National Research Council

Committee on Selection and Training of Aircraft Pilots

Executive Subcommittee

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LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

2101 Constitution Avenue, Washington, D. C.
Division of Anthropology and Psychology

Committee on Selection and Training of Aircraft Pilots

February 12, 1946

Dr. Dean R. Brimhall
Asst. to Administrator for Research
Civil Aeronautics Administration
Room 3895, Commerce Building
Washington 25, D. C.

Dear Dr. Brimhall:

Attached is a report entitled A Study of Individual Differences Among Flight Instructors in Making Spot Landings by R. Y. Walker, S. V. Bennett, and E. S. Ewart. This report is submitted by the Committee on Selection and Training of Aircraft Pilots with the recommendation that it be included in the series of Technical Reports issued by the Division of Research, Civil Aeronautics Administration.

The study described in this report was in a large sense the outcome of your interest in the data pointing to consistent differences among transport pilots with respect to the portion of the runway used in landing a plane reported in a study by the Technical Development Section, Civil Aeronautics Administration. While the present study of individual differences among experienced pilots in the execution of "spot" landings is preliminary in character, it nevertheless indicates an area of investigation which can produce extremely practical and useful results in relation to the determination of flight examination standards by the Civil Aeronautics Administration.

Cordially yours,

M S Viteles

Morris S. Viteles, Chairman
Committee on Selection and
Training of Aircraft Pilots
National Research Council

MSV:rm

EDITORIAL FOREWORD

Every day observation has given rise to the belief that there are wide differences among even skilled pilots in the performance of maneuvers required for the certification of pilots. Experimental evidence to this effect appears in a number of studies conducted by the Committee on Selection and Training of Aircraft Pilots.[1] Further indications to this effect are found in an investigation conducted by the Technical Development Section, Civil Aeronautics Administration, which provides data pointing to consistent differences among transport pilots with respect to the portion of the runway used in landing a plane.[2]

Such observations are at the background of the experiment described in the attached report involving a study of individual differences among experienced pilots in making precision or "spot" landings under a variety of conditions. It is believed that the results from such experiments can have important practical implications in determining the conditions which should be imposed in formulating standards for the performance of maneuvers in the flight examination.

The experiment was exploratory in character and involved only a few subjects. For this reason alone the results and the conclusions stated in the report must be viewed as tentative in character. In addition, the experimental flights were made in a plane which was somewhat heavier than those to which the pilots (flight instructors with more than one thousand hours of instructional experience) were accustomed. This increase in weight resulted from the fact that the criterion plane included experimental apparatus not found in the planes in which the pilots were giving

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[1] Viteles, M. S., and Thompson, A. S. The use of standard flights and motion photography in the analysis of aircraft pilot performance. Washington, D. C.: CAA Division of Research, Report No. 15, May 1943.

Viteles, M. S., and Thompson, A. S. An analysis of photographic records of aircraft pilot performance. Washington, D. C.: CAA Division of Research, Report No. 31, July 1944.

Viteles, M. S., and Backstrom, O., Jr. An analysis of graphic records of pilot performance obtained by means of the R-S Ride Recorder, Part I. Washington, D. C.: CAA Division of Research, Report No. 23, November 1943.

Backstrom, O., Jr., and Viteles, M. S. An analysis of graphic records of pilot performance obtained by means of the R-S Ride Recorder, Part II. Washington, D. C.: CAA Division of Research, Report No. 55, January 1946.

McFarland, R. A., and Holway, A. H. The measurement of flight performance in relation to piloting. Progress report in the files of the Committee. March 1942.

[2] Morse, A. L. The correlation of aircraft take-off and landing characteristics with airport size. Washington, D. C.: U. S. Department of Commerce, Civil Aeronautics Administration. Technical Development Report No. 40, April 1944.

instruction from day to day. It is difficult to evaluate the limitations placed upon the findings and conclusions from the use of this heavier plane. It should be noted that the same plane was used in the comparison of two sets of conditions identified as "Trick" and "No Trick," under which precision landings were made. Nevertheless, it may be that, in view of the change in flight characteristics associated with overloading, the results obtained may reflect individual differences among instructors in quickly adapting to the overloaded plane as well as differences inherent in the performance of a precision or "spot" landing.

In spite of such limitations it is of interest to observe that statistically significant individual differences appeared in the accuracy with which precision landings were executed under the more restricted set of conditions ("No Tricks") while significant individual differences in accuracy did not occur under the less restricted conditions ("Tricks") and that the incidence of overshooting and undershooting was markedly greater during the landings executed under the former conditions. While such observations cannot be accepted as final, they are nevertheless of interest in relation to the restrictions actually imposed by the Civil Aeronautics Administration in defining standards for "spot" landings and in pointing to the desirability of further investigations in this and related areas.

The study was designed by the staff of the Institute of Aviation Psychology, University of Tennessee, Knoxville, Tennessee, in cooperation with the staff of the Chairman, National Research Council Committee on Selection and Training of Aircraft Pilots, with the assistance of Dr. P. J. Rulon, Harvard University, a member of the Executive Subcommittee. The field work was carried on at the Institute of Aviation Psychology, University of Tennessee, under the direction of R. Y. Walker. The statistical analysis was made by the staff of the Committee's Statistical Unit, University of Rochester, under the direction of S. Wapner.

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SUMMARY

Precision, or "spot" landings, are generally considered to be an important item of the flight test. An investigation of individual differences among experienced pilots in the execution of precision landings can have important implications in assessing the conditions and restrictions imposed upon the pilot in this part of the flight test.

The present study, utilizing only five pilots, represents a preliminary investigation of individual differences among skilled pilots in making "spot" landings. A series of four experimental flights, consisting of take-offs and precision landings, were made by five experienced flight instructors in a specially equipped Piper Cub J-3 plane. Each subject made two series of flights: the first series "Without Tricks," during which slipping, "mushing" or other methods of altering the gliding angle of the plane were not allowed; and the second series with "Tricks Allowed," during which any procedure to increase the accuracy of the landing, within the limits of safe flying, was allowed except the use of additional throttle. The "Tricks Allowed" condition resembles the situation under which precision landings are executed in the present private flight tests in that intentional slips were permitted.

During these experimental flights data were gathered on a number of measures associated with flight proficiency. A number of these measures, in particular those obtained from the Ohio State Flight Inventory and from motion photographs taken of a concealed instrument panel, were relatively objective in nature. The data were analyzed by analysis of variance procedures.

The most important practical implications of this study are summarized as follows:

1. The results cast doubt upon the advisability of the restrictions against intentional slipping during precision landings which have been in force until recently in the private pilot's flight examination, since under the "No Tricks" condition skilled pilots proved both extremely variable and inaccurate in their execution of this maneuver. Under the condition of "Tricks Allowed" marked decrease in variability of performance and an increase in accuracy of the landings were evident.

2. In spite of the emphasis on maintaining the "normal glide" under the "No Tricks" condition significant individual differences among instructors were evident in the terms of Range of Airspeed during the approach glide. Significant differenses among instructors were also evident in terms of variability of Mean Airspeed during the approach glide over the four flights. This indicates that the "normal" gliding speed varied significantly more from flight to flight in the case of certain instructors than in the case of others.

While this experiment cannot be considered definitive, the results indicate the desirability of further and more elaborate investigation of individual differences in the performance of pilots. The results of such investigations would have important practical implications in reference to the realistic nature of specific flight test requirements.

A STUDY OF INDIVIDUAL DIFFERENCES AMONG FLIGHT INSTRUCTORS IN MAKING SPOT LANDINGS

INTRODUCTION

Precision, or "spot" landings, are an important part of the flight examination. The applicant for the flight instructor's rating is required to land the plane within a specified area 200 feet square, or more frequently within a specified section of the runway 200 feet in length. For the private pilot's license the landing must be made within an area 300 feet square. Until recently the pilot was required to maintain a constant and proper gliding speed throughout the approach and was not allowed to slip the plane intentionally in order to increase the accuracy of his landing. Recently, however, in the case of the private pilot flight test the restrictions have been eased and intentional slipping of the plane is allowed.[1]

Strictly interpreted, CAA regulations require that a pilot who fails any maneuver in the flight test be given a failing grade for the test as a whole, irrespective of the excellence of his performance in other maneuvers. In many cases this limitation has been most rigidly applied to precision landings. Because of this fact, and because of the rather stringent requirements which have been set up for this maneuver, it might be expected that the performances of skilled and experienced pilots in executing precision landings would have become standardized. For these reasons a study of individual differences in performance among skilled pilots in the execution of precision landings is of considerable importance.

The present study, utilizing only five pilots, represents a preliminary investigation of individual differences among experienced pilots in executing precision landings under two conditions: (1) in which slipping, "mushing" or other methods of altering the gliding angle in order to increase the accuracy of the landing were not allowed, and (2) in which no such restrictions were imposed, except the requirements that a three-point full stall landing be made at or beyond the designated point, that the use of throttle be prohibited, and that the limits of safe flying should not be exceeded. The second set of conditions, outlined above, resembles the restrictions under which precision landings are executed in the present private flight tests in that intentional slips were permitted.

It is recognized that definitive conclusions cannot be drawn solely on the basis of the determination of individual differences exhibited in terms of the several criterion measures. If significant differences between pilots are not found, due to the small number of cases in the present study it cannot be concluded that such individual differences of

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[1]These restrictions were in force at the time this experiment was designed.

necessity would not have been significant had the number of cases been larger. Furthermore, if significant differences are found the necessity of establishing norms remains. Nevertheless, the investigation of individual differences among the pilots serving as subjects in this experiment is a necessary basis from which subsequent procedures and recommendations can develop.

PROBLEM

The nature of the problem to be examined in this experiment may be stated in the form of the following null hypothesis, viz.:

> There are no significant differences in performance of spot landings among experienced pilots in terms of criterion measures designed to reveal accuracy of landing, vertical acceleration developed during landing, angle of attack at time of contact with ground, magnitude and constancy of airspeed, and certain qualitative aspects of performance.

Data gathered under the "Without Tricks" and the "With Tricks" situations were evaluated separately in terms of this hypothesis.

SUBJECTS

The subjects in this investigation were the five regular flight instructors employed at the Institute of Aviation Psychology, University of Tennessee, Knoxville, Tennessee. These men all held flight instructor ratings, and were all experienced flight instructors, each subject having logged in excess of 1000 hours instructional time.

PLANES

All flights were conducted in one airplane, a Piper J-3 Cub, powered by a Continental 65 horsepower motor. Although the recent instructional experience of the subjects had been in J-3 Cubs, the plane used in the experiment was somewhat heavier than the J-3 Cubs the subjects had been used to flying because of the inclusion in the plane of certain criterion apparatus (described below) used in collection of data for this study. The inclusion of this apparatus did not alter the center of gravity of the plane, however.

CRITERION FORMS AND APPARATUS

<u>Ohio State Flight Inventory</u>. The performance of the pilot subjects was recorded by the check pilot on the sheets for "Gliding Turn" and

"Landing" taken from the Ohio State Flight Inventory.[2] (See Appendix 1.)

Vertical Accelerometer. A Vertical Accelerometer was mounted in the front instrument panel of the plane. This instrument was used to determine the maximum vertical acceleration resulting from contact with the ground on landing, thus furnishing a measure of the smoothness of the landing.

Photographic Unit. The Photographic Unit, which was mounted behind the rear seat of the plane consisted of a concealed instrument panel, and a motion-picture camera by means of which photographic records of the instruments in the panel were taken.[3] The camera was controlled (turned off and on) by the check pilot. The following instruments were included in the panel:

1. Artificial horizon
2. Ball-bank indicator
3. Rate of turn
4. Tachometer
5. Airspeed indicator
6. Sensitive altimeter
7. Kollsman angle-of-attack indicator (the external apparatus for this instrument was attached to the right wing at the strut roots).
8. Control indicator, in terms of which the position of throttle, elevator, rudder, and aileron were represented on a linear scale.
9. Sweep second clock

[2]The Ohio State Flight Inventory is composed of a series of check-sheets in terms of which the performance of a pilot on given maneuvers can be rapidly and conveniently recorded by the check pilot. See: Edgerton, Harold A., and Walker, Robert Y. History and development of the Ohio State Flight Inventory, Part I: Early versions and basic research. Washington, D. C.: CAA Division of Research, Report No. 47, July 1945. NRC Committee on Selection and Training of Aircraft Pilots: History and development of the Ohio State Flight Inventory, Part II: Recent versions and current applications. Washington, D. C.: CAA Division of Research, Report No. 51, November 1945.

[3]For details of the photographic installation, see: Viteles, Morris S., and Thompson, Albert S. An analysis of photographic records of aircraft pilot performance. Washington, D. C.: CAA Division of Research, Report No. 31, July 1944.

Runway Marker. A dauber was attached to an arm, which was hinged to the landing gear of the plane. The arm was retractable during taxiing and while taking off, but could be lowered during the approach to landing. The dauber, which was covered with blue chalk, marked the point on the runway at which the plane landed.

ADMINISTRATION OF EXPERIMENTAL FLIGHTS

Administrative Personnel. Experimental flights were administered by two check pilots, who operated the photographic unit and recorded the required data on the Ohio State Flight Inventory. The specific duties of the check pilots are outlined in Appendix 2. Two field assistants measured the distance between the point at which the plane landed, as marked by the runway marker, and the designated "spot" on the runway[4] in terms of which the accuracy landings were to be made. Other administrative personnel included a research assistant who collected the data sheets, serviced the camera, etc., and the men who serviced and maintained the experimental plane.

Procedure. Check flights were administered only under wind velocity conditions of less than 10 miles per hour, and when less than 15° of cross-wind prevailed. However, if the wind velocity was less than 5 m.p.h. this latter condition was ignored. The series of "With Tricks" and "Without Tricks" landings, respectively, were executed on different days. The same administrative procedures were followed in both parts of the experiment. The experimental flights consisted of take-offs, followed by 180° rectangular approaches to precision landings. In both parts of the experiment each subject made one practice flight during which no criterion measures were taken followed by a series of four experimental flights during which all criterion measures were taken. The two check pilots alternated on successive flights with each subject, including the practice flight. The subject flew the plane from the front seat, the check pilot sitting in the rear seat. (The subjects were flight instructors who were used to flying from the front seat.)

As indicated in the Directions to the Subject (see Appendix 3), the subjects were directed, in executing the 180° rectangular approach, to close the throttle directly opposite the spot, at 800 feet altitude. They were directed to make a full stall, three-point landing at, or as close as possible beyond, the designated "spot."

Under the condition of "No Tricks" the subject was instructed that the correct gliding speed was to be maintained, and that the only adjustment he would be allowed to make in order to alter his point of landing was to "play the turn," i.e., to increase or decrease his rate of turn on the last turn into the field. Other devices such as slipping, going beyond the wind line, "fishtailing," "mushing" or diving were not allowed.

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[4]The spot consisted of a 24-inch yellow strip across the runway, at right angles to the edges of the runway, 600 feet from the downwind end.

Under the condition of "Tricks Allowed" the subject was instructed that with the exception of use of additional throttle, he could employ any procedure he desired (within the limits of safe flying) to increase the accuracy of his landing.

CRITERION MEASURES

The following criterion measures were obtained from the several instruments and criterion forms.

1. The distance from the designated "spot" at which a full-stall three-point landing was made. Distances measured (in feet) on the far side of the designated spot were recorded as positive quantities. Distances on the near side (i.e., if the pilot landed "short") were recorded as negative quantities.

2. The maximum vertical acceleration (in G's) developed during the landing.

3. Angle of attack at time of contact with the ground. This yielded a measure of the degree to which the plane was fully stalled at landing.

4. Range of airspeed during that part of the approach beginning at the completion of the recovery from the turn into the crosswind leg, and ending at an altitude of 100 feet above the ground. Range was defined as the difference between maximum and minimum airspeed readings during this period, as determined from the photographic records. This variable represented a measure of the pilot's ability to maintain a constant airspeed during the approach, one of the requirements for the instructor's rating.

5. Average airspeed during that part of the approach defined in 4 above. This measure was obtained from readings of the photographic records, taken at two second intervals, and indicated whether or not the pilot's gliding speed was optimal.

6. The Ohio State Flight Inventory summation score, represented by the summation of the item weights of items marked by the check pilots on the [illegible] sheets for "Gliding Turns" and "Landings."[5]

7. A "corrected" Flight Inventory summation score, in which items dealing with slips or skids were ignored in the summation. This score was used in view of the fact that in the second half of the experiment intentional slipping was allowed.

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[5]In terms of this scoring system each item in the Ohio State Flight Inventory is given a unit weight; a weight of -1 if an error in performance is indicated, a weight of +1 if satisfactory performance is indicated by the [illegible]

8. An over-all grade for the complete maneuver, representing the check pilot's general evaluation of the subject's performance in terms of the standards of performance for the instructor's rating which applied.

9. The degree of slip and skid in turns, and duration of slips or skids. This item represented primarily a control variable to determine whether or not the subject slipped markedly during the turn into the field in order to lose altitude rapidly, thereby correcting for overshooting.

10. Time to complete final turn into field. This value was obtained in the course of determining the percentage of the final turn during which slips occurred, and was included as a criterion variable only because of the insight it might furnish in regard to individual differences in performance.

RESULTS

Data collected under the "No Tricks" and "Tricks Allowed" conditions were treated separately by an analysis of variance technique.[6] The scores of subjects on all of the criterion measures are given in Appendices 5 and 6, for the "Tricks" and "No Tricks" parts of the experiment, respectively. The individual means and standard deviations of the criterion measures for each subject are included in Appendix 7. In Table 1 are presented the mean scores in terms of each criterion measure, and the range of each criterion score as determined from the pooled data from all subjects.

Comparability of Instructors in Terms of Variability of Performance. The "L" test[7] was used as a measure of the homogeneity of variance, i.e., to determine if the variability of performance on the four landings was constant from subject to subject, or varied from subject to subject more than could be attributed to chance. The results of the "L" test are summarized in the first and third columns of figures in Table 2.

It will be noted that if a value for "L" of .491 or less is obtained the hypothesis of comparable variability (homogeneity of vari-

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[6]The particular analysis of variance procedures used in this investigation were derived by Dr. P. J. Rulon, Harvard University, a member of the Executive Subcommittee of the Committee on Selection and Training of Aircraft Pilots. This derivation is presented as Appendix 4 to this report.

[7]See Appendix 4. See also: Jackson, R. W. B., Applications of analysis of variance and covariance to educational and psychological research. Toronto Education Bulletin No. 11, 1940, p. 103.

TABLE 1

MEANS AND RANGES OF CRITERION MEASURES

	No Tricks		Tricks	
Criterion	M	Range	M	Range
Distance from spot	+107.8'*	-258' to 441'	+7.1*	-249' to 155'
Number of G's	2.07	1.6 - 2.8	1.98	1.4 - 3.0
Angle of attack	28.3 *	25.5 - 29.5	17.2*	13.5 - 22.0
Variability in airspeed (m.p.h.)	8.5	5 - 16	11.4	5.0 - 18.0
Mean airspeed (m.p.h.)	62.4	58.0 - 64.1	61.6	57.9 - 67.1
OSFI uncorrected score	13.2	-3 - 26	14.2	-1 to 24
OSFI corrected score	10.4	-2 - 19	12.9	6 to 19
Over-all grade	75.0	60 - 100	83.3	60 - 95
Seconds to complete turn	18.6	11 - 22	20.4	10 - 32
Per cent of slipping (any degree)	60	18 - 100	71	14 - 100

***The actual means of the measurements of "Distance from Spot" and "Angle of Attack" under the two experimental situations are not directly comparable since the adjustments of the angle-of-attack indicator and the runway marker were not the same under the two conditions (see page 12 ff.).**

TABLE 2

SIGNIFICANCE OF INDIVIDUAL DIFFERENCES AMONG INSTRUCTORS IN MAKING SPOT LANDINGS

	No Tricks		Tricks Allowed	
Criterion	"L" Test***	"F" Test	"L" Test	"F" Test
Distance from spot	.464	----	.711	2.24
Number of G's	.739	1.[illegible]	.451	----
Angle of attack	.786	1.63	.972	2.55
Range of airspeed	.895	8.[illegible]**	.697	6.32**
Mean airspeed	.369	----	.727	8.08**
OSFI uncorrected score	.724	5.66**	.917	2.36
OSFI corrected score	.816	3.59*	.885	3.84*
Over-all grade	.290	----	.596	1.06
Seconds to complete turn	.722	6.80**	.960	2.25

*Denotes "F" significant at between the 5% and 1% levels of confidence.

**Denotes "F" significant at lower than the 1% level of confidence.

***L values of less than [illegible]9 indicate that variance within pilots is not constant, i.e., that differences (significant at the 5% level of confidence) exist between pilots in terms of variability of performance.

ance) can be rejected at the 5% level of confidence, i.e., there can be considered to be 5 or less chances in 100 that the differences in variability, or consistency of performance among the five instructors are attributable to chance. Examination of Table 2 indicates that under the condition of "No Tricks" values of less than .491 are obtained for (1) Distance from Spot, (2) Average Airspeed, and (3) Over-all Grade. Under the condition of "Tricks Allowed" a value of less than .491 was obtained for the variable "Number of G's (vertical acceleration) produced by landing."

It is of interest that in terms of the various criterion measures there was a greater incidence of individual differences in variability of performance under the restricted condition of "No Tricks" than under "Tricks Allowed." It is particularly noteworthy that such individual differences were evident in terms of the measure of accuracy of landing, probably the most critical of the measures, as well as in terms of "Over-all Grade" which was largely a function of the accuracy of the landing. Under the unrestricted conditions, "Tricks Allowed," the only significant difference in variability was in terms of the number of G's developed during the landing. This might be accounted for by the different methods used by the instructors on the various trials to increase the accuracy of their landings.

<u>Examination of Individual Differences in Mean Performance Between Subjects</u>. The "F" test was used in determining the significance of individual differences in mean performance, each criterion measure being treated separately. The results of the "F" test are presented in the second and fourth columns of figures in Table 2.[8] Examination of this table indicates that under the "No Tricks" condition significant individual differences among instructors were evident in terms of (1) Range of Airspeed, (2) Ohio State Flight Inventory scores, and (3) "Number of seconds required to complete the final turn." With the exception of the Ohio State Flight Inventory corrected score the "F" statistic for these measures was significant at less than the 1% level of confidence, indicating that such individual differences as these could be expected to occur by chance in comparable samples less than 1% of the time. For the variable "OSFI corrected score" the "F" statistic was significant at the 5% level.

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[8]It will be noted that the "F" statistic is not presented for the variables "Distance from the Spot," Mean Airspeed, and Over-all Grade under the "No Tricks" condition, and for "Number of G's" under the "Tricks Allowed" condition. One of the assumptions on which use of the "F" test is predicated is homogeneity of variance. The "L" test, previously applied, indicated that for these criteria this assumption was not satisfied, i.e., in terms of these variables significant differences in variability of performance among instructors existed. Although rendering the use of the "F" test invalid, the demonstration of significant differences in variability represents a positive finding in itself, as indicated above.

Under the "Tricks Allowed" condition significant individual differences between instructors in mean performance were evident in terms of (1) Range of Airspeed, (2) Mean Airspeed, and (3) Ohio State Flight Inventory corrected score. The "F" statistic was significant at the 1% level of confidence for Mean Airspeed and Range of Airspeed, and at the 5% level of confidence for the OSFI corrected score.[9]

Under the "Tricks Allowed" condition certain procedures used to increase the accuracy of landing might well involve flying at airspeeds other than required for the "normal glide." Therefore the finding of individual differences in Mean Airspeed, and in Range of Airspeed during flights conducted under unrestricted conditions is not surprising. However, for flights conducted under the more restricted "No Tricks" condition emphasis was placed on maintaining the normal glide. For this reason the fact that significant individual differences were found both in Mean Airspeed and in Range of Airspeed during the approach to landing is noteworthy.

Examination of Criterion Measures for which Individual Differences were Evident Under Both Experimental Conditions. The practical significance of the demonstrable individual differences will be dealt with more thoroughly under the detailed discussion of individual criterion measures, following. However, brief attention should be given to the question of individual differences between instructors in terms of variability of performance, and in mean performance, considered together.

Examination of Table 2 indicates that under both "No Tricks" and "Tricks Allowed" conditions significant individual differences (either in mean performance or variability of performance) were evident for (1) Range of Airspeed, (2) Average Airspeed during approach glide, and (3) the Ohio State Flight Inventory corrected score. As noted above, the demonstration of significant individual differences in terms of airspeed under the "No Tricks" condition is of interest. Under the "No Tricks" condition, but not under the "Tricks Allowed" condition, significant individual differences were evident in terms of (1) Distance from the Spot at which the landing was made, (2) OSFI uncorrected score, and (3) Over-all grade. The presence of significant individual differences in these critical measures, particularly Distance from the Spot and Over-all grade, is of importance. Under the "Tricks Allowed" condition, but not under "No Tricks" significant individual differences

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[9] In considering the significance of individual differences as indicated by the "F" test, as well as the "L" test, it should be remembered that the fact that in this study significant differences in terms of specific criterion measures are not shown to exist does not indicate that such individual differences might not be evident if a larger study utilizing a greater number of subjects were carried on. The significant differences, either in variability of performance or in mean performance, that are demonstrated are of importance, however, because of the fact that they were evident in spite of the few number of cases.

were evident only in terms of "Number of G's produced by landing." As noted previously, this may be considered to reflect the various methods used at different times by given instructors under the "Tricks Allowed" condition to increase the accuracy of their landing.

Other Sources of Variance. The primary concern in this study has been the investigation of variations in performance attributable to individual differences among the flight instructors who served as subjects. However, it should be noted that as a byproduct of this principle analysis it was possible to investigate whether variations in pilot performance occurred which were (1) attributable to the observer or check pilot with whom the flight was made, and (2) attributable to whether the trial represented the first or second flight with a given observer. For both "Tricks Allowed" and "No Tricks" flights such analysis indicated that in terms of the Ohio State Flight Inventory scores, corrected and uncorrected, variance in scores attributable to the observer was significant at the 1% level. It can thus be concluded that the OSFI score assigned to a subject's performance was a function, to a significant degree, of which observer did the rating. In view of the fact that the OSFI score is to some degree subjective, this finding is not surprising. Under the "No Tricks" condition observer variance was significant at the 5% level only in terms of the measure "Over-all grade," also a subjective evaluation of performance. Except for the criterion "Mean Airspeed" there were no significant differences in performance attributable to whether or not the measures were taken during the first or second flight with an observer. In the case of "Mean Airspeed," variance attributable to trial was significant under the "No Tricks" condition at the 5% level.

Consideration of "Residual" Variance. Through use of the analysis of variance technique a measure can be obtained of the variability in performance which cannot be accounted for by the identity of the pilot, or of the observer, or of the number of the trial. Such variability can be referred to as "residual" or "chance" variance, although it might more properly be attributed to uncontrolled factors associated with the airplane, or to other unspecified conditions surrounding the flight. Examination of "residual" or "chance" variance is of importance since if it greatly exceeds pilot variance (variance attributable to the pilot) suspicion is cast on the meaningfulness of the criterion in question as a measure of pilot performance.

The analysis indicated that under the conditions of "No Tricks" pilot variance was greater than the residual variance for all criteria except Number of G's and Angle of Attack, relatively non-critical criteria. In these latter cases the residual variance, while somewhat larger than the pilot variance, was not significantly so. Under the condition of "Tricks Allowed" the pilot variance was greater than the residual variance for all criteria except Distance from Spot, Over-all grade, and Seconds to complete turn, although again the residual variance was not significantly greater in these latter cases. Due to the fact that the runway marker was improperly adjusted during the latter part of the experiment, the relatively large residual variance for the measure "Distance from Spot" might be accounted for by apparatus error. However, it should be noted that the residual variance was also larger for the variable "Over-all grade," which was to great degree a function of the accuracy of the landing, and which was not affected by apparatus error, the grade being assigned without knowledge of the objective determination of the accuracy of the landing.

In any event, it is [illegible] far as the present experiment is concerned in no case was the residual variance significantly greater than the variance attributable to pilots. It is possible that were the number of cases greater, the residual variance, under the "Tricks Allowed" condition would prove significantly greater than the pilot variance for the critical variables "Distance from Spot" and "Over-all grade."

Slipping and Skidding during Final Turn into Field. Through analysis of the photographic records a study was made of the slipping and skidding which occurred during the execution of the final turn into the field before landing. The primary purpose of this analysis was to determine if a marked degree of slipping occurred under the "No Tricks" condition as a check on whether subjects might have used this technique to lose altitude intentionally.[10]

Analysis of the data indicated that no skids greater than degree 1 (sufficient to cause an excursion of more than ½ ball diameter) occurred during any of the flights. It should be noted, in this connection, that even slight variations of the ball were considered degree 1. Since it was evident that no serious skids occurred, no detailed treatment of this measure was made. It is of some interest to note, however, that in terms of pooled data from all flights of all subjects, skidding occurred under conditions of "No Tricks" 8% of the time spent in the final turns, whereas under "Tricks Allowed" condition skidding was observed 4% of the total time spent in the turn.

Analysis of slips was also made in terms of the pooled data from subjects and flights, although meaningful comparisons of performance under the "No Tricks" with performance under the "Tricks Allowed" are difficult to make due to the fact that under the latter conditions intentional slipping was allowed. It may be noted in passing, however, that the mean degree of slip was 3.25 degrees during the "Tricks Allowed" trials, and 1.20 degrees during the "No Tricks" trials. However, under the "No Tricks" condition, approximately one-third of all slips were of degree 2 or greater.

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[10]Excursions of the ball in the ball-bank instrument were quantified as follows (calibration marks being drawn on the tube of the instrument):

Degree 1: Up to and including ½ ball width.
Degree 2. More than ½ and including one ball width.
Degree 3; More than 1 ball width and less than 2 balls width.
Degree 4: Two balls width or more.

The proportion of the turn during which slips to any degree were present was 59% under the "No Tricks" condition and 70% during the "Tricks Allowed" flights. As might be expected then, during the "Tricks Allowed" flights slipping was more pronounced. Analysis of variance indicated that significant differences existed between pilots in the percentage of time during which slips occurred in the final turn. There seems to be little evidence, however, that under the "No Tricks" conditions slipping was of such a pronounced and prolonged nature as to represent an intentional effort to "cheat."

PRACTICAL IMPLICATIONS

In considering the practical implications of the findings of this investigation, it is desirable to consider the results for each criterion measure individually. Criterion scores on all variables under both experimental conditions are given in Appendices 5 and 6.

Distance from "Spot" at which Plane was Landed. Under the "No Tricks" condition the fact that there was a demonstrably significant difference in the variability of the performances of the five pilots indicates that as far as the accuracy of the landing was concerned certain pilots tended more than others to be inconsistent. Furthermore, only one of the pilots landed within the specified area on all four landings. Four of the five pilots overshot[11] on one or more of their landings, and two of these men overshot more than 100 feet, i.e., landed more than 300 feet beyond the "spot." Three of the pilots undershot, two of them landing more than 100 feet short on one of their landings. Three pilots both undershot and overshot. It is significant to note that four of the five pilots would have been failed on their flight test because of lack of accuracy in precision landings, under the restriction that no slips or other tricks could be used. Granting that the instructors may not have been familiar with the particular plane used in this investigation,[12] nevertheless these results cast doubt on the advisability of the restrictions against intentional slipping which have been in force until recently.

Under the conditions of "Tricks Allowed" individual differences between pilots were not evident, either in terms of variability, or in terms of mean performance. Under these conditions no pilots overshot, only one pilot landing as much as 155 feet beyond the designated "spot." Four pilots undershot, but only two of the eight landings short of the spot were more than approximately 50 feet short. During the "Tricks Allowed" part

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[11]The yellow strip across the runway which constituted the "spot" represented the near boundary of the segment of the runway, 200 feet in length, in which the landing was to be made. Overshooting therefore is defined as landing beyond this segment of the runway, or more than 200 feet beyond the designated "spot." Undershooting is defined as landing anywhere short of the "spot."

[12]The instructors expressed confidence that had training planes been used with which they were familiar, they would have "hit the spot" on each trial.

of the experiment faulty adjustment of the runway marker resulted in its hanging several inches below the level of the bottom of the wheels of the plane. Particularly, since in this part of the experiment the pilots used a fast glide on the landing approach, holding the plane just off the ground until past the runway marker, some of these measures of undershooting are suspect.

It should be emphasized that while the faulty adjustment of the runway marker during the "Tricks Allowed" part of the experiment rendered measures showing a small amount of undershooting suspect, it is exceedingly improbable that the total absence of indications of overshooting (landing more than 200 feet beyond the spot) during this part of the experiment can also be attributed to apparatus error. A landing on the spot or immediately beyond the spot was at times recorded as undershooting because of the fact that the runway marker hung below the wheel level during this part of the experiment. For the same reason a landing made immediately beyond the point on the runway representing 200 feet beyond the spot might have been classified as a satisfactory spot landing. However, only one landing was made as far as 155 feet beyond the spot, only two were made as far as 120 feet beyond the spot, and eight of the 12 recorded landings beyond the spot were less than 50 feet beyond (see Appendix 6). These facts indicate that the absence of overshooting was almost certainly not due to apparatus error. At very least, not more than one landing (the landing 155 feet from the spot) could have actually been overshot and erroneously recorded as a satisfactory landing and even this is improbable. However, in five of the eight recorded instances of undershooting, the mark on the runway was 51 feet or less short of the spot, four of them being 41 feet or less short. There is a possibility that some of these five landings were actually "on the spot" landings mistakenly recorded as "undershot" because of the faulty adjustment of the runway marker during the "Tricks Allowed" part of the experiment. (The runway marker was properly adjusted during the "No Tricks" phase of the experiment.)

The conclusion, therefore, seems justified that under the "Tricks Allowed" condition the precision landings were made with a greater degree of accuracy than under the "No Tricks" condition, and that unquestionably greater uniformity in performance of the group of pilots was evident. Suspicion is cast on the realistic nature of the restrictions on execution of precision landings, incorporated, until recently, in the private flight test, since under these restricted conditions even the performance of skilled pilots proved so variable and inaccurate. This study indicates that the removal of the restrictions against intentional slips in the private pilot flight test represents a step in the right direction. It should be emphasized, however, that establishment of norms of performance, through further experimentation using larger groups, appears to be needed.

<u>Number of G's Produced by Landing</u>. The fact that no individual differences in number of G's produced on landing were evident under the "No Tricks" condition, while significant differences in variability occurred under the "Tricks Allowed" condition reflects the fact that different "Tricks" may have been used by certain pilots on different landings. The

mean number of G's produced under the "No Tricks" and "Tricks Allowed" situations were 2.07 and 1.98, respectively. In no case, under either condition, was a vertical acceleration of more than 3.00 G's recorded.

Angle of Attack. No individual differences among instructors in Angle of Attack at time of landing were evident under either set of experimental conditions. The indicated mean Angle of Attack under the "No Tricks" condition was considerably greater than under the "Tricks Allowed" landings. However, there was reason to believe that the adjustment of the vane on the instrument was not comparable for flights made under the two sets of conditions. Although the lack of individual differences in terms of Angle of Attack is of passing interest, this measure cannot be given serious weight in the consideration of experimental findings.

Range of Airspeed. Significant individual differences in Range of Airspeed were evident under both "No Tricks" and "Tricks Allowed" conditions. This would appear to be an important development, particularly in regard to the "No Tricks" flights, in view of the considerable emphasis on the maintenance of airspeed during the approach glide. It should be noted, however, that there were only four cases in which Range of Airspeed was greater than 10 miles per hour during the "No Tricks" flights, the maximum range being 16 miles per hour. At least this latter variation might have been considered disqualifying by a CAA inspector.[13] The wide Range of Airspeed under the "Tricks Allowed" condition undoubtedly reflects the different procedures used by the various instructors in effecting accuracy landings.

Mean Airspeed. Individual differences in Mean Airspeed were evident under both conditions. Under "Tricks Allowed" significant differences between instructors were evident in terms of Mean Airspeed. As above, this may reflect differences in procedures used in executing precision landings. Under the "No Tricks" condition, however, significant differences among instructors were evident in terms of variability of Mean Airspeed over the four flights. Because of the emphasis of the "normal glide" it may be noteworthy that the "normal" gliding speed, as established by the pilots, varied significantly more from flight to flight in the case of certain instructors than in the case of others. The greatest range in Mean Airspeed, over the four flights, for any instructor was 6 miles per hour, from 58 to 64 m.p.h. Two instructors were extremely consistent over their four flights; the other three showed greater variation. The Mean Average Airspeed for all flights of the individual instructors varied from 61 to 64 miles per hour.

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[13]According to CAA specifications for the private pilot flight examination available to the investigators, variations in airspeed of greater than 10 miles per hour during the approach to precision landings are considered "unsatisfactory." See Instructions to flight examiners for conducting private pilot examinations. Washington, D. C.: Civil Aeronautics Authority, April 1, 1940, page 14, Section 16, A, (1).

Ohio State Flight Inventory Scores. In the "No Tricks" situation significant individual differences occurred in terms of both the corrected and uncorrected scores. Under "Tricks Allowed" significant differences between instructors were evident only in terms of the corrected scores.

Over-all Grade. Significant individual differences in the Over-all Grades assigned to the instructor subjects were evident only under the condition of "No Tricks." These differences were evident in terms of the variability of grades assigned to the four landings made by each instructor. These results are similar to the results of the analysis of the criterion "Distance from Spot." As noted previously, this is in line with expectation, since the Over-all Grade was influenced markedly by the accuracy with which the landing was made, particularly under the "No Tricks" condition. Under these restricted conditions, 11 of the 12 failing grades were associated with cases of either undershooting or overshooting. In the case of the twelfth failing grade, the landing was made 199 feet from the spot, and was undoubtedly regarded by the check pilot as being beyond the limit of 200 feet. Only one subject received a passing grade on all four landings under the "No Tricks" condition. Two pilots received failing grades on all four landings, and two pilots received failing grades on two landings.

Under the condition of "Tricks Allowed" no individual differences, either in terms of mean grade or variability of grades were evident. Under the "Tricks Allowed" condition, 5 failing grades were given to the execution of precision landings, three out of the five pilots receiving failing grades on one or more landings. (Two of these subjects received a failing grade on two landings.) In this part of the experiment, however, a failing Over-all Grade was given to only four of the eight indicated cases of undershooting. This is probably explained by the fact that the runway marker was out of adjustment as noted previously, and certain indicated cases of undershooting were undoubtedly considered as satisfactory landings beyond the spot. However, one failing grade was given to an indicated landing 39 feet beyond the spot. Whether this was due to an error of judgment on the part of the check pilot, or was due to pilot performance not measured by the other criteria, is uncertain.

The conclusions to be drawn from study of the Over-all Grades assigned by the check pilots are essentially the same as the conclusions drawn from analysis of the measure "Distance from Spot." It should be noted, however, that in a situation where attention was focused completely on execution of the precision landing, in the opinion of the check pilots three of the five pilots did not meet the requirements for the instructors license even under the "Tricks Allowed" situation.

Time to Complete Final Turn. The fact that significant individual differences in mean performance were evident, in terms of this variable, under the "No Tricks" condition would appear to have few meaningful implications. Under the restricted conditions the pilot was allowed to select that rate of turn which would best enable him to land at the designated spot. This device was presumably the only correction he was permitted to employ. Thus, it is not surprising that individual differences in time to complete turn were evident under "No Tricks," but were not evident under "Tricks Allowed." It may also reflect the fact that certain pilots habitually flew the crosswind leg of their approach closer to, or farther from the field than others.

Slipping and Skidding during Final Turn into Field. As noted previously, slips and skids were not sufficiently pronounced to warrant serious consideration. Significant individual differences were evident under both experimental conditions in terms of the percentage of the time spent in the final turn during which slips of any degree occurred. However, since intentional slips were permitted under the "Tricks Allowed" condition, interest centers on the practical significance of degree and amount of slipping under the "No Tricks" situation. In view of the fact that in only four of the twenty times did slips of degree 3 (representing excursion of between 1 and 2 ball widths) occur, it can be concluded that the incidence of serious slips was not great enough to warrant further consideration.

DISCUSSION

On the basis of the performances of the pilots in this experiment, particularly in regard to accuracy of landing, it might be concluded (1) that the restrictions, particularly on "No Tricks" landings, were unreasonably stringent; (2) that the sample of flight instructors used in this study were unusually poor pilots; or (3) that the pilots' unfamiliarity with the plane rendered the flight test situation unrealistic. The second of these conclusions seems patently unwarranted, since the subjects were, in fact, a highly selected group of flight instructors in terms of experience, training, and education. In regard to the third of these conclusions, it is undoubtedly true that the pilots' unfamiliarity with the plane used in the investigation, and the fact that it was somewhat heavier than the planes with which they were familiar, had a deleterious effect on their performance. The exact degree to which the flight test conditions were rendered "unrealistic" by this fact is impossible to determine. It is noteworthy that student pilots in elementary training regularly switched to this special plane for their check flights, apparently without unusual difficulty. Nevertheless, this factor of unfamiliarity with the plane must be taken into account in evaluating the results.

It seems doubtful, however, that the extreme inaccuracy in landings under the "No Tricks" condition could be due entirely to the factor of unfamiliarity. Rather, it seems possible that these data suggest confirmation of the axiom current in some quarters that the most certain way to pass the accuracy landing test, under the restrictions in force until recently, was to "cheat," i.e., to employ some device which the inspector would not recognize, or would overlook. In any event, the increase in accuracy of landing, and the decrease in variability of performance under the less restricted condition of "No Tricks" suggest that the current revision of the requirements for the private pilot flight test by which intentional slips are allowed is a step in the right direction. Further experimentation in which the present restrictions are duplicated exactly, would appear to be indicated.

SUMMARY AND CONCLUSIONS

In this investigation series of four experimental flights consisting of take-offs and precision landings were made by five experienced flight instructors in a specially equipped Piper Cub J-3 plane. Each subject made two series of flights: the first series "Without Tricks," during which slipping, "mushing," or other methods of altering the gliding angle of the plane were not allowed; the second series with "Tricks Allowed," during which any procedure to increase the accuracy of the landing, within the limits of safe flying, was allowed except the use of additional throttle.

Analysis of criterion data collected during these flights indicated that:

1. The performance of individual pilots showed more variability under the restricted condition of "No Tricks" than under "Tricks Allowed." Significant individual differences between pilots in terms of variability in performance were evident in terms of accuracy of the landing, Over-all grade, and Mean Airspeed. Under "Tricks Allowed" significant differences in variability were evident only in terms of number of G's produced during the landing.

2. Individual differences in mean performance were evident in terms of Range of Airspeed during approach and OSFI corrected score under both experimental conditions. In addition, such differences were evident under "No Tricks" in terms of OSFI corrected score, and the number of seconds required for the final turn. Under "Tricks Allowed" individual differences were evident also in terms of "Mean Airspeed."

3. In no case was the residual variance significantly greater than the pilot variance.

4. Significant differences, attributable to which of the two pilots did the rating, were evident in the "subjective" criterion measures represented by the Ohio State Flight Inventory scores and the Over-all grade. In the latter case, significant differences were evident only under the "No Tricks" condition.

The most important practical implications of this study would seem to be:

1. The results cast doubt upon the advisability of the restrictions against intentional slipping which have been in force until recently, since under the "No Tricks" condition skilled pilots proved both extremely variable, and inaccurate, in their execution of precision landings. Under the conditions of "Tricks Allowed" marked decrease in variability of performance, and an increase in accuracy of landing were evident.

2. In spite of the emphasis on maintaining the "normal glide" under the "No Tricks" condition, significant individual differences among instructors were evident in the Range of Airspeed readings during the approach glide, and significant differences among instructors were evident in terms of variability of Mean Airspeed over the four flights. This indicates that the "normal" gliding speed varied significantly more from flight to flight in the case of certain instructors than in the case of others.

While this experiment cannot be considered definitive, the results indicate the desirability of further and more elaborate investigation of individual differences in the performance of pilots. The results of such investigations would have important implications in reference to the realistic nature of specific flight test requirements.

APPENDIX I

OBSERVERS RECORD SHEETS FOR REPORTING OBSERVATIONS
ON THE QUALITY OF THE LANDING

CHECK PILOTS RECORD SHEETS FOR
RECORDING OBSERVATIONS ON FINAL
APPROACH AND LANDING

Pilot________________________________

Observer_____________________________

Date________________ Time________________

Wind Velocity__________ Degrees of X-wind__________

Landing distance from line____________________Feet

+ or -

Over-all grade___

GLIDING TURN

CONTROL USE

	Entry	Turn	Recovery
Simultaneous........	☐	☐	☐
Successive	☐	☐	☐
Slips	☐	☐	☐
Skids..........	☐	☐	☐
Neither.............	☐	☐	☐
Rudder pressure:			
Correct	☐	☐	☐
Incorrect	☐	☐	☐

PRECISION

Speed................___MPH

Correct gliding-
speed reading......___MPH

Speed is... { Constant ☐
Varies ___MPH

Heading:
Heading correct ☐
Incorrect ☐

Allows for drift:
Does ☐
Does not ☐

FINAL APPROACH & LANDING

CONTROL OF PLANE

Direction during approach.............	Constant ☐ / Varies... ☐
Wing-level during approach............	Constant ☐ / Varies... ☐
Direction during roll.................	Constant ☐ / Varies... ☐
Wing-level during roll................	Constant ☐ / Varies. ☐
Stalls............................	Completely ☐ / Not stalled ☐
Stalls..................................	Smoothly ☐ / Abruptly ☐

PRECISION

Speed...	____MPH
Correct gliding-speed reading is...............	____MPH
Speed is..............................	Constant ☐ / [illegible] MPH
If drifting............	Corrects............ ☐ / [illegible] correct..... ☐
No drift / Levels off............	At appropriate height ☐ / [illegible] ☐
Height above ground at stall...........	Correct ☐ / [illegible] ☐
Landing..................................	Satisfactory ☐ / [illegible] ☐
In case of poor landing, corrects ... by adequate use of controls	Does ☐ / Does [illegible] ☐

SAFETY

Clearance turn is..........................	Correct ☐ / [illegible] ☐
Observer assisted in landing....	Did not ☐ / [illegible] ☐

L R	B	G
T	No B	

Wind velocity______MPH X-wind______° R or L

APPENDIX 2

DUTIES OF CHECK PILOT

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DUTIES OF CHECK PILOT

The duties of the check pilot shall be as follows:

1. When approximately one-third of the way on the downwind leg, he shall:

   a. Lower the runway marker.

   b. Instruct the subject (in the front seat) to reset the vertical accelerometer.

2. When on the downwind leg the plane is at 800 feet altitude and opposite the designated spot on the runway, he shall instruct the subject to close the throttle.

3. At the completion of the recovery from the turn into the crosswing leg he shall instruct the subject to turn on the camera switch (which is located beside the front seat of the plane).

4. Beginning with the entry to the last turn, he shall make the required entries on the OSFI.

5. At the completion of the landing run he shall instruct the subject to turn the camera off, shall record the vertical accelerometer reading and associated data on the proper form, and shall complete his entries on the OSFI. He shall also retract the runway marker.

6. If the subject fails to follow the procedures in regard to altitude requirements, or if "cut out" by other traffic, the check pilot shall direct the subject to "go around" and re-enter the landing pattern.

7. After the completion of the landing run, he shall retract the runway marker and direct the pilot to taxi over to the service crew.

APPENDIX 3a

INSTRUCTIONS TO PILOT SUBJECTS UNDER "NO TRICKS" CONDITION

APPENDIX 3b

INSTRUCTIONS TO PILOT SUBJECTS UNDER "TRICKS ALLOWED" CONDITION

APPENDIX 3a

INSTRUCTIONS TO PILOT SUBJECTS UNDER "NO TRICKS" CONDITION

You are being asked to participate in an experiment on landings. You are to do your best to make the type and precision of landing required of the applicant for an instructor's rating. The observer riding with you will give you instructions as to when to cut the throttle, etc. The landing area starts at the black strip across the runway approximately 600 ft. from the end of the runway. Measurements will be made from the midpoint of this strip. You are to make a normal three-point power-off landing as near to but beyond the black strip as possible.

On instructions from the observer taxi out and take off into the wind on the designated runway. Fly the normal rectangular field pattern. One-third of the way down the downwind side of the field the observer will ask you to reset the vertical accelerometer. When you have gained 800 feet altitude hold it in pattern until you are opposite the mark on the runway when the observer will ask you to close the throttle and make a precision landing. Establish your glide and make a standard 180 degree rectangular pattern precision landing at or beyond the 12-inch black line across the runway.

Arrangements have been made with the tower that you do not have to acknowledge the green light. On recovery from the first turn onto the crosswind leg the observer will ask you to start the camera. This is done by closing the indicated switch. You may "play" the final turn but you may not cross the wind line, slip, mush, dive, fishtail or use any other "trick" to correct for errors of judgment. If for any reason you do not have 800 feet opposite the spot, are "cut out" by other traffic during the approach, or get a red light, you are to open the throttle and go around for another attempt.

After completion of the landing run the observer will ask you to turn off the camera. When you have done this taxi in to the servicing crew.

You will not be checked on the first of five landings. The first landing is to permit you to become familiar with the wind conditions at the time of this test.

Two observers will alternate rides with you until you have had a practice trial and four recorded trials. Remember the crew at the line are going to measure off how far you have landed from the line.

Do not discuss your flight with any of the other instructors.

Remember you are to:

1. Make a standard 180° rectangular approach at 800 feet altitude.
2. Cut the throttle at the direction of the check pilot, when opposite the "spot" on the downwind leg.
3. You may vary your glide path by "playing" the final turn. However, you are not to slip, mush, fishtail, cross the wind line, or use any other "tricks" to correct for errors of judgment.

APPENDIX D

INSTRUCTIONS TO PILOT SUBJECTS UNDER "TRICKS ALLOWED" CONDITION

In the execution of precision landings under the condition of "Tricks Allowed" exactly the same traffic pattern is to be flown as under the "No Tricks" condition, and an 180° rectangular approach is to be made as before. However, under the "No Tricks" condition you will be allowed to use intentional slips, or any other device (within the limits of safe flying) you wish to increase the accuracy of your landing <u>except the use of additional throttle</u>.

As under the other experimental condition a series of five flights, consisting of take-offs and precision landings, will be made. As before, two observers will alternate rides with you until you have had a practice trial and four recorded trials.

APPENDIX 4

RATIONALE OF STATISTICAL PROCEDURES

APPENDIX 4

RATIONALE OF STATISTICAL PROCEDURES[14]

The analysis of variance procedures outlined below are designed for the experimental situation in which there are five subjects (flight instructors) and two observers, or check pilots. Each observer is to ride twice with each pilot during the execution of take-offs and landings. Let the first ride by one observer with one pilot be called the first "trial" and the second ride of the same observer with the same pilot the second "trial." Of the actual flights of any pilot, the first flight will be with one observer and the second flight with another, while the third flight will be with the first observer again. Thus, one observer will ride with a pilot during his first and third landings, and the other observer will ride with this same pilot during this pilot's second and fourth landings.

Various records will be made of the characteristics of the landings and for all of the records which are made upon a continuous variable, and analysis will be the same. Therefore, let one criterion measure be considered as an example of the analysis, choosing for this example the accelerometer reading.

Let X_{sti} be the accelerometer reading by the _s_th observer on the _t_th trial with pilot _i_. Then _s_ will take values 1 and 2 for the two observers, _t_ will take values 1 and 2 for the two trials for each observer with each pilot, and _i_ will take values 1, 2, 3, 4, 5, for the five pilots. There will be 20 scores X_{sti}.

In the population from which the sample data are drawn it may be supposed that

$$X_{sti} = \alpha + \beta_s + \sigma_i + \delta_t + \omega_{sti} \qquad (1)$$

where α is the factor common to all pilots, observers, and trials; β_s is the observer factor; σ_i is the pilot factor; δ_t is the factor characteristic of the particular trial, a factor which is different from zero if the pilot's second landing is systematically better (or worse) than his first; and ω_{sti} is the individual factor for a particular trial by a particular pilot with a particular observer. ω_{sti} is the individual factor not characteristic of the pilot, the observer, or the order of the trial.

It is here assumed that there is no interaction between pilots and observers. It is necessary to assume this, because the proposal for the experiment does not plan for the gathering of enough data to study interaction. If it is thought that some pilots do better with

[14]The derivation presented herein was developed by Dr. P. J. Rulon, Harvard University.

certain observers than with other observers and it is wished to make an investigation of this suspicion, the term ϵ_{si} must be added to the above expression. Although this would be an extremely interesting study, this particular investigation is not concerned with that problem and not enough data are going to be gathered to make any good attack on it. So let us go on.

To establish individual differences between pilots as regards accelerometer reading on landing, it must be proved that the pilot factor δ_i in the population is different from zero. The null hypothesis is therefore

$$H: \delta_i = C, \; i = 1, 2, 3, 4, 5 \tag{2}$$

The analysis of the data will be directed to determining whether the observed differences between pilots are so great as to warrant rejecting the null hypothesis.

The analysis proceeds as follows: by analogy to (1), write for the sample

$$X_{sti} = A + B_s + C_i + D_t + z_{sti} \tag{3}$$

in which A, both B's, all five C's, and both D's are unknown, but will be determined so as to make

$$\sum_{sti} z^2_{sti}$$

a minimum. To determine these values, define

$$\chi^2 = \sum_{sti}(X_{sti} - A - B_s - C_i - D_t)^2 \tag{4}$$

and differentiate, first with respect to A:

$$\frac{\partial \chi^2}{\partial A} = -2 \sum_{sti}(X_{sti} - A - B_s - C_i - D_t) \tag{5}$$

Next with respect to B_1:

$$\frac{\partial \chi^2}{\partial B_1} = -2 \sum_{ti}(X_{1ti} - A - B_1 - C_i - D_t) \tag{6}$$

Differentiating with respect to B_2, gives a result similar to (6) with B2 for B1, so it is possible to write in general for the differentiation with respect to B_s

$$\frac{\partial \chi^2}{\partial B_s} = -2 \sum_{ti}(X_{sti} - A - B_s - C_i - D_t) \tag{7}$$

which represents two equations, one when s equals 1, another when s equals 2.

Next differentiating with respect to C_1 gives

$$\frac{\partial \chi^2}{\partial C_1} = -2 \sum_{st}(X_{st1} - A - B_s - C_1 - D_t)$$

and in general

$$\frac{\partial \chi^2}{\partial C_i} = -2 \sum_{st}(X_{sti} - A - B_s - C_i - D_t) \qquad (8)$$

This (8) represents any of five equations, depending on whether s equals 1, 2, 3, 4, or 5.

Next differentiating with respect to D_1 gives

$$\frac{\partial \chi^2}{\partial D_1} = -2 \sum_{si}(X_{s1i} - A - B_s - C_i - D_1)$$

and in general

$$\frac{\partial \chi^2}{\partial D_t} = -2 \sum_{si}(X_{sti} - A - B_s - C_i - D_t) \qquad (9)$$

which represents two equations, one when t equals 1, another when t equals 2. Since (5) is one equation, (7) is two, (8) is five, and (9) is two, there are apparently ten expressions which can be set equal to zero and solved for the ten unknowns A, B_1, B_2, C_1, C_2, C_3, C_4, C_5, D_1, and D_2. However, adding the two equations (7) with respect to s gives exactly equation (5), and so there are only two independent equations among the three of (5) and (7). Similarly, adding the five equations (8) with respect to i gives exactly equation (5), and so only four of the five equations in (8) are independent. Likewise adding the two equations in (9) with respect to t gives exactly equation (5), so only one of the two in (9) is independent. These are then, not 1 + 2 + 5 + 2 = 10 independent equations, but only 1 + 1 + 4 + 1 = 7. Three more equations involving the unknowns A, B_s, C_i, and D_t are needed. Restrictions on the unknowns may be made use of to give the required three additional equations. Without impairing the utility of our analysis, it may be proposed that the B's be measured from the mean of the B's, that the C's be measured from the mean of the C's, and that the D's be measured from the mean of the D's. This results in the following equations:

$$\sum_s B_s = 0$$

$$\sum_i C_i = 0$$

$$\sum_t D_t = 0$$

These restrictions may be introduced each with its own Lagrange multiplier, defining $G = \chi^2 + \lambda_1 \sum_s B_s + \lambda_2 \sum_i C_i + \lambda_3 \sum_t D_t$

$$= \sum_{sti}(X_{sti} - A - B_s - C_i - D_t)^2 + \lambda_1 \sum_s B_s + \lambda_2 \sum_i C_i$$

$$+ \lambda_3 \sum_t D_t$$

u may now be differentiated with respect to all of the variables as though all of the variables were independent, this being justified by our having taken care of the dependences by means of the Lagrange multipliers. Let each derivative or set of derivatives be set equal to zero as we derive it:

$$\frac{\partial u}{\partial A} = -2 \sum_{sti}(X_{sti} - A - B_s - C_i - D_t) = 0 \tag{10}$$

$$\frac{\partial u}{\partial B_s} = -2 \sum_{ti}(X_{sti} - A - B_s - C_i - D_t) + \lambda_1 = 0 \tag{11}$$

$$\frac{\partial u}{\partial C_i} = -2 \sum_{st}(X_{sti} - A - B_s - C_i - D_t) + \lambda_2 = 0 \tag{12}$$

$$\frac{\partial u}{\partial D_t} = -2 \sum_{si}(X_{sti} - A - B_s - C_i - D_t) + \lambda_3 = 0 \tag{13}$$

Now adding the two equations (11) with respect to s and comparing with (10) shows that λ_1 equals zero. Adding the five equations (12) with respect to i and comparing with (10) shows that λ_2 equals zero. Similarly, adding the two equations (13) with respect to t and comparing with (10) shows that λ_3 equals zero. Dropping the -2 throughout yields

From (10),

$$\sum_{sti}(X_{sti} - A - B_s - C_i - D_t) = 0 \tag{14}$$

From (11),

$$\sum_{ti}(X_{sti} - A - B_s - C_i - D_t) = 0 \tag{15}$$

From (12),

$$\sum_{st}(X_{sti} - A - B_s - C_i - D_t) = 0 \tag{16}$$

From (13),

$$\sum_{si}(X_{sti} - A - B_s - C_i - D_t) = 0 \tag{17}$$

Distributing the $\sum_{sti}$ in (14) and remembering that $\sum_s B_s = \sum_i C_i = \sum_t D_t = 0$, gives

$$A = \frac{1}{20} \sum_{sti} X_{sti} = \bar{X}_{...} \quad \text{, say.}$$

Similarly, from (15),

$$B_s = \frac{1}{10} \;{}_{ti}X_{sti} - A$$

$$= \bar{X}_{s..} - \bar{X}_{...} \quad \text{, say.}$$

From (16),

$$C_1 = \frac{1}{4} \sum_{st} X_{sti} - A$$

$$= \bar{X}_{..i} - \bar{X}_{...} \quad , \text{ say.}$$

And from (17),

$$D_t = \frac{1}{10} \sum_{si} X_{sti} - A$$

$$= \bar{X}_{.t.} - \bar{X}_{...} \quad .$$

Denoting the value of χ^2 after these values of the unknowns have been substituted in it, χ^2_a, then

$$\chi^2_a = \sum_{sti} (X_{sti} - \bar{X}_{s..} - \bar{X}_{.t.} - \bar{X}_{..i} + 2\bar{X}_{...})^2 \quad .$$

For this χ^2_a a computational formula is needed and the number of degrees of freedom associated with it. A little algebraic manipulation shows that the computational formula is

$$\chi^2_a = \sum_{sti} X^2_{sti} - \frac{1}{10} \sum_s (\sum_{ti} X_{sti})^2 - \frac{1}{10} \sum_t (\sum_{si} X_{sti})^2 - \frac{1}{4} \sum_i (\sum_{st} X_{sti})^2 + \frac{1}{10} (\sum_{sti} X_{sti})^2 \qquad (18)$$

The computer may wish the following suggestion: the first term above is to be obtained by squaring each of the accelerometer readings and then adding all 20 squares. The second term is obtained by adding the 10 readings for each observer, squaring the sum, adding the two such sums for the two observers, and dividing by 10. The other terms are to be read in the same manner.

The number of degrees of freedom is 13, as can be shown from the following considerations; the number of degrees of freedom in χ^2_a is always equal to the number of independent observations, diminished by the difference between the number of variables fitted by differentiation and the number of restrictions imposed upon the variables. The number of observations was 20. The number of variables was 10: A, B_1, B_2, C_1, C_2, C_3, C_4, C_5, D_1, and D_2. The number of restrictions was three:

$\sum_s B_s = 0$, $\sum_i C_i = 0$, $\sum_t D_t = 0$. Hence ndf = 20 − (10 − 3) = 13.

The purpose in determining χ^2_a was to use it in the F-test, calculating

$$F = \frac{\dfrac{\chi^2_F - \chi^2_a}{f_1}}{\dfrac{\chi^2_a}{f_2}} \qquad (19)$$

So far the formula for χ^2_a has been determined, and it has been determined that f_2 which goes with it is 13. The denominator of the F is then taken care of. For the numerator χ^2_r and f_1 are needed. The χ^2_r is determined by rewriting (1) under the hypothesis that $\gamma_i = 0$. Then

$$X_{sti} = \alpha + \beta_s + \delta_t + \omega_{sti}$$

By analogy write in the sample

$$X_{sti} = A + B_s + D_t + z_{sti}$$

and again determine A, B_s, and D_t so as to make $\Sigma_{sti} z^2_{sti}$ a minimum. Proceeding as before,

$$\chi^2 = \Sigma_{sti}(X_{sti} - A - B_s - D_t)^2 \qquad (20)$$

and find that the values of A, B_s, and D_t which make the minimum are the same values as derived above for the other minimum. Substituting them back into (20) and calling the resulting minimum a <u>relative</u> minimum, gives

$$\chi^2_r = \Sigma_{sti}(X_{sti} - \bar{X}_{s..} - \bar{X}_{.t.} + \bar{X}_{...})^2$$

This is not convenient for computational purposes, so a little algebraic juggling indicates that

$$\chi^2_r = \Sigma_{sti}X^2_{sti} - \frac{1}{10}\Sigma_s(\Sigma_{ti}X_{sti})^2 - \frac{1}{10}\Sigma_t(\Sigma_{si}X_{sti})^2 + \frac{1}{20}(\Sigma_{sti}X_{sti})^2 \qquad (21)$$

In (19) $\chi^2_r - \chi^2_a$ are going to be needed and not χ^2_r itself, so (18) may be subtracted from (21), getting

$$\chi^2_r - \chi^2_a = \frac{1}{4}\Sigma_i(\Sigma_{st}X_{sti})^2 - \frac{1}{20}(\Sigma_{sti}X_{sti})^2 \qquad (22)$$

The number of degrees of freedom associated with this is the number of independent statements in the null hypothesis being tested. The null hypothesis was

$$\gamma_i = 0, \quad i = 1, 2, 3, 4, 5.$$

However, the analysis necessitated setting in the sample $\Sigma_i C_i = 0$, which leaves only 4 independent statements in the expression $C_i = 0$. If in the population γ_i is measured from the mean of the γ's, as the C's in the sample were measured, then there are only four independent statements in the hypothesis H: $\gamma_i = 0$, so that $f_2 = 4$. The F-test is now complete as follows:

$$F = \frac{\dfrac{\chi^2_r - \chi^2_a}{4}}{\dfrac{\chi^2_a}{13}} \qquad (23)$$

in which $\chi^2_r - \chi^2_a$ is to be calculated from (2x) and χ^2_a from (18). As usual, the resulting F is looked up in Snedecor's table, and if it exceeds the 5% point the hypothesis $\sigma_i = 0$ may be rejected and the presence of significant individual differences among pilots as regards their accelerometer readings will be indicated.

The following remarks may be of interest:

1. An estimate of the variance among pilots as regards accelerometer readings on landings is given by the numerator of (23), namely $\frac{1}{4}(\chi^2_r - \chi^2_a)$.

2. An estimate of the variance (among accelerometer readings) not accounted for by the identity of the pilot or of the observer or of the number of the trial, is given by the denominator of (23), namely $\frac{\chi^2_a}{13}$.

3. If it is desired to test whether there is any difference between the two observers, the F-test may be used with the same denominator as in (23) but with numerator given by

$$\frac{1}{10}\sum_s\left(\sum_{ti} x_{sti}\right)^2 - \frac{1}{20}\left(\sum_{sti} x_{sti}\right)^2$$

with one degree of freedom. This comes out by setting the hypothesis $\beta_s = 0$ in (1) and determining χ^2_r from

$$x_{sti} = a + \sigma_i + \delta_t + \omega_{sti}.$$

4. If it is desired to test whether there is any difference between trial 1 and trial 2 by a given pilot and observer, the F-test may be used with the denominator equal to the denominator of (23) and with numerator equal to

$$\frac{1}{10}\sum_t\left(\sum_{si} x_{sti}\right)^2 - \frac{1}{20}\left(\sum_{sti} x_{sti}\right)^2$$

with one degree of freedom.

5. The F-test proposed in paragraphs 3 and 4 above will naturally lead to the same results as employing the t-test in the same situation.

6. The validity of the above analysis depends upon two assumptions: (a) that ω_{sti} in (1) is for each i normally distributed in the population from which the sample was drawn and (b) that the variance of ω_{sti} is equal for all values of i. It is desirable to test whether in the sample the variance of x_{sti} differs so much for different i as to cast suspicion on the equality of the variances in the population. This can be tested as follows:

For the first [illegible]

$S_1 = S_1$ [illegible]

Find $\log_{10}\theta_1$. Similarly find θ_i for $i = 2, 3, 4, 5$, and find $\log_{10}\theta_i$. Determine log L from the equation

$$\log_{10}L = \frac{1}{5}\sum_i \log_{10}\theta_i - \log_{10}\frac{1}{5}\sum_i \theta_i$$

and from the log obtained from this, look up the antilog, getting L. If the L is <u>less</u> than .491, the hypothesis that the variance of $(U)_{sti}$ is the same for all <u>i</u> must be rejected at the 5% level.

7. However, if L turns out less than .491, an experimental finding is represented, without pursuing the analysis which leads to (23).

APPENDIX 5

INDIVIDUAL DIFFERENCES IN LANDING
MASTER DATA SHEET
"No Tricks"

APPENDIX 5

INDIVIDUAL DIFFERENCES IN LANDING
MASTER DATA SHEET
"No Tricks"

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			INVENTORY DATA				SPECIAL FORMS					CAMERA DATA				
							Distance	Wind					Slips in Turn		Skids in Turn	
Subj.	Obs.	Trial	Over-all	OSFI	G's	B's	Feet from Spot (+ or -)	Wind Vel.	Drift∠ (R or L)	A.A.	Var. in Airspeed	Mean Airspeed	Max. Deg.	% of Slip	Max. Deg.	% of Skid
1	A	1	100	26	2.0	0	+ 57	8	15	16.2	8.5	64.1	1	57	0	0
		2	95	22	2.0	0	+ 36	7	5	20.0	5.0	60.3	1	25	1	13
	B	1	95	18	2.2	0	+ 93	10	10	16.5	6.5	64.1	1	50	0	0
		2	95	16	1.8	0	+ 52	10	15	24.0	5.5	60.4	2	67	1	19
2	A	1	90	22	2.8	0	+ 118	12	5	27.5	7.5	60.3	3	42	0	0
		2	95	20	1.6	0	+ 167	5	15	29.0	10.0	60.4	1	30	1	45
	B	1	65	-3	1.8	0	- 65	10	15	27.5	8.5	64.2	3	53	1	7
		2	65	5	1.6	0	+ 223	8	5	29.0	8.5	58.0	2	21	1	29
3	A	1	65	16	1.7	0	+ 213	5	15	28.5	5.0	64.1	2	100	0	0
		2	65	22	2.2	0	+ 199	10	10	28.0	9.5	61.9	2	88	0	0
	B	1	60	7	1.8	0	- 258	10	15	29.5	6.0	61.2	2	100	0	0
		2	60	9	2.4	1	- 44	10	15	28.5	7.0	60.8	3	95	0	0
4	A	1	65	8	1.6	0	+ 404	8	10	29.0	13.0	63.8	2	74	1	10
		2	95	16	2.8	0	+ 34	8	5	28.0	12.0	63.8	2	50	0	0
	B	1	70	1	2.6	0	0	5	10	25.5	16.0	63.6	2	18	1	27
		2	65	5	2.6	0	+ 224	5	0	28.5	11.0	63.4	3	63	1	6
5	A	1	65	16	1.6	0	- 103	8	10	28.5	8.0	63.6	2	59	1	28
		2	65	17	1.6	0	+ 381	3	5	28.5	6.0	63.2	2	66	1	11
	B	1	65	8	2.6	2	- 16	0	0	(28.5)	6.0	64.0	2	86	0	0
		2	60	13	2.0	0	+ 441	10	15	28.5	9.5	62.4	2	45	1	10

APPENDIX 6

INDIVIDUAL DIFFERENCES IN LANDING
MASTER DATA SHEET
"Tricks Allowed"

APPENDIX 6

INDIVIDUAL DIFFERENCES IN LANDING
MASTER DATA SHEET
"Tricks Allowed"

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			INVENTORY DATA				SPECIAL FORMS					CAMERA DATA				
							Distance	Wind					Slips in Turn		Skids in Turn	
Subj.	Obs.	Trial	Over-all	OSFI	G's	B's	Feet from Spot (+ or -)	Wind Vel.	Drift (R or L)	A.A.	Var. in Airspeed	Mean Airspeed	Max Deg.	% of Slip	Max. Deg.	% of Skid
[illegible]	A	1	90	20	2.0	0	+ 155	8	0	16.0	5.0	64.2	1	17	1	67
		2	95	20	3.0	0	+ 33	5	15	18.5	9.5	64.1	4	60	0	[illegible]
	B	1	95	12	1.8	0	+ 26	10	10	15.0	7.5	64.5	3	40	1	20
		2	95	9	1.8	0	+ 18	10	10	19.0	10.0	67.1	4	46	[illegible]	[illegible]
[illegible]	A	1	65	18	2.0	0	- 249	10	10	17.0	18.0	59.4	4	100	0	[illegible]
		2	90	18	2.4	0	+ 49	10	0	19.5	9.5	63.9	2	80	0	[illegible]
	B	1	90	11	1.8	0	+ 90	10	5	16.0	12.0	57.9	4	65	0	[illegible]
		2	65	5	2.0	0	- 27	10	15	16.0	13.0	60.9	4	100	0	[illegible]
[illegible]	A	1	90	24	1.6	0	+ 103	7	5	18.0	5.5	65.5	1	50	0	[illegible]
		2	95	18	1.8	0	- 41	9	45	16.5	7.5	62.7	4	100	0	[illegible]
	B	1	65	13	1.8	0	+ 39	4	20	16.0	12.5	61.6	4	100	0	[illegible]
		2	65	9	1.6	0	- 51	6	10	19.0	9.0	62.8	4	100	0	[illegible]
4	A	1	95	18	1.4	0	- 41	5	25	18.0	11.0	60.8	3	22	0	[illegible]
		2	80	24	2.4	1	+ 35	4	5	18.5	12.0	62.1	1	17	0	0
	B	1	90	13	2.6	0	+ 120	1	15	22.0	12.5	60.3	4	46	1	[illegible]
		2	60	11	1.9	0	- 126	5	10	18.5	10.0	61.0	4	79	0	0
5	A	1	70	12	2.0	0	+ 36	5	10	17.0	16.0	54.6	4	100	0	0
		2	85	22	1.8	0	- 35	10	10	13.5	14.0	60.4	4	100	0	0
	B	1	95	7	1.8	0	- 38	10	5	14.5	17.0	59.5	4	78	0	0
		2	90	-1	2.0	0	+ 45	8	15	16.0	15.0	58.2	4	87	0	0

APPENDIX 7

MEANS AND STANDARD DEVIATIONS IN TERMS OF INDIVIDUAL PILOTS

INDIVIDUAL MEANS* AND SIGMAS

PILOT	No Tricks 1	No Tricks 2	No Tricks 3	No Tricks 4	No Tricks 5	Tricks 1	Tricks 2	Tricks 3	Tricks 4	Tricks 5
Distance from spot	59.50	110.75	27.50	165.50	175.75	58.00	-34.25	12.50	-3.00	2.00
	20.84	108.06	193.94	162.01	238.20	56.25	55.95	62.82	91.03	[illegible]
G's	2.00	1.95	2.03	2.40	1.95	2.15	2.05	1.70	2.08	[illegible]
	0.14	0.50	0.29	0.47	0.41	0.50	0.22	0.10	0.27	[illegible]
Angle of Attack	19.18	28.25	28.62	27.75	28.50	17.13	17.13	17.38	19.25	[illegible]
	3.16	0.75	0.55	1.35	0.00	1.67	1.43	1.19	1.60	1.25
Airspeed variation	6.38	8.63	6.88	13.00	7.38	8.00	13.15	8.65	11.98	14.50
	1.34	0.89	1.67	1.87	1.47	3.97	3.09	2.56	.96	[illegible]
Average airspeed	62.23	60.73	62.00	63.65	63.30	64.98	60.53	63.15	[illegible]	[illegible]
	1.88	2.22	1.27	0.37	0.59	1.24	2.22	1.44	[illegible]	[illegible]
OSFI uncorrected	20.50	11.00	13.50	7.50	13.50	15.25	13.00	16.00	[illegible]	10.00
	3.84	10.42	5.94	5.50	3.50	4.87	5.43	5.31	[illegible]	[illegible]
OSFI corrected	14.50	8.00	10.50	8.50	10.50	12.75	10.50	14.50	[illegible]	10.75
	2.96	6.67	3.64	3.20	3.20	2.49	2.87	2.69	[illegible]	[illegible]
Over-all grade	96.25	78.75	62.50	73.75	63.75	93.75	77.50	78.75	[illegible]	85.00
	2.17	13.86	2.50	12.44	2.17	2.17	12.50	13.86	[illegible]	9.35
Time to complete turn	26.25	15.63	19.88	14.13	17.00	16.00	21.00	23.00	20.00	[illegible]
	4.81	1.51	2.07	3.85	2.52	5.10	7.68	7.63	7.07	[illegible]
% slipping of any degree	49.75	39.00	95.75	51.25	64.00	45.75	91.25	87.50	39.00	[illegible]
	15.51	9.35	44.92	20.99	14.78	17.55	8.93	21.65	26.26	9.3[illegible]

*Upper figure is the mean. Lower figure is the standard deviation.

APPENDIX 7

MEANS AND STANDARD DEVIATIONS IN TERMS OF INDIVIDUAL PILOTS