RESTRICTED Not for publication

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE OBTAINED BY MEANS OF THE R-S RIDE RECORDER

PART I

SECTION A: THE RELIABILITY AND VALIDITY OF QUALITATIVE TECHNIQUES FOR THE EVALUATION OF FLIGHT PERFORMANCE

by

MORRIS S. VITELES

and

OSCAR BACKSTROM, JR.

(with the assistance of Albert S. Thompson)

with an

Exhibit

A Summary of the Graphic Records Program Carried out at Tulane University under the direction of H. M. Johnson

SECTION B: SUPPLEMENTAL REPORT - THE CAPABILITIES AND DEFICIENCIES OF THE R-S RIDE RECORDER AND THE FRIEZ CABLE CONTROL RECORDER

by

OSCAR BACKSTROM, JR.

A report of a study conducted at the University of Pennsylvania, Philadelphia, Pennsylvania, on records collected at Tulane University, New Orleans, Louisiana, by means of grants-in-aid from the National Research Council Committee on Selection and Training of Aircraft Pilots from funds provided by the Civil Aeronautics Administration.

November 1943

CIVIL AERONAUTICS ADMINISTRATION

Division of Research

Report No. 23

Washington, D. C.

National Research Council

Committee on Selection and Training of Aircraft Pilots

Executive Subcommittee

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National Research Council

1943

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

November 18, 1943

Dr. Dean R. Brimhall
Director of Research
Civil Aeronautics Administration
Washington, D. C.

Dear Dr. Brimhall:

Attached is a report entitled An Analysis of Graphic Records of Pilot Performance Obtained by Means of the R-S Ride Recorder by M. S. Viteles and Oscar Backstrom, Jr. This 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 report reflects the interest of the Committee on Selection and Training of Aircraft Pilots in arriving at objective and reliable measures of pilot performance. It is significant to note that available commercial flight recording instruments were not neglected in this search for adequate criteria. Although the study described in the report was confined to a relatively small number of cases, the results serve to indicate the manner in which flight recording instruments can be used both in the field, in connection with flight training, and in facilitating research in aviation psychology.

Cordially yours,

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

MSV/es

EDITORIAL FOREWARD

In the search for objective measures of pilot efficiency the attention of the Committee on Selection and Training of Aircraft Pilots was early directed towards instruments, already in existence, designed to record graphically plane performance and control movements. While such flight recorders, including the Friez Analyzer and the R-S Ride Recorder, were intended primarily for use in investigating the influence of design on plane performance, it nevertheless seemed that they might also serve a useful purpose in the evaluation of flight performance in psychological experimentation. These instruments were therefore procured and subjected to experimental study at Tulane University, under the direction of Dr. H. M. Johnson; at Harvard University, by Dr. R.A. McFarland and Dr. A.H. Holway; at the University of Maryland, by Dr. J.G. Jenkins and Dr. R.M. Bellows; at the University of Pennsylvania, by Dr. M.S. Viteles and Mr. O. Backstrom, Jr.

The purpose of the investigation conducted at the University of Pennsylvania was to make an extensive and detailed qualitative and quantitative analysis of the characteristics of records obtained with one commercial instrument, the R-S Ride Recorder, and of the usefulness of such records in providing objective indices of pilot proficiency. The study was designed, also, to uncover the limitations of the commercial recorders with the view of arriving at specifications for an improved recorder providing more satisfactory measurements of pilot proficiency of the type required in psychological experimentation.

The report on the investigation at the University of Pennsylvania is presented in two sections. Part I, which follows, describes the conditions under which graphic records were obtained and presents an analysis of qualitative techniques for the evaluation of such records in the assessment of pilot proficiency. Methods used in the experiment are described in great detail so as to provide, in a sense, a basic manual for the treatment and interpretation of records obtained not only with the R-S Ride Recorder, but of those procured through the use of similar instruments.

Part II, to be published at a later date, will present a report on the quantitative analysis of the graphic records obtained through the use of the R-S Ride Recorder. There will also appear, in a later report, a description of an improved flight recorder developed, in large part, from an analysis of the data and the characteristics, advantages and limitations of commercial recording instruments gathered in the course of the investigation conducted at the University of Pennsylvania.

PREFACE

One major objective in the research program of the Committee on Selection and Training of Aircraft Pilots has been the development of methods for objectively evaluating the pilot's performance. Research at the University of Pennsylvania has been centered upon this problem, with particular reference to the use of instruments capable of providing objective records of pilots' skill in handling a plane.

Two methods of objective recording of flight performance have been studied:

1. The graphic method, by means of a flight recorder which records the effect of accelerations upon masses which are free to move in restricted planes, and

2. The photographic method, by means of motion photography of flight instruments and a control movement recorder.

The outcomes of research involving the use of photographic methods recording of pilot response of plane attitude are described elsewhere.[1] The present report is concerned with studies involving the application of graphic methods in evaluating pilot performance.

Graphic recording of flights is not a novel procedure. As early as 1914 German investigators recorded load factors occurring in various maneuvers for the purpose of guiding airplane design.[2] In the early 1920's, the Army Air Corps of the United States and the National Advisory Committee for Aeronautics conducted numerous flight tests with specially developed instruments, the results of which are presented in NACA Technical Reports and Technical Notes for those years. Similar research was undertaken in Germany and in Great Britain.[2] More recently, in the United States, over 20,000 hours of airline transport flying were recorded by means of the National Advisory Committee for Aeronautics V-g Recorder with a view of obtaining data concerning loads imposed by gusts in normal commercial flying operations.[3]

In the case of all such research, however, attention has been centered upon the performance of the airplane, and the emphasis has been upon airplane

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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.: C.A.A. Division of Research, Report No. 15, May, 1943.

[2] See especially Technical Reports Nos. 99 and 100, for the year 1921, No. 163 for the year 1923, and No 203 for the year 1925, and Technical Notes Nos. 64, 97, 112, 117, and 154. Similar research conducted in Germany is reported in the Zeitschrift fur Flugtechnik und Motorluftschiffahrt (Munich and Berlin). Studies conducted in Great Britain are described in the Aeronautical Research Committee Reports and Memoranda (London) for the year 1928-1930.

[3] This program is reviewed in: Rhode, R. V., Gust Loads on Airplanes, S.A.E. Journal, March, 1937.

design. In contrast, the emphasis of the present investigation is upon the performance of the pilot with the view of arriving at an objective appraisal of pilot proficiency.

In undertaking an analysis of the usefulness of graphic records in evaluating pilot performance, it was immediately recognized that such a record could not supply all of the data needed for a complete appraisal of the pilot. As has been pointed out by J. G. Jenkins, Lt. Cdr., H(V)-S, USNR, "excellent performance in flying implies far more than the coordination of control movement in ways that would produce an aerodynamically correct pattern in the motions of the airplane. It implies judgment as regards to climbing and orientation of maneuvers; it implies a continuing awareness of the behavior of other airplanes in the vicinity; it implies a knowledge of an attitude of respect for highly necessary regulations in regard to flying; and, finally, it implies certain facilities of attitudes and emotional reactions during a variety of flight situations."[4]

In other words, a satisfactory performance as a pilot involves a balanced combination of judgment, skill, and emotional stability under the conditions of flight. The graphic recorder supplies, essentially, only an evaluation of the skill of the pilot in conforming to the aerodynamic requirements of the prescribed maneuvers included in a flight test situation.[5] So, for example:-

1. Graphic records cannot show whether the pilot followed the intended or prescribed path relative to the ground.

2. Graphic records cannot show how the pilot reacted in the multitude of situations where judgment is of prime importance. They do not, for instance, reveal whether the pilot, before taking off, made sure that the airplane had been given a line inspection; whether he checked his gasoline supply; or whether he adjusted his parachute straps properly. In the all-important matter of conduct in traffic, graphic records are useless for informing the interpreter as to the safety with which the pilot handled the airplane. Graphic records cannot show whether the pilot avoided flying over restricted areas, or whether, in performing acrobatics, he flew over an area where such flying is prohibited, etc.

3. Graphic records supply no information about other characteristics which have a bearing on the success of the pilot, particularly in the military situation. For example, if the pilot is an aviation cadet in training for an officer's commission, the degree to which he possesses officer-like qualifications must enter into his over-all merit as a military pilot. Graphic records of flight performance do not supply data which contribute to the assessment of such traits.

Items such as those mentioned in the preceding paragraphs must be evaluated

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[4] From a letter by J. G. Jenkins, Lt. Cdr., H(V)-S, USNR, dated 2/6/43.

[5] It is to be noted that limitations which apply to graphic records also apply, although not to the same extent, to photographic records of flight performance. A consideration of this problem is to be found in the report by M. S. Viteles and A. S. Thompson, op. cit.

by other, possibly subjective techniques. The graphic method is incomplete insofar as it omits them. It is safe to say, however, that an acceptable pilot must be able to execute skillfully a series of prescribed maneuvers appropriate for the task for which he is training. He must be able to make the airplane do what he intends it to do or what he is instructed to make it do. On the basis of the evidence accumulated in this study, it may be stated that graphic records supply data which can be employed in the assessment of such proficiency. In other words, the flight recorder can be employed to furnish objective data for the evaluation of flying skill -- to substitute objective recordings for subjective estimates of this important element in a complete criterion of flight performance.

The study described in this report represents an attempt to determine the reliability of assessments of flight performance, based upon objective records obtained through the use of the R-S Flight Recorder.[6] The study is exploratory in character, and is devoted to an intensive evaluation of the graphic recording technique rather than to a survey of the entire field of graphic recording. The investigation is actually limited to an analysis of only one maneuver -- the 720° power turn.[7] However, the failure to include other maneuvers is no indication that such other maneuvers do not lend themselves to the same type of analysis. As a matter of fact, there is every reason to believe that practically all of the maneuvers included in the elementary flight training program can be treated in the same manner to produce results of interest and significance equal to those resulting from the investigation of the 720° power turn, provided that a completely adequate flight recorder is available.[8]

In this study, the graphic recorder was initially viewed chiefly as a source of criterion data. However, as the investigation has progressed, it has become increasingly apparent that a suitably designed graphic recorder may prove to be an extremely useful aid to training. An instrument providing records of control movements, as well as of airplane attitudes, can undoubtedly be used to advantage in demonstrating to student pilots, and also to instructors, errors in handling the controls and resulting faults in flight performance.

It is quite possible that the graphic recording technique may ultimately have more practical value in this field than as a means of obtaining objective

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[6]Part I is limited to the evaluation of flight recording through the use of qualitative methods. In Part II will be presented a detailed discussion of quantitative techniques in the evaluation of flight records.

[7]The study is also limited to an exploration of the consistency of evaluations by a single experimenter. The reliability of evaluation by multiple raters remains to be investigated.

[8]Such a recorder has been constructed on the basis of specifications formulated by M. S. Viteles, Oscar Backstrom, Jr., and J. G. Jenkins largely on the basis of the findings of this study: This flight recorder, built at the Massachusetts Institute of Technology, will be described in a subsequent report.

criterion data in the experimental situation. For example, records of control movements may be used to point out to a student his faults in "riding" the rudder; in failing to use enough rudder; in faulty coordination between aileron and rudder in turns, etc. With the aid of flight records, it can be clearly and unequivocally demonstrated to the student that when he failed to use enough rudder into a turn, he slipped extensively; when he used too much rudder, he skidded extensively; when his rudder adjustment was approximately correct, he entered the turn in lateral balance, or with at most a slight slip or skid, and so on. At the same time, correct adjustments may be demonstrated in a particularly impressive manner if instructor and student alternate in performing a given maneuver. Graphic recording has a particular advantage for such purposes, in that the automatically registered records may be inspected immediately upon completion of the flight. Such considerations accentuate the desirability of further consideration of graphic recording techniques in future investigations concerned with the nature and development of pilot skill.

In presenting this report it should be pointed out that it is the outcome of collaborative effort. H. M. Johnson and Percy W. Cobb, Tulane University, supervised the collection of graphic records at the New Orleans Airport, and contributed much in the way of suggestions with respect to the treatment of records. Vidkunn Coucheron - Jarl assisted in the collection and identification of the records. The statistical treatment of Part I of this report was checked by Malcolm G. Preston, University of Pennsylvania. The report was reviewed for publication by J. G. Jenkins, Lt. Commander, USNR, Psychological Section, Aviation Medicine Division, Bureau of Medicine and Surgery, and by David L. Webster, Chief Physicist, Ballistics Laboratory, Aberdeen Proving Ground, Maryland. The latter gave particular consideration to the treatment of aerodynamic concepts.

University of Pennsylvania
Philadelphia, Pa.

Morris S. Viteles

Oscar Backstrom, Jr.

September 1, 1943

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SUMMARY

1. Performance during a standard flight flown three times each by 28 pilots of various levels of flying experience was recorded graphically by means of the R-S Ride Recorder. The records of the right 720° power turn were selected for an intensive analysis in order to:

a. provide detailed information concerning the interpretation of the traces;

b. develop and evaluate methods for the qualitative analysis of flight performance through an examination of the graphic records.

2. The R-S Ride Recorder used in this investigation records flight attitude effects by means of a weight-and-spring accelerometer mounted in the airplane vertical, two pendulums free to move only in the airplane lateral, and one pendulum free to move only in the airplane longitudinal. An intensive physical and aerodynamical study of the instrument revealed the following information relative to interpretation of the traces in records:

a. The lateral imbalance pendulums are analogous to the ball of a standard ball bank indicator and thus provide data as to the slipping or skidding characteristics of the flight. The exact angle of slip or skid, however, cannot be determined from the lateral imbalance traces.

b. The load factor trace (made by the accelerometer mounted in the airplane vertical) provides data as to the angle of "proper" bank when the readings are converted from units of g (gravity) to bank angles.

c. The remaining trace (pitch-and-longitudinal-acceleration) is equivocal since the pendulum is affected both by longitudinal acceleration and by change in pitch. The separate effect of each cannot be isolated.

3. Two methods of qualitative analysis of the records were devised: one, by means of a <u>Data Sheet</u>, resulted in a detailed record of observations and rough quantifications of the traces; the other, by means of a <u>General Description Sheet</u>, resulted in a freely running description and "clinical" evaluation of the records. In addition, both methods resulted in an over-all rating of the excellence of the maneuver as a whole, based upon 7 aspects of the performances referring to bank and lateral balance.

Separate readings were made of the records of the right 720° power turns as performed by the 28 subjects during the latter two of the three standard flights flown. Each record was rated using both methods of analysis and, in addition, one set of records was re-rated by each method. The records were given code numbers and re-coded each time so as to reduce recognition or identification of individual records.

4. The distributions of over-all ratings resulting from the readings were then compared with each other and with external criteria to provide information as to the reliability of the methods, the comparability of the methods, and the relationship between the ratings and other measures of pilot skill. Values of p were obtained from χ^2, and contingency coefficients were computed in order to determine the significance and extent of the association between the various sets of data.

5. Analysis of the resulting p values and contingency coefficients (presented in Tables 2 to 6) and an evaluation of the experimental procedures used resulted in the following conclusions:

a. The two methods of rating (Data Sheet and General Description Sheet) were found to give comparable results as evidenced by the significant and high degree of association between the sets of ratings obtained by the two methods.

In practice, the two methods, originally conceived to differ in amount of detail, were found to approach each other as to amount of detail observed and to differ chiefly in method of recording. As such, they are analogous to alternate forms of a test.

Since the method underlying the General Description Sheet is less time-consuming and is essentially a "clinical" evaluation, selecting the salient features of the record, this method would seem preferable to the more controlled and elaborate Data Sheet method.

b. A significant and fairly high degree of association was found between the ratings obtained during first and repeat readings by the same method of rating. This association, however, cannot be offered as final proof of the test-retest reliability of the rating methods since it is affected by a number of cases of recognition of individual records due to growing familiarity with the records.

The association between the ratings by the two methods, however, can be considered as evidence in favor of satisfactory reliability of the ratings since the methods turned out to be essentially equivalent forms.

c. Two types of validity are of importance in this study:

(1) the validity of the ratings as descriptive of the recorded flight performance; and

(2) the validity of the ratings as representative of levels of over-all pilot proficiency.

(a) The first type of validity may be assumed (limited, of course, to those aspects of the performance which are accurately recorded by the R-S Ride Recorder). Since the traces are an objective record of attitude effects during flight, the ratings based upon those traces (if reliable) are themselves criterion data, representing relative degrees of excellence of performance as compared with an "ideal" performance in terms of aerodynamic principles. Since there is some evidence as to their reliability, the ratings can be considered valid descriptions of those aspects of flight performance recorded by the tracings.

(b) The validity of the ratings as representative of over-all pilot proficiency was determined by comparing the ratings with external criteria obtained by classifying the 28 subjects into groups according to pilot status. Pilot Status classifications were based upon license status (student, private pilot, or instructor) and amount of flying time in the testing airplane used during the standard flights.

The association obtained during these comparisons (Table 6) was not found to be statistically significant. The fact that the various contingency coefficients are consistently positive, however, suggests that there may actually exist significant relationship between the ratings and over-all flight proficiency.

6. A method is suggested for the use of pattern scales by instructors in the field in the qualitative evaluation of graphic records of pilot performance.

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE OBTAINED BY MEANS OF THE R-S RIDE RECORDER

PART I

SECTION A

The Reliability and Validity of Qualitative Techniques for the Evaluation of Flight Performance

by

Morris S. Viteles

and

Oscar Backstrom, Jr.

(with the assistance of
Albert S. Thompson)

University of Pennsylvania
Philadelphia, Pennsylvania

November, 1942

INTRODUCTION

During the spring and summer of 1940, two graphic recorders were employed at Tulane University in making simultaneous records of airplane attitude effects and control movements during flight. The R-S Ride Recorder was employed to obtain records of data pertaining to flight attitude; the Fries Cable Control Recorder was employed to obtain records of control movements. Records obtained in the course of this investigation included those of 28 pilots who flew prescribed standard flights three times.[1] The procedure used in obtaining records is described in Exhibit I, abstracted from a Progress Report dated September 1, 1940, submitted by H. M. Johnson, Tulane University, to the Committee on Selection and Training of Aircraft Pilots.

Objectives in Analyzing Graphic Records of Data Pertaining to Flight Attitude

In January of 1941, the records obtained at Tulane University were brought to the University of Pennsylvania for analysis. This transfer was made with a view to determining the usefulness of graphic recorders of the type represented by the R-S instrument in obtaining records of airplane attitude effects, and comparing the advantages and disadvantages of such records with those of records obtained by means of photographic techniques.

Since the primary interest of the Pennsylvania group was that of obtaining records of the attitude of the airplane during flight for comparison with simultaneous photographic records of control movements, attention was centered upon the study of those portions of the R-S Ride Recorder records pertaining to flight attitude. The present report deals, in the main, with the qualitative analysis of these records.

Graphic Records as a Source of Criterion Data

The importance which attaches to records of airplane attitude in investigations of pilot skill arises from their possible utility in supplying objective criterion data. If, during flight, it were possible to record accurately the position of each axis of the airplane with respect to earth horizontal and earth vertical, the history of the constituent maneuvers could be reconstructed and analyzed into mechanical descriptive components. Such an analysis and description would be entirely objective.

It is obvious that simply to analyze a performance of a maneuver into its mechanical descriptive components will tell only how the maneuver was performed and not how well. In order to arrive at a statement of the merit of the performance, it is necessary to know not only what those descriptive components are, but also what they should be. In other words, it is necessary to know not only what the pilot caused the airplane to do, but also what he intended it to do, or what he was told to make it do. Unless both types of information

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[1]See pages 124-128, inclusive, Exhibit I.

are given, it is impossible to appraise the merit of the subject's performance.

Of the latter type of information, that is, what the attitude of the airplane should be, some items are supplied by aerodynamic theory and the conventions of instruction. Thus, it is taken for granted that in executing a turn in the horizontal plane, the pilot should maintain lateral balance, nose-level longitudinal attitude, and (providing there is no requirement to follow a ground pattern) a constant given bank appropriate to the radius of the turn. The reasons for these prescriptions are found in aerodynamic theory. In smooth air, when the above conditions obtain, the horizontal turn will be executed without change of altitude and the flight path will approximate a perfect arc having a constant radius of turn. Also, the "ride" will be smooth, and the comfort of occupants will presumably be served. More important still, from the viewpoint of C.P.T. instruction, the turn will be executed in the most efficient and safest manner.[2]

Records of airplane attitude during flight can be meaningful as criterion data in evaluating pilot performance only if maneuvers to be performed are fully set forth in rigid prescriptions to the pilot (or reported by the pilot to the experimenter). Criterion data then are essentially represented by the deviations of the pilot's performance from these prescriptions. In other words, for the purpose of research, the most effective use of graphic records can be made only in connection with <u>standard flight situations</u>. This is not to deny that such records may be applicable over a wide range of ordinary "informal" instruction situations, particularly when, as is frequently true, there exist definite conventions of instructions, such as are represented in the prescription of a 60° bank for the 720° turn in the C.P.T. course. However, where the "ideal" attitude situation is not given by formal prescriptions, such as are included in standard flights, or by conventions of instruction, records of flight attitude cannot be used as criterion data.[3]

Criterion data obtained from graphic records of airplane attitude find their application:

1. In <u>research</u> directed towards developing and improving methods of selecting and training pilots, and

2. In the actual task of training pilots in the field.

Such criterion data may be expressed in (a) qualitative or (b) quantitative terms.

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[2]From the viewpoint of advanced training, the above conditions may be desired in some situations and may not be desired in others. For example, if a combat pilot in a dogfight wishes to make a 180° turn, it may be desirable to forego attention to lateral balance for the sake of other advantages. Nevertheless, these prescriptions are almost universal conventions, and whether practical in all situations or not, exist, and are justified in aerodynamic theory.

[3]This limitation applies not only to graphic records of pilot performance but also to photographic records, notes made by an observer, etc., except where "judgment" is to be given prime consideration in the evaluation of performance.

The fundamental aim of the investigation carried on at the University of Pennsylvania has been to determine the utility, as a source of criterion data, of graphic records of data pertaining to airplane attitude obtained in the course of standard flights and treated both qualitatively and quantitatively.

Description of the R-S Ride Recorder and Records

The R-S Ride Recorder, used in obtaining the graphic records of data pertaining to airplane attitude, was originally designed to indicate the quality and characteristics of the "ride" and to record impacts and shocks occurring in moving railway cars. The instrument used in the Tulane project, shown in Plate V, page 60, is a duplicate of this ride-recording instrument[4] with certain minor modifications suggested by preliminary trials of the instrument in the flights made at the New Orleans Airport. Specimens of the chart of this R-S Ride Recorder are shown in photostatic reproduction in Plates Ia, Ib, II, III, and IVa-IVj.

The Chart and Chart Traces

The chart is waxed red paper. All traces are made by unheated metal styluses. The drive roll of the instrument is pegged at each end. The pegs fit into the marginal holes of the chart and serve to prevent fouling or malposition of the chart. The chart is divided horizontally into feet, inches, and tenths of inches; these units represent time intervals which depend on the paper speed. The paper speed used in making all records in the present experiment was

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[4]Several models of the R-S instrument are currently in use. The term "Ride Recorder" is here applied throughout to the earliest model, which employs a system of electrical switches to record control movements and has a chart width of 4 15/16 inches. The term "Redhed Flight Recorder," with distinguishing model number, is applied to the later models A-2 and A-3, which employ a mechanical cable system to record control movements and have a chart width of 6 15/16 inches. (Other names have been applied to all models in correspondence and discussion, including "Impact Recorder," "Impact Register," "Pendulum Recorder," etc. The manufacturer formerly applied the name "R-S Airplane Attitude and Controls Movement Recorder" to the newer models A-2 and A-3, but in April, 1942, adopted "Redhed Flight Recorder.") All records with which this report deals were made with the Ride Recorder; but since the models have certain features in common, much of the discussion in this report is applicable to records made with the Flight Recorders as well. Specifically, discussion of the left-wing-low trace, the right-wing-low trace, and the pitch-and-longitudinal-acceleration trace will be applicable to both Flight Recorders A-2 and A-3; discussion of the "load factor" trace will be applicable to load factor indicators of Model A-2 instruments which have the same calibration, and partially applicable to load factor indicators having different calibrations. (Since the load factor indicator of Model A-3 provides for the recording of negative as well as positive load factor, it cannot have the same calibration as the load factor indicator of the Ride Recorder.)

1 1/2 inches per minute. Each tenth inch = 4 seconds.[5] The chart is divided vertically into tenths of inches. The general character of the chart and traces can be seen from an examination of Plates IVa-IVl.

The R-S Ride Recorder provides seven traces as follows:[6]

I. Signal Trace

The top trace on the chart is made by an electrically motivated signal marker and serves to indicate the beginning and end of each maneuver. When used in conjunction with a like trace on other simultaneous records, such as the Fries Cable Control Recorder records, it provides a means of synchronizing records. The marker was operated by means of a pushbutton inserted into the rear stick (for soloing student's use) or one inserted into the dashboard (for instructor's use in dual flights). Current was supplied by a 1.5 V. dry cell.

II. Traces pertaining to Flight Attitude

Four of the traces refer to flight attitude. These include:

A. A trace of positive load factor.[7]

1. This trace is produced by a stylus actuated by a weight-and-spring accelerometer constrained to move only verti-

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[5]The chart is so wound that the 0 feet mark is at the end of the roll in order that the operator may tell directly how much of the roll remains at a given point. Hence, there is an apparent discrepancy between the notations "Begin" and "End" on the plates and the horizontal scale, since although the records read from an observer's left to his right, the horizontal scale reads from his right to his left.

[6]This discussion of each trace of the R-S Ride Recorder is summarized from the results of an extended inquiry covering the capabilities of the Recorder. A detailed analysis of capabilities and deficiencies of both the R-S Ride Recorder and the Fries Cable Control Recorder is presented in the attached Supplemental Report

[7]Throughout this report, the term "load factor" is used to indicate the ratio of the imposed total air load (i.e., force) on the wings to the weight of the airplane, or the mathematically equivalent ratio of the air load per unit mass to true gravity. The term "apparent gravity" is sometimes applied to the air load per unit mass.

In mathematical terms:

$$\text{Load factor} = \frac{\text{total air load}}{\text{weight}} = \frac{(\text{mass})\ (\text{"apparent gravity"})}{(\text{mass})\ (\text{gravity})}$$

cally to the base of the instrument.[8] The spring had an initial tension of 1.05 g. The baseline thus indicates 1.05g. The top extreme of the scale is 2.05 g, by static calibration. Each vertical tenth-inch by static calibration = 0.10 g.[9] The system, ignoring slight dry frictional factors, is virtually undamped, except for the stops placed at each extreme. Consequently there is superposed on the load factor curve a complex of sine curve traces of engine, propeller, and frame vibrations.

2. In level flight the airplane is subjected to a positive load factor of 1 g.[10] Whenever the airplane follows a

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[8]The effect measured by this accelerometer is the "apparent gravity" component of the force on the wings. The ratio of the "apparent gravity" to true gravity is the load factor. (See preceding footnote.) Since the accelerometer is calibrated in units of gravity (g), it therefore indicates the load factor directly.

"Apparent gravity" is often called "vertical acceleration", meaning the acceleration along the vertical axis of the airplane. This usage has been particularly widespread among the projects of the Committee on Selection and Training of Aircraft Pilots and among instrument makers. It is not in keeping with accepted physical usage, however, and may lead to misconceptions in the discussion of certain subjects.

The term "load factor", with which most pilots are familiar because of its popularization by the Civil Aeronautics Administration and the National Advisory Committee for Aeronautics, was adopted at the suggestion of Professor David L. Webster.

Further discussion of load factors and the measurement of load factors may be found in C.A.A. Aircraft Airworthiness Section Report No. 10, <u>Load Factor Information for Pilots</u>. This report is reproduced in pages 311-320 of Civil Aeronautics Bulletin No. 23, <u>Civil Pilot Training Manual</u>, Washington, D. C.: Government Printing Office, September, 1941. A more technical presentation is given in pages 16-17 of Jones, B. M., "Dynamics of the Aeroplane", Durand, W. F. (ed.), <u>Aerodynamic Theory</u>, Volume 5, Berlin: Julius Springer, 1935.

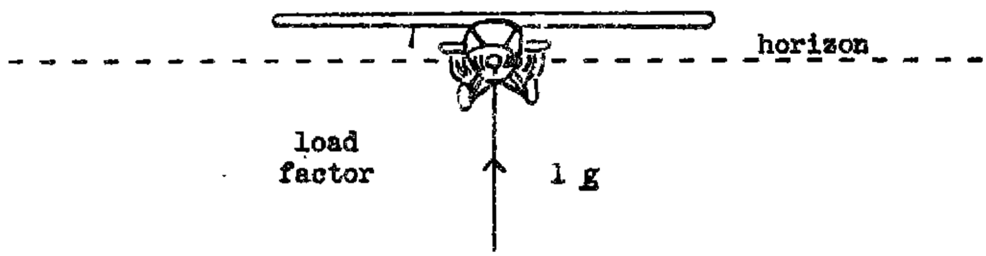
[9]The accelerometer had not been calibrated dynamically. The static calibration was therefore employed in this study, with recognition of the fact that the values of load factor so obtained might differ from those which would have been obtained if a dynamic calibration had, properly, been employed. It was not deemed necessary to take account of the possible differences between the static and dynamic calibrations of the accelerometer for reasons given in detail in pages 177-178 of the <u>Supplemental Report</u>.

[10]Since the load factor is actually a ratio, it should properly be expressed simply as a number, and not in units of acceleration. The wide-spread usage of gravitational units in expressing load factors, however, has led to an acceptance of the practice.

Diagram 1

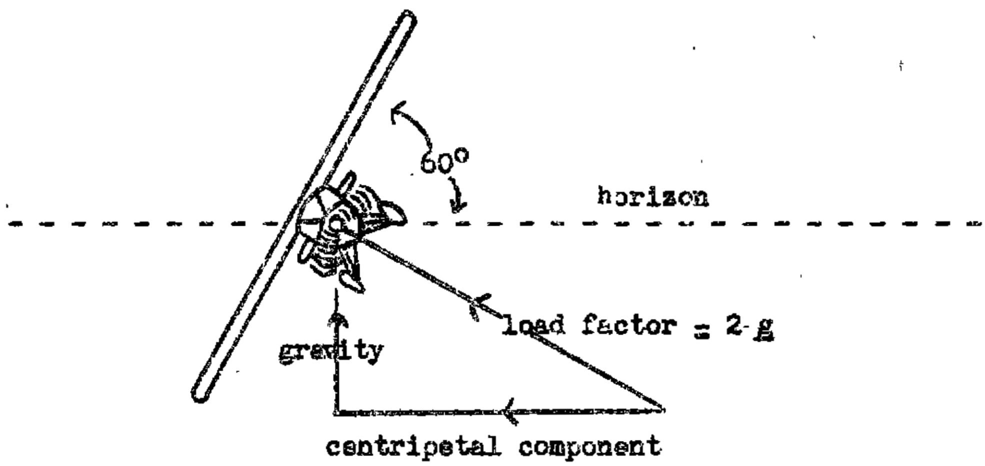
LOAD FACTORS IN NORMAL FLIGHT

Figure A -- Straight and Level Flight



In straight and level flight the load factor of the airplane has only a gravitational component. Hence load factor = + 1 g.

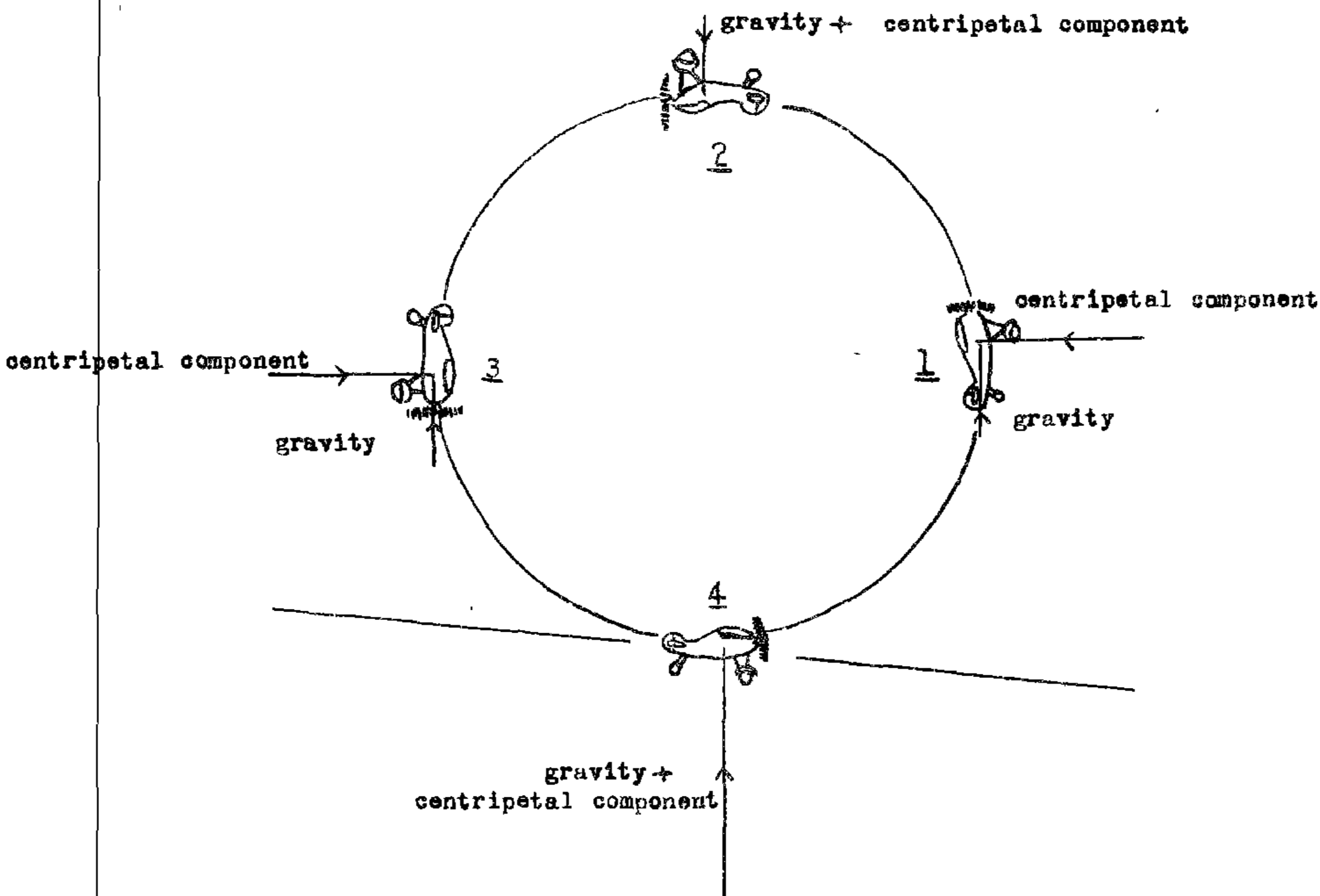
Figure B -- Curved Flight in Earth Horizontal (Banked Turn)



In curved flight in the earth horizontal, the apparent gravity of the airplane is the resultant of a gravitational component and a centripetal component. Hence the load factor is greater than + 1 g.

Diagram 1
(Continued)

Figure C -- Curved Flight in Earth Vertical (Normal Loop At Constant Speed)[11]



A perfectly circular loop executed in the earth vertical at constant speed is accompanied by a constant centripetal acceleration, which lies along the airplane vertical. Gravitational acceleration will also lie along the airplane vertical when airplane and earth vertical coincide. The apparent gravity of the airplane is the sum of the centripetal and gravitational accelerations in such instances. In Figure C it was assumed that the radius of the loop and the speed of the airplane were such that the constant centripetal acceleration = 2 g. Thus:

In 1, load factor = 2 g (0 g gravitational component + 2 g centripetal component).

In 2, load factor = 1 g (-1 g gravitational component + 2 g centripetal component).

In 3, load factor = 2 g (0 g gravitational component + 2 g centripetal component).

In 4, load factor = 3 g (1 g gravitational component + 2 g centripetal component).

11 Figures B and C were adapted from Figures 1(c) and 2, respectively, page 12 of the CAA Aircraft Airworthiness Section Report No. 10, "Load Factor Information for Pilots." This report is reproduced in Civil Aeronautics Bulletin No. ' "' '1 Pilot Training Manual " September, 1941 pages 311-320

curved flight path, it is subjected to a positive load factor whose value is greater than 1 g, and is dependent upon the plane within which the airplane is turning, the rate of turn, and the velocity of the airplane.

3. A positive trace will appear on the load factor line whenever the airplane, as illustrated in Diagram 1, pages 6-7, is following a curved flight path whose direction and radius are such that the "load" imposed upon the plane is greater than 1.05 g, the value of the initial bias of the restraining spring. This statement holds whatever the plane within which the airplane is traveling. Thus, a curved flight path in the earth's vertical, as in, e.g., the curved ascent during a normal loop, will produce a positive trace on this line, and likewise, a curved flight path in the earth's horizontal, as in banked turns, will produce a positive trace.

4. Since a constant relation holds between the angle of bank in horizontal turns and the load factor to which the airplane is subjected, the load factor trace finds a particularly important use in supplying information about the subject's performance with respect to bank. The emphasis of this study has been directed towards the examination and analysis of elementary maneuvers, many of which require a curved flight path in the earth horizontal. Particular attention has therefore been given to use of this trace in supplying information about the bank of the airplane.

5. In this and subsequent discussions, it will be necessary to distinguish carefully among the terms prescribed bank, "proper" bank, and actual bank.

   a. The prescribed bank is that bank which the subject is instructed to attain and maintain during the particular maneuver.

   b. The "proper" bank is

      (1) that bank at which the airplane, having a given forward velocity, would be in perfect lateral balance for the particular rate of turn the pilot has assumed, or, stated in other terms,

      (2) that bank at which the resultant of gravitational and centripetal accelerations would be vertical to the wing span for the particular rate of turn (at the given forward velocity) or

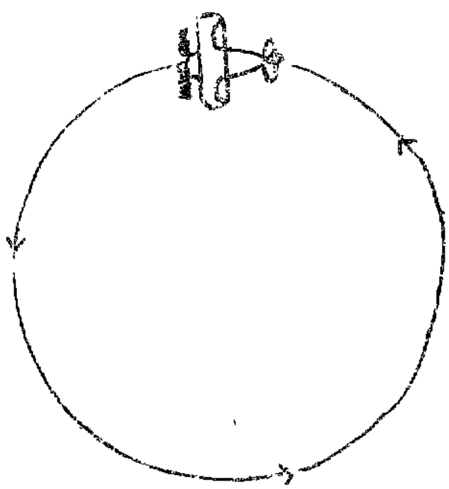
      (3) the appropriate bank for the rate of turn (at the given forward velocity).

Diagram 2

LATERAL BALANCE, SKID, AND SLIP IN LEFT HORIZONTAL TURN[12]

Figure A -- Lateral Balance

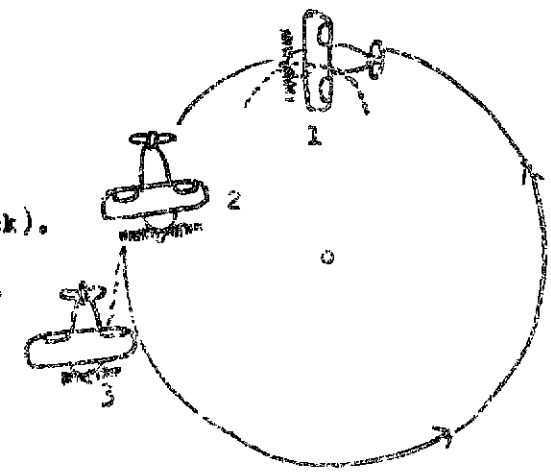
Rudder streamlined in left turn; proper left aileron and elevator deflection.



Airplane follows flight path in balance.

Figure B -- Skid

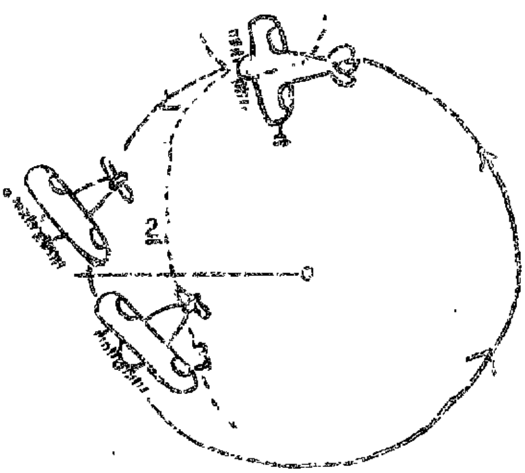
Too little left aileron in left turn (or, excess left rudder and back stick). Attempts to force a decrease in radius of turn. Skid results.



Depending on extent of deflections, airplane may follow approximately flight path represented by solid line, in relative position shown in 2, or may move upward and outward following new flight path, as illustrated by dotted line in 3.

Figure C -- Slip

Too much left aileron in left turn (or, too little left rudder and back stick). Attempts to force an increase in radius of turn. Slip results.



Depending on extent of deflections, airplane may follow approximately flight path represented by solid line, in relative position shown in 2, or may move downward and inward, following new flight path, as illustrated by dotted line in 3.

12 Diagram 2 was adapted from Figure 75, page 126, of Civil Aeronautics Bulletin No. [illegible], "Civil Pilot Training Manual," September, 194[illegible].

[illegible] angle of inclination of the wing span to the horizontal. In a laterally balanced turn, the actual bank is equal to the "proper" bank, but it will still not be equal to the prescribed bank unless the pilot has selected the proper rate of turn corresponding to the bank called for in the prescribed maneuver. In a turn with slip (overbank), the actual bank is equal to the "proper" bank plus the angle of slip. In a turn with skid (underbank), the actual bank is equal to the "proper" bank minus the angle of skid.

6. As illustrated in Diagram 2, page 9, a slip results when the pilot, having established a radius of turn by deflection of the rudder to the right or left, applies too much corresponding aileron, depressing the corresponding wing to a position which is too low for perfect lateral balance. Thus in a left turn, a slip will result when the pilot applies too much left aileron for the left rudder deflection and the left wing is brought below the position of balance.

7. A skid results when the pilot, having established a radius of turn by deflection of the rudder to the right or left, applies too little corresponding aileron (or too much opposite aileron), depressing the corresponding wing to a position which is not low enough for perfect lateral balance (or depressing the opposite wing to a position which is too low for perfect lateral balance). Thus, in a left turn a skid will result when the pilot applies too little left aileron, or when he applies too much right aileron after neutralizing and the right wing is thus brought below the position of balance.

8. In this discussion of the load factor trace, it is important to note that in any given horizontal turn with angle α of "proper" bank, the load factor is given by the relation

$$\text{Load factor} \doteq \sec \alpha,$$

subject to an error in certain situations which may usually be regarded as negligible. The recorded load factor is read directly from the chart (See footnote, 8 page 5). The attained load factor at any point within a horizontal turn is the secant of the angle of "proper" bank at that point.[13]

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13 The attained load factor may differ somewhat from the recorded load factor taken with the static calibration, because of differences in the static and dynamic calibrations of the accelerometer. (See Supplemental Report, page 177.)

The attained load factor will not be equal to the secant of the angle of actual bank unless the airplane is in lateral balance. Whenever the airplane is in a slip or skid, the attained load factor will therefore not be equal to the secant of the angle of actual bank.

9. In reading this report it will be noted that "proper" bank has been used to derive indices of pilot skill in preference to actual bank. Reasons for giving such preference to "proper" bank are outlined in detail in the Supplemental Report, pages 166-168. It need be said here only that the "proper" bank is a physical entity which affords a direct indication of one and only one important aspect of the subject's performance, viz., his estimate of the proper rate of turn (at the given forward velocity) to achieve the desired or prescribed bank. The concept of the actual bank is perhaps somewhat more readily grasped, inasmuch as it represents the actual inclination of the wings to the horizon. The actual bank may nevertheless be considered a less useful item because it is a compounding of two different effects, neither of which it indicates directly or simply. (See Supplemental Report, pages 167-168.)

10. Reference to Plates IVa - IVj will indicate the utility of the load factor trace in supplying information about the subject's performance with respect to "proper" bank. For example, in Plates IVa, IVb, and IVc it is apparent that the subject's "proper" bank varies considerably and might be characterized somewhat impressionistically as "ragged". In Plates IVf and IVj are seen examples of relatively constant "proper" bank. Further discussion of these plates will be presented later, since the present discussion and examination are designed only to indicate the general nature and utility of the load factor trace.

B. Immediately below the load factor trace are two traces indicative of lateral imbalance. One of these (upper) indicates that the left wing is low, i.e., that the inclination of the wing to the horizontal is too great for perfect lateral balance in the maneuver. The other (lower) indicates that the right wing is low. These traces will be discussed jointly and will be referred to collectively as the "lateral imbalance traces".

1. Each of these lateral imbalance traces is produced by a pendulum free to move only laterally. These pendulums are stopped in such a manner that each may execute only half an oscillation. Thus the left-wing-low pendulum may move only to the left (pilot's or airplane's) in the lateral plane, and the right-wing-low pendulum may move only to the right in the lateral plane.[14]

2. Each of the lateral imbalance traces was calibrated statically. The scale is such that each 0.10 inch in

14 The purpose of employing two pendulums, each stopped at the midpoint, is to minimize the errors due to limited damping. These errors would be excessive in an unstopped single pendulum.

height of trace represents 2° additional deviation from the level position under static conditions. The limit of the scale for each trace is 14°. This static calibration, however, does not hold under conditions of flight.

3. For reasons given in detail in the Supplemental Report, pages 179-186, it is impossible to calibrate these pendulums to show slip or skid angle. For all practical purposes, however, each trace may be regarded as indicating deviation of the ball of the ball-bank indicator from its center position, the upper trace deviation to the left, the lower trace deviation to the right. (See Supplemental Report, page 184.) Thus in Plate IVa, it is apparent that the subject was in a long and extensive slip (right wing low) throughout the maneuver (720° Right Power Turn). The subject whose performance for the same maneuver is represented by Plate IVb also slipped extensively, but somewhat more irregularly, and for a shorter time than the subject of Plate IVa. Slight to fairly extensive amounts of slipping are shown in Plates IVc, IVd, IVe, and IVf. In Plates IVg, IVh, and IVj are examples of performances exhibiting relatively little lateral imbalance. Plate IVg shows several minor skids (left-wing-low). Plate IVh shows several minor slips (right-wing-low), and Plate IVj shows one slight skid (left-wing-low) towards the end of the maneuver.

C. The next and lowest line on these records is produced by a stylus actuated by an undamped pendulum which is free to move only in the longitudinal plane of the airplane, free to swing on both sides of its mid-position, and stopped at each extreme. The pendulum is subject to two effects, viz.: longitudinal acceleration and changes in the longitudinal pitch of the airplane. The trace represents the algebraic sum of these two effects and under certain conditions may apparently be subject to other effects as well.

1. Longitudinal acceleration and changes in longitudinal pitch will ordinarily occur in such fashion as partially to offset each other in the recorded trace. A negative change in pitch (lowering the nose of the airplane) tends to produce a downward trace. But lowering the nose of the airplane will ordinarily result in a positive acceleration along the longitudinal axis; so, e.g., when the nose is lowered below the horizon, the airplane is subjected to a positive longitudinal acceleration because of the pull of gravity. Positive longitudinal acceleration tends to produce an upward trace. The two effects thus tend to cancel, insofar as the recorded trace is concerned. Conversely, a positive change in pitch, tending to produce an upward trace, is ordinarily accompanied by a negative longitudinal acceleration (longitudinal deceleration), as in, e.g., a stall; and

the resulting trace does not show unequivocally the nature and extent of each effect.

2. Under most conditions, the pitch-and-longitudinal-acceleration trace is therefore not interpretable, and no use has been made of it in this investigation, although the trace can be used as an aid in identifying maneuvers. (See Exhibit I, pages 141-142.) Referring to Plate IVa, it may be seen that the trace under consideration is very nearly a straight line. Unfortunately this cannot be taken to indicate that the pilot maintained a nose-level attitude (i.e., that the longitudinal axis lay in the plane of the horizon), because the pilot may have operated the airplane in such a way as to produce longitudinal acceleration and changes in longitudinal attitude which practically offset each other in the trace. Likewise, in Plate IVb, the short section of trace towards the end of the maneuver may mean that the pilot has pulled up the nose of the airplane. On the other hand, an identical trace might also be produced by positive longitudinal acceleration occurring when the nose of the plane is actually below the horizon.

III. Traces of Control Movements.

The final two traces provided by the R-S Ride Recorder show aileron movement, and rudder movement, respectively. These traces are not shown on any of the plates.[15]

The control-movements recording systems of the R-S Ride Recorder were discarded in the first week at the field because they were judged to be less desirable than those of the Friez Cable Control Recorder, which was installed and employed in conjunction with the Ride Recorder.[16]

All the traces described in the preceding paragraphs and illustrated in Plates IVa - IVj -- including the signal marker trace and those pertaining directly to flight attitude -- are common to all models of the instrument. (The initial tension of the restraining spring in the accelerometer may be varied as desired for any individual instrument; hence the particular calibration and readings referred to in this report may not be applicable to other models.)

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15 If present, the trace indicating aileron movements would lie in about the center of the chart, and the trace indicating rudder movements would lie below the pitch-and-longitudinal-acceleration trace at the bottom of the chart.

16 A complete description and critical analysis of the control-movements recording systems of the R-S Ride Recorder are found in the Supplemental Report, pages

The Approach of this Investigation

The discussion thus far has indicated that the records of the R-S Ride Recorder may be used in arriving at quantitative indices of pilot performance. One objective of this investigation has been to determine the utility of these records in obtaining quantitative data on flight attitude to be used as criteria in evaluating pilot performance. In addition the investigation includes an examination of the utility of the records in arriving at reliable and valid qualitative estimates of pilot performance.

In the search for, or development of, criteria for use in problems of selection, classification, and training, preference is customarily given to those criteria which may be quantified and expressed in cardinal numbers. Such criteria admit of more extensive and more exact treatment than those which may be expressed only in qualitative terms. It may be asked, since the data provided by the R-S records lend themselves to quantitative treatment, why a qualitative approach was also employed. The answer to this question lies in the time required and the difficulties encountered in the treatment of the data of the R-S Ride Recorder chart to provide quantitative indices of pilot performance.[17]

Difficulties in Arriving at Quantitative Data

I. In order to obtain quantitative indices of pilot performance from the data provided by the R-S Ride Recorder chart, the various traces considered must be accurately measured at some arbitrarily established time interval. In this process, error of measurement may be incurred in two respects: in measuring vertical chart distance (i.e., the

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17 It should be noted that certain data of the chart -- namely, those data provided by the load factor trace, the left-wing-low trace, and the right-wing-low trace -- are quantified in the sense that they are "graphed" on the record. The load factor trace may be viewed as a graph of positive load factor "plotted" against time; the left-wing-low trace may be viewed as a graph of the deviation of the ball of the ball-bank indicator to the left of its center position, "plotted" against time; and the right-wing-low trace may be viewed as a graph of the deviation of the ball to the right of its center position, "plotted" against time.

These data, however, are not in themselves criterion data. Criterion data are the deviations of these effects "graphed" on the chart from what those effects should be.

In many instances, it might be said that the lateral imbalance lines (left-wing-low and right-wing-low) are graphs of the deviations of the actual performance from the prescribed performance, viz., in the case of those maneuvers in which no positive trace of lateral imbalance should appear.

In the case of maneuvers which do require a positive trace in the case of one of these lines, such as forward and side slips, this statement cannot hold. Moreover, even in those instances where the data "graphed" on the chart might be considered to be themselves criterion data, they are not expressed in index form.

height of each trace from its base-line) and in measuring <u>horizontal</u> chart distance (setting off the arbitrarily established time interval at which measurements are taken).

II. The chart is printed with both horizontal and vertical scales, each graduated in tenths of inches. Each scale may be read directly with fair accuracy to .05 inch, i.e., to the midpoint between two printed scale marks. Accuracy of direct readings to any finer amount is highly questionable, owing to the difficulty of any finer estimation, and to the fact that it is necessary to use a transparent scale device (external to the chart) to synchronize the traces. This synchronizing scale, the use of which is described more fully in the <u>Supplemental Report</u>, pages 192-194, must be adjusted to the chart so that it is properly aligned with the chart base-lines; each trace is then read at the point at which it is intersected by an appropriate line of the synchronizing scale. Even if it were possible to estimate accurately to a lesser distance than .05 inch on the chart, slight misalignments of this synchronizing scale would cause sufficient error to offset the fineness of measurement so gained.

III. The finest accurate measurement possible by direct scaling of the chart is thus .05 inch. Unfortunately, the quantities of the effects to be measured corresponding to this chart interval are too large to furnish fine indices of performance:

A. A chart height of .05 inch corresponds to .05 g of load factor; .05 g of load factor may correspond to a "proper" bank interval as great as 7°.

B. A chart height of .05 inch corresponds to 1° of lateral imbalance (slip or skid) by static calibration.

C. A chart length of .05 inch corresponds, in the case of these records, to a time interval of 2 sec.

IV. Indices computed from measurements accurate only to the orders stated above may serve to rank or categorize performances, but they can hardly be considered to be sensitive enough to reveal small gradations in proficiency from subject to subject. In order to obtain such indices, it is necessary to magnify the records by projection and obtain accurate fine measurements of the chart data.[18]

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18 Projection is necessary primarily to obtain suitably accurate fine measurements of vertical chart distance, i.e., of the height of each trace from its base-line. This difficulty is not necessarily confined to the Redhed instrument. It might be encountered in any graphic recorder which records several flight attitude effects. The chart space of the graphic recorders used in airplanes is limited by considerations of installation and weight. In small airplanes a chart width of 15 inches is a generous maximum. If several traces are contained in this available width, the maximum excursion of each is likely to be less than desirable.

The difficulty with regard to horizontal chart length might be solved by increasing the paper speed.

V. Projection of the records for measurement is admissible for purposes of research employing laboratory analysis of the records, but it is most unsuitable for frequent use of the records at the field in the task of training pilots. Indeed, in view of the conditions of instruction, little measurement of any sort, whether by projection or direct scaling, would be admissible for field use of the records. For such use, an approach other than one involving the computation of fine quantitative indices is required. Such an approach must be qualitative and "clinical" in nature.[19]

Quantitative and Qualitative Aspects of the Investigation

The complete study includes both a quantitative and qualitative examination of the records of flight attitude effects obtained by means of the R-S Ride Recorder. The qualitative analysis was designed to define, insofar as possible, the utility of certain features[20] of the R-S records to the instructor in the field, while the quantitative analysis was designed to test the practicability of a quantitative approach to data provided by these same traces, and to apply this approach to as large a number of specific problems as possible.[21]

I. The general character of both investigations has been more intensive than comprehensive. It was decided to select from maneuvers included in the records of the standard flights one or two which would afford a complete investigation of the flight attitude traces of the R-S instrument and focus attention upon the definitive statement of the capabilities of these records when employed to give quantitative and qualitative results. It was also thought desirable that the maneuver be one on which the performances of elementary students, private pilots, and instructors would be likely to vary widely.

II. The 720° power turn was selected as best fulfilling the conditions stated above:

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19 The qualitative study was undertaken at the suggestion of H. H. Johnson, who prior to the initiation of the qualitative study also reviewed the experimental design as prepared by M. S. Viteles, Oscar Backstrom, Jr., and A. S. Thompson.

20 These features are the load factor trace, the left-wing-low trace, and right-wing-low trace, discussed above. These traces comprise all those features of the records of all models of the instrument which pertain directly to flight attitude, with the exception of the equivocal pitch-and-longitudinal-acceleration trace.

21 The results of the quantitative study are to be reported separately as Part II of "An Analysis of Graphic Records of Pilot Performance Obtained by Means of the R-S Ride Recorder."

A. Its execution invariably produces a positive trace on the load factor line of the R-S Ride Recorder, and positive traces may appear on the other flight attitude lines. An analysis of records of this maneuver would then take into account all the flight attitude traces of the instrument.

B. This maneuver may be expected to reveal rather large differences in performance at varying levels of experience. This expectation is particularly justified in the case of the right 720° power turn, if there is any truth in "hangar flying", since performance of elementary students is reputed not only to vary widely from that of more experienced pilots on this maneuver, but also to be inferior to their own performance on the left 720° power turn.[22]

III. The qualitative analysis was confined to the right 720° power turn because this investigation was designed only to test the practicability of a qualitative approach. The quantitative analysis, on the other hand, included both left and right 720° power turns because it was designed both to test the practicability of a quantitative approach and to compare performance on turns of each direction by means of the quantitative indices derived from the data.

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22 It will be noted that the 720° power turn is therefore one of the optimal elementary maneuvers for this exploratory research. It does not follow, however, that the use of the R-S Ride Recorder, or of graphic recorders in general, is restricted to maneuvers of similar type. Any maneuver may be analyzed by the R-S Ride Recorder or any other recorder insofar as it can be described in terms of the functions provided by that recorder.

a. A necessary condition of analysis, however, is that the interpreter or reader of the record know what maneuver was attempted. (See pages 1-2.) Since a number of elementary maneuvers do not show characteristic traces on the R-S Ride Recorder chart, an external means of identification, such as signal marks, is necessary. (See Exhibit I, pages146-147) Provided the maneuvers are executed, as recommended (page 2), in standard flights, a single dot or dash signal is all that is required to identify any maneuver. Provided a suitable paper speed is employed, maneuvers may also be identified in records of unstandardized instruction flights by means of a simple code of dot-dash signal patterns. This method, however, will usually be found less satisfactory than the employment of standard flights. (See Supplemental Report, pages195-199.)

b. It should be noted that the R-S Ride Recorder provides records of only three functions: load factor, lateral imbalance, and pitch-and-longitudinal-acceleration. The addition of other functions to this catalog would add to the list of maneuvers identifiable by means of characteristic traces.

c. Obviously the completeness of the analysis of any maneuver is dependent on the number of functions provided by the particular recorder. If a recorder provides a reliable indication only of load factor and lateral imbalance, these are the only aspects of the maneuver which can be evaluated from the records. In some maneuvers, certain functions have a primary significance, whereas in others their significance is secondary. In the case of straight and level flight, for example, the only function of primary importance supplied by the R-S Ride Recorder is lateral imbalance, but other significant data can be supplied by a more adequate recorder. (See Appendix A to Supplemental Report.)

THE SAMPLE QUALITATIVE ANALYSIS

I. Objectives

As stated in the Introduction, the purpose of the qualitative analysis was to investigate the value and practicability of obtaining data from the R-S Ride Recorder by means of direct inspection of the records such as might be made by an instructor in an ordinary training situation in the field. Specifically, the investigation attempted to answer two questions:

A. Will qualitative observations of the records yield reliable data which will aid in evaluating pilot performance?

B. Is the method of analysis practicable with respect to use in the field?

II. Design and Procedure

A. The qualitative analysis involved a comparison of two types of qualitative observations:

1. A fairly intensive study of the records, by means of a check sheet providing for a complete detailed description of the record (the Data Sheet) and

2. A free "clinical" description of the salient features of the record, by means of a General Description Sheet.[23]

B. In evaluating pilot performance by either sheet, the rater rated it on a five-point scale: Very Poor, Poor, Average, Good, Very Good. The analysis then took the form of investigating the reliability and "statistical" validity of each of the two methods of reading the records and comparing the results of the two methods.

C. Two samples of the 720° right power turn[24] of each of the 28 subjects[25] were examined. The turns from Flights 2 and 3 were used in the belief that irregularities due to unfamiliarity with the test situation would be more likely to occur in Flight 1 than in these later flights.

D. To minimize the possibility of bias, the procedure was so designed that the rater[26] did not know the identity of the subjects. The procedure in detail was as follows:

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[23] Specimens of each will be found in Appendix A.

[24] Selected for reasons described in the Introduction.

[25] Detailed description of the subjects and their classification as to pilot status may be found in Exhibit I, Pages 124-127.

[26] Ratings were in each case made by Oscar Backstrom, Jr.

1. The R-S record of the right 720° power turn of the third flight of each subject was marked with a code number, assigned at random, and records were presented to the rater in random order. The rater then examined the records by direct inspection and made his ratings with the Data Sheet. (The series number corresponding to this reading is 300-Ds-1.)

2. The record of the second flight of each subject was marked with a code number assigned at random, and the records were presented to the rater in random order. The rater then read the records and made his ratings with the General Description Sheet. (The series number corresponding to this reading is 200-Gd-1.)

3. The records of the third flight were then re-coded, and the rater read and rated them using the General Description Sheet. (The series number corresponding to this reading is 300-Gd-1.)

4. The records of the second flight were re-coded and the rater read and rated them using the Data Sheet. (The series number corresponding to this reading is 200-Ds-1.) In steps 1 and 4 the rater made a note of any record he identified as that of a particular subject.

5. By means of 5 x 5 contingency tables, ratings of each flight made by the two methods were compared, and ratings of the two flights by each method were compared. The theoretical frequencies in a number of cells of the 5 x 5 tables were small since the total N was either 27 or 28. The results of the 5 x 5 tables were therefore checked by repeating the calculations in 2 x 2 tables.

6. After a lapse of three weeks, records of the third flight were re-coded, and the rater read and rated them using the Data Sheet. (The series number corresponding to this reading is 300-Ds-2.)

7. After a lapse of a week, which the rater spent in quantitative computations and making quantitative readings of left turns, the records of the third flight were re-coded, and the rater read and rated them using the General Description Sheet. (The series number corresponding to this reading is 300-Gd-2.) In both steps 6 and 7 the rater recorded recognition of identified records and his recollection of the ratings he gave them on the first reading.

8. By means of 5 x 5 contingency tables, the ratings given in step 6 were compared with those given in step 1, the ratings given in step 7 were compared with those given in step 3, and the ratings given in step 6 were compared with those given in step 7. Again, all comparisons made with 5 x 5 tables were checked with 2 x 2 tables.

9. The proportion of the reader's correct recollections of previous ratings was obtained, in order to appraise the extent of bias in the results obtained in step 8.

10. Comparisons of the [illegible] ratings with other criteria were sought. These criteria were:

   a. Ratings to be derived from an early form of the Ohio State Check List filled in by the instructor who administered the flight.

   b. The pilot-status of the subjects, of which several indices were devised.

11. After consideration of the results, steps were taken toward establishing a concrete procedure for use of the qualitative approach in the field.

III. A Discussion of the Methods of Rating Performances, Difficulties in Making Readings, and Flaws in the Procedure.

A. Bases of rating[27]

1. In making the ratings, the record of each turn was divided into three sections which are defined with reference to the chart as follows:

   a. Entry: that section between the signal indicating the beginning of the maneuver and the first peak or plateau in the load factor trace following a fairly consistent rise of the trace from the base-line. This section corresponds to that portion of the turn in which the subject starts from the bank of zero, or nearly zero degrees, and rolls up to the bank at which he "intends" to fly the turn, and which, presumably, he considers to be the appropriate bank for the turn. On the record the entry is characterized by a consistent upward slope of the load factor trace except for the presence of "steps," momentarily held peaks or plateaus.

   It is apparent from the above definition that the determination of this point of termination of the entry is a judgment on the part of the rater and is subject to certain ambiguities. A discussion of these ambiguities and of the accuracy of this treatment is presented in pages 26-27.

   b. Recovery: that section between the last stable peak or plateau in the load factor trace and the terminating signal. This section corresponds to that portion of the turn in which the subject comes out of the turn by rolling off bank and returning to level attitude. It is characterised on the chart by a consistent downward slope of the load factor trace except for the presence of "steps."

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[27] The following discussion will be facilitated by reference to Plates IVa to IVj, inclusive, and their corresponding protocols, found in Appendix A. The plates are photostatic reproductions of records which illustrate the types of record to which each of the indicated ratings was assigned.

c. Turn proper: the section between entry and recovery, i.e., the section between the first stable peak or plateau in the load factor trace after the beginning signal and the last stable peak or plateau before the terminating signal.

2. Seven aspects of performance were considered in making the qualitative readings and in arriving at ratings:[28]

a. "Over-all" fluctuation in bank during the turn proper.

b. Deviation of average bank from the prescribed bank during the turn proper.

c. Intermittent ("side-by-side") fluctuations in "proper" bank during the turn proper.

d. Lateral balance.

e. Hitting the prop-wash (slip-stream).

f. Length and step-like character of the entry.

g. Length and step-like character of the recovery.

3. A detailed description of each of the seven aspects follows:

a. Overall fluctuation in bank is defined as the range of fluctuation of bank, i.e., the difference in degrees between the highest and lowest angle of bank attained during the turn proper. The appropriate values were obtained by transmuting the height of the load factor trace, in terms of chart spaces, into corresponding angles of "proper" bank by means of a table of equivalents (see Table 1). These angles were then transformed into assumed actual bank[29] values by correcting for simultaneous lateral imbalance (if present) by adding the number of degrees of slip or subtracting the number of degrees of skid, as required.

b. Deviation of average bank from prescribed bank: To obtain a measure of the pilot's approximation of the prescribed bank of 60° the rater roughly estimated the average "proper" bank from the load factor trace and calculated the average assumed actual

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[28] The first four items correspond to items which the investigation of the errors of the instrument revealed to be justifiable quantitative data. The latter three items are the more purely qualitative in character. The seven items include all the data which a consideration of the capabilities of the instrument revealed to be useful and obtainable by a qualitative treatment.

[29] Actual rather than "proper" bank was used in Items a and b for reasons explained on page 23, which also indicates the treatment of errors arising out of this procedure.

bank value[30] by adding the average extent of slip and subtracting the average extent of skid. This value was then subtracted from 60° in order to obtain the deviation from the prescribed bank. This procedure was varied somewhat in that if the subject's bank fluctuated around no fairly well defined mid-point, the rater would estimate deviations from prescribed bank during fractional divisions of the turn proper. For example, if the rater thought that an estimate of 15° average deviation did not give a true picture of the deviation owing to marked inconsistency he would note it, perhaps, as a deviation of 0° during one-third, 15° during one-third, and 30° during one-third.

c. Intermittent fluctuations in "proper" bank are defined as step-wise deviations (taken without regard to sign) in "proper" bank at successive time intervals throughout the turn proper. A rough estimate of the average of these fluctuations was obtained in the following manner:

The rater considered the load factor trace to be marked off in intervals of .05 inches (2 seconds).[31] He then "ran through" the "turn proper" section of the turn, estimated step-wise deviations in the readings of "proper" bank from interval to interval, and estimated an average. The rough estimate thus obtained represents intermittent or side-by-side fluctuations in "proper" bank.

d. Lateral balance: It will be recalled that the left-wing-low and right-wing-low traces treated in conjunction give a trace which for practical purposes may be regarded as similar to the deviation of the ball in the standard ball-bank indicator from its zero position, "plotted" against time. The rater's judgments of the extent and importance of lateral imbalance are thus based on data analogous to those commonly used by the instructors to appraise lateral imbalance during flight. Ratings of lateral imbalance were obtained separately for the entry, turn proper, and recovery. The rater judged the extent and seriousness of slipping and skidding in each section.

e. Hitting the prop-wash: It is commonly accepted that hitting the prop-wash upon the completion of the first 360° of a 720° turn is an indication of excellent performance of the first 360°, in that this section of the turn was carried through with negligible change in altitude, and approximated a perfect circle. The rater noted those cases of hitting the prop-wash which he could identify from the records and took account of this fact in making his final rating.[32]

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30 Actual rather than "proper" bank was used in Items a and b for reasons explained on page 23, which also indicates the treatment of errors arising out of this procedure.

31 The horizontal chart scale is marked in tenths of inches; thus this estimate was facilitated.

32 Not all cases of encountering the prop-wash can be identified from the records. A short discussion of this difficulty is presented on page 29, and a more complete discussion is presented in the Supplemental Report, pages 168-1

The record presented in Plate IVi is typical of those records showing identifiable prop-wash effects. These effects consist of a rapid dip of load factor trace to its base-line, followed by a rapid return to approximately its previous height, and accompanied by a simultaneous spike-shaped trace of a sudden extensive slip or skid, or traces of both.

f. Length and step-like character of the entry, and g. Length and step-like character of the recovery: Other things being equal, it would seem that the more proficient performance is one in which the subject rapidly and smoothly attains the bank at which he "intends" to fly the turn, and upon completion of the turn returns to level attitude rapidly and smoothly. For this reason the rater made judgments of the characteristics of the entry and recovery. No attempt at even rough quantification of these judgments was made when the General Description Sheet was used. Rough time measurements of the sections were made using the Data Sheet but it was found, in the course of the study, that these for the most part represent wasted labor because the rater rarely needed to refer to them in making these judgments.

4. Upon completion of observation of the above seven aspects of performance, the rater assigned an over-all rating of the subject's performance on the five-point scale: Very Poor, Poor, Average, Good, Very Good. Although no standard weights were assigned to individual items in obtaining the final rating, the following general principles guided the rater in making an over-all judgment:

a. The absence of the "characteristic" effects due to hitting the prop-wash was given very little weight in making a rating, for several reasons:

(1) The absence of these effects does not necessarily indicate that the subject did not hit his prop-wash, although their presence almost invariably indicates that he did.

(2) It is impossible to evaluate the fact that the subject did not hit his prop-wash other than to note that he changed altitude or did not approximate a perfect circle in the pattern of his first 360° turn. It cannot be stated how much his altitude changed, or in what direction; or in what manner the pattern of his 360° turn deviated from a perfect circle. The use made of Item e was therefore very restricted. Presence of prop-wash effects was considered evidence that the rating must almost inevitably be one of the upper categories; but absence of prop-wash effects was not interpretable.

b. Item b, the deviation of the subject's bank from the prescribed bank, was also given relatively little weight, for several reasons. The first of these is the well known inability of even expert pilots to estimate correctly an attained angle of bank. The second is that in the actual performance situation, deviations which look large "on paper" would seem to be of minor actual importance. Rather large deviations (up to 10° or 15°) were therefore treated as negligible. Deviations greater than these values were viewed as debits to the performance, but the debit was not considered of major importance unless the deviation was in the region of 25-30°, at which point the subject's bank would approach the range of shallow banks. The chief use made of this item was to "place" borderline cases.

c. Items f and g (length and character of entry and recovery) were assigned about the same importance as Item b and were treated in somewhat the same manner, i.e., the "classes" were rather wide. The best entry and recovery were assumed to be those which were rapid and free from stops. Rather wide divergences from such optimal performance were allowed without assigning the performance a debit, and conversely, the occurrence of the optimal forms, while viewed as contributing to the excellence of the performance, was held to be of less importance that Items a, c, and d, discussed immediately following.

d. The items weighted most heavily were over-all fluctuation in bank (Item a), intermittent ("side-by-side") fluctuation in "proper" bank (Item c), and lateral balance (Item d). These were viewed to be of about equal importance.

In the case of lateral balance, slipping and skidding were held to be equally bad, and the occurrence of a slip or skid in one of the three sections of the turn was held to be neither more nor less objectionable than its occurrence in another section.

There is a rather widespread tendency to emphasize the fault of slipping in the entry (more than skidding), and skidding in the recovery (more than slipping). This emphasis seems to have arisen from casual (i.e., uncontrolled) observation of the reputed "leads with aileron" fault of the beginning student. This differential emphasis might be justified in a study of coordination of pilot response, but need not be considered in a study designed to evaluate performance in terms of flight attitude.

In addition, it was not thought necessary that the commonly accepted view of the slip as a "safer" fault than the skid be taken into account. Such discrimination would seem to be hair-splitting, particularly in view of the nature of the rating procedure.

5. The final rating on the five-point scale was then assigned by "balancing" all these items and expressing the result as an estimate of the over-all excellence of the performance.

B. A Consistent Error in Making the Qualitative Ratings

1. At the time the qualitative analysis was being made, the investigation of the capabilities of the R-S Ride Recorder was still incomplete. In

particular, it had not been determined whether the lateral imbalance traces supply an accurate measure of the angular extent of slipping and skidding. In making the qualitative readings, however, it was decided to assume that the traces <u>did</u> measure the extent of slipping and skidding in degrees without excessive error.

2. The assumption was made because, given the actual slip or skid angle in degrees and the angle of "proper" bank in degrees (as derived from the load factor trace), it is possible to determine the actual bank. At that time, the actual bank was believed to be a more meaningful and useful item than the "proper" bank, although data on the latter were more directly available, since the actual bank at any point in the turn is determined by adding the slip angle to, or subtracting the skid angle from, the angle of "proper" bank.

3. As described in the <u>Supplemental Report</u>, however, both the assumption that the lateral imbalance traces accurately measure the angle of slip or skid[33] and the belief that the actual bank is preferable to the "proper" bank[34] as an indicator of pilot skill were shown to be false as a result of further investigation of the R-S Ride Recorder. The readings of actual bank, therefore, as used in <u>items a</u> and <u>b</u>, have an error due to the use of angular readings of slip and skid as derived from the lateral imbalance traces. As explained in the <u>Supplemental Report</u>, these errors are of unknown magnitude and no correction is thus possible.

4. When these facts were discovered, it was necessary to determine in what manner they would influence the results of the qualitative readings. If it could be shown that the <u>items</u> derived from the <u>erroneous</u> actual bank did not differ materially from those derived from the more accurate and useful "proper" bank[35] the results would be acceptable, for the overall ratings given to the performance would be the same in either case. By means of a checking procedure

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33 Pages 32-33

34 Pages 10-12

35 In considering this problem, it was anticipated that even if the <u>true</u> actual bank values and "proper" bank values differed materially, the <u>erroneous</u> actual bank values might be closer to the "proper" bank values than to the true actual bank value.

The nature of the error in any erroneous actual bank value is such that this value lies between the "proper" bank value and the true actual bank value. (The erroneous angular value of slip or skid supplied by the lateral imbalance traces is always smaller than the true slip or skid value.) (See <u>Supplemental Report</u>, page 185.)

Thus, in adding an erroneous angular value of slip to, or subtracting an erroneous angular value of skid from, a value of "proper" bank, there is always obtained an erroneous value of actual bank which lies between the "proper" bank value and the true actual bank value.

outlined in Appendix C it was found that there is little likelihood of a material difference between the over-all ratings obtained using the erroneously computed actual bank and the overall ratings that would have been obtained had the "proper" bank been used,[36] because the actual bank, as computed, tends to approximate the "proper" bank.

C. Outstanding Difficulties in Arriving at Ratings

The process of making qualitative readings and ratings, as stated above, was of course subject to the limitations of the instrument; hence it met all those difficulties encountered also in making the quantitative determinations and outlined in the Supplemental Report. Following are the major difficulties encountered in the qualitative analysis.

1. A minor inconvenience in reading the records arises from the necessity of using a transparent scale to synchronize the traces. Though this procedure does not cause great inconvenience in the laboratory, this would undoubtedly be magnified in field use at an ordinary airport. Provided the bank items are derived from the "proper" bank, the seven items noted in the qualitative analysis may be obtained with little necessity for using the scale, but its use is necessary whenever it is desired to synchronize traces.

2. a. The determination of separation points between the three arbitrary divisions of the 720° power turn (entry, turn proper, and recovery) presents a major difficulty. In many cases, one or both of these points is ambiguous. This difficulty is illustrated by the left turn of Plate II, where either point a or point b might be taken to terminate the entry. Other less marked examples may be noted in several other plates.

b. Obviously, the point selected will influence several items included in the bases of rating. But it is to be noted that the selection of a later (and higher) point as the termination of

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36 It would have been desirable to repeat a set of readings and obtain ratings using "proper" bank and carry through a statistical comparison of the two sets of ratings. This procedure seemed impracticable, however, because of the certainty that unbiased results could not be obtained upon repetition, owing to the rater's increasing familiarity with the records. (See page 42.) Moreover, certain of the statistical comparisons would hardly be affected by the possible error, however large: namely those comparisons between various sets of ratings, all of which were made by using actual bank. It seemed possible that comparisons of ratings with the pilot-status indices would be affected, but the evidence presented in Appendix C indicates that the effect can be disregarded. In comparisons of ratings with indices by means of 2 x 2 and 3 x 3 tables, classes of ratings were combined. The likelihood of a material difference in the results had the ratings been made using the "proper" bank is even slighter in these cases.

the entry will always tend to improve the proficiency-judgment made of over-all fluctuation in bank, intermittent fluctuation in bank, and deviation of the proper bank attained from the prescribed bank while, at the same time, the judgment of proficiency of entry with respect to length and step-like character is adversely affected. Conversely, selection of a later (and lower) point as the origin of the recovery will always tend to lower the proficiency judgment made of these three bank items, while at the same time it will raise the proficiency judgment made of the length and step-like character of the recovery. Whenever ambiguous cases, such as those illustrated, were encountered, due account was taken of the above facts. Thus, even if different separation points were selected on successive readings, the possibility was known and considered in making ratings. This compensating procedure, while minimizing the possible effects of the ambiguity making for variation, nevertheless increases the difficulty of assigning an appropriate over-all rating in such cases.

3. The rater experienced somewhat more difficulty than had been anticipated in translating observed scale values of load factor into angles of bank. As an aid in the process, he used a rough table (Table 1, Page 28) on the first sets of readings. On later sets, reference to the table was ordinarily unnecessary. Despite the fact that the bank values can be memorized easily, the chart would be definitely improved for use in the field if it were scaled in values of "proper" bank rather than values of load factor. For a further discussion of this recommendation, see Supplemental Report, pages 199-200.

4. A corollary difficulty is exemplified by the values in the column of Table 1 headed "$\Delta\alpha$". In interpreting the observed curve of load factor as a curve of "proper" bank, it must be remembered that this "proper" bank curve is not "plotted" on linear coordinates. The X - axis (the horizontal axis) is linear, being scaled so that equal chart units are equal to equal time periods. But the Y - axis (considering the curve as a curve of "proper" bank) is trigonometric, and equal vertical chart spaces do not represent equal angles of "proper" bank. The angular value of each vertical space is greater in the lower part of the load factor scale than in the upper part. Thus, variations in load factor of equal chart magnitude do not represent equal variations in "proper" bank. Relatively large curve changes in the upper part of the scale represent no greater variation in "proper" bank than relatively small changes in the lower part of the scale. This fact makes difficult simple visual comparison, or "pattern" comparison, of records having load factor curves in different parts of the scale. Unless this situation is constantly borne in mind, the estimate of any performance will be erroneous. Scaling the load factor chart space in angles of "proper" bank would minimize this difficulty. A reader unfamiliar with the records may test the extent of this difficulty for himself by comparing the load factor curves in Plates IVa - IVj, with the aid of the above table.

TABLE I.[37]

Converting Chart Values of Load Factor into Values of "Proper" Bank

(Horizontal) Chart Line	α (angle of "proper" bank) in°	$\Delta\alpha$ in°
Base-line of load factor trace	0 - 18	-
1st printed line above base-line	25	7
2nd " "	34	9
3rd " "	40	6
4th " "	44	4
5th " "	48	4
6th " "	51	3
7th " "	54	3
8th " "	56	2
9th " "	58	2
10th " "	60	2
Top extreme	61	1

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37 This table was prepared as follows:

The value of load factor in g was obtained for each of the above chart lines. The base-line indicates 1.05 g or less, since the restraining spring of the accelerometer was set with an initial tension of 1.05 g. Each additional 0.10 in. height of trace = 0.20 additional g, by static calibration.

The value of α corresponding to each value of load factor was then obtained according to the relation:

$$\text{load factor} = \sec \alpha$$

(See Supplemental Report, page 160)

The column headed $\Delta\alpha$ gives the absolute difference of each "proper" bank value from the one preceding. The first $\Delta\alpha$ value of 7° and the last value of 1° are not the values of whole vertical chart spaces (i.e., the distance between printed chart lines) as are the other values.

The value of 7° represents approximately the first half-space, since the true base-line of the load factor trace was approximately half-way between the printed line which should have been the base or 0 line, and the first printed line.

This location of the true base-line also caused the top extreme of the scale to fall not on the tenth printed line, but approximately one-half space beyond it; hence the last $\Delta\alpha$ value of 1° represents approximately the last half-space.

5.a. Difficulty in ascertaining whether the subject encountered his prop-wash has been mentioned. Although certain "characteristic" effects of hitting the prop-wash[38] are readily identified in the records, they do not invariably accompany hitting the prop-wash. Plate IVi, for example, exhibits no sign of these effects although in this performance as well as in that of Plate IVi, both the pilot and the accompanying observer attested to the fact that the prop-wash had been encountered.

5.b. The absence of the particular effects does not necessarily denote that the subject failed to hit his prop-wash; neither does their presence invariably denote that he did, for the particular effects might be produced by other events as well, e.g., an encounter with a violent gust or "bump". Presence of the effects, however, may be taken as evidence of hitting the prop-wash, provided:

(1) The effects occur approximately halfway through the maneuver (i.e., at the end of the first 360° of the turn).

(2) The "proper" bank in the first 360° is not very variable; otherwise the pilot's rate of turn would have varied and the flight path would not have approximated a perfect circle.

(3) There is not much slipping or skidding in the first 360° of the turn, resulting in sizeable changes in altitude.[39]

Applying these provisions, it is possible to judge with a reasonable and practical degree of certainty whether the effects represent hitting the prop-wash, or whether they should be suspect.

5.c. The reasons for such wide divergences in records of the same event are discussed in full in the Supplemental Report, pages 168-171, which present a detailed consideration of the effects of prop-wash on the R-S Ride Recorder records.

6.a. Another difficulty was the occasional occurrence of records of performances which were outstandingly good in certain respects, but fairly poor or very poor in others. Such a "weed" performance is reproduced in Plate III. All the bank items of this performance would place it in the Very Good category. Likewise, the occurrence of prop-wash effects would tend to place it in the category of Very Good. On the other hand, there occur an extensive initial slip and extensive and prolonged clip lasting almost for the duration of the second 360° of the turn. The lateral balance performance on the second 360° is in the Poor or Very Poor category. The rating

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38 Illustrated in Plate IVi.

39 Altitude changes resulting from slipping or skidding might be offset by climbing or diving in some instances. In such instances provision (3) would not hold, i.e., the effects might actually be prop-wash effects despite extensive slipping or skidding. Failure to attribute the effects to prop-wash in such instances, however, would not seem to be a serious error.

finally given in both readings (Series 200-Dm-1 and Series 200-Gdl) was <u>Very good</u>, which, however, is highly questionable.

6.b. Another "weed" performance, though not such a marked example, is represented by the right turn of <u>Plate II.</u> The bank here is almost as variable as will be encountered, with respect to both over-all and intermittent fluctuation. Only in the first part of the maneuver did the subject approach the prescribed bank. Yet a large section of the turn is in good or fairly good balance. The ratings given this performance on separate readings were: <u>Poor</u>, <u>Poor</u>, <u>Poor</u>, and <u>Very Poor</u>. The left turn immediately adjacent would probably be rated at least <u>Good</u>, if not <u>Very Good</u>.

7. When the presence of bumpy air had been noted by the field experimenter on the record, the rater took account of that fact in making the judgments and ratings.

8.a. The "haywire" effect, discussed in the <u>Supplemental Report</u>, pages 172-175 and illustrated in <u>Plates Ia</u> and <u>Ib</u>, caused a good deal of difficulty in reading and in making judgments. The only possible treatment of records containing this effect (other than discarding them) was to attempt readings of the load factor trace, considering the true reading to be the midpoint of the superposed vibration traces as in the cases of "normal" records, and to interpret such readings in accordance with the knowledge of their questionable accuracy. These records were treated in this manner, and the ratings obtained were included in treatment of the results.

8.b. The most difficult judgment in such cases is that on intermittent fluctuation in bank. Although the over-all fluctuation value and the deviation of attained bank from prescribed bank may ordinarily be determined with fairly sufficient accuracy, the intermittent fluctuation is at best a guess. In these cases the rater adopted the method of estimating the slope of the trace as determined by the midpoints of the vibration traces and then estimating the intermittent fluctuation value from the slope.

D. <u>Possible Biases in Making Readings and Ratings</u>

1. The possibility that the ratings might be influenced by biases was explored. Four types of possible bias were considered:

   a. Identification of a record as belonging to a particular subject.

   b. Identification of a record as belonging to a subject in a particular group.

   c. Recall of a rating previously assigned to a record.

   d. Halo effect resulting from casual examination of other maneuvers on the record.

2. Consideration of these biases, as discussed in Appendix D, resulted in the conclusion that the findings of the sample qualitative analysis are negligibly influenced by the above sources of bias, with the possible exception of comparisons between early ratings and repeat ratings by the same method. The possible influence of bias in such test-retest reliability comparisons is discussed in the section on Results, pages 42-43. Discussion of these sources of bias believed to be negligible is found in Appendix D.

E. Relation Between the Two Rating Methods

1. Although all the items listed and discussed on pages 21-24, inclusive, as bases of rating were to be used in both the Data Sheet and General Description Sheet rating methods, it was originally intended that the General Description Sheets would contain little detail and that the judgments would be noted in general descriptive terms, while use of the Data Sheets would involve a more detailed analysis with rough quantification of the data. It was furthermore assumed that the process of making rough quantifications would be more difficult and would require more time than verbal description of these tiems.

2. These assumptions were borne out in the case of Item d (lateral imbalance) and Items f and g (length and steplike character of entry and recovery). Practice with both methods soon revealed, however, that it actually required less time and that it was essentially an easier task to record rough quantifications of bank items (Items a, b, and c) than to employ verbal descriptions. Such rough quantifications of bank items were therefore used in completing the General Description Sheet as well as in completing the Data Sheet.[40] In other words, early in the course of the qualitative analysis, there came about a merging of the two methods, with the result that the method involving use of the Data Sheet differs from the method involving use of the General Description Sheet in only the following respects:

   a. On the Data Sheet, estimates of slipping and skidding (item d) were expressed as rough quantifications in terms of chart scale units, while a verbal statement was employed on the General Description Sheet.

   b. Rough measurements of the length of the manuever, entry, turn proper, and recovery were made on the Data Sheet, and were omitted on the General Description Sheet. These time measurements were made primarily for use in evaluating the record with respect to Items f and g (length and steplike character of the entry and recovery, re-

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40 It was recognized at the time that this practice would eliminate an essential difference between the two methods of treating the bank items. The point in question, however, was not the value of verbal description as against rough quantification, but the value of a simple method as against a fairly cumbersome method. Since rough quantification, involving more "detail", proved to be less cumbersome than verbal description, to have expressed the items verbally would in effect have posed and answered an entirely academic and impractical question.

spectively). The rater, however, found it largely a waste of time to make these time measurements. Since they were used only in conjunction with another datum -- steplike character of the entry or recovery -- a single inspection would take both aspects into account and result in an estimate of the proficiency of the entry or recovery. He continued to record the time measurements, however, since it was desired to retain all the detail possible on the Data Sheets, and to use them in deriving his estimates of Items f and g.

3. These actual differences between the two methods are evidently not very great. Indeed, after reading a very few cases with the General Description Sheet, the rater was able to note more conveniently by this method information containing as much useful detail as that obtained with the Data Sheet. In effect, then, the two methods shortly reduced to one. For all practical purposes, in the consideration of findings, they may be viewed as analogous to parallel forms of tests.

IV. Results

A. Explanation of Code Numbers employed in Labeling

1. The qualitative analysis resulted in six sets of ratings identified in the following discussion as Series 300-Ds-1, Series 200-Gd-1, Series 300-Gd-1, Series 200-Ds-1, Series 300-Ds-2, and Series 300-Gd-2.[41] These code numbers are interpreted as follows:

   a. The first digit indicates the order of the flight. Series "200" represents the second Flight C1 and Series "300" the third Flight C1. Records of individual pilots in any given series (as shown in the protocols in Appendix A) are identified by the next two digits.

   b. The two letters indicate the type of rating method used. "Ds" represents use of the Data Sheet and "Gd" use of the General Description Sheet.

   c. The final digit ("1" or "2") indicates the first or second reading of the series by the specified method.

2. According to the above coding method, Code No. 310-Gd-2 would be interpreted as the third Flight C1, Subject No. 10, General Description Sheet - second reading.

B. Statistical Treatment

1. The six sets of data obtained by the rating procedure were studied in order to determine:

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41 In the order obtained by the procedure described on pages 18-20.

a. The extent of agreement between the two methods of rating;

b. The test-retest reliability of each method of rating; and

c. The relationship between the ratings and two flight performance criteria: Pilot Status Indices 1 and 2.

2. All comparisons took the form of testing for association between two given distributions of variates arranged in a contingency table.[42] In evaluating the association between the two distributions so treated, X^2 and the contingency coefficient C, are of primary importance. Both these statistics are evaluated in terms of probability p, which is in turn dependent on the number of degrees of freedom n. The following considerations guided the interpretation of these two statistics:[43]

a. The larger the deviation of the observed frequency from the theoretical "chance" frequency in each cell of the contingency table, the larger is the value of X^2 and the lower the value of p (for any given number of degrees of freedom). Low values of p then indicate low probability that the association between the two sets of variates may be attributed to the chance fluctuations of random sampling; in other words, they indicate that there exists a significant association between the two sets of variates.

b. The value of p for any given value of X^2 depends upon the value of n, the number of degrees of freedom. For any given contingency table, several values of n may be used, depending upon the conditions attached to the hypothesis one wishes to test, as follows:

(1) Perhaps the most commonly employed value of n is that value equal to the product of (k - 1) columns and (r - 1) rows. Peters and Voorhis[44] have recently pointed out, however, that use of this value of n entails the provi-

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42 The dimensions of the table were 5x5, 3x3, or 2x2. See procedure, pages 18-20.

43 Although these considerations are self-evident to the technical reader, they are nevertheless included (1) because of their possible value to the non-technical reader and (2) because of the specific significance of the discussion referring to the value of n.

44 Peters, C. C. & Van Voorhis, W. R. Statistical Procedures and their Mathematical Bases. New York: McGraw-Hill Book Co., 1940, pp. 412-414.

sion that the marginal subtotals of each row and column in the contingency table remain fixed from sample to sample and that this fact results in a restricted utility of the p value based on this value of n. Specifically, this p value refers not to all random samples of the same N, but only to that series of samples of the same N in which the marginal subtotals remain constant.

(2) If it is desired to consider a series of samples in which the marginal subtotals of both distributions are free to vary from sample to sample, i.e., the general case, the value of n is equal to the total number of cells minus 1. Here the one degree of freedom is absorbed by N, the total population.

(3) In this study it was not thought desirable to interpret X^2 and C in terms of that p value obtained using n = (k - 1) (r - 1). In all comparisons, one or both sets of variates are distributions of ratings.

(a) To use the value of n = (k - 1 (r - 1) in the case of a comparison between two distributions of ratings would entail the provision that the frequency in each category of the rating scale of each distribution (i.e., the marginal subtotals of each distribution) would remain fixed from sample to sample. For example, the value of p corresponding to n = 16 (i.e., k - 1 times r - 1), in the case of a 5x5 table between sets of ratings indicates the significance of the association between only those samples of ratings of the particular flight in which the rater so classified the performances that the number falling into each category of the rating scale would be the same, sample after sample, for each respective method of rating. It does not indicate the significance of the association between those sets of ratings in which the rater might place a number in each category different from the number he placed in each of the sets of ratings for which X^2 was computed.

(b) To use the value of n = (k-1) (r-1) in the case of a comparison between a set of ratings and a distribution of the subjects according to either Pilot Status Index would similarly entail the provision that the frequency in each category[45] of the rating scale and the frequency in each category of the Pilot Status Index (i.e., the marginal subtotals of each distribution) remain fixed from sample to sample. For example, the value of p corresponding to n = 4 (i.e., k-1 times r-1), in the case of a 3x3 table between ratings and Pilot Status Index 1, refers only to that series of samples of the same N as the given samples in which the frequency in each category of the Pilot Status Index (i.e., the marginal subtotals) is the same, and the frequency in each marginal subtotal of the distribution of ratings is the same.

(4) In all comparisons it was thought more in accord with the demands of the situation to consider a series of samples (of the same total population) in which the frequency in each category of the rating scale (or Pilot Status Index) was assumed to be free to vary from sample to sample; n was therefore taken to be equal to the total number of cells minus 1. The p value for X^2 corresponding to this n was therefore used in interpreting the comparisons presented in Tables 2, 3, 4, and 6.[46]

(5) Values of C, the contingency coefficient, are included to indicate the amount of association present between the two sets of variates considered. Raw values of C were corrected according to Pearson and Heron's procedure.[47] This procedure involves two corrections: one for the number of cells, which tends to lower the raw

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45 Or, in the case of 3x3 tables, classes formed by combination of categories. In comparisons of ratings with Pilot Status Index 1, which has only three categories, ratings of "Very Good" and "Good" were combined to form a class called "Superior" and ratings of "Very Poor" and "Poor" were combined to form a class called "Inferior." The frequencies in the category "Average" and the classes "Superior" and "Inferior" are therefore the marginal subtotals. Pilot Status Index 2 had five categories.

46 Except in the case of 2x2 tables, the values of p corresponding to n = (k - 1) (r - 1) are included in the tabulated results, however, for the convenience of readers who employ the more conventional value of n and may wish to interpret the results in terms of these corresponding p values.

47 Pearson, K., & Heron, D. On theories of association. Biometrika, 1913, 9, p. 217ff. Also Kelley, T. L. Statistical Method. New York: MacMillan Co., 1924, p. 266 ff.

values and one for the "broadness" of categories, which tends to raise the raw value. The latter correction was made with the use of tabled values.[48]

C. Presentation of the Results

Results are presented in tabular form. Each table includes for each comparison the value of N,[49] the value of X^2, several values of p for this X^2 value, the raw value of the contingency coefficient, raw C, and the corrected value of the contingency coefficient, cC.

1. Comparisons of Ratings on the Same Flight Using Data Sheet and General Description Sheet, Respectively.

a. The results presented in Table 2 were obtained in steps 1 to 5 of the procedure.

b. Inspection of Table 2 reveals that in the case of each flight, the probability that the association between ratings made by the two methods may be attributed to chance is below the 5% level of significance. The significance of the association is demonstrated both in the case of calculations made by the use of 5x5 contingency tables and in the case of calculations made by the use of 2x2 tables.

In evaluating the extent of the association, interpretation of the corrected value of C is aided by the knowledge that in the case of the comparisons presented in Table 2, the divergence between the rating of any performance by one method and its rating by the other did not exceed one category of the five-point scale. This agreement and the values of corrected C indicate that the association is of high degree.

c. As indicated in the preceding pages this high degree of association may indicate that the procedures of the two methods

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48 Obtainable in Peters & Van Voorhis, op. cit. (Table XXXIII)

49 The value of N in all comparisons involving ratings of performances on the third flight (all series the code number of which has "3" for the first digit) is 28. On the second flight, however, one of the students, through a misunderstanding of instructions, made medium turns instead of steep turns. His record was discarded. Hence in all comparisons involving ratings of performances on the second flight, N = 27. No records were discarded in making the qualitative readings on account of instrumental deficiences, such as the "haywire" effect in the load factor trace, or vibrations traces in the lateral imbalance traces. The rater of the records made "clinical allowance" for instrumental deficiencies in interpreting and rating records which showed such deficiencies. (See page 30.)

Table 2

Showing comparisons of ratings of performances of the right 720° power turn on each flight obtained with the use of the Data Sheet, with ratings of the same performances obtained with the use of the General Description Sheet.

A.

Comparisons made by means of 5 by 5 contingency tables

Between	N	χ^2	p (n=16)	p (n=24)	Raw C	cC
Ratings, Series 200-Ds-1 & Ratings, Series 200-Gd-1	27	33.74	.0012	.0256	+.77	+.76
Ratings, Series 300-Ds-1 & Ratings, Series 300-Gd-1	28	42.07	.0007	.0193	+.77	+.77

B.

Comparisons made by means of 2 by 2 contingency tables

Between	N	χ^2	p (n=3)	Raw C	cC
Ratings, Series 200-Ds-1 & Ratings, Series 200-Gd-1	27	10.78	.0132	+.53	+.69
Ratings, Series 300-Ds-1 & Ratings, Series 300-Gd-1[50]	28	16.76	.0008	+.61	+.73

The results of the comparison of ratings, Series 300-Ds-2, with ratings, Series 300-Gd-2, are not presented because these ratings are subject to a bias, discussed in pages 42-43.

The categories of each side of the 5 by 5 tables were: Very Poor, Poor, Average, Good, Very Good.

In reducing the 5 by 5 tables to 2 by 2 tables, categories Very Poor and Poor were combined, and categories Average, Good, and Very Good were combined.

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50 The theoretical frequency of one cell of the contingency table for this comparison was 3.93. The theoretical frequencies of the remaining three cells were all greater than 5.0.

were in fact the case. The rater suspected that after an initial "warm-up" period on each method, the methods reduced in practice to the same procedure. It was furthermore noted that later sets of the <u>General Description Sheets</u> (the "clinical" method) contained a great deal of detail, perhaps more than early sets of the <u>Data Sheets</u> (the "detailed" method.) It seems reasonable, therefore, to view the two methods as analogous to two parallel forms of a psychological test, a long form and a short form. The comparisons presented in <u>Table 2</u> might thus be viewed as reliability comparisons.

d. However, this may be, the point of major importance is that ratings may be obtained by a "clinical" method of notation and appraisal requiring comparatively little time which agree very well with ratings obtained by an elaborate method of notation and appraisal designed to take into account all items of the records amenable to qualitative treatment. Whether this agreement results from the fact that the "clinical" method adequately selects the significant features of the performance, or from the fact that it duplicates in concise form the information obtained by the longer "detailed" method, does not matter from the standpoint of its relative utility in the field. The significant fact is that it is a more practical way of obtaining approximately the same ratings as the longer method.

2. <u>Comparison of Ratings On Different Flights by the Same Method</u>

a. The results presented in <u>Table 3</u> were obtained in steps <u>1</u> to <u>5</u> of the procedure.

b. Inspection of <u>Table 3</u> reveals that in the case of neither method is the association between ratings of performances on the two turns consistently significant. In the case of the "detailed" method (using the Data Sheet) the comparison between ratings of performances on the two flights made by means of a 5 by 5 contingency table indicates a significant association, but this significance does not hold up when the data are treated by means of a 2 by 2 table.

c. Factors which may account for this lack of significance are:

(1) the variability of each respective method of rating, and

(2) the variability of the subjects' performances from flight to flight

The extent to which it is attributable to each cannot be isolated.[51]

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51 The findings concerning successive-flight variability encountered in the sample quantitative analysis (<u>Part II</u>), as well as results reported by other investigators, cast doubt on the adequacy of a single performance of a maneuver as representative of the pilot's proficiency in executing the maneuver, because of subject variation from flight to flight.

Table 3.

Showing comparisons of ratings of performances of right 720° power turn of the second flight (200 series) with ratings of performances of the right 720° power turn of the third flight (300 series); ratings for Ds series obtained by means of the Data Sheet and ratings for Gd series obtained by means of the General Description Sheet.

A.

Comparisons made by means of 5 by 5 contingency tables

Between	N	χ^2	P (n = 16)	P (n = 24)	Raw C	$\bar{C}$
Ratings, Series 200-Ds-1 & Ratings, Series 300-Ds-1	27	39.26	.0021	.0335	+.77	+.76
Ratings, Series 200-Gd-1 & Ratings, Series 300-Gd-1	27	22.66	.1238	.5400	+.68	+.50

B.

Comparisons made by means of 2 by 2 contingency tables

Between	N	χ^2	P (n = 3)	Raw C	$\bar{C}$
Ratings, Series 200-Ds-1[52] & Ratings, Series 300-Ds-1	27	3.05	.3851	+.32	+.34
Ratings, Series 200-Gd-1[53] & Ratings, Series 300-Gd-1	27	1.18	.7601	+.20	+.33

The categories of each side of the 5 by 5 tables were: Very Poor, Poor, Average, Good, Very Good.

In reducing the 5 by 5 tables to 2 by 2 tables, categories Very Poor, and Poor were combined, and categories Average, Good, and Very Good were combined.

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52 The theoretical frequency of one cell of the contingency table for this comparison was 4.81. The theoretical frequencies of the remaining three cells were all greater than 5.0.

53 The theoretical frequencies (4.67 and 4.33, respectively) of two cells of the contingency table for this comparison were less than 5.0. The theoretical frequencies of the remaining two cells were greater than 5.0.

Table 4.

Showing comparisons seeking to determine the test-retest reliability of each method: namely, comparisons between the first ratings ("1" series) given by each method to performances of the right 720° power turn on each flight with the second ratings ("2" series) given to those performances by the same method.

A.

Comparisons made by means of 5 by 5 contingency tables

Between	N	χ^2	p (n = 16)	p (n = 24)	Raw C	c^C
Ratings, Series 300-Ds-1 & Ratings, Series 300-Ds-2	27	37.22	.0056	.0668	+.76	+.73
Ratings, Series 300-Gd-1 & Ratings, Series 300-Gd-2	27	50.02	.0000	.0014	+.80	+.83

B.

Comparisons made by means of 2 by 2 contingency tables

Between	N	χ^2	p (n = 3)	Raw C	c^C
Ratings, Series 300-Ds-1 & Ratings, Series 300-Ds-2[54]	27	20.26	.0002	+.65	+.76
Ratings, Series 300-Gd-1 & Ratings, Series 300-Gd-2	27	9.96	.0190	+.51	+.62

The categories of each side of the 5 by 5 tables were: Very Poor, Poor, Average, Good, Very Good.

In reducing the 5 by 5 tables to 2 by 2 tables, categories Very Poor and Poor were combined, and categories Average, Good, and Very Good were combined.

54 The theoretical frequency of one cell of the contingency table for this comparison was 4.32. The theoretical frequencies of the remaining three cells were all greater than 5.0.

Table 5.

Showing rater's recollections of previous ratings, noted during the retest readings of records of the third flight by each method: Series 300-Ds-2 and 300-Gd-2

Series	Not Recognized	Recognized but rating not re-called	Recalled rating same as that given on both first readings (Series 300-Ds-1 & Series 300-Gd-1)	Recalled rating same as that given in Series 300-Ds-1, but not in Series 300-Gd-1	Recalled rating same as that given in Series 300-Gd-1 but not in Series 300-Ds-1	Recalled rating different from rat-ing in either of first readings	Totals
300-Ds-2	4	14	5	1	4	0	28
300-Gd-2	5	10	8	2	3	0	28

3. <u>Comparison of ratings on the Same Flight at Different Times by the Same Method</u>

a. The results presented in <u>Tables 4</u> and <u>5</u> were obtained in steps <u>6</u>, <u>7</u>, <u>8</u>, and <u>9</u> of the procedure.

b. It may be seen from <u>Table 4</u> that the original and later ratings of performances on the right turn of the third flight are significantly associated to a high degree, in the case of ratings both by the Data Sheet and by the General Description Sheet. In the case of the comparison with the Data Sheet ("detailed" method) made by a 5 by 5 contingency table, the <u>p</u> value does not quite attain the 5% level of significance.[55] The <u>p</u> value for the same comparison made by a 2 by 2 table, however, is highly significant. Differences in these two values are of course due to the differences in grouping between a 5 by 5 table and a 2 by 2 table. The corrected value of the contingency coefficient, <u>C</u>, is also high in each case.

c. The high degree of association, however, cannot be considered finall to establish the test-retest reliability of either method, owing to the possible bias introduced by the rater's re-collection of previous ratings.

d. Before reading Series 300-Ds-2, the rater had inspected some records of the third flight at least three times: twice in making the first ratings by each method, and in the case of some records, once again in making quantitative readings. It is not surprising, therefore, that in spite of the effort to interpolate confusing material between successive readings, many of the previous ratings were recalled. As stated in the description of the procedure (page 19) the rater noted all cases of recognition and recollection. The results of such notation are presented in <u>Table 5</u>.

e. In the first readings, divergence between ratings by either method did not exceed one category in either direction. Obviously then, if the rating the reader recalled was the same as that given to the performance by <u>either</u> method in the first reading, his rating of the performance on the second readings, almost inevitably influenced by this recollection, is open to the suspicion of bias.

f. Considering a correct recollection to be recollection of the rating given the performance in the first readings by <u>either</u> method, there were in the case of Series 300-Ds-2 ten correct recollections; 0 incorrect recollections, and 18 non-recollections.

g. In the case of series 300-Gd-2 (readings of which were made after readings of series 300-Ds-2), the possible contribution of the bias is even greater, as indicated by the fact that there were 13 correct

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55 Ratings of 3 performances on the first reading differed from ratings of the same performances on the second reading by two categories of the five-point scale in the case of this comparison. All other ratings in the comparisons presented in <u>Table 4</u> agreed within one category of the scale.

recollections, 0 incorrect recollections, and 15 non-recollections.

h. The correct recollection of previously assigned ratings is itself open to divergent interpretations, however. In some cases, the recollection may actually be due to the stability of the method of rating, for a consistent procedure in rating a given record may itself be the clue prompting recall of a previously assigned rating. In some instances, also, the recollection of a previous rating could hardly have influenced an assigned rating because the assigned rating was obvious. Among such cases are the "extreme" ratings, which "fit" the categories of the scale so well that there could hardly be any displacement from reading to reading: e.g., "Very Good" turns in which the subject maintained a consistent bank and hit his prop-wash. It seems likely, therefore, that the bias did not operate so extensively as Table 5 would indicate.

IN SUMMARY - Summarizing the preceding discussion, it is found that the ratings of the same flight by the two methods (which are considered essentially a shorter and longer form of a single method) are consistent. Moreover, the re-rating after a lapse of time of the same flight by the same method also proves to be statistically consistent. While it has seemed desirable to discuss the possible effect of growing familiarity with the records upon the consistency of re-rating by the same method, it nevertheless seems possible to conclude that the presumptive evidence favors the position that re-ratings by the same method, as well as rating by the two methods, give reliable estimates of performance on the Right 720° power turn.

4. Comparisons of Ratings by Each Method with Other Flight Performance Criteria

a. Treatment of the Ohio State Check List

It was originally intended to compare ratings with criterion data obtained from a scoring of the appropriate sheet of the Ohio State Check List which the administering instructor filled in during the flight. Because of omissions in completing the Ohio State Check List, however, and for other reasons stated fully in Appendix E, it proved impossible to use the Ohio State Check List data for criterion purposes.

b. The Pilot Status Indices

(1) The data finally used to supply external criteria include: (a) the license status of the subject (i.e., whether student, private, pilot, or instructor) and (b) the flying time of the subject in the Aeronca tandem trainer (the test airplane). Pilot Status Indices were developed from these data, which are presented in Table I, pages 125-127 Exhibit I.

(2) Pilot Status Index 1 classifies subjects into three groups in the following ascending progression: (a) elementary students, (b) private pilots, and (c) instructors.[56]

(3a) Reference to Table I, pages 125-127, Exhibit I, will reveal several shortcomings of this index. One of these is the rather small difference in flying time between certain students and private pilots. A second is the relative heterogeneity of each group. A third is the fact that the index considers only flying time per se and not flying time in an airplane of the same make and model as the test airplane.

(3b) Some of the subjects had all their C.P.T. training in the test airplane, an Aeronca tenadem trainer, but others had been trained in Piper Cubs. According to many pilots, there is considerable difference in the flight characteristics of these two airplanes. The one or two practice flights in the test ship, given students and private pilots who were unfamiliar with the ship, would hardly seem to give sufficient time for an inexperienced pilot to "catch on to the tricks" of an unfamiliar airplane which, according to skilled pilots, is relatively hard to fly. This handicap would seem to be enhanced by the fact that all the flying time of the students and private pilots in the Aeronca tandem trainer was in the particular test plane. Subjects trained in this plane could be expected to have an advantage over other subjects with respect to knowledge of the peculiarities of the individual airplane.

(4) Because of these facts, Pilot Status Index 2 was developed. This index takes into consideration both the license status of the subjects, and their flying time in the Aeronca tandem trainer. Pilot Status Index 2 classifies the subjects into the following ascending progression:[57] (a) elementary students not trained in the Aeronca tandem trainer, (b) private pilots with little time in the Aeronca tandem trainer, (c) elementary students having all C.P.T.

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56 Student 2d was classified with the private pilots because of the fact that his total flying time exceeded the time of the C.P.T. course.

57 The progression of this index may be questioned. It is to be noted, however, that the order of classes (b) and (c) could be reversed and the results of the computations presented would still be the same. The positions of whole rows or columns in a contingency table may be interchanged without affecting the arithmetical values of X^2 and C. This particular reversal would also not affect the sign of C in these computations.

training in the Aeronca tandem trainer;[58] (d) private pilots having all C.P.T. training in the Aeronca tandem trainer, and (e) instructors. The composition of each group according to Pilot Status Index 2 is given in Table 1, Exhibit I.

(5) Although Pilot Status Index 2 represents a refinement of Pilot Status Index 1, it is still a fairly gross method of classifying the subjects.[59] Each class of Pilot Status Index 2, except for Class (b) is still somewhat more heterogeneous than desirable. This is especially true of the instructor group, Class (e). Instructors 3d and 3f, for example, had no time in the Aeronca tandem trainer.[60]

C. Comparison of Ratings and Pilot Status Indices

(1) In Table 6 are presented the results of comparisons between ratings and pilot status indices.

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58 Private pilots 2f and 2h were difficult to classify. Their greater amount of time in the test plane (4.5 and 3.5 hours, respectively) presumably enough for thorough familiarization, plus their greater total flying time (64 and 52 hours, respectively) would seem to place them above subjects in Class (b), but not high enough to be in Class (d). Accordingly, they were placed in Class (c). Computations were also made with the distributions resulting when they were placed in Class (d) and when they were eliminated. The results did not differ materially. Only the results of computations with the distribution resulting from their classification in Class (c), therefore, are presented.

59 The question of the statistical reliability of each of these criteria naturally arises. Reliability cannot be checked statistically, but since the classification in each case depends upon certain unchanging facts, it can be concluded that repeated classifications of the same subjects will remain consistent.

60 The total flying times of instructors 3a and 3b (300 and 500 hours, respectively) are considerably less than that of the other instructors. To separate any of these from the instructor group, however, would necessitate the addition of a class to the index unless they were grouped with some other class. Such grouping would seem to be quite as undesirable as the present grouping, if not more so, since, for example, it would conform to no reasonable weighting of the two variables of flying time in the test plane and total flying time. (The classes of Pilot Status Index 2 were defined on a purely qualitative basis, but inspection of the resulting distribution reveals it to conform very well to a distribution ranking the subjects according to a score compounded by adding twice the flying time in the Aeronca tandem trainer to the total flying time.) Furthermore, it was felt that Pilot Status Index 2 represents about the reasonable limit of refinement in the treatment of such a small sample.

Table 6

Showing Comparisons of Ratings of all Flights by Each Method with Pilot Status Indices 1 and 2.

A.

Comparisons involving Pilot Status Index 1, made by means of 3 by 3 contingency tables

Between	N	χ^2	p $(n = 4)$	p $(n = 8)$	$_c\phi^2$	Raw C	$_cC$
Ratings, Series 200-Ds-1 and Pilot Status Index 1	27	7.85	.0982	.4489	0.14	+.47	+.44
Ratings, Series 200-Gd-1 and Pilot Status Index 1	27	3.04	.5518	.9313	-0.04	+.32	ND
Ratings, Series 300-Ds-1 and Pilot Status Index 1	28	4.99	.2885	.7586	0.04	+.39	+.23
Ratings, Series 300-Gd-1 and Pilot Status Index 1	28	8.20	.0855	.4152	0.15	+.48	+.45

B.

Comparisons involving Pilot Status Index 1, made by means of 2 by 2 contingency tables

Between	N	χ^2	p $(n = 3)$	$_c\phi^2$	Raw C	$_cC$
Ratings, Series 200-Ds-1 and Pilot Status Index 1	27	3.29	.3539	.08	+.33	+.35
Ratings, Series 200-Gd-1 and Pilot Status Index 1	27	0.51	.8986	-.02	+.14	ND
Ratings, Series 300-Ds-1 and Pilot Status Index 1	28	1.46	.6960	.02	+.22	+.15
Ratings, Series 300-Gd-1 and Pilot Status Index 1	28	0.44	.9126	-.02	+.12	ND

ND = Not derivable

The column headed $_c\phi^2$ gives values of the corrected mean square contingency. These values were included to indicate the reason that certain corrected C values could not be derived; whenever the corrected mean square contingency is negative, the corrected C cannot be derived because the negative value is found under a radical.

In the case of each comparison of sections B and D of this table, the theoretical frequency of one or two cells of the contingency table is less than 5.0, the theoretical frequencies of the remaining cells being greater than 5.0.

Table 6 (Continued)

C.

Comparisons involving Pilot Status Index 2, made by means of 5 by 5 contingency tables

Between	N	χ^2	P ($n = 16$)	P ($n = 24$)	$c\phi^2$	Raw C	c^C
Ratings, Series 200-Ds-1 and Pilot Status Index 2	27	21.54	.1594	.6066	0.21	+.67	+.46
Ratings, Series 200-Gd-1 and Pilot Status Index 2	27	12.80	.6870	.9689	-0.12	+.57	ND
Ratings, Series 300-Ds-1 and Pilot Status Index 2	28	28.93	.0245	.2229	0.46	+.71	+.63
Ratings, Series 300-Gd-1 and Pilot Status Index 2	28	29.36	.0218	.2074	0.48	+.72	+.64

D.

Comparisons involving Pilot Status Index 2, made by means of 2 by 2 contingency tables

Between	N	χ^2	P ($n = 3$)	$c\phi^2$	Raw C	c^C
Ratings, Series 200-Ds-1 and Pilot Status Index 2	27	3.29	.3539	0.08	+.33	+.35
Ratings, Series 200-Gd-1 and Pilot Status Index 2	27	5.78	.1249	0.18	+.42	+.49
Ratings, Series 300-Ds-1 and Pilot Status Index 2	28	2.53	.4766	0.05	+.29	+.27
Ratings, Series 300-Gd-1 and Pilot Status Index 2	28	7.52	.0584	0.23	+.46	+.52

In comparing distributions of ratings with distributions of rank on Pilot Status Index 1, ratings of "Very Poor" and "Poor" were grouped into a class called "Inferior" and ratings of "Very Good" and "Good" were grouped into a class called "Superior." Comparisons were made by means of 3 by 3 contingency tables, and the results were checked by means of 2 by 2 contingency tables. In the 2 by 2 tables, the instructors and private pilots were combined, and the classes "Average" and "Superior" were combined.

Computations involving Pilot Status Index 2 were made by means of 5 by 5 contingency tables, and the results were checked by means of 2 by 2 tables. In the 2 by 2 tables, Classes A and B of Pilot Status Index 2 were combined, and Classes C, D, and E were combined; ratings of "Very Poor" and "Poor" were combined and ratings of "Average," "Good," and "Very Good" were combined.

(2) Employing the 5% criterion, and the n values noted on page 35, Table 6 reveals only one instance of near-significant association in terms of p between a set of ratings and either Pilot Status Index: namely, the comparison between Series 300-Gd-1 and Pilot Status Index 2 made by means of a 2 by 2 contingency table. (See Section D of the table.) The association between these two distributions is not significant when the comparison is made by means of a 5 by 5 table, however, the p value being .2074. (See Section C of the table.)

(3) Turning to the values of C, it is seen that all values of raw C are positive, and all derivable values of corrected C are positive.[61]

d. <u>The significance of comparisons between ratings and Pilot Status Indices.</u>

(1) The only evidence of a significant relationship between ratings of flight performance and pilot status (as shown by the Pilot Status Indices) is to be found in the fact that all raw C values are positive.

(2) It is not possible to evaluate this fact precisely in terms of probability by application of the probability binomial, since the sets of ratings are interdependent. (See Tables 2 and 3.)

(3) Despite the interdependence of the sets of ratings, the fact that all raw C values are positive constitutes presumptive evidence pointing to the existence of a positive association[62] between the qualitative ratings and flying experience of the subjects of an order that is not revealed to be significant in terms of values derived from the treat-

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61 There are several instances of non-derivable corrected C values. When a corrected C value is not derivable, a near 0 correlation is indicated, inasmuch as the negative value of corrected ϕ^2 indicates that the possible "chance" contribution of the fineness of the tabular classifications to the correlation is greater than the obtained raw C value.

62 This fact does not necessarily indicate that each raw C considered represents a real positive association between the two sets of variates. It is evidence, however, that positive association exists in at least some of the cases.

ment of the small number of cases (N = 27 or 28) included in this investigation.[63]

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63 In treating such small samples by the contingency method, it is possible to guard against the acceptance of positive results arising from possible "freak" sampling by proper conservation in treatment and interpretation:

1. Preparation of the data in tables of several dimensions and comparing the results of both will take account of enhancement of the X^2 value by "freak" frequencies in certain cells. In the case of any one comparison, if significant association is indicated when the data are treated in a table of one set of dimensions, but not when they are treated in tables of other dimensions, the significance of the association would be regarded as doubtful.

2. Selection of the proper value of n, the number of degrees of freedom, for obtaining p is especially important in the treatment of such small samples. Use of the conventional value of n (that value equal to the product of (k - 1) columns and (g - 1) rows) will result in lower p values than those obtained when either or both sets of marginal subtotals are considered free to vary from sample to sample. (See pages 33-35.)

3. With the exercise of these precautions, and care in interpretation of the results, one may guard against the acceptance of dubious evidence of association between two small distributions of variates. The small size of a sample, however, can serve not only to produce "freak" enhancement of the ^{2} value, but also to produce "freak" diminution of the X^2 value. Thus, even though a significant association may be present between the two sets of variates in the parent populations from which small samples are drawn, it may not be revealed in the small samples themselves. There is no adequate and conservative way to take account of this possibility in the treatment of small samples by the contingency method, other than to note the possibility and to state that the absence of significant association in the samples treated is not definitive evidence of its absence in the parent populations.

4. It is furthermore to be noted that the comparisons presented in Table 6 encounter a sampling difficulty not encountered in the comparisons presented in Tables 2, 3, and 4. Each comparison in Tables 2, 3, and 4 is a comparison between two sets of ratings; each set of ratings is a sample drawn from a parent population of ratings of the same performances. On the other hand, each comparison presented in Table 6 is a comparison between a set of ratings (drawn from a parent population of ratings) and a distribution of pilots classified according to flying experience (drawn from a parent population of pilots).

5. It seems reasonable to assume *a priori* that a distribution of ratings of 27 or 28 performances is more likely to be a truly representative sample of the parent population of ratings of those same performances than is the sample of 27 or 28 pilots likely to be truly representative of the parent population of pilots.

(Continued)

(4) Apart from the influence of the small number of cases, the non-significance of association may be attributable to imperfections in both the methods of rating and to the Pilot Status Indices as means of expressing pilot skill. The extent to which the lack of significant association can be attributed to the method of rating or to the Pilot Status Indices cannot be isolated from these results.[64] However, the following facts may be of interest in the consideration of Table 6:

Comparison of the p values for computations involving Pilot Status Index 1 with the p values for corresponding computations involving Pilot Status Index 2 shows that,

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(Footnote [63] Continued)

6. Moreover, even if a particular set of ratings is not truly representative of the parent population of ratings, this fact might be inferred from an examination of another set of ratings of the same performances (made by another method or by a repeat reading of the records by the same method). The fact that in Tables 2 and 4 the results obtained by rating the same performances by two different methods - and in the case of the third flight, on two different occasions - are substantially the same, indicates that these small samples are truly representative of the parent populations of ratings. Otherwise, if any one set of ratings were a "freak" sample, e.g., one would expect differing results in the case of comparisons involving two methods of rating or successive ratings.

7. This internal check on the representative character of the small sample is not possible in the case of the Pilot Status Indices, however. Each Pilot Status Index is only one sample of flying experience of a group of pilots drawn from a parent population of pilots. From the data at hand, there is no way to state definitively the extent to which this small sample of pilots is representative of the parent population with respect to flying experience.

[64] It should be noted that these results do not necessarily indicate a lack of validity of the qualitative ratings as a measure of pilot performance because:

1. The Pilot Status Indices are themselves gross criteria.

2. The ratings are themselves estimates which involve comparison of the observed performances, as recorded in the traces of the R-S Ride Recorder chart, with the optimal performance which would produce traces of known form determined by the aerodynamic characteristics of the prescribed maneuver; hence they have some measure of inherent validity. Such validity might be denominated "physical validity," indicating that the ratings are descriptive of the merit of certain physical aspects of the performance (bank and lateral balance); in contrast to "statistical validity," which refers to the association of the ratings with external criteria, such as the Pilot Status Indices.

in general, the p values for computations involving Pilot Status Index 2 are lower.

Moreover, the values of the raw and corrected C values are in general higher for computations involving Pilot Status Index 2.[65] The differences between the C values are of course not significant, as the C values are not themselves significant with but one exception. The trend, however, is consistent and is of interest in view of the fact that Pilot Status Index 2 takes into consideration the number of hours of flying in a particular airplane as well as pilot-status.

IN SUMMARY: Comparison of ratings of flight performance with pilot status provides inferential evidence pointing to a relationship between qualitative ratings of R-S Ride Recorder records of right 720° power turns and pilot skill as expressed in flying time. The results are not adequate to demonstrate the existence of this relationship or to pass final judgment upon the usefulness of qualitative estimates of graphic records as indicators of pilot skill.

65 All values of raw C for comparisons involving Pilot Status Index 2 are greater than the values of raw C for corresponding comparisons involving Pilot Status Index 1, with one exception, viz: the value of raw C for the comparison of each Index with Series 200-Ds-1 by means of a 2 by 2 table is +.33. All values of corrected C for comparisons involving Pilot Status Index 2 are greater than the values of corrected C for corresponding comparisons involving Pilot Status Index 1 with two exceptions: (1) the value of corrected C for the comparison of Pilot Status Index 1 with Series 200-Gd-1 by means of a 3 by 3 table is not derivable, and the value of the corresponding comparison of Pilot Status Index 2 with Series 200-Gd-1 by means of a 5 by 5 table is not derivable and (2) the value of corrected C for the comparison of each index with Series 200-Ds-1 by means of a 2 by 2 table is +.35.

V. Suggestions on the Application of the Qualitative Approach in the Field

A. Introduction

1. The fact that the evidence presented in this report does not demonstrate acceptable relationship between qualitative estimates of pilot performance derived from graphic records and pilot status should not be interpreted as rejecting the desirability of further research in this field.

2. The research program described in this report involved the use of an inadequate recorder. An improved recorder is now under construction. The experimental design was adversely affected by an incomplete knowledge of the properties of the graphic recorder, which could only be discovered by preliminary research of the type described in this report. The number of cases is small. There are many other factors in the experiment which make it unacceptable as a definitive experiment for the investigation of the qualitative aspects of graphic records obtained during flight. Nevertheless, on the basis of this experiment, it seems possible to suggest steps which may be taken by those who undertake further investigations in this field and which can prove useful in obtaining definitive and useful findings.

3. Further studies of this type, in the opinion of the investigators, can profitably include the construction and use of pattern scales in estimating the quality of flight performance from the examination of the graphic record. A manual describing the use of such a pattern scale in the evaluation of right 720° power turns is attached to this report as <u>Appendix B</u>. Following is a brief discussion of the factors which underlie the preparation of this manual

B. Practicability of Qualitative Methods Used in This Study

1. The <u>General Description Sheet</u> proved to be the more practicable of the two methods for field use. On the first two sets of records read with the <u>Data Sheet</u>, the average time for one reading was about 25 minutes, and the estimate was made that this time could be reduced to 20 minutes. The average time for one reading with the <u>General Description Sheet</u> was 15 minutes. The discrepency in the two average times is largely due to the fairly long time required for the time-measurements of the <u>Data Sheet</u> and to the cumbersome form of the sheet itself. At this point in the analysis, the estimate was made that the time for reading the <u>General Description Sheet</u> could certainly be reduced to 10 minutes and probably to 5 minutes. On a portion of the last set of <u>General Description Sheets</u> filled in, the reader dictated as completely detailed a description as possible of each of four turns, stating the complete history of each insofar as derivable from the records; the average time per sheet was slightly less than 4 minutes.

2. Furthermore, all the times stated above resulted by obtaining <u>Items a</u> and <u>b</u> ("overall" fluctuation in bank during the turn proper, and deviation of average bank from the prescribed bank) from the "actual" bank. To derive these items from the actual bank requires considerably more time than to derive them from the "proper" bank. To determine the ac-

tual bank at any point requires the synchronization of the load factor trace with the lateral imbalance lines; making two readings, one of load factor and the other of slip or skid; and performing an addition or subtraction to obtain the actual bank value. To determine the "proper" bank at any point, only the load factor trace need be read. The only mathematical operation is to convert this reading into a value of "proper" bank. This operation might be omitted if the chart scale were graduated to show "proper" bank in degrees rather than load factor.

3. If an instructor noted <u>only</u> the seven items employed in this study, using values of "proper" bank to obtain <u>Items a</u> and <u>b</u>, an estimate of 2 or 3 minutes for a complete evaluation of the performance on the power turn is not unduly optimistic. If he chose not to record his observations the time would be even less. These estimates are made, of course, with the proviso that the instructor thoroughly learn the method, and with the further proviso that he become very proficient in converting scale values of load factor into values of "proper" bank, or that the scale of this portion of the chart be altered to indicate directly the angle of "proper" bank. With a possible short-cut aid in the form of a pattern scale and manual, the time would be even further reduced.

C. <u>Steps taken to Facilitate the Establishment of Qualitative Rating Procedures in the Field.</u>

1. Use of either method of rating described in this study requires that the rater be thoroughly familiar with the characteristics of the instrument and the chart. It is possible, however, to avoid making undue demands upon the instructor, in the way of detailed knowledge of recorders and their characteristics, by supplying a short-cut method of rating records. A graded scale of trace patterns with which the instructor could "match" students' records would be suitable for this purpose.

2. <u>Plates IVa - IVj</u> and the accompanying manual (<u>Appendix B</u>) represent the first steps towards the establishment of such a scale. Even upon casual inspection, a progression in pattern is readily observable in each row. This progression is, of course, much more readily apparent when the nature of the load factor scale is known: i.e., when the load factor trace is regarded as a curve of "proper" bank, the scale is non-linear, and the chart spaces in the lower part of the scale represent greater values of bank than the chart spaces in the upper and middle portions of the scale. Thus, for example, the "peaks" in the load factor trace in <u>Plate IVa</u> represent greater fluctuations in bank than "peaks" of about the same height in <u>Plate IVh</u>. In the case of these same two plates, the "over-all" fluctuation in bank in <u>Plate IVh</u> would appear to be somewhat greater than the over-all fluctuation in <u>Plate IVa</u>. But this value is about the same (approximately 14^{o}) for both plates.

3. Certain apparent discrepancies are also present. The prop-wash effects in Plate IVi, appearing as a dip in the load factor trace to the base-line and a sharp fairly large (right) slip, of course, destroy the pattern progression. Not only must these effects, which "look bad," be discounted, but their presence must also be taken as a credit to the performance. There is, of course, a certain amount of overlapping, resulting from the fact that several traces must be considered in making the rating. Thus the load factor trace of Plate IVf is preferable to the load factor trace of Plate IVg, and only slightly inferior to those of Plates IVh and IVi. But there is a prolonged slip lasting almost throughout Plate IVf.

4. Such difficulties, however, are relatively minor. Their nature and the appropriate ways to handle them are readily grasped. If an instructor were provided with a concise statement of fundamentals such as that presented in Appendix B and such a scale to assist him in rating and learning the technique of rating, he could, it is believed, with the exercise of reasonable judgment and care, rate performances in an entirely practicable and easy manner.

5. The utility of such a scale might be enhanced by providing one or two more patterns for each category. Likewise, borderline patterns might be selected and appropriate suggestions for their placement might be presented. In view of the limited scope of these comparisons, however, these additional steps were considered, at present, inadvisable. The plates and this discussion are presented, as stated, as the first steps towards a complete set of concrete specifications for field use of the instrument and as an indication of the direction the development of such a set of specifications must take.

6. An alternative to such a scale would be separate scales, one for the load factor trace and one for the lateral imbalance traces in conjunction. Such scales might be employed to give separate ratings, which would in turn be weighted and combined in a prescribed manner to give an overall rating.

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION A

PLATES Ia - IVj

University of Pennsylvania
Philadelphia, Pennsylvania
November, 1942

PREFACE TO PLATES Ia, Ib, II, III, and IVa-IVj.

These plates are actual-size photostatic reproductions of R-S Ride Recorder records of maneuvers of the University of Pennsylvania standard flight C1, flown in an Aeronca tandem trainer, model 50-TL.

In the case of each plate, attention is centered upon the record of the 720° left power turn or the 720° right power turn as selected out of the complete record of Standard Flight C1. Records of the whole or a portion of other maneuvers, however, may be included on each plate. The maneuvers are identified by the code number appearing at the initial signal of each on the signal marker trace. Each plate may contain records of the whole or a portion of the following maneuvers (in the order appearing on the record from left to right):

Maneuver No.	Description
B	A transition maneuver (i.e., a maneuver for which the attitude of the airplane is not prescribed, and the record of which is not used to indicate the proficiency of the pilot). In this transition maneuver, the pilot attained an altitude suitable for performing the power turns. (The latter "B" does not appear on any plate, since the initial signal of the maneuver is not included on any plate.)
6	720° left power turn. Prescribed bank: 60°.
7	Short straight and level recovery flight.
8	720° right power turn. Prescribed bank: 60°.
C	A transition maneuver for getting the airplane into proper position with reference to the ground for executing the succeeding (numbered) critical maneuver.

The maneuvers follow each other in immediate succession. Hence the initial signal of a given maneuver is also the terminal signal of the preceding maneuver.

On each plate, barred arcs, representing the marks on a transparent synchronizing scale used in reading the records, have been inserted. In the case of each plate, except Plate II, these arcs serve to indicate the beginning and end of the 720° right power turn (maneuver 8). Maneuver 8 begins at the intersection of each trace with its corresponding barred arc marked "Begin" and ends at the intersection of each trace with its corresponding barred arc marked "End". The significance of the arcs inserted on Plate II is explained in the legend of that plate.

In the case of each plate, the base-lines of the signal marker trace, the load factor trace, the left-wing-low trace, and the right-wing-low trace, and the signal "dots" have been outlined with a stylus. These alterations were necessary in order to obtain clear and readily readable reproductions.[66]

Calibrations

1. Chart speed = $1\frac{1}{2}$ in. per min. Each 0.10 in. therefore = 4 sec.

2. Load factor (static calibration):
   Base-line = 1.05 g
   Top extreme = 2.05 g
   Each 0.10 in. height of trace = additional load of 0.10 g
   The calibration of the load factor trace in terms of bank is given in Table 1, page 28 of Part I.

3. Left-wing-low and right-wing-low (static calibration):
   Base-line = 0° or 0 g
   Top extreme = 14°, or 0.249 g
   Each 0.10 in. height of trace = 2°, or 0.035 g

Subjects

Subjects of Group I were elementary students in the C.P.T. primary course.
Subjects of Group II were recently licensed private pilots.
Subjects of Group III were re-rated instructors.

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[66]The adjustment of the recording styluses of the particular instrument was such that no true base-line fell onto a printed line of the chart. This arrangement is, of course, not inherent in the instrument. It was simply an inconvenient adjustment in the particular instrument used, and could easily have been remedied but for the inconvenience of disturbing the installation.

PLATES Ia AND Ib,

ILLUSTRATING THE "HAYWIRE" EFFECT OCCASIONALLY PRESENT IN THE LOAD FACTOR TRACE OF R-S RIDE RECORDER RECORDS

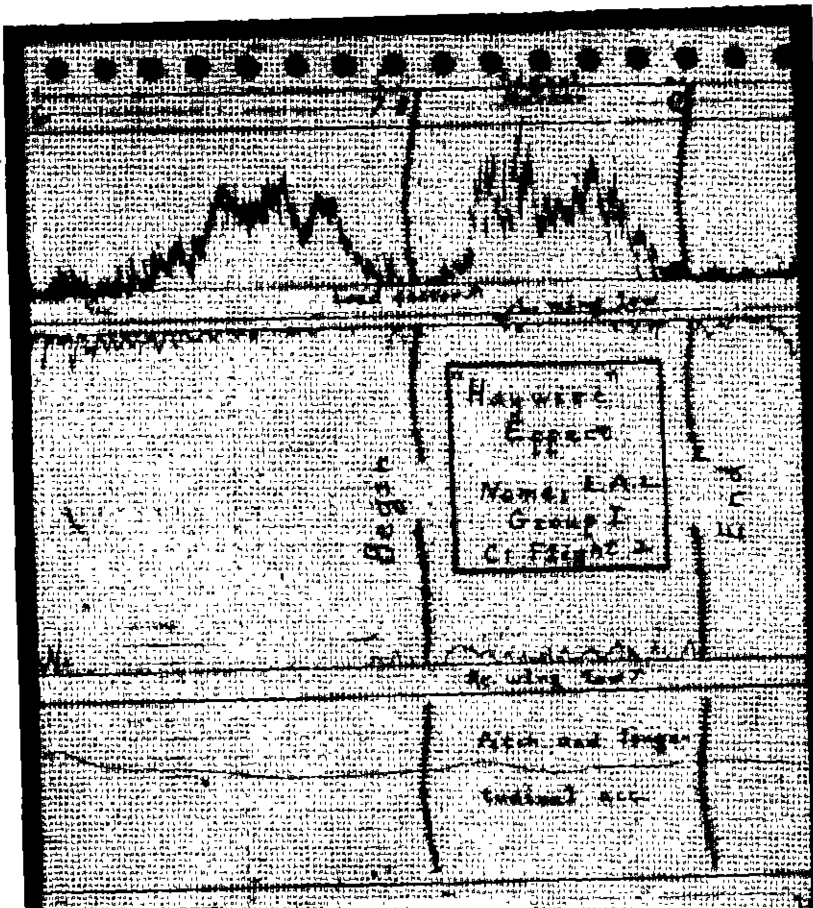


PLATE Ia

In both the power turns (maneuvers 6 and 8) of each plate, the load factor trace displays a damping curve, characterized by rapid and relatively wide up-and-down excursions of the stylus. This damping curve was denominated the "haywire" effect. Whenever it is present, readings of load factor are of dubious accuracy.

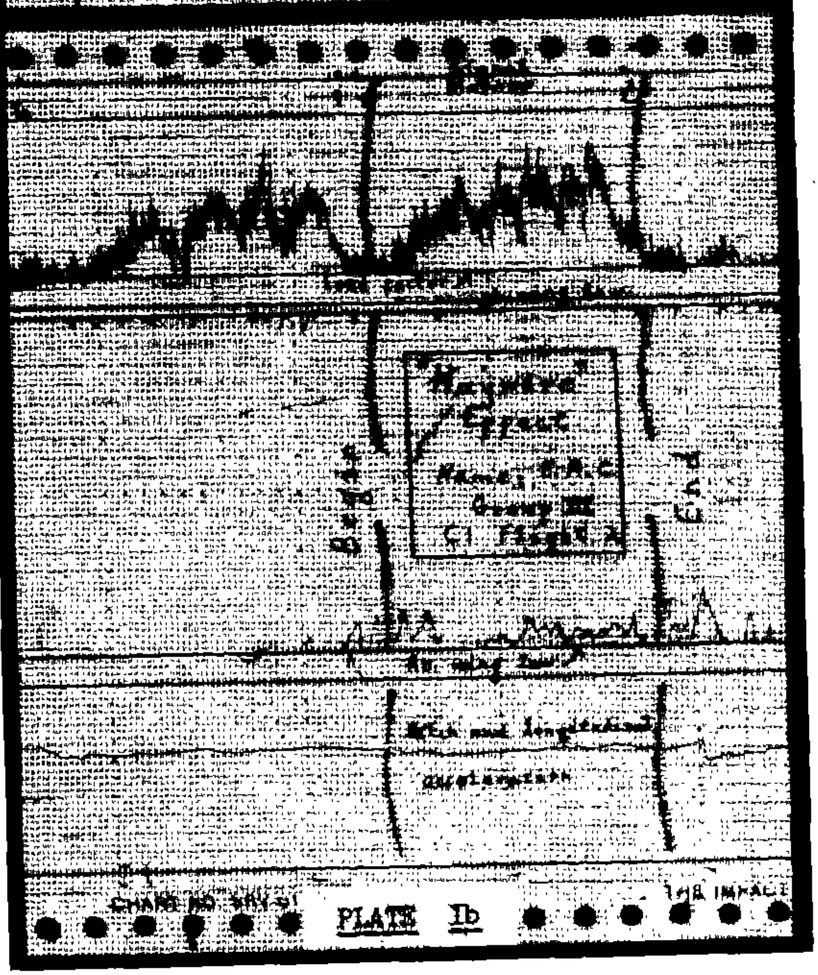


PLATE Ib

In the case of each plate, the effect is somewhat more marked and prolonged in the record of the right turn (maneuver 8) than in the record of the left turn (maneuver 6). Contrast of the load factor trace of these plates with the load factor trace of Plates II, III, and IVa-IVj will readily indicate the difference between this damping curve and the superposed sine curve of high-frequency engine, propeller, and frame vibrations which normally appears on the trace and has negligible effect on the accuracy of recording.

PLATES II AND III,

ILLUSTRATING DIFFICULTIES IN MAKING QUALITATIVE RATINGS AND QUANTITATIVE MEASUREMENTS OF R-S RIDE RECORDER RECORDS OF POWER TURNS

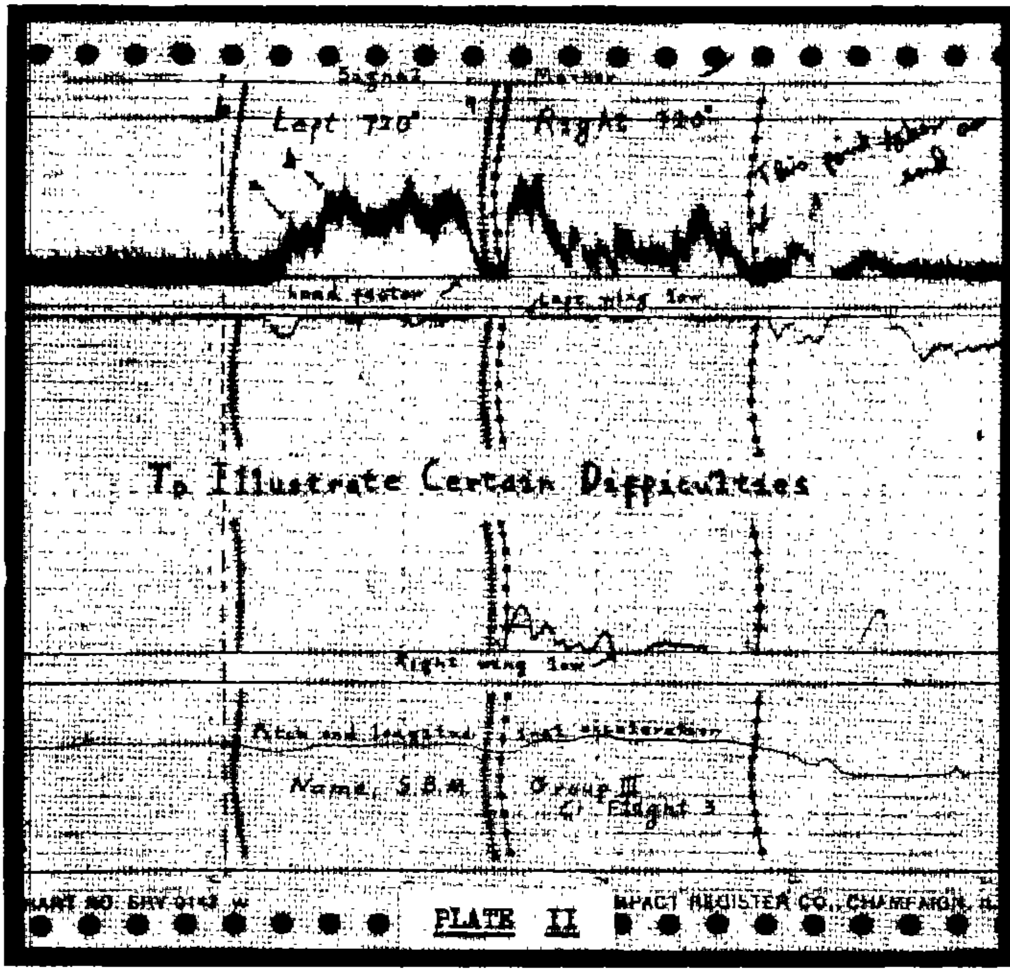


PLATE II

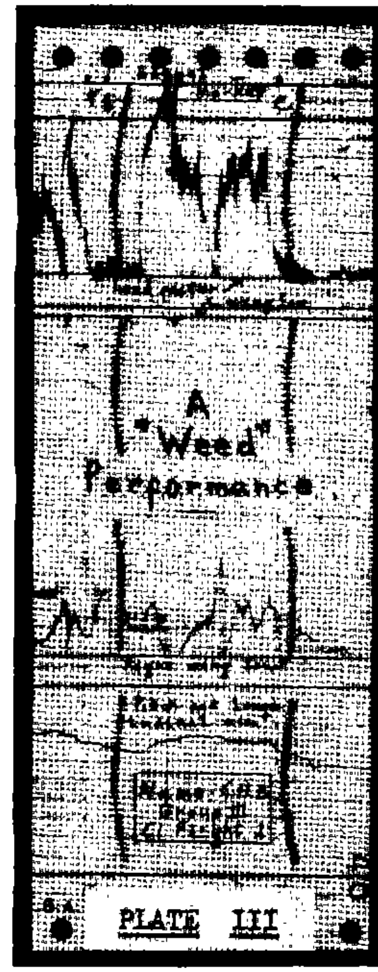


PLATE III

Plate II illustrates certain difficulties encountered in treating the R-S Ride Recorder records of 720° power turns:

(1) Need for use of a synchronizing scale in reading the records
(2) Ambiguity of the point separating the arbitrarily designated entry from the arbitrarily designated "turn proper" in the qualitative analysis
(3) Ambiguity of initial and terminal points of a maneuver when signals are missing
(4) Liability of qualitative ratings of right 720° power turns to a halo effect due to juxtaposition of the left turn on the record

These difficulties are discussed in detail in the main Report & Supplemental Report.

The beginning and end of the left 720° power turn (maneuver 6) of Plate II are denoted by the inserted barred arcs. Initial signals are lacking for maneuver 8 and transition maneuver C. The assumed beginning and end of maneuver 8 are therefore indicated by the arcs on which are superposed small circles.

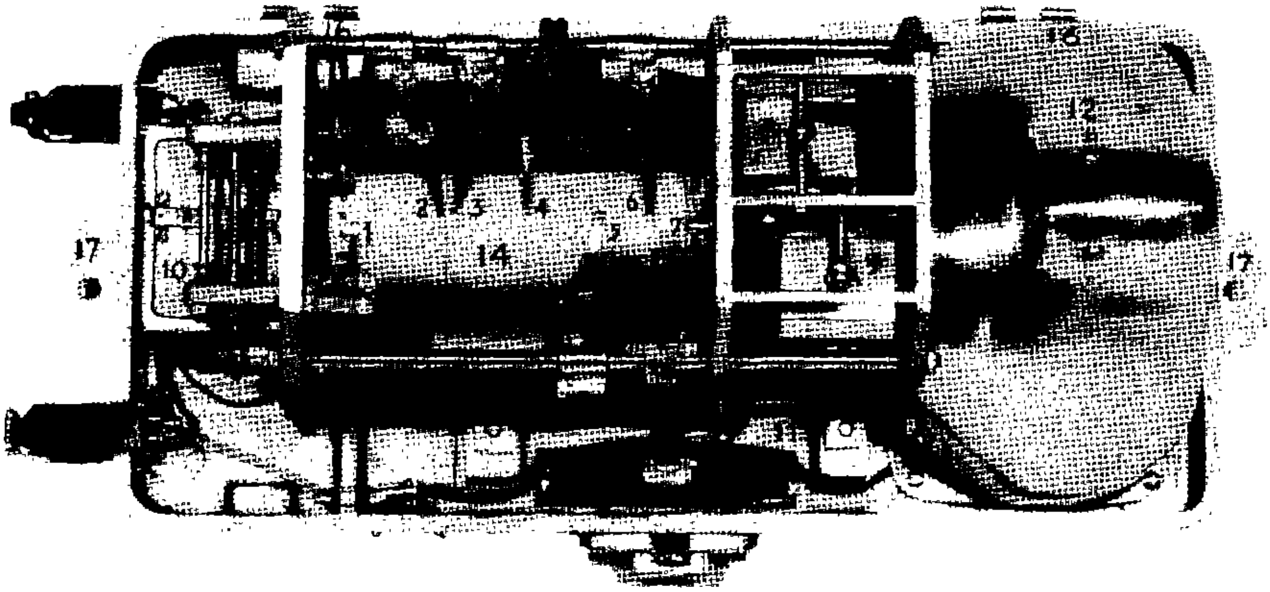
Plate III is the record of a right 720° power turn which is outstandingly good in certain respects, but poor in others, making difficult the assignment of a satisfactory qualitative rating to the performance. This difficulty is discussed in detail in the main Report.

PLATE V

THE R-S RIDE RECORDER

Airplane Rear

Airplane Right



Airplane Left

Airplane Front

In this view of the instrument the detachable cover has been removed. The accerlerometer, (i.e., the load factor indicator), which is enclosed by housing (10), and the pitch-and-longitudinal-acceleration pendulum, which hangs below pendulums (8) and (9) are not visible in this view. The visible parts are identified as follows:

1. Signal marker stylus, actuated by single solenoid immediately above and to the front
2. Load factor recording stylus, actuated by movement of the accelerometer weight, suspended in and enclosed by the housing (10) at the right end of the case.
3. Left-wing-low recording stylus, actuated by movement of pendulum (8)
4. Stylus for recording aileron movement, actuated by double solenoid immediately above and to the rear
5. Right-wing-low recording stylus, actuated by movement of pendulum (9)
6. Pitch-and-longitudinal-acceleration recording stylus, actuated by movement of a pendulum suspended underneath pendulums (8) and (9) and free to swing only in the longitudinal plane
7. Stylus for recording rudder movement, actuated by double solenoid immediately above and to the front
8. Left-wing-low pendulum
9. Right-wing-low pendulum
10. Housing of the weight-and-spring accelerometer. (load factor indicator)
11. Spirit level
12. Housing of spring-wound clockwork
13. Supply roller
14. Timing roller
15. Receiving roller
16. Hinges for detachable cover
17. Aluminum ears with holes for securing Recorder in airplane

Photograph by courtesy of the Impact Register Company, Champaign, Illinois

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION A

APPENDIX A

QUALITATIVE STUDY PROTOCOLS FOR PLATES Ia - IVj

University of Pennsylvania
Philadelphia, Pennsylvania
October 1942

For Plate Ia

Data Sheet
Page 1

DATA SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS
SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK   Instrument: R-S RIDE RECORDER

Code No. 210 - Ds - 1   Title of Flight C1   Hours: Dual ______

Name ______   No. of Flight 2   Solo ______

Group ______   Weather notations: none

I. Approximate time of maneuvers in sec. 56

II. ENTRY

A. Approximate time of entry in sec. 15
Approximate time in sec. between beginning and attainment of bank of approximately 30° 6

B. Lateral imbalance

1. Slipping (right-wing-low).

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X		1	
Between 1st and 2nd chart spaces		X	1 (Almost	throughout)
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No Skidding			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series (e.g., makes several discrete slips, then several discrete skids) ______

III. TURN

A. Bank

1. Fluctuations in bank
   a. Angle of bank nearly constant ________
   b. Angle of bank fairly constant ________
   c. Angle of bank very variable ___X___
   d. Angle of bank extremely variable ________
   e. Side-by-side (stepwise) fluctuations average approximately _2_ degrees (absolute, i.e., without regard to sign)
   f. Overall fluctuation (from smallest degree of bank to largest): approximately _15_ degrees.
   g. Hit prop-wash _No_ (N. B. Fluctuations in bank due to hitting prop-wash are not to be considered in making the above ratings).

2. Accuracy of bank
   a. During most of the maneuver, bank about _50_ degrees.
   b. Attained 60° bank and held it during _0_ (fraction) of maneuver.
      Did not attain 60° bank _X_.
   c. Overbanked approximately ____ degrees (average) during about _all_ (fraction) of maneuver.
   d. Underbanked approximately _10_ degrees (average) during about _1/2_ (fraction) of maneuver, (about 16° during 1/2).

   (N. B. Deviations from 60° bank due to hitting prop-wash are not to be considered in making the above judgment.)

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instanc
Less than 1st chart space	X		X	
Between 1st and 2nd chart spaces	X		4	
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instance
Less than 1st chart space		X	X	
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation X
Slipping and skidding in series ____

IV. RECOVERY

A. Approximate time of recovery in sec. ____
Approximate time in sec. between bank of approximately 30° and end of maneuver 6

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X		X	
Between 1st and 2nd chart spaces	X		1	
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X		X	
Between 1st and 2nd chart spaces	X		1	
Beyond 2nd chart space				

3. Slipping and skidding in alternation ____
Slipping and skidding in series X

V. DESCRIPTION AND REMARKS:

The load factor trace displays "haywire" effect; thus statements about bank must be considered very tentative, and liable to a possible large error. On the other hand, considerable indication of bumpy air from the traces. Bank seems to fluctuate around several well-defined midpoints; one at 50° and one at 44°; and was fairly stable.

Entry slow, and some indication of steps. Recovery rapid. Can't tell about steps because of possible presence of "haywire" effect.

Lateral imbalance performance looks amateurish, as though S were following the ball. On the other hand, may be due to bumpy air. If so, not bad. Same rating whether air bumpy or smooth; because if air smooth, I assume presence of "haywire" effect to explain aberrations of load factor trace.

OVERALL RATING: AVERAGE

DATA SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS
SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK   Instrument: R-S RIDE RECORDER

Code No. 218 - Ds - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 2 Solo ______

Group ______ Weather notations none

I. Approximate time of maneuver in sec. 56

II. ENTRY

A. Approximate time of entry in sec. 10
Approximate time in sec. between beginning and attainment of bank of approximately 30° 5

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than first chart space				
Between 1st and 2nd chart spaces				
Beyond 2nd chart space		X	1 (throughout)	

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than first chart space	No skidding			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skdding in alternation ______
Slipping and skidding in series, (e.g., makes several discrete slips, then several discrete skids) X

III. TURN

A. Bank

1. Fluctuations in bank
   a. Angle of bank nearly constant ______
   b. Angle of bank fairly constant ______
   c. Angle of bank very variable __X__
   d. Angle of bank extremely variable ______
   e. Side-by-side stepwise fluctuations average approximately _2_ degrees (absolute, i.e., without regard to sign)
   f. Overall fluctuation (from smallest degree to bank to largest): approximately _15_ degrees.
   g. Hit prop-wash _No_ (N. B. Fluctuations in bank due to hitting prop-wash are not to be considered in making the above ratings)

2. Accuracy of bank
   a. During most of the maneuver, bank about _42-46_ degrees.
   b. Attained 60° bank and held it during about ______ (fraction) of
      Did not attain 60° bank _X_
   c. Overbanked approximately _o_ degrees (average) during about _all_ (fraction) of maneuver.
   d. Underbanked approximately _14-18_ degrees (average) during about _2/3_ (fraction) of maneuver, (about 10° during 1/3).
   (N. B. Deviations from 60° bank due to hitting prop-wash are not to be considered in making the above judgment.)

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X		3 (momentarily)	
Between 1st and 2nd chart spaces		X	4	
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No skidding			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series ______

IV. RECOVERY

A. Approximate time of recovery in sec. 6
Approximate time in sec. between bank of approximately 30° and end of maneuver 1

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No slipping			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X		1 (momentarily)	
Between 1st and 2nd chart spaces	X		1	
Beyond 2nd chart space	X		1	

3. Slipping and skidding in alternation ______
Slipping and skidding in series X

V. DESCRIPTION AND REMARKS:

Load factor displays "haywire" effect to pretty bad degree. All readings of bank thus subject to worst degree of uncertainty. Bank nevertheless seems to fluctuate around 45° as a midpoint, throughout -- slightly lower during first half, slightly higher during second half. Overall fluctuation in any case not great.

Both entry and recovery rather slow and steplike.

Lateral balance performance none too good, but not egregiously bad. Altitude probably didn't change very much. Trace looks as though S made number of incomplete corrective movements and possibly was looking at ball sporadically.

Absence of "haywire" effect might raise this rating one step, but no more. With or without it, could be rated only in this class or one next higher.

For Plate II

Data Sheet
Page 1

DATA SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS
SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 313 - Ds - 1 Title of Flight C 1 Hours: Dual ____________

Name ____________ No. of Flight 3 Solo ____________

Group ____________ Weather notations: none

I. Approximate time of maneuver in sec. not derivable

II. ENTRY

A. Approximate time of entry in sec. not derivable
Approximate time in sec. between beginning and attainment of bank of approximately 30° not derivable

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space				
Between 1st and 2nd chart spaces				
Beyond 2nd chart space		X	1 (throughout)	

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No skidding			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation ____________
Slipping and skidding in series (e.g., makes several discrete slips, then several discrete skids) ____________

III. Turn

A. Bank

1. Fluctuations in bank

a. Angle of bank nearly constant ____________
b. Anlge of bank fairly constant ____________
c. Angle of bank very variable ____________
d. Angle of bank extremely variable ___X___
e. Side-by-side fluctuations average approximately __3__ degrees (absolute, e.i. without regard to sign)
f. Over-all fluctuations (from smallest degree of bank to largest): approximately __25__ degrees.
g. Hit prop-wash __No__ (N.B. Fluctuations in bank due to hitting prop-wash are not to be considered in making the above ratings.)

2. Accuracy of bank

a. During most of the maneuver, gank about __34__ degrees.
b. Attained 60° bank and held it during about ________(fraction) of maneuver.
Did not attain 60° bank __X__
c. Overbanked approximately __0__ degrees (average) during about __all__ (fraction) of maneuver.
d. Underbanked approximately __25__ degrees (average) during about __1/2__ (fraction) of maneuver, (15° during 1/4 10° during 1/4)

(N.B. Deviations from 60° bank due to hitting prop wash are not to be considered in making the above judgment.)

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	elatively rlong time	few instances	many instances
Less than 1st chart space	X		2	
Between 1st and 2nd chart spaces		X	2	
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No skidding			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

Data Sheet
Page 3

3. Slipping and skidding in alternation X
Slipping and skidding in series ______

IV. RECOVERY

A. Approximate time of recovery in sec. not derivable
Approximate time in sec. between bank of approximately 30° and end of maneuver not derivable

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	Questionable, due to lack of final signal			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

2. Skidding (left wing low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	Questionable, due to lack of final signal			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series ______

V. DESCRIPTION AND REMARKS:

Signals missing. End of maneuver cannot be certainly discriminated.

Bank bad throughout, both in regard to correctness and consistency. Load factor line full of peaks. Bnak almost constantly changing. Slipping not expecially serious.

Whatever point might be taken for the end of the maneuver, it would hardly change the rating, except perhaps to lower it. Everything immediately following the selected end point is equally bad. Record was marked at pointed selected as end, and point was identified for the second reading. Will certainly recognize this one, anyway.

OVER-ALL RATING: POOR

For Plate XII

Data Sheet
Page 1

DATA SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS
SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 223 - Ds - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 2 Solo ______

Group ______ Weather notations none

I. Approximate time of maneuver in sec. 36

II. ENTRY

A. Approximate time of entry in sec. 8
Approximate time in sec. between beginning and attainment of bank of approximately 30° 4

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X		1	
Between 1st and 2nd chart space				
Beyond 2nd chart space	X		1	

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No skidding			
Between 1st and 2nd chart space				
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series (e.g., makes several discrete slips, then several discrete skids) X

Data Sheet
Page 2

III. TURN

A. Bank

1. Fluctuations in bank

a. Angle of bank nearly constant________
b. Angle of bank fairly constant____X____
c. Angle of bank very variable________
d. Angle of bank extremely variable________
e. Side-by-side stepwise fluctuations average approximately__1 - 2__ degrees (absolute, i.e., without regard to sign)
f. Over-all fluctuations (from smallest degree of bank to largest): approximately__13__ degrees
g. Hit prop-wash__Yes__ (N.B. Fluctuations in bank due to hitting prop-wash are not to be considered in making the above ratings)

2. Accuracy of bank

a. During most of the maneuver, bank about__55__ degrees.
b. Attained 60° bank and held it during about__1/8__ (fraction of maneuver.
c. Did not attain 60° bank________
c. Overbanked approximately__0__ degrees (average) during about __all__ (fraction) of maneuver.
d. Underbanked approximately__5 - 8__ degrees (average) during about __7/8__ (fraction) of maneuver.

(N.B. Deviations from 60° bank due to hitting prop-wash are not to be considered in making the above judgment.)

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	X			
Between 1st and 2nd chart space				
Beyond chart space		X	2 (almost	throughout)

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No skidding			
Between 1st and 2nd chart space				
Beyond 2nd chart space				

3. Slipping and skidding in alternation______
   Slipping and skidding in series X

IV. RECOVERY

A. Approximate time of recovery in sec. 5
   Approximate time in sec. between bank and approximately 30° and end of maneuver 3

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space		X	almost throughout	
Between 1st and 2nd chart spaces	X		1(persisting from turn proper)	
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space				
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation______
   Slipping and skidding in series X

V. DESCRIPTION AND REMARKS:

Very interesting performance, and almost a bang-up one. Rolled very rapidly up to about 60°, almost on the dot, as nearly as can be told from direct inspection, then bank fell gradually to about 52 - 55°. Then prop-wash caused return to base-line, after which another rapid roll to about 55°, which was held fairly consistently, with a marked slip, through the second 360° turn. The performance affords a fairly good example of the difficulties with the signal system: 4 seconds elapse after signal before a discriminable bank; then bank of 60° attained in 4 seconds, with very rapid roll. It seems almost certain that the roll was not started until between 2 - 3 seconds after signal - an allowable error considering the method, but one which would affect the time quantities in this sheet, with the exception of total time, to a great extent. Whole performance very rapid, including recovery. Lateral imbalance performance not so good, but not so bad as it would look. Slip on entry accompanied very rapid roll, second slip was due to prop-wash, and 3rd was in turn following prop-wash, beginning with rapid roll back. Probably lost a decent amount of altitude in second turn, which is the worst feature of the maneuver.

OVER-ALL RATING: VERY GOOD

For Plate IVa

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: B-S RIDE RECORDER

Code No. 392 - Gd - 1 Title of Flight G 1 Hours: Dual

Name ____________ No. of Flight 3 Solo ____

Group ____________ Weather notations none

Already in minor slip at signal. This rapidly grew to become large in extent (frequently to 5th space or over) and persisted throughout entry, turn, recovery, and well into transition maneuver 9. Extremely bad performance in this respect; couldn't be much worse.

Entry slow, with steps. Recovery rather rapid, one step.

Impossible to state over-all fluctuation exactly, because trace returned to base line for good length of time. Best approximation: greater than 26° (from 35° to 61°). Side by side fluctuations about 2°. Two fairly distinct turns. First resembles normal distribution curve, with apex at 61°. Would average about 50°. Second turn has one long plateau, then gradual peak, at about 55°, minor peaks interspersed. Would average also about 50°.

Very bad performance.

OVER-ALL RATING: VERY POOR

For Plate IVb

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 326 - Gd - 1 Title of Flight G 1 Hours: Dual ________

Name ________ No. of Flight 3 Solo ________

Group ________ Weather notations ________

Already in slight prolonged slip at signal, which became fairly large and persisted through entry. Slight period of good balance followed, after which a very prolonged slip of various magnitudes which finally reached nearly to 8th space, or scale's length, when it was suddenly corrected and followed by minor skid, evidently result of overcorrection. This followed by large slip which persisted, reduced in extent, through recovery, and very far into transition maneuver C with increased magnitude. Very bad performance in this respect.

Entry rather slow, with steps. Recovery very rapid, without discriminable steps.

Load factor trace jagged with peaks throughout. Best estimate of over-all fluctuation 31°: from 22° (base line slip) to 53°. No telling what bank would average, but 42° is as good an estimate as possible. Side by side fluctuations 2 - 3°.

Performance and traces both give rise to suspicion of bumpy air; but whatever the condition of the air, the performance is of the worst.

OVER-ALL RATING: VERY POOR

For Plate IVa

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 314 - Gd - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 3 Solo ______

Group ______ Weather notations none

Short minor slip on entry, persisting into turn proper. This is another example of an ambiguous entry-turn separation point. During turn a prolonged slight slip, returning to base line just before beginning of recovery and increasing to fair extent in recovery. Ended with final signal. Ragged, but not excessively bad performance in this respect.

Entry rapid, if first peak taken as terminating point, (1st peak came at 29°). If not, very slow, and step-like. Recovery rather rapid, and step-like.

Over-all fluctuation about 22°; from 29° to 51°. Bank pretty variable, but all fluctuations gradual. Bank would average about 39°. Side-by-side fluctuations about 2°. Bank in continuous gradual fluctuation. Engine vibrations somewhat smaller than usual.

Ragged in every respect.

OVER-ALL RATING: POOR

For Plate IVd

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK   Instrument: R-S RIDE RECORDER

Code No. 225 - Gd - 1   Title of Flight C 1   Hours: Dual ____

Name ____   No. of Flight 2   Solo ____

Group ____   Weather notations ____ none

Fair-sized slip on entry, short in duration. Throughout turn, prolonged minor slipping, negligible. Minor skid followed by prolonged slight slip, lasting several seconds into transition maneuver C, on recovery.

Entry rather slow and step-like. Recovery more rapid, steps not pronounced.

Over-all fluctuation in bank about 14°. Load factor marked with peaks and plateaus. Side-by-side fluctuations would probably average around 2° - 3°. Bank fluctuates around about 37° as midpoint. Fluctuation gradual but continuous. Bank higher than 40° only once, and then only 44°. Amateurish performance.

OVER-ALL RATING: POOR

For Plate IVe

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 327 - Gd - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 3 Solo ______

Group ______ Weather notations none

Rapid balanced entry. Balance perfectly maintained throughout most of first turn, after which 2 slight slips and 1 minor slip, the latter one ending with beginning of recovery. On recovery a slight short skid, disappearing before final signal. A good, if not outstanding, performance in respect to lateral balance.

Entry fairly rapid. Recovery rapid, with one step.

Two distinct 360° turns, peaks throughout both. In first, bank would average about 40°, a well defined midpoint, though variations around that point are fairly large and frequent. In second, bank would average about 48°, less clearly defined as a midpoint. Over-all fluctuation about 18°: from 35° to 53°. Side-by-side fluctuations would average about 3°. This variability in bank and wide deviation in first turn from prescribed bank detract from maneuver.

OVER-ALL RATING: AVERAGE

For Plate IVf

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK   Instrument: R-S RIDE RECORDER

Code No. 309 - Gd - 1   Title of Flight C 1   Hours: Dual ____

Name ____   No. of Flight 3   Solo ____

Group ____   Weather notations none

Minor short skid on entry followed by prolonged slight slip extending to recovery. Fair-sized short skid on recovery, returning to base-line at final signal. Rather ragged, but not very bad.

Both entry and recovery slightly slow, with steps.

Over-all fluctuation about 8° - 9°; from 41° to 49°. Load factor trace regular, but shows continuous gradual fluctuation. First half of curve over 45°, second hald below 45°, which is approximate average. Side-by-side fluctuations about 1° on the average.

OVER-ALL RATING: AVERAGE

For Plate IVg

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK   Insturment: R-S RIDE RECORDER

Code No. 328-. Gd - 1   Title of Flight G 1   Hours: Dual ______

Name ______   No. of Flight 3   Solo ______

Group ______   Weather notations none

Short minor slip, followed by period of balance on entry. Turn mostly balanced with intermittent minor skidding. Short minor skid on recovery. Unusual performance in this respect.

Entry rather slow, with steps. Recovery fairly rapid with no discriminable steps.

Two fairly distinct 360° turns. In first, bank pretty stable, varying around 42° as midpoint. Insecond , wider over-all variation, but gradual fluctuations 2° or less.

Would be rated "average" except for proficiency in maintaining lateral balance. Probably did rate it "average" on previous reading.

OVER-ALL RATING: GOOD

For Plate IVh

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 312 - Gd - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 3 Solo ______

Group ______ Weather notations none

Prolonged minor to slight slip on entry. In turn, 1 slight and 1 minor slip. On recovery, prolonged slight to fair-sized slip persisting into transition maneuver C. Not bad showing in this respect.

Entry fairly rapid, with steps. Recovery likewise.

Over-all fluctuation about 14°: from 48° to 62°. Trace went off scale at one point however. Attained 62° bank on entry, then rest of turn bank declined, with peaks. Changes fairly rapid, but not especially so. Bank would average about 54°, but this not a well defined midpoint. Side-by-side fluctuations somewhat less than 2°.

OVER-ALL RATING: GOOD

For Plate IVi

GENERAL DESCRIPTION SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS, SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK Instrument: R-S RIDE RECORDER

Code No. 227 - Gd - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 2 Solo ______

Group ______ Weather notations none

Slight slip on entry, prolonged, persisting into turn and becoming minor in extent. Period of near-perfect balance, followed by a rapid slip, large in extent and short in duration, due to prop-wash. Minor skidding during rest of turn and recovery. Excellent performance in this respect.

Rapid, clean entry and recovery, both almost free of steps.

Over-all fluctuation about 13°, from 42° to 55°. First turn fairly regular in that no rapid fluctuations occur. Second turn has several peaks and rapid fluctuations, but extent not great. Bank in each would average about 48°, side-by-side fluctuations 1° - 2°.

OVER-ALL RATING: VERY GOOD

Additional Note to Original Protocol: Prop-wash effects ignored in obtaining bank fluctuation values. Cf. a copy of Data Sheet, p.70, III., A., g.

For Plate III

DATA SHEET FOR QUALITATIVE ANALYSIS OF TULANE STANDARD FLIGHT RECORDS
SUMMER 1940

Maneuver: 720° RIGHT POWER TURN AT 60° BANK   Instrument: R-S RIDE RECORDER

Code No. 224 - Ds - 1 Title of Flight C 1 Hours: Dual ______

Name ______ No. of Flight 2 Solo ______

Group ______ Weather notations none

I. Approximate time of maneuver in sec. 40

II. ENTRY

A. Approximate time of entry in sec. 7
Approximate time in sec. between beginning and attainment of bank of approximately 30° 3

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No slipping			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No skidding			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series (e.g., makes several discrete slips, then several discrete skids) ______

III. TURN

A. Bank

1. Fluctuations in bank

a. Angle of bank nearly constant ___X___
b. Angle of bank fairly constant ______
c. Angle of bank very variable ______
d. Angle of bank extremely variable ______
e. Side-by-side (stepwise) fluctuations average approximately ___1___ degree (absolute, i.e., without regard to sign)
f. Over-all fluctuation (from smallest degree of bank to largest): approximately ___7___ degrees
g. Hit prop-wash ___No___ (N.B. Fluctuations in bank due to hitting prop-wash are not to be considered in making the above ratings)

2. Accuracy of bank

a. During most of the maneuver, bank about ___44___ degrees.
b. Attained 60° bank and held it during about ______ (fraction) of maneuver.
Did not attain 60° bank ___X___
c. Overbanked approximately ___0___ degrees (average) during about ___all___ (fraction) of maneuver.
d. Underbanked approximately ___16___ degrees (average) during about ___all___ (fraction) of maneuver.
N.B. Deviations from 60° bank due to hitting prop-wash are not to be considered in making the above judgment.)

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No slipping			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space		X	(intermittently) throughout	
Between 1st and 2nd chart spaces	X		4 "spikes"	
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series X

IV. RECOVERY

A. Approximate time of recovery in sec. 4
Approximate time in sec. between bank of approximately 30° and end of maneuver 2

B. Lateral imbalance

1. Slipping (right-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space	No slipping			
Between 1st and 2nd chart spaces				
Beyond 2nd chart space				

2. Skidding (left-wing-low)

Extent	relatively short time	relatively long time	few instances	many instances
Less than 1st chart space				
Between 1st and 2nd chart spaces		X	1 (throughout)	
Beyond 2nd chart space				

3. Slipping and skidding in alternation ______
Slipping and skidding in series X

V. DESCRIPTION AND REMARKS:

Remarkable performance in respect to bank. Rolled up to it rapidly, without discriminable steps, held it very well, and rolled out rapidly without discriminable steps. As a 45° turn, as good as you'd want.

Skid "spikes" during maneuver negligible, probably in fact, not caused by pilot, as line shows a good deal of vibration. Lateral imbalance performance also remarkable: perfect balance throughout entry and turn. Slight skid on recovery.

Except for failure to attain proscribed bank and hit prop-wash, hang-up.

OVER-ALL RATING: VERY GOOD

Additional note to Original Protocol: "Failure to hit prop-wash" is interpreted as "absence of propwash effects on the record."

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION A

APPENDIX B

A PROPOSED MANUAL FOR THE USE OF R-S RIDE RECORDER RECORDS IN EVALUATING PERFORMANCES OF RIGHT 720° POWER TURNS

by

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and

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November, 1942

FOREWORD

This set of directions was prepared as a specimen of the type of manual which might be issued to instructors for use with pattern scales for rating graphic records of performance on various maneuvers.

Both the pattern scale for rating performances on the right 720° power turn (Plates IV_a-IV_j) and this manual are intended only as exploratory steps towards the use of graphic records in the field, and it is not anticipated that actual use will be made of either, for the following reasons:

(1) Since the scale has been prepared, the 360° turn has been substituted for the 720° turn in the C.P.T. course. The scale is, of course, inapplicable to 360° turns. (See page 90.)

(2) The R-S Ride Recorder is not recommended for field use because:

a. There are currently available several later model Redhed Flight Recorders of the same manufacturer which supply more information than the Ride Recorder. (See page 3 of the Introduction, Part I.)

b. An improved graphic recorder, designed to correct or minimize the defects of the R-S Ride Recorder and other commercial flight recorders which have been employed in projects of the Committee on Selection and Training of Aircraft Pilots, is currently under construction. (See page 205, Supplemental Report.)

It is to be noted also that this manual contains general information applicable to all maneuvers and not only to power turns. It is thus somewhat longer than necessary for a single maneuver if the instrument were actually to be employed in the field. In actual use, the general information contained in the Introduction (pages 89-90), the section entitled "Interpretation of the Traces" (pages 90-93), and Table A, page 99, would probably be supplied in a separate manual with the instrument, and the length of manuals for individual maneuvers would be correspondingly reduced.

DIRECTIONS FOR USING PATTERN SCALE FOR RATING PERFORMANCES ON THE RIGHT 720° POWER TURN AT 60° BANK AS RECORDED BY THE R-S RIDE RECORDER

INTRODUCTION

It has been found by experiment with records of the R-S Ride Recorder that performances of the right 720° power turn show certain record "patterns" which vary with the quality of the performance. The records of very poor performances look very different from the records of average performances, and they differ to a very marked degree from the records of very good performances. This fact suggested the construction of this graded scale of records to aid instructors in rating students' performances of this maneuver. This scale is made up of full-size R-S Ride Recorder records of right 720° power turns which were rated by standard procedures, and given an over-all mark of Very Poor, Poor, Average, Good, or Very Good. All that is needed to rate a performance of the right 720° power turn by means of this scale is to "match" the R-S Ride Recorder record of the performance with the one most nearly resembling it in the scale.

Why Use Flight Recorders?

Flight recorder records have a number of advantages in furnishing objective information about pilot performance. A recorder can go along with the student on solo flights and supply a permanent record which helps the instructor to check his progress at a stage when observation of the student is usually very limited. Even in dual flight, a recorder can "take down" many details about the student's performance which the instructor might not see at the time because he might be paying attention to other details of the student's performance. Some racing pilots have even used recorders to check up on their own flying to make sure they are holding a constant bank around pylons.

Disadvantages of Recorders

Flight recorders also have a number of disadvantages. Perhaps the outstanding disadvantage is the time required to judge a record carefully and make an accurate rating of the performance. Another disadvantage is the fact that in order to interpret the records accurately, one must be thoroughly familiar with them through regular daily experience.[66]

Reducing the Disadvantages of Recorders by Using "Pattern" Scales

In order to cut down these disadvantages, this pattern scale and these directions were prepared. By "matching" the records of students' performances with the records reproduced on this scale, you can place your students' records in one class of a five-point scale ranging from Very Poor to Very Good, and thus obtain a standardized rating in a very short time. Although even a person unskilled in either flying or the use of flight recorder records could do this,

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66 These general advantages and disadvantages apply to all flight recorders and not only to the R-S Ride Recorder.

the efficiency and accuracy of rating will be greatly helped by considering the information given in pages 90 to 98, and use of the records will be more interesting with this "background" knowledge.

GENERAL REMARKS ABOUT THE SCALE

Bank and Lateral Balance Considered in Making Scale Ratings

The R-S Ride Recorder supplies information about bank and lateral balance during flight, and the ratings of these performances are based on this information. The instrument does not supply information about altitude or airspeed; nor does it supply reliable information about longitudinal pitch.

Chart Speed

In making the records reproduced on this scale, the chart was driven at a speed of 1½ inches per minute. 1 (horizontal) inch of chart thus represents 40 sec. Each horizontal tenth inch[67] of chart space = 4 sec.

CAUTION:

It is important to note that a change in chart speed will change the appearance of maneuvers on the chart. Therefore, THIS SCALE CANNOT BE USED PROPERLY UNLESS YOUR INSTRUMENT IS SET FOR A CHART SPEED OF 1½ INCHES PERMINUTE.

Explanation of Arcs Drawn in on Scale Records

The beginning of each power turn on this scale is indicated by the set of barred arcs which have been drawn in on the records and marked "Begin". The end is indicated by the set of barred arcs marked "End".[68]

CAUTION:

This scale may be used only to rate performances on the <u>720° RIGHT POWER TURN AT 60° BANK</u>. It CANNOT be used to rate LEFT POWER TURNS, which have a considerably different appearance on the records. It CANNOT be used to rate either CLIMBING OR GLIDING TURNS. It CANNOT be used to rate MEDIUM OR SHALLOW TURNS. It CANNOT be used to rate 90°, 180°, or 360° TURNS.[69]

INTERPRETATION OF THE TRACES

Signal marker trace

The signal "dots" on the signal marker trace are made during flight by the instructor or pilot, who presses a push-button contact inserted into the instrument panel or control

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67 The chart is marked into tenths of inches by the dots of the horizontal line in its center.

68 These arcs represent the marks on a transparent plastic ruler used for synchronizing the traces. You do not need to use this transparent synchronizing ruler in order to read and rate the records of right 720° power turns by means of this pattern scale.

69 The fact that this <u>scale</u> can be used only for rating right 720° power turns of course does not indicate that the only use of the <u>instrument</u> is to record right 720° power turns. Similar scales, after proper experiment, may be constructed for other maneuvers.

stick to make the signals. The signals may be used for two purposes:

Use of Signal Marker Trace

(1) To identify maneuvers on the record by means of a specially designed signal code, using different combinations of dots and dashes for different maneuvers, or

(2) To indicate the beginning and end of maneuvers, by means of a single dot or dash.

When the order of maneuvers is arranged and known beforehand, as in standard flights,[70] the signal marker trace will usually be used only to indicate the beginning and end of maneuvers, since there is then no need for signals to identify them.

The load factor trace

The load factor trace is used to supply information about bank in horizontal[71] turns.

Load Factor Trace Records "Loads"

As you know, any curved flight path, such as a normal loop or the pull-up following a dive, "throws a load" onto the airplane. The magnitude of the load factor which the airplane undergoes depends upon the rate of turn of the airplane, the plane of the earth within which it is turning (that is, earth vertical, earth horizontal, etc.) and its velocity. An accelerometer, or load factor indicator, mounted in the R-S Ride Recorder records this load factor directly.

Constant Relation between Bank Angle and Load Factor

Since the flight path is also curved in banked turns, they also "throw a load" onto the airplane. In horizontal turns, there is a constant relation between the angle of bank and the load factor to which the airplane is subjected.[72]

Load Factor Trace may be considered a Curve of Bank

Each point on the load factor trace of these records thus represents a particular value of load factor and also a particular bank angle corresponding to the load factor value. The load factor trace on the record of each turn may therefore be viewed as a curve of load factor or as a curve of bank.

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70 A standard flight consists of a series of maneuvers which are very carefully specified as to wind or ground direction, bank, etc.; which follow each other in a definite order; and which are to be flown under specified conditions of wind velocity and smoothness of the air. The object of standard flights is to provide a standard method of comparing students.

71 That, is, turns in the plane of the horizon -- not climbing or gliding turns.

72 (For the benefit of those readers interested in aerodynamics):
This relation may be stated as follows: the value of load factor, expressed in g (units of gravity) is equal to the secant of the angle of bank.

Trace of Engine and Propeller Vibrations Placed on the Load Factor Curve

The heavy "fuzzy" trace which is placed on this curve is a record of engine and propeller vibrations. The true reading of load factor at any point is the midpoint (halfway between the bottom and top) of this vibrations trace.

The height of this vibrations trace varies with the airplane, the location of the instrument in the airplane, propeller setting, throttle setting, and flight attitude. No matter what it its height, however, the true reading of load factor is always given by its midpoint.[73]

Lowest Load Factor and Bank Angle Recorded

On the particular instrument used in making the records reproduced in this scale, the accelerometer had an initial tension of +1.05 g,[74] that is, it would not record a load factor of less than 1.05 g. Wherever such load factors are encountered -- as in straight and level flight, where the load factor is +1g, or in glides -- the load factor trace is at its base-line, that is, the bottom line. This value of 1.05g corresponds to a bank of 18°. Thus, when the bank is <u>18° or less</u>, <u>no positive trace</u> appears.

Highest Load Factor and Bank Angle Recorded

The top extreme of this trace (which the trace reaches in <u>Plate IVh</u>) represents a load factor of 2.05g, which corresponds to a bank angle of 61°.

Value of each Chart Space

Each vertical tenth inch of chart space[75] represents 0.1g load factor. It is important to remember, however, that the relation between load factor and bank is such that equal amounts of load factor do <u>not</u> represent equal angles of bank. For example, a chart height of .10 inch (which always corresponds to a load factor value of 0.10g) may represent a bank angle of 9° in the <u>lower</u> part of the chart, but an angle of only 2° in the <u>upper</u> part of the chart. Thus, relatively large fluctuations in the trace when it is toward the upper part of the chart, as in <u>Plate IVh</u>, represent no greater bank variations than relatively small fluctuations of the trace when it lies near the base-line, as in <u>Plate IVd</u>.

The bank value of each printed line of the chart is given by <u>Table A</u>, page 99, for the convenience of those readers who may wish to make detailed examination of the plates

CAUTION:

Examine the specifications supplied by the manufacturer with your instrument. If the accelerometer of your instrument has an initial tension other than 1.05g, it does not have the

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73 (For the benefit of readers especially interested in instruments): The reasons for this are: (1) Since these vibrations have a very high frequency, whereas changes in the load factor recorded are comparatively slow, there is no "interference" between the vibrations and the load factor; and the vibrations record is <u>placed on</u> the record of the load factor and (2) the superposed vibrations trace has the symmetrical form of a sine curve.

74 g, a unit of acceleration = acceleration of gravity = 32.17 foot/sec./sec.

75 The chart is divided vertically into tenths of inches by the printed lines.

same calibration and chart values as the accelerometer of the instrument used in making these records, and YOU CANNOT APPLY THIS PATTERN SCALE TO RECORDS MADE WITH YOUR INSTRUMENT.

Left-wing-low trace and right-wing-low trace

Left-Wing-Low Trace and Right-Wing Low Trace Represent Movements of the Ball of the Ball-bank Indicator

The left-wing-low trace represents movement of the ball of the standard ball-bank indicator to the left of its center position. The right-wing-low trace represents movement of the ball to the right of its center position.

Taken together, these traces give a curve which for all practical purposes is the same as the curve which would be obtained if it were possible to record the movements of the ball in a ball-bank indicator.[76] The traces thus give a record of slipping and skidding. In this scale for right turns, a trace on the left-wing-low line represents skidding and a trace on the right-wing-low line represents slipping.

All the plates except IVj show slipping to varying extents and for varying amounts of time. None of the plates shows any marked skidding, although a few slight traces appear on the left-wing-low line between the barred area in Plates IVb, IVd, IVe, IVf, IVg, IVi, and IVj.

Pitch-and-longitudinal-acceleration trace

Pitch-and-longitudinal Acceleration Trace Supplies no Useful Information concerning Power Turns

The pitch-and-longitudinal-acceleration trace supplies no valuable information concerning power turns. This trace cannot be interpreted in the case of power turns, because it records a combination of two effects which tend to cancel each other in the trace, and which cannot be separated in the trace. It should be disregarded.

RATING PERFORMANCES OF THE 720° RIGHT POWER TURN BY MEANS OF THE PATTERN SCALE

As indicated in the Introduction, all that is needed to rate a performance of the right 720° power turn by means of this scale is to "match" the record with the one most nearly resembling it in the scale.

You will note that two patterns are included for each class of the scale, and that these two patterns in some in-

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[76] (For the benefit of readers interested in aerodynamics): This situation results from the fact that the particular effects recorded are independent of the masses involved. The ball and the pendulums of the R-S instrument which produce these traces respond to imposed accelerations in the same manner. Certain differences result from the fact that the ball is "damped" by being constrained to move through a restraining fluid, whereas the pendulums are undamped. Consequently the pendulums respond more quickly to imposed accelerations and respond to slight accelerations, such as vibrations, to which the ball is relatively insensitive.

stances show marked differences between themselves. These differences in patterns which were assigned the same rating are due to the fact that several aspects of the performance are included in the rating. One student might be better in one way than a second student, but be poorer than the second student in another way. Considered as a whole, however, their performances might be about the same.

Each Class of the Rating Scale may be Characterized by Several Patterns

For example, the pilot who flew the turn recorded in Plate IVe allowed his bank to vary widely and frequently. The load factor trace of this plate is full of jagged "peaks". Moreover there is a noticeable difference in the bank during the first half and the bank during the second half. This bank performance is not as good as the one shown in Plate IVf, where the bank angle shows no wide and sudden fluctuations. Yet the turn reproduced in Plate IVf is worse than the one recorded in Plate IVe with respect to lateral balance. As shown by the right-wing-low trace, the pilot was in a slight slip almost throughout the turn recorded in Plate IVf; while in the case of Plate IVe, the pilot corrected both slipping and skidding fairly promptly. Considering everything, neither performance is much better or worse than the other.

How the two Patterns For Each Class Were Selected

In constructing this scale, the attempt was made to select for each class (that is, Very Poor, Poor, etc.) two records which would be about as different from each other in pattern as possible These two patterns represent the limits of the class. Any record which resembles either pattern would be given the rating which is marked on it, and any record which "falls between" the two pattern would be given the rating marked on them. For example, a pattern which looks like a "cross" between the two patterns marked Good on the scale would also be rated Good.

"Borderline" Records

Of course, "borderline" records will be found which may resemble patterns in two classes of the scale. For example, a record might be found which looks like a "cross" between Plate IVe, marked Average, and Plate IVg, marked Good. In such cases, if there is great difficulty in deciding which pattern the record resembles most, it would be well to examine the record for a few significant details, and make the judgment on the basis of this examination:

How Hitting The Prop-wash Appears on The Record

1. Prop-wash effects. Many cases of hitting the prop-wash (slipstream) can be identified by means of characteristic effects on the record. These characteristic effects are shown in Plate IVj. They consist of: a. A rapid drop of the load factor trace to its base-line, or a point near the base-line, b. At the same time, a rapid and rather extensive slip (right-wing-low) or skid (left-wing-low), or both, usually quickly corrected, and c. A rapid return of the load factor trace to approximately its previous height.

   Since if the prop-wash is hit at all, it will be hit at the end of the first 360° of the turn, these effects must occur about halfway through the turn. If they occur elsewhere, a "bump" or gust might be the cause.[77]

If these prop-wash effects are present, the rating of the performance will ordinarily be very high, since hitting the prop-wash indicates that the first 360° of the turn was nearly a perfect circle and showed negligible change in altitude.

Absence of Prop-Wash Effects from The Record Does not Mean that Rating Should be Low

On the other hand, when these prop-wash effects do not appear on the record, it does not necessarily mean that the performance should be given a low or average rating. Frequently these effects do not appear on the record even when the pilot does hit his prop-wash; or if they do appear, are much less marked than those shown in Plate IVi. These effects are marked only when the pilot encounters his full slip-stream; if he hits only the edges, the effect on the records is slight.

Moreover, even if all cases of hitting the prop-wash could be identified, it would be impossible to say exactly what it means when the pilot did not hit his prop-wash. From these records, one could say only that the pilot did not fly a perfect circle in the first 360° of his turn, or that he changed altitude, or both. One could not say how far the first 360° varied from a perfect circle, or whether the pilot lost or gained altitude, or how much the altitude changed.

To sum up, presence of these prop-wash effects on the record indicates that the rating must be high. Their absence is not interpretable.

2. What to look for in the load factor trace. The load factor trace will reveal many faults and merits of bank performance. Essentially banking faults in power turns have to do with two things: attaining a given bank and maintaining a given bank.[78]

   a. Attaining the 60° bank

      (1) Perhaps the first question should be, Does the

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77 Since the prop-wash is merely a mass of turbulent air, any effect which it produces on the record might be produced by any turbulent air of similar velocity. It should be noted, however, that gusts of sufficient velocity to produce such violent effects upon the record are infrequent in weather conditions during which student flying is permitted.

78 In maneuvers prescribed with respect to a point or pattern on the ground, such as a rectangular course, this would become "appropriate variation of the bank".

Difference of Bank Attained From Prescribed Bank of 60°

student attain a bank of 60°, or if not, how much does his bank differ from it? In considering this aspect of performance, it is well not to be too severe in rating, for many expert pilots are quite inaccurate in estimating bank. Too, in some light airplanes a bank of 60° cannot be maintained for any length of time without loss of altitude.

For example, only one plate in this scale shows a bank of 60° (Plate IVh, at the beginning of the turn.)

In general, the best practice would be not to consider differences as large as 15° to be serious. If the student banks within the range of steep banks (45° - 60°) throughout the turn, this is quite acceptable. Thus, in Plate IVi rated Very Good, the pilot's bank during the turn averages about 50°. In Plate IVj, also rated Very Good, the bank averages about 45°.

If, however, the bank averages a figure which is well in the range of medium banks (30° - 45°), as in Plate IVa, or approaches the range of shallow banks (10° - 30°), as in Plate IVd, this should be counted against the performance.

(2) A second question might be, How does the student attain his bank? Does he roll up bank rapidly and smoothly, as in Plates IVh, IVi, and IVj, or does he attain it in "steps", as in Plates IVa, IVg, IVc, and IVd?

Rolling Up Bank

A very clear progression in the step-like characteristics of the entry can be seen in these plates. The plates ranked Very Poor, and Poor all exhibit a "ragged" step-like entry. The plates marked Average show a few "steps" in rolling up bank. Plate IVg, marked Good, also shows several minor "steps". Plate IVh, marked Good, and Plate IVi and IVj, marked Very Good, show no "steps" at all, but a smooth, rapid rise of the trace from its base-line.[79]

(3) A third question might be, How does the student roll off bank? That is, does he return to level attitude rapidly and smoothly as in Plates IVh, IVi, and IVj, or does he recover slowly and haltingly, as in Plates IVa, and IVb?

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79 It is important to note, however, that slight bumps in the air can produce similar steps, so it is wise to take air conditions into account. These records were all made in smooth air.

Rolling Off Bank

The same remarks apply to the length and step-like character of the recovery as to the length and step-like character of the entry. It might be noted, however, that the pilots whose records are reproduced in this scale tend to roll off bank more smoothly than they attain it.

b. Maintaining a constant angle of bank.

Relative to maintaining a constant angle of bank, one might ask two questions:

(1) After the student has attained his bank, How great is the range of fluctuation in his bank, throughout the turn? That is, what are the limits within which his bank fluctuated?

(2) How much does his bank fluctuate within those limits?

Range of Fluctuation in Bank

With regard to question (1), the better student will maintain his chosen bank within a few degrees. Thus, having attained his bank, the pilot whose performance is recorded in Plate IVj allowed it to vary only about 6° -- within a range of 42° to 48°. Plate IVi shows an "over-all" fluctuation in bank of about 14° -- within a range of 38° to 52°. (In considering this fluctuation, the large variation in the curve occurring at the point of hitting the prop-wash should be ignored. since it is mark of excellence rather than a fault.) The pilot whose performance is recorded in Plate IVh allowed his bank to vary about 15° -- within a range of 45° - 60°.

On the other hand, the pilot whose performance is recorded in Plate IVa allowed his bank to vary about 29° or more. The highest bank he attained during the turn was about 47°. The lowest was at least 18°, and perhaps less, for the load factor trace is at the base-line for several seconds at about the middle of the manouver.

With regard to question (2), within the limits of his bank fluctuation, the poorer student will allow his bank to fluctuate very rapidly and often, and the better student will show only a gradual fluctuation.

Frequency and Size of Bank Fluctuations

Thus, the bank fluctuation in Plate IVj is very gradual; the load factor curve is almost straight. The fluctuation in the Very Poor and Poor plates is marked.

An interesting contrast is the one between Plates IVh and IVe. In each of these plates, the "over-all" fluctuation is about the same -- 14° to 16°. Plate IVe shows continual, rather sharp, minor variations, however, while Plate IVh shows a gradual decline in bank with few sharp variations.

This contrast is particularly interesting because it emphasizes the nature of the load factor curve when treated as a curve of bank. The curve of Plate IVh lies in the upper part of the chart, in which trace variations represent fairly small bank fluctuations. The first part of the curve of Plate IVe, however, lies in the lower part of the chart, in which trace variations represent greater amounts of fluctuation in bank.

CAUTION

THE FACT THAT EQUAL HEIGHTS OF THE LOAD FACTOR TRACE REPRESENT DIFFERENT BANK VALUES IN DIFFERENT PARTS OF THE CHART MUST BE BORNE IN MIND IN CONSIDERING ALL QUESTIONS WHICH RELATE TO BANK PERFORMANCE.

3. What to look for in the left-wing-low and right-wing-low traces

Essentially there are two questions relating to slipping and skidding: a. To what extent does the student slip or skid and b. How long and how often does he slip or skid?

Slipping and Skidding Vary in Time and Extent

The two factors of time and extent must be balanced. The best student does not slip or skid to a great extent, and he does not slip or skid often or long. The average student may slip or skid to a slight extent for a fairly long period of time, or on several occasions; or he may slip or skid to a fairly large extent for a short time. The worst student slips or skids to a large extent either often or constantly.

Marked Differences in Slipping

Perhaps the clearest progression to be seen in this scale is in the appearance of the right@wing-low (slip) trace. Even a casual inspection shows the marked differences in slipping from class to class. (The slip due to prop-wash in Plate IVi should, of course, be ignored.) The Very Poor pilots tend to slip extensively and for a great proportion of time. The Poor pilots slip to a less extent and occasionally correct their slipping. The Average pilots tend to correct even more frequently. The Good and Very Good pilots show only occasional slight slips, quickly corrected. Plate IVj, in fact shows no slipping at all.

No Marked Differences In Skidding

On the other hand, there are no marked differences in skidding. The Very Poor and Poor Pilots show little or no skidding, but this fact is only a reflection of the time they spend in slipping: they slip so much that they cannot skid.

As indicated earlier in this report, the present manual is intended to indicate how pattern scales may be employed in helping to evaluate performance on 720° right power turns. Similar pattern scales can be developed for other maneuvers in the interest of facilitating the instructor's task in estimating the progress of students in learning to fly.

TABLE A

Converting Chart Values of Load Factor into Values of Bank

Chart Line	Angle of bank in °	Value of Each Chart Space
Base-line	0 - 18	-
1st printed line	25	7
2nd " "	34	9
3rd " "	40	6
4th " "	44	4
5th " "	48	4
6th " "	51	3
7th " "	54	3
8th " "	56	2
9th " "	58	2
10th " "	60	2
Top extreme	61	1

This table was prepared as follows:

The value of load factor in g was obtained for each of the above chart lines. The base-line indicates 1.05g or less, since the restraining spring of the accelerometer was set with an initial tension of 1.05g. Each additional 0.10 in. in height of trace = 0.10 additional g.

The bank value corresponding to each value of load factor was then obtained according to the relation:

load factor = secant of the angle of bank.

The column headed "Value of Each Chart Space" gives the difference between each bank value and the one preceding. The first value of 7° and the last value of 1° are not the values of whole vertical chart spaces (i.e., the distance between printed chart lines) as are the other values.

The first value (7°) represents only the first half-space, since there was only one half-space between the base-line and the first printed line.

The last value (1°) represents only the last half-space since there was only one half-space between the tenth printed line and the top extreme.

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SECTION A

APPENDIX C

INVESTIGATION OF THE POSSIBLE DIFFERENCES IN OVER-ALL QUALITATIVE RATINGS IF "PROPER" BANK, RATHER THAN ERRONEOUS ACTUAL BANK, HAD BEEN USED IN DERIVING QUALITATIVE BANK ITEMS

University of Pennsylvania
Philadelphia, Pennsylvania
November, 1942

APPENDIX C

INVESTIGATION OF THE POSSIBLE DIFFERENCES IN OVER-ALL QUALITATIVE RATINGS IF "PROPER" BANK, RATHER THAN ERRONEOUS ACTUAL BANK, HAD BEEN USED IN DERIVING QUALITATIVE BANK ITEMS

1.a. The value of Item a, "over-all" fluctuation in bank, for each performance on the third flight was re-computed by derivation from the "proper" bank and was compared with the previously obtained value derived from the "actual" bank in the first reading with Data Sheet (Series 300 - Ds - 1). This comparison is presented in following Table A. The difference values should be interpreted without regard to sign.

b. Inspection of Table A reveals that paired values derived from the two sets of data do not differ materially with perhaps 3 exceptions: those pairs in which the difference values are 5,6, and 11, respectively. Even in these three cases in which the value for the individual item would admittedly differ, it is extremely doubtful that the final over-all rating would have been affected.

c. In the case of the pair of values differing by 11°, the rating could not vary at all since the value derived from the proper bank is a "worse" value than the one used in the original final rating, which was Very Poor.

d. Moreover, the greatest variation in any pair of values will occur with large readings of intermittent slipping or skidding. The larger the lateral imbalance readings, the greater the possible variation in the two values; but also, the larger the lateral imbalance readings, the less the possibility that the rating would be changed by substituting the new value of over-all fluctuation, because:

(1) An increase in the "over-all" fluctuation value would tend to lower the rating, which, if the slip or skid readings are large enough to produce a material change in the over-all fluctuation value, is already in the lowest or next-lowest category.

(2) A decrease in the over-all fluctuation value would tend to

TABLE A

Over-all Fluctuation in Degrees

Subject No.	As noted on Series 300-Ds-1, derived from erroneous actual bank values	Re-read, derived from "proper" bank values	Difference in degrees
1	29	32	+3
2	20	14	-6
3	14	14	0
4	24	19	-5
5	8	7	-1
6	16	18	+2
7	13	16	+3
8	8	8	0
9	9	9	0
10	25	26	+1
11	20	19	-1
12	20	20	0
13	25	23	-2
14	8	9	+1
15	16	16	0
16	18	17	-1
17	6	6	0
18	10	12	+2
19	13	9	-4
20	20	21	+1
21	8	7	-1
22	*22	33	+11
23	19	16	-3
24	32	34	+2
25	32	32	0
26	20	17	-3
27	13	10	-3
28	21	17	-4

* Scale-length slip used in determining the lowest "actual" bank in this case.

raise the rating, but not in proportion to the value of that decrease.[80]

2. As to possible changes on account of differences in values of <u>Item b</u>, (deviation of subject's bank from the prescribed bank) the following is to be said:

   a. It is obvious that in any one case, the two values could differ at the most only by the <u>average</u> lateral imbalance reading, for the average erroneous actual bank can differ from the average "proper" bank only by the average lateral imbalance reading.

   b. If both slipping and skidding occurred, the lateral imbalance readings would tend to cancel each other, and the difference would be even less. Except in cases of extreme and prolonged slipping <u>or</u> (not and) skidding, this difference could not exceed 4 or 5°.

   c. It will be recalled that the values of this item were very loosely interpreted; in effect, were grouped into three classes. It will be recalled furthermore that relatively little weight was given to the item. Such small differences in the two values would be negligible in view of this treatment. As in the case of the <u>Item a</u>, large differences would occur only with large readings of lateral imbalance. The effect of a large difference in values of <u>Item b</u> is even less than its effect in the case of the <u>Item a</u>, and here also would hardly change the rating, even if the value of the particular item were changed.

3. <u>Item c</u>, intermittent ("side-by-side") fluctuations in bank, is not affected at all as this item was taken solely from the load factor trace in the original readings, i.e., was in terms of "proper" bank.

4.a. As for <u>Item d</u>, lateral balance, it was known at the time of the readings that even though the lateral imbalance traces may not be an accurate measure of angle of slip or skid, they represent the deviation

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80 For example, consider the following hypothetical case:

	Highest reading	Lowest reading	Over-all fluctuation
"Actual" bank	54°(40° + 14° slip)	30° + 0 imbalance	24°
Proper bank	40°	30°	10°

The difference here in the two over-all fluctuation values is 14°, a discrepancy greater than the value derived from the "proper" bank. But a decrease in over-all fluctuation of 14° could hardly produce a change in the rating of a performance which contains a scale-length slip. The lowest "actual" bank value above might be assumed to be 16° (30° - 14° skid), in which case the over-all fluctuation value of 24° would become 38°. The discrepancy between the two over-all fluctuation values would then be 28°, but the notion of an improvement in the rating of such a performance because of a decrease in the over-all fluctuation value is very far-fetched.

of the ball of the ball-bank indicator from its center position. The rater thus interpreted lateral imbalance in terms of the chart scale.

b. The resulting qualitative judgments of lateral imbalance would be the same whether the chart scale was taken to represent true slip or skid angle in degrees, or deviation of the ball from its center position. For example, the rater's judgment that a slip was "slight in in extent", referred to the chart scale, would be the same, whichever of the two data the scale would ultimately be taken to represent. If the calculations of the error in the lateral imbalance lines had proved it to be negligible, the judgment would have been interpreted as "slight in angular extent". Since the error did not prove to be negligible, the judgment is interpreted as "slight in extent as 'measured' by the deviation of the ball from its center position."

5. Items e, f, and g are not affected. Identification of prop-wash effects (Item e) does not depend on which bank value is employed. Items f and g, length and steplike character of the entry and recovery, respectively, were obtained, as was Item c, by use of the load factor trace alone, and thus by using "proper" bank rather than erroneous actual bank.

6. To summarize the above discussion, it may be stated that there is little chance that there would have been a material difference between the over-all ratings obtained using the erroneously computed actual bank, and the over-all ratings that would have been obtained had the "proper" bank been used.

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SECTION A

APPENDIX D

THE INFLUENCE OF POSSIBLE BIASES
IN MAKING READINGS AND RATINGS

University of Pennsylvania
Philadelphia, Pennsylvania
November, 1942

APPENDIX D

THE INFLUENCE OF POSSIBLE BIASES IN MAKING READINGS AND RATINGS

1. General

a. Possible sources of bias in preparing qualitative ratings might arise out of the reader's growing familiarity with the records. Such bias would operate:

(1) In comparisons of ratings made by one method (Data Sheet) with ratings made by the other (General Description Sheet);

(2) In the repeat comparisons of ratings by the same method, obtained with the view of determining the reliability of the method;

(3) In comparisons of ratings made by each method with indices of pilot status.

b. In the case of the first two types of comparison, an effective bias would arise from the rater's recollection of the previous rating of the performance. In the case of the latter comparisons an effective bias would arise from the rater's recognition of a record as that of one of a particular group of subjects. The possible influence of biases due to the reader's familiarity with the records is presented below.

2. Recognition of a Record as belonging to a Particular Subject

a. Whenever the rater recognized the record as that of a particular subject, both types of comparisons might be influenced by the possible bias. As a matter of fact there were only 4 cases in which there was a positive identification of the record by the rater: 2 in the records of the second flight, and 2 in the records of the third flight.

b. The rater was familiar with two of these records because of an intensive treatment of them in a preliminary trial of the quantitative technique. In both these performances, however, the subject hit his prop-wash. Thus, displacement of the resulting high rating on account of recognition seems most unlikely.

c. The other two were recognized because of irregularities in the record with which the rater was familiar. In one of these, the subject maintained a bank throughout of 60° ± a few degrees; possible displacement of this excellent performance on account of bias also seems far-fetched. In the other, the subject was known to be an instructor, and the rating given on the first reading was Average; here, if the bias was effective, it was in prompting a "leaning over backwards."

3. Recognition of a Record as belonging to a Subject in a Particular Group

a. A possible bias might have arisen from the way in which the records were noted at the field. Each of the two field experimenters noted a portion of the records, identifying each maneuver by numbering or lettering the appropriate signal. One, however, noted more records of the student group, and one noted more records of the instructor group. Since the rater was one of the field experimenters, he could easily tell which records he had noted and which records the other experimenter had noted.

b. This fact, however, did not occur to the rater until a late point in the readings. At this point it was useless to have all the records re-noted by a third person. Consequently, the rater estimated the number of records of each group that he had noted, and the number that the other field experimenter had noted.[81] The actual numbers were obtained on completion of the readings. A comparison of the estimates with the actual number is given below:

Noted by Rater

	Elementary Students	Private Pilots	Instructors
Rater's estimate	4	7	6
Actual number	0	4	8

Noted by other field experimenter

	Elementary Students	Private Pilots	Instructors
Rater's estimate	6	3	2
Actual number	10	6	0

It is apparent that the rater's recollection of the number noted is so erroneous as to cast doubt on the effectiveness of this possible bias.

4. Recall of Previous Ratings.

a. In the first readings by each method, the rater recalled a few ratings given by one rating method upon second inspection for

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81 The rater's estimate of the numbers noted by each man were based on his recollection of the number of standard flight sessions of each group that each had administered. The experimenter who administered the standard flight session did not necessarily number the record of that session, however. Notation of each 14-foot record and examination of the check sheets which the instructor had filled out was quite a long process, and frequently could not be completed immediately after a flight. Each record was first inspected for irregularities and identification of the maneuvers by appropriate numbers or letters was accomplished at later convenience. Thus one field experimenter would number in his spare time any records as yet unnoted, whether the flight was administered by himself or the other experimenter. The rater was fairly sure only of his estimates of the instructor group, because most of the flights of this group took place in the last week that the other experimenter was attached to the project.

initial rating with the other method. The cases of recall were those records which had been identified on the first reading, and three or four cases placed at the very extremes of the scale in the case of each flight. The latter cases could hardly have been rated in any other category.

b. Cases of recall on the second inspection by each method were much more numerous. They are discussed in the section on test-retest reliability comparisons.

5. Possible Halo Effect

A possible halo effect might result from casual inspection of maneuvers other than the right turn. For example, the fact that a left 720° turn was adjacent to the right turn on each record could especially be suspected of giving rise to such a bias (See Plate II.) Facts making for a denial of such a bias are: (1) more than a casual inspection is necessary for evaluation of the record, especially in the case of the load factor trace; (2) the rater was prepared, because of the results of a preliminary trial of the quantitative analysis, to expect variability from left turn to right turn, and hence to discount the value of information about the left turn as an indicator of the merit of the right turn. It is needless to say that the rater attempted to minimize all possible biases and to make an impartial judgment at all times.

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE
OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION A

APPENDIX E

REASONS FOR DISCARDING THE DATA OF THE OHIO STATE CHECK LISTS FILLED IN BY THE ADMINISTERING INSTRUCTOR DURING THE STANDARD FLIGHT SESSION

University of Pennsylvania
Philadelphia, Pennsylvania
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APPENDIX E

REASONS FOR DISCARDING THE DATA OF THE OHIO STATE CHECK LISTS FILLED IN BY THE ADMINISTERING INSTRUCTOR DURING THE STANDARD FLIGHT SESSION

1. In the form of the Ohio State Check List used in this study,[82] the failure of the observer to judge all the items results in ambiguity as to the interpretation of those items not checked. The original Ohio State Check List was so designed that a check mark alongside an item indicates a judgment of "Yes," and a blank should indicate a judgment of "No," in regard to the descriptive text of the item. It is evident, therefore, that "No" judgments may be confused with omissions, and are inseparable from omissions.

2. After judgments of several items for the 28 subjects had been tabulated, it was concluded that this set of data contains so large a proportion of unjudged items that the fidelity of the indicated "No" judgments is highly questionable. This conclusion was reached after tabulating judgments of several items for the 28 subjects. For example, in the case of a pair of contradictory items of the "Power Turns" sheet, "No skidding" and "Skids," the instructor failed to check either item for any subject, although one must necessarily apply. Tabulations of other items revealed similar inadequacies.

3. The frequent occurrence of unjudged items should not be attributed to mere carelessness on the part of the instructor who observed the subjects during flight. The Ohio State Check List was quite long; the "Power Turns" sheet alone contained 57 items Despite a carefully designed procedure for inspecting the records and Check Sheets at the end of each flight, the practical difficulties encountered when the flights were made under busy field conditions prevented a complete check at the time.[83]

4. The "Yes" judgments of the sheets may represent data both acceptable and accurate insofar as they are applicable. Even if such is the case, however, little meaningful use can be made of these data without knowledge of the "No" judgments as well, and the "No" judgments and omissions cannot be separated.

5. For the above-stated reasons no comparisons were made between ratings obtained from the R-S records and criterion data from the Ohio State Check Lists.

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[82] See Sample sheet, Pages 137-138, Exhibit I. This is the earliest form of the Ohio State Check List. The present form of the Ohio State Flight Inventory is so designed that omissions and "No" judgments cannot be confused.

[83] See Exhibit I, Page 128.

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE
OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION A

EXHIBIT I

SUMMARY OF THE GRAPHIC RECORDS PROGRAM

CARRIED OUT AT TULANE UNIVERSITY

under the direction

of

H. M. Johnson

November, 1942

Preface

The following is a summary, with slight revision, of a Progress Report submitted September 1, 1940, to the Executive Subcommittee of the Committee on Selection and Training of Aircraft Pilots by H. M. Johnson, director of the Tulane project.

The research staff of the Tulane project, who, with Professor Johnson prepared this Progress Report, included: Percy W. Cobb, Research Professor of Psychology and immediate supervisor of the project; Vidkunn Coucheron-Jarl, Research Assistant; and Oscar Backstrom, Jr., Research Assistant.

Oscar Backstrom, Jr.

EXHIBIT I

SUMMARY OF THE GRAPHIC RECORDS PROGRAM

CARRIED OUT AT TULANE UNIVERSITY

I. Introduction

A. As originally conceived, the graphic records project initiated at Tulane University in February, 1940, had three primary aims:

1. The discovery of suitable means of obtaining objective criteria of pilot performance by the use of graphic records of data relevant to airplane attitude. This aim included the evaluation of commercial flight recorders when employed for the purpose of supplying objective criterion data.

2. The comparison of criteria obtained by means of graphic records with data obtained from simultaneous records of the pilot's movements of the controls, with the object of discovering the relationship between methods of moving the controls and merit of flight performance.

3. The comparison of graphic records obtained on students at various stages of instruction, with the object of investigating the development of pilot skill.

For these three purposes, R-S Ride Recorder records and Friez Cable Control Recorder[84] records were obtained during the daily instruction flights of a group of ten subjects enrolled in the Civilian Pilot Training Program primary instruction course at the New Orleans Airport.

B. In May, 1940, however, a joint standard flight program was projected to be carried out at Tulane University, in addition to the program outlined above. The aims of this program were:

1. Further investigation of suitable means of obtaining objective criteria of pilot performance, by the use of graphic records of standard flights.

2. The comparison of the performances of groups of relatively widely separated experience flying the same maneuvers under standard conditions.

3. The comparison of an instructor's direct observations of control movements and the merit of flight performance with graphic records of both.

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84 This instrument is designated the "Friez Flight Analyzer No. 642" by the manufacturers. The name "Friez Cable Control Recorder" (or "Control Cable Recorder") has been adopted by various users, however, being more descriptive and readily distinguishing this instrument from the Friez Flight Analyzer No. 644, which is commonly called simply the "Friez Flight Analyzer". (See page 122 of this Exhibit.)

In this standard flight program, graphic records were obtained by means of the R-S Ride Recorder and Fries Cable Control Recorder, of the performances on standard flights of three groups of subjects: elementary students, recently licensed private pilots, and re-rated instructors. These standard flights were administered by an experienced and competent instructor who also filled in, during the time of flight, observations on the merit of the subject's performance and his methods of moving the controls by means of several check sheets: the Ohio State Check List, the University of Pennsylvania" Analysis of General Flying Habits" sheet and the University of Pennsylvania "Evaluation of Flight" sheet. The procedure of each program is outlined in detail in this Exhibit, pages 123-139.

II. Selection of Instruments.

A. As indicated above, the instruments employed in this study were the R-S Ride Recorder and the Friez Cable Control Recorder. Both instruments, records of each, and capabilities and deficiencies of each, are discussed in full in the Supplemental Report, "The Capabilities and Deficiencies of the R-S Ride Recorder and the Friez Cable Control Recorder".

B.1. In the early stages of the project, a few records were made with the Friez Flight Analyzer (no. 644). This instrument provided the following traces relevant to airplane attitude.

a. A trace of load factor (labelled "vertical acceleration" on the chart).
b. A trace of altitude.
c. A trace of airspeed.

Of these traces, the altitude trace was found to be unsatisfactory for use in obtaining criterion data. A change of 50 feet in altitude was barely perceptible on the record. This calibration was much too gross for use in investigating problems of pilot skill in elementary maneuvers. The other two traces were not evaluated in detail.[85]

2. Shortly after the Friez Analyzer had been installed, the R-S Ride Recorder was brought to the attention of the Tulane investigators by Mr. Byron Armstrong, of the Isaac Delgado Central Trades School, New Orleans, who had made several flights with this instrument.

As noted elsewhere (page 3 , Part I of the main report), the R-S Ride Recorder was originally designed for use in railway cars. The manufacturer of the instrument, Mr. W. S. Redhed, at the request of the Tulane project brought an R-S Ride Recorder to the New Orleans Airport for inspection, trial, and comparison with the Fries Flight Analyzer. Trial flights were made at the New Orleans Airport by Messrs. Armstrong and Fred Jurgens, of Isaac Delgado Central Trades School.

3. As a result of these flights and the comparison of records made by

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85 Further description of the Friez Flight Analyzer No. 644, and data provided by it, is contained in a Progress Report by R. M. Bellows and J. T. Fontaine, Jr., issued at the University of Maryland, July, 1940.

the R-S Ride Recorder and the Friez Flight Analyzer, the decision was made to substitute the R-S instrument for the Friez Analyzer. Of the two possibly useful traces of the Analyzer, the R-S instrument provided one (load factor); in addition, the R-S instrument provided several other traces (a trace indicating that the left wing is held low, a trace indicating that the right wing is held low, and a trace of pitch-and-longitudinal-acceleration) which the Analyzer did not provide and which looked promising as a means of obtaining data concerning the attitude of the airplane.

C. Also as a result of these flights, several minor modifications were made in the R-S Ride Recorder to adapt it for recording flights. Those modifications consisted in the provision of an apparatus designed to indicate the direction of turn.[86] This apparatus, later discarded at the field, is described and reasons for discarding it presented in the Supplemental Report, pages 190-191.

III. Procedures in Detail

A. The program for obtaining records of instruction flights.

1. At the Isaac Delgado Central Trades School, New Orleans, Louisiana, applications had been received from non-collegiate students for C.P.T. flight instruction. Out of those who completed ground school and subsequently passed the written examination, the ten students who ranked highest in the written examination were appointed to receive C.P.T. instruction in the primary course. These ten students were the subjects of the portion of the Tulane program devoted to obtaining "progress" records of daily instruction flights.

   All ten subjects were male. Nine of them were part-time students in the night school; the other a full-time day student. One of the group had had 43 hours of previous flying instruction (10 hours dual instruction and 33 hours solo) spread over a period of 1½ years. He held a solo license, but had never applied for a private license. Another had had 4 hours of dual instruction and 10½ hours of solo instruction, a third, 8 hours dual instruction and 15 hours solo. The instruction of both of these had begun only a short while before the research began. A fourth subject had had 8 hours dual instruction a year previous, and a fifth had had 2½ hours dual instruction. The remaining five had had no previous flying instruction.

2. These students were assigned to the Southern Aviation School for training in an Aeronca Tandem Trainer, Model 50-TL,[87] under the instruction of Edward R. Casey. They flew only this airplane, except for cross-country trips, during which records were not taken.

3. Except for records of cross-country trips and those missing on account of instrument trouble, or negligence, complete records of the flying instruction of eight of these subjects were obtained, including records

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86 Unless the direction of the turn is known it is not known whether a trace on the left-wing-low line, or the right-wing-low line, represents slipping or skidding.

87 A stick-type airplane.

of the C.A.A. inspector's flight test on completion of the course. In the case of the other two subjects there are no records for the inspector's flight test and the last five and fifteen hours of instruction, respectively.

4. The instruments were started just before the plane taxied out and were stopped when it returned to the hanger. Thus the whole of the instruction flight was recorded.

During dual flights the instructor was asked to signal in on the record (by means of a push-button contact inserted into the control panel) code signals[88] for the maneuvers performed and ratings of the performance. The students were asked to cooperate by signalling their maneuvers during solo flying. For this purpose a push-button contact was conveniently placed on the top of the stick.

As often as possible, the instructor or student, or both, were consulted to clear up uncertain sections of the record and to identify doubtful maneuvers. It would have been desirable as a routine procedure to discuss each record immediately after completion of the flight with both the instructor and the student. The congested conditions of instruction prevented such conferences, however, in many instances.

5. Each record was marked with the name of the student, the ordinal number of his record, the date and time of the flight, whether dual or solo; and the maneuvers were identified so far as possible. The number of previous flying hours, both in the C.P.T. course and all previous flying, is also available for each record.

B. The standard flight program.

1. Twenty-eight subjects were employed in the standard flight program, including one group of ten elementary students, one group of ten recently licensed private pilots, and one group of eight re-rated instructors. The composition of these groups with respect to flying experience is given in Table IA - C, pages 125-127 of this Exhibit. All 28 subjects were male.

2. Each of these subjects was required to pilot the test airplane (the same airplane used in obtaining records of students' instructions flights) in a series of standard flights diagrammed and described in detail, pages 129-134 inclusive, under the administration of an experienced instructor having approximately 5,000 hours flying time.[89]

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88 The signal code is reproduced in the Supplemental Report, page 196.

89 The administering instructor was Mrs. Edna Gardner Kidd of the Southern Aviation School.

TABLE I

Classifying Subjects According to License Status and Flying Time

A

Elementary Students in the Civilian Pilot Training Program Primary Course

Symbol for Subject	Flying Time Previous to C.P.T.*	C.P.T. Flying Time	Total Flying Time	Flying Time in Aeronca Tandem Trainer	Trained Primarily in	Class in Pilot Status Index 2, Sample Qualitative Analysis (See page 44, <u>Part I</u>, main report)
1a	0	25.5	25.5	25.5	Aeronca tandem	C
1b	0	22.0	22.0	22.0	Aeronca tandem	C
1c	8.0[90]	21.0	29.0	21.0	Aeronca tandem and Piper Cub tandem	C
2d	23.0[91]	17.0	40.0	17.0	Aeronca tandem and Piper Cub tandem	D
1d	0	14.5	15.0	0.5	Piper Cub tandem	A
1e	0	16.5	16.5	16.5	Aeronca tandem	C
1f	0	16.5	17.0	0.5	Piper Cub tandem	A
1g	0	17.0	18.5	1.5	Piper Cub tandem	A
1h	0	20.5	20.5	20.5	Aeronca tandem	C
1i	0	15.5	15.5	15.5	Aeronca tandem	C

All time figures are given to the nearest half hour. All flying time in the Aeronca tandem trainer was in the <u>particular</u> test airplane.

90 Time lapse of one year between this training and C.P.T. training.

91 This training "spread out" over period of little more than a year. Little time lapse between it and C.P.T. training. This subject was grouped with the private pilots in making statistical analyses of the data in both the qualitative and quantitative studies, since the amount of his total flying time exceeds that of the usual time allotted for completion of the C.P.T. primary course and is greater than the total flying time of several of the private pilots.

TABLE X

B.

Recently Licensed Private Pilots[92]

Symbol for Subject	Flying Time Previous to C.P.T.	C.P.T. Flying Time	Total Flying Time	Flying Time in Aeronca Tandem Trainer	Flying Time Between Private License and Standard Flight Session	Flying Time Primarily in	Class in Pilot Status Index 2, Sample Qualitative Analysis (See page 44, Part I, main report)
2a	2.5	37.0	39.5	37.0	0	Aeronca tandem	D
2b	43.0	36.0	83.5	36.0	4.5	Aeronca tandem and Piper Cub tandem	D
2c	0	35.0	35.5	0.5	0.5	Piper Cub tandem	B
2e	0	35.0	35.0	1.0	0	Piper Cub tandem	B
2f	64.0	0	64.0	4.5	13.0	Piper Cub tandem	C
2g	0	35.0	35.5	1.0	0.5	Piper Cub tandem	B
2h	52.0	0	52.0	3.5	13.5	Piper Cub tandem	C
2i	18.5	35.5	54.0	35.5	0	Aeronca tandem and Piper Cub tandem	D
2j	0	35.0	35.0	0.5	0	Piper Cub tandem	B
2k	0	35.0	35.0	1.0	0	Piper Cub tandem	B

[92] All time figures are given to the nearest hour or half hour.

All flying time in the Aeronca tandem trainer was in the particular test airplane.

Table 7

C.

Re-rated Instructors

Symbol for Subject	Approximate Total Flying Time[93]	Approximate Flying Time in Aeronca Tandem Trainer	Principal Types of Flying	Class in Pilot Status Index 2, Sample Qualitative Analysis (See page44, Part I, main report)
3a	300	Several hours	Class 1 seaplanes, chiefly Aeronca	E
3b	500	200[94]	Class 1	E
3c	1500	150	Class 1 and 2	E
3d	1900	None	Miscellaneous -- large amount Class 1	E
3e	1750	Several hours[94]	Airline and Class 1	E
3f	1700	None	Airline and Class 1	E
3g	2100	150	Class 1 and advanced trainers (Class 2)	E
3h	2850[95]	100	All types	E

93 As estimated by each subject.

94 These times in the particular test airplane; all other times in this column in other Aeronca tandem trainers.

95 Logged time only; estimated 4000-5000 hours, including unlogged time.

Six standard flights were flown by each subject: three brackets each consisting of the University of Pennsylvania Standard Flight A and Standard Flight C-1, respectively.

Except in a few cases where weather or instruction conditions did not permit, the three brackets were flown in immediate succession in one session: Standard Flight A, Standard Flight C-1, Standard Flight A, Standard Flight C-1, Standard Flight A, and Standard Flight C-1.

3. The subject examