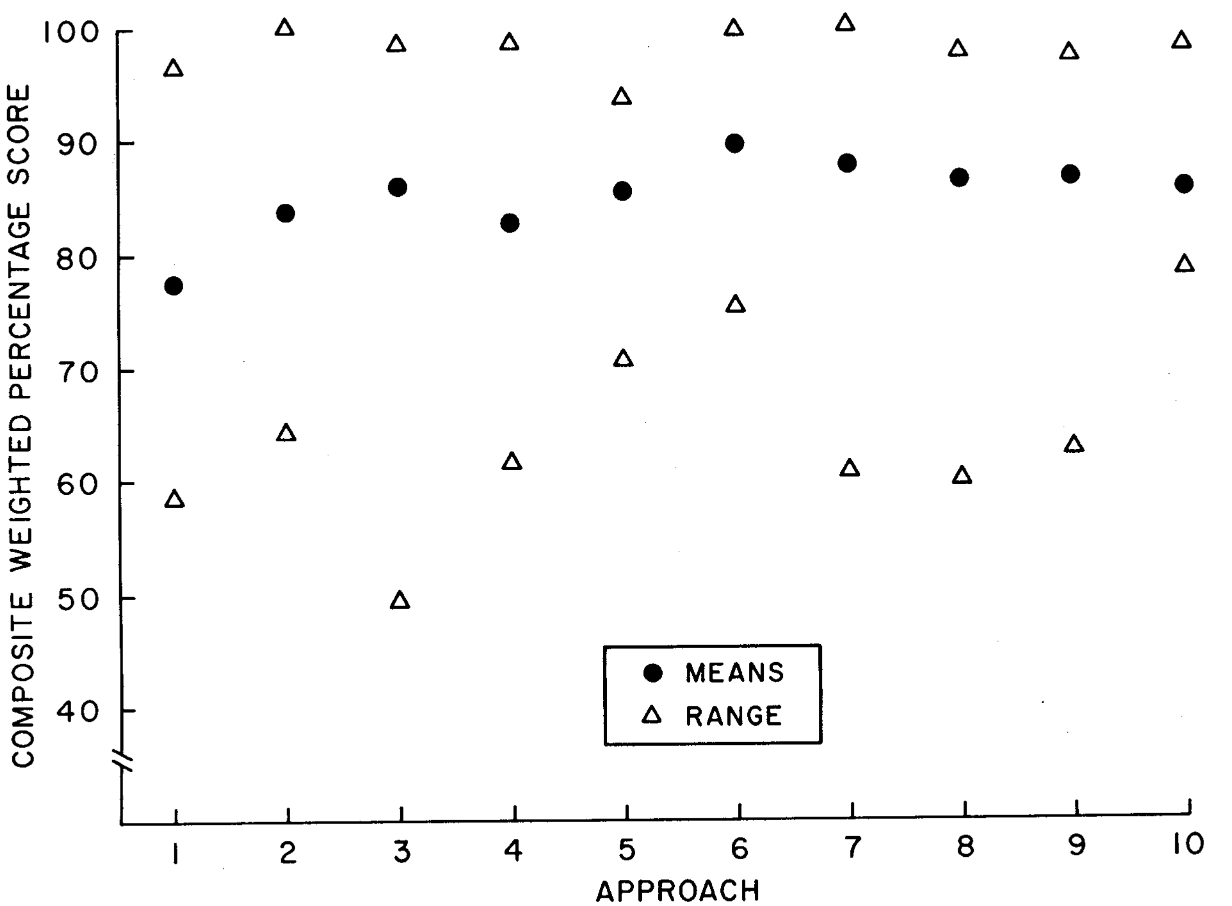


FIGURE 6. Means and ranges of weighted glide slope tracking scores.

approaches by the same subject. The means of these differences range from 2.2 to 17.3 percentage points. Individual difference scores range from zero to 36.2 percentage points. There are no significant differences among the comparison pairs as tested by analysis of variance but the trend of the scores is significant ($p<.05$).

(2) *Localizer Data.* The means and ranges of composite localizer tracking scores are presented in Figure 7. The means range from 82.1 to 94.4%. Individual scores range from 58.8 to 100.0%. The differences among approaches are statistically significant ($p<.01$) and the trend is essentially linear ($p<.005$). The analysis is summarized in Table 1.

TABLE 1.—Composite Weighted Localizer Tracking Scores

(Analysis of Variance)

Source	df	MS	F	P
Subjects	7	384.31		
Approaches	(9)	149.41	2.96	<.01
Linear	1	822.87	16.28	<.005
Quadratic	1	167.60	3.31	<.10
Other	7	50.60	1.00	
Error	63	50.56		
Total	79			

Consistency of performance was examined by the same method as the other scores. The means and maxima of the difference scores are presented in Figure 8. The means range from 2.8 to 13.3 percentage points. Individual difference scores range from zero to 30.1 percentage points. Differences among successive comparisons are significant ($p<.01$) and the trend is essentially linear. The analysis of variance is summarized in Table 2.

TABLE 2.—Consistency of Localizer Tracking on Successive Approaches
(Analysis of Variance)

Source	df	MS	F	P
Subjects	7	191.54		
Approach Pairs	(8)	112.68	3.26	<.01
Linear	1	409.22	11.83	<.01
Quadratic	1	3.31	.10	
Other	6	81.48	2.36	<.05
Error	56	34.58		
Total	71			

Maximum Deviations from Centerlines Withi Successive Segments of Approach

This performance measure examines the relative accuracy of glide slope and localizer tracking at various stages of the approach. Each approach was divided into ten equal time segment based on the transistion time between the oute and middle markers. The magnitudes of th maximum deviations from centerline during eac segment were used as the performance measure Unlike the procedure for the weighted trackin scores, the duration of the deviation was nc taken into consideration. Consistency by ir dividual subjects was not evaluated for th performance measure.

(1) *Glide Slope Data.* The means of tł maximum deviations from glide slope centerlir during successive segments of the approach, t gether with the ranges of the means for the ir dividual approaches, are presented in Figure Data for all approaches have been combined b cause the individual means all fall within relatively narrow range. The means of the max mum deviations within segments tend to be at near the equivalent of one "dot" during the fir half of each approach and then gradually increa to approximately twice that value as the midd marker is approached. With a few notable e ceptions, individual deviations by subjects tend to be fairly consistent. There were four instanc in which deviations exceeded four "dots" and o instance of an "off scale" (more than five "dots" deviation. There are no significant differenc among approaches with respect to this perforn ance measure. The differences among segmen however, are significant ($p<.001$). The analys is summarized in Table 3.

(2) *Localizer Data.* The means of the ma mum deviations from localizer centerline duri successive segments of the approaches, togeth with the ranges of means for all approaches, a presented in Figure 10. As with the glide slo data, results for all approaches have been co bined. The means tend to be less than t equivalent of one "dot" throughout most of t approach, but exhibit a gradual increase duri the last three segments before reaching t middle marker. Deviations by individual su jects of 3.0 "dots" or more occurred during of the 800 segments. A disproportionate numb

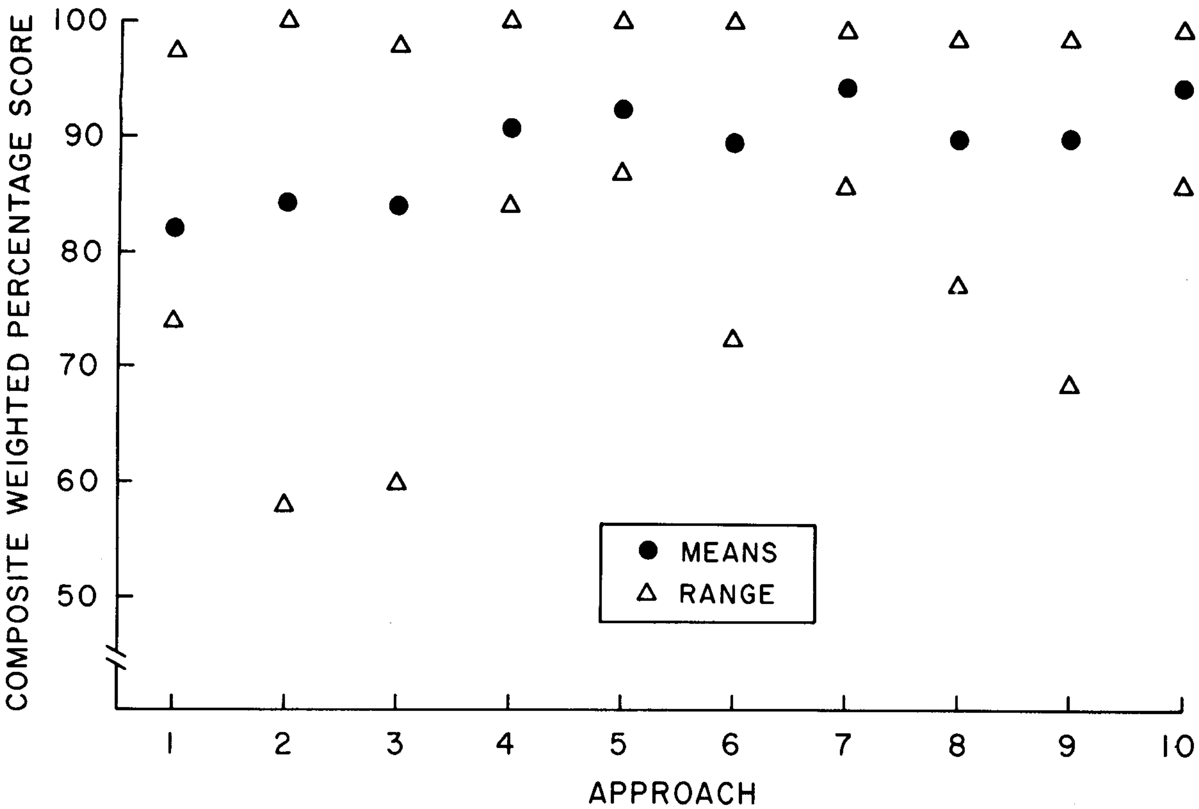


FIGURE 7. Means and ranges of weighted localizer tracking scores.

ıBLE 3.—Maximum Deviations from Glide Slope Centerline Within Successive Segments of Approach

(Analysis of Variance)

Source	df	MS	F	P
-Approaches	(9)	59.23	.63	
A—Lenear	1	104.50	1.11	
A—Quadratic	1	184.28	1.96	
A—Other	7	34.92	.37	
-Segments	(9)	1,032.26	17.18	<.001
B—Linear	1	7,011.21	116.68	<.001
B—Quadratic	1	2,140.20	35.62	<.001
B—Other	7	15.56	.26	
-Subjects	7	563.11		
A x B	81	27.18	1.09	
A x C	63	94.01		
B x C	63	60.09		
A x B x C	567	25.03		
Total	799			

these larger deviations were contributed dur- ; isolated instances where a single subject uld introduce a single large deviation over a :iod of several segments of a single approach. Differences among approaches are significant <.01) as are differences among segments (p<.001). There are no significant interactions between approaches and segments. The trend of both variables has a definite linear component. The analysis of variance is summarized in Table 4.

TABLE 4.—Maximum Deviations from Localizer Centerline Within Successive Segments of Approach

(Analysis of Variance)

Source	df	MS	F	P
A—Approaches	(9)	236.87	2.89	<.01
A—Linear	1	1,104.14	13.48	<.001
A—Quadratic	1	456.86	5.58	<.05
A—Other	7	80.26	.98	
B—Segments	(9)	493.01	7.51	<.001
B—Linear	1	2,269.81	34.58	<.001
B—Quadratic	1	1,821.69	27.76	<.001
B—Other	7	49.37	.75	
C—Subjects	7	729.27		
A x B	81	24.48	.79	
A x C	63	81.89		
B x C	63	65.63		
A x B x C	567	30.93		
Total	799			

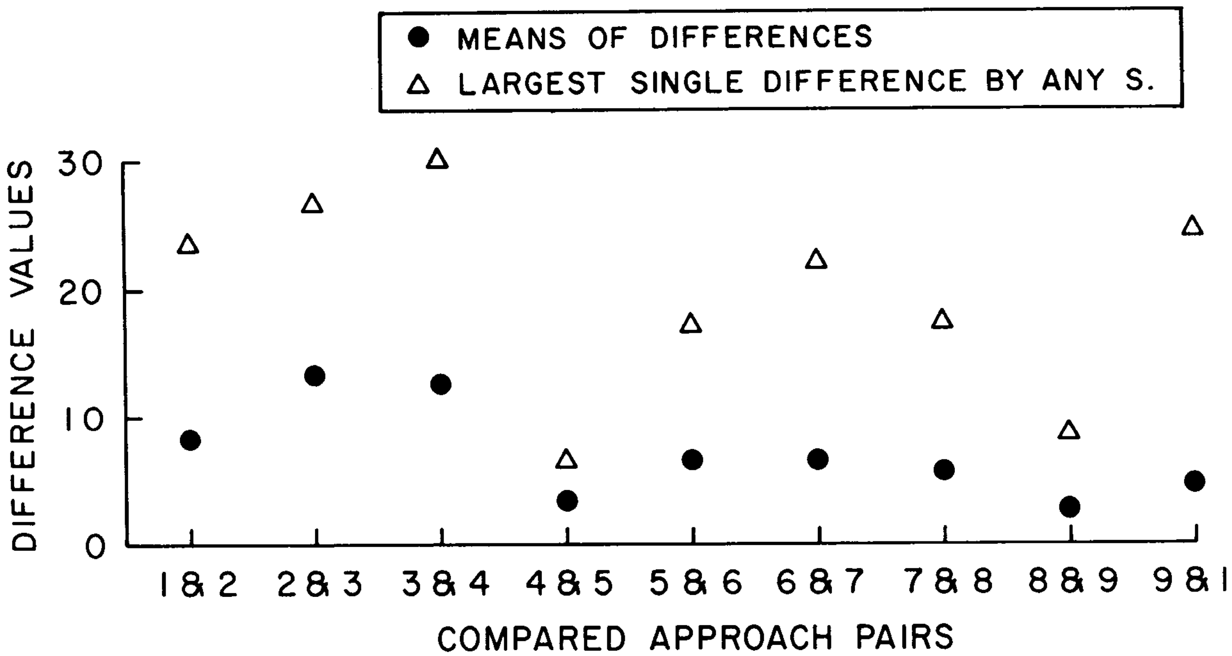


FIGURE 8. Means and maximum differences between weighted localizer tracking scores on sucessive approach€

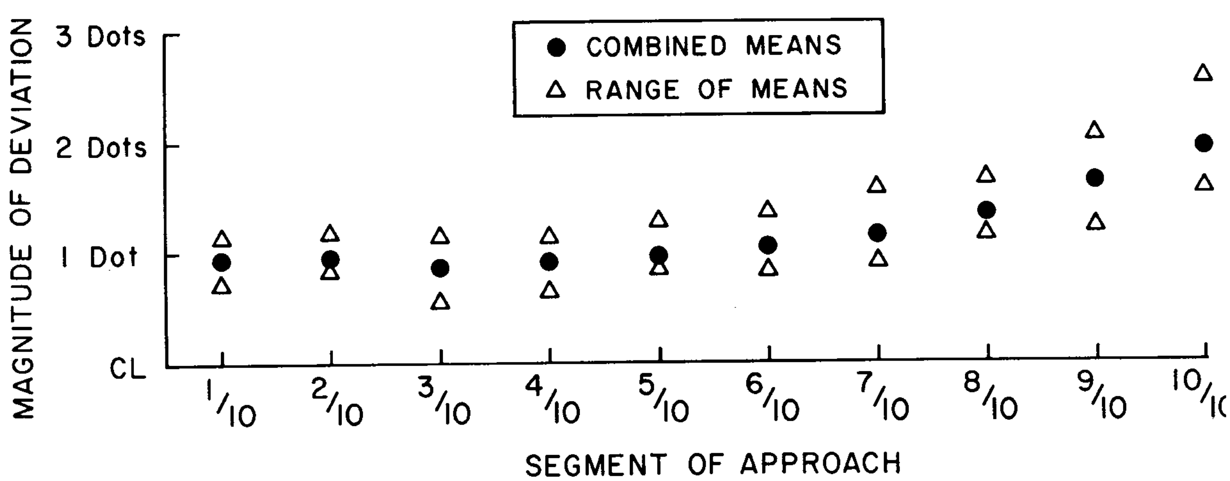
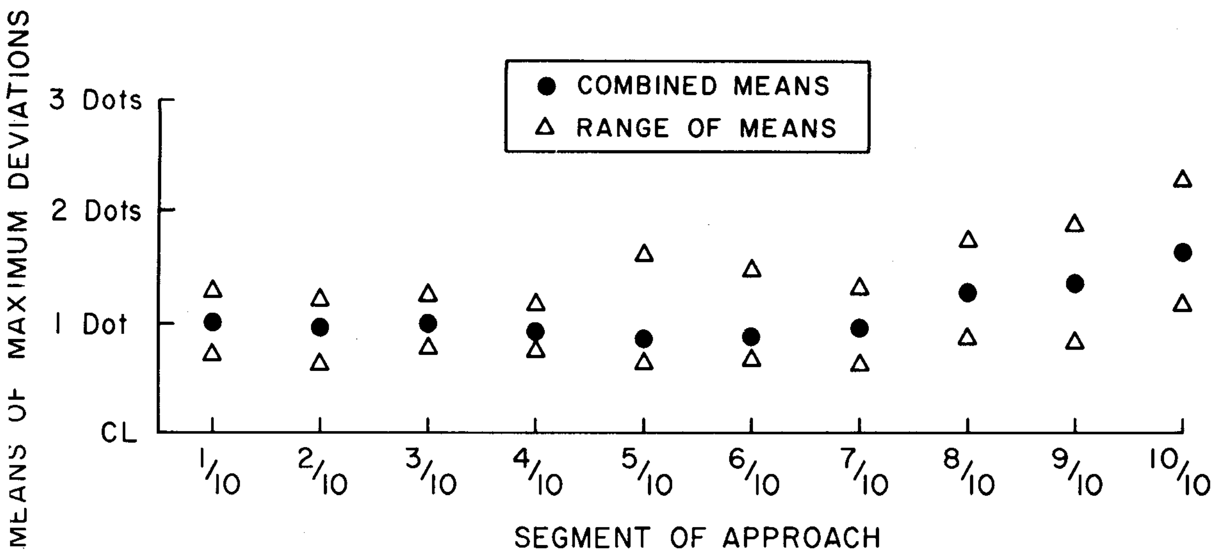


FIGURE 9. Combined means and range of means of maximum deviations from glide slope centerline during ten eq segments of the approaches.

IV. Discussion.

Probably the most significant finding resulting from this study is that there was practically no change in glide slope tracking performance as a function of the practice gained by the ten successive approaches. There was a small, but statistically significant, improvement in localizer tracking on two of the measures. This improvement may be attributed to increasing familiarity with the prevailing wind conditions, which turn made possible an earlier and more accur heading correction and thus tended to minim the effects of incipient localizer deviations. T result of this input would contribute more raising performance scores than to improvi basic tracking ability.

The lack of overall improvement was express not only in terms of unchanged tracking accura



·URE 10. Combined means and ranges of means of maximum deviations from localizer centerline during ten equal segments of the approaches.

: also by an undiminished variability in per- ·mance and the continuation of the instability the track during the last stages of the ap- ›ach. This evaluation does not deny the tistical significance of the differences reported some of the localizer performance scores, but her evaluates the magnitude of the improve- ıt as having little, if any, practical implica- ı from the standpoint of actual operational ›lications.

'here are several significant factors that may ·e been operating to limit the effects of prac- during the ten approaches. These may in- le, but are not necessarily limited to, one or ·e of the following: (1) the subjects initially ibited a high degree of tracking proficiency : left little room for improvement in terms increased overall accuracy; (2) system in- ›ility introduced by external variables such as eorological conditions; (3) lack of instruc- al input to the subject coupled with a limited wledge of results; (4) monotony or lack of ·ific motivation; (5) the subjects may have pted lower performance standards than they ɜ capable of attaining.

onsidering the performance data as a whole, ppears that, as a group, the subjects per- ıed at a relatively high degree of proficiency permitted only a very limited opportunity increased accuracy. This is perhaps best ·essed by the tracking accuracy reflected by the means of the maximum deviations from centerline illustrated in Figure 9 and Figure 10. This level of tracking performance appears to be somewhat better than that generally found during actual ILS approaches by pilots of comparable experience. Unfortunately, quantitative data are not available from actual instrument weather ILS approaches for comparison purposes. If the apparent differences are accepted as real, they are readily explained by the operational differences between the approaches flown as part of this study and those encountered during actual ILS approaches, i.e., the subjects were not required to read approach plates, conduct ATC communications, or to monitor power plant performance. The initiation of the approach by the safety pilot, and the subject's knowledge that the safety pilot had constant visual contact outside the aircraft, may also have had some effect on the subject's subsequent performance. This unburdening of the pilot permitted concentrated attention to the primary tracking task with an adequate margin of residual attention for airspeed and attitude control, which, subjectively judged, were adequately accomplished.

As indicated by the ranges for the respective performance measures, the extreme values that comprise the worst performance by any subject during a given approach, are well below the group mean. Though a disproportionate number of these data points were contributed by relatively few subjects, the latter by no means account for all of them. This aspect of individual performance is emphasized by the data comparing the differences on successive approaches by the same subject. The means of the differences are frequently equal to or greater than, the means of the absolute deviations from glide slope and localizer centerlines. This makes individual variability on the same order of magnitude as the absolute deviations. This variability would seem to indicate that a few instances of demonstrated proficiency may not be adequate to determine an individual's practical performance level. It is, after all, the occasional extreme deviation from an otherwise acceptable performance level that poses the greatest threat to the safety of the pilot and the aircraft.

The fact that the group as a whole did perform at a high level of proficiency in spite of the differences in total flying experience, would seem to call for a closer examination of the present standards and requirements of proficiency and currency. Such an evaluation cannot be made on the basis of the limited data reported here. However, considering that the present standards apparently have been established on less substantive evidence, it would appear that certain economies might be realized in initial and recurrent training if more accurate data were available to define the practical limits of performance imposed by the whole man-machine system. If, for example, the level of tracking accuracy exhibited in the present study can be accepted as an approximation of an optimal level, then training and performance standards should probably be more heavily weighted toward the management of the whole approach task, rather than toward increasing accuracy beyond a practical level. It may be that improvement in overall performance should be sought by somehow achieving a better degree of repeatability or predictability of successive performances.

Of particular interest, and not unexpectedly, there is a significant increase in tracking error, as measured by the maximum angular deviation from centerlines, during successive segments of the approach. This increase in tracking error occurs primarily during the last half of the approach between the outer and middle markers. This increase is only slightly larger for glide slope tracking error than for localizer error in terms of "dots" of deviation. This small difference in indicated tracking error is particular noteworthy in that the ratio of the beam widtl is such as to make the glide slope indicat roughly four times more sensitive with respect registering linear deviations of the same magr tude at any given point along the approac Absolute linear accuracy may actually impro even though the angular deviation increases the aircraft approaches the middle marker. Ho ever, the pilot is required to react more rapid to the angular deviations indicated by the cro pointer instrument in order to achieve the great degree of absolute linear accuracy required dı ing the last stage of the approach. Since the ra of indicated angular error to absolute linear (viation from centerlines is a constantly changi value as a function of the aircraft's progr along the approach, it is impossible for the pi to translate angular error to linear deviatic with any degree of practical usefulness. T deterioration in tracking accuracy as measu by angular deviation errors is, therefore, the sult of the increasing requirement for absol accuracy as measured by angular deviation. Sı demands impair the pilot's ability to maintai consistent track within the framework of the m machine system dynamics. This situation is f ther aggravated by the pacing stress imposed the pilot. His control inputs must be conti ously more rapid, but of a diminishing mag tude, to correct indicated deviations of a cc parable magnitude from centerlines dur successive segments of the approach.

Perhaps of the greatest practical significa is the tracking behavior exhibited during period immediately prior to reaching the mid marker. When we consider the instantane deviations from centerlines registered at middle marker, we have a rough indication the proximity of the aircraft to the desired fli path at a critical point in the approach, but s values do not reflect any indication of the bility of the track at that point in time. examining the period immediately prior to rea ing the middle marker (in this case arbitra set at thirty seconds) it is found that there often large excursions in glide slope deviati These excursions must be attributed to untim excessive, or inappropriate control inputs tended to correct what were actually relati minor tracking errors in terms of linear distar The excursions frequently appear as a sequ

›f oscillatory reversals that can best be inter- ›reted as indicating the aircraft was "getting ›head of the pilot". Such a condition occurs vhen proper control actions lag far enough be- ıind the appropriate point in time to be no longer ›pplicable and to become potentially inappro- ›riate. Though the mean values of these excur- ions are equivalent to less than three "dots", a ›umber of individual instances of more than five dots" (and one spanning more than seven "dots") vere recorded. Many of these occurred over a eriod of only a few seconds, indicating rapid ut excessive attempts at correction. Though ıch control actions never caused a serious threat › adequate control of the aircraft, they are ıdicative of an inadequate control-display rela- onship with respect to the dynamic character- tics of the system and the ability of the human ɔerator to respond reliably with a high degree f precision. It is not improbable to speculate ıat it would be possible for the pilot of a high ɜrformance aircraft to introduce such excessive ›cillatory control inputs that the aircraft might › forced outside its acceptable performance ıvelope with potentially serious consequences.

Considering that performance measures were fectively limited to glide slope and localizer acking, it is possible that less obvious practice fects did in fact occur, but were not recorded otherwise observed. One possibility is that ther than being reflected as a performance ange in a relatively consistent and controlled uation, the added practice on the tracking task ıy have resulted in an increase in residual atten- ›n. Such an increase could make it possible r the pilot to deal more effectively with the cillary sub-tasks that comprise the total ILS proach or to handle the added demands of an ıergency condition. There are no direct per- rmance data to support this possibility, but ırt-rate data on the subjects which have been ɔorted elsewhere[3] may be suggestive of this. ıe mean heart rate for the group of subjects ɔlined significantly as a function of the number approaches flown. This has been interpreted indicate a reduction of anxiety-induced stress. ›wever, if a relatively low degree of residual ention in the performance of a task can be epted as being stress-inducing, and conversely, an increase in residual attention is, therefore, ely to result in a reduction in stress, it is pos- le that the reduction in heart rate may in part be due to an increasing residual attention resulting from extended practice. If further investigation were to verify this assumption, it would support the desirability, stated earlier, for reevaluating the criteria for proficiency and currency.

V. Summary and Conclusions.

There were few significant changes in tracking behavior as a result of the practice on ten successive approaches flown under the conditions of this study. Whether this overall lack of change was due to an artificial performance ceiling attributable to an initially high proficiency level, or whether the practice effects were limited by system characteristics, cannot be determined by the present data. It is suggested that a number of complex and interrelated factors may be operating.

It appears that the difficulties encountered in performing an ILS approach with a high degree of precision are related only in part to the difficulty of the tracking task involved in following the glide slope and localizer centerlines to the middle marker. Under optimized conditions, this task can apparently be accomplished with a relatively high degree of precision even though certain undesirable tracking characteristics remain operative. Under actual ILS conditions, the main difficulty may be associated with the pacing stress introduced by ancillary activities that must be performed, as well as by the psychological stress experienced by the pilot. This would suggest that once an acceptable level of tracking proficiency has been attained, further improvement of the whole task should perhaps be sought in exercising the management and allocation of attention to the component tasks.

Though the conventional crosspointer instrument can be considered generally adequate for most of the approach there appears to be an inherent deficiency in the control display ratio and relationship with respect to the requirements for rapid and precise control adjustments at the most critical stage of the approach at the middle marker.

Individual variability by subjects on successive approaches raises the question of what constitutes an adequate criterion for an acceptable level of performance. Further study will be required to determine suitable methods for increasing consistency of performance.

REFERENCES

1. Airman's Information Manual, Part 1. Basic Flight Manual and ATC Procedures. Department of Transportation, Federal Aviation Administration. Government Printing Office, Washington, D.C. (current issue date).
2. Fox, J. G., I. Ferguson and I. D. C. Andrews: An Annotated Bibliography of Presentation of Information in Aircraft Cockpits, S & H Memo 3/66, p. 77–78. Technical Information and Library Services, Ministry of Aviation, England, May 1966. (Available as AD 634575).
3. Hasbrook, A. H. and P. G. Rasmussen: Pilot Heart Rate During In-Flight Simulated Instrument Approaches in a General Aviation Aircraft. FAA Office of Aviation Medicine Report No. AM–70–7, Oklahoma City, Oklahoma, April 1970.
4. Hasbrook, A. H. and P. G. Rasmussen: Aural Glide Slope Cues: Their Effects on Pilot Performances During In-Flight Simulated ILS Instrument Approaches FAA Office of Aviation Medicine Report No. AM–71–24 Oklahoma City, Oklahoma, May 1971.
5. Instrument Flying Handbook AC–61–27A. Depart ment of Transportation, Federal Aviation Administra tion. Government Printing Office, Washington, D.C 1968.
6. Povenmire, H. K., K. M. Alvares and D. L. Damos Observer-Observer Flight Check Reliability. Technica Report LF–70–2. Aviation Research Laboratory, In stitute of Aviation, University of Illinois. Octobe 1970.
7. Williams, A. C., Jr., M. Adelson and M. L. Ritchie A Program of Human Factors Engineering Researc on the Design of Aircraft Instrument Displays an Controls. WADC Technical Report 56–526, Wrigh Air Development Center, WPAFB, Ohio. Decembe 1956. (Available as AD 110424.)

22477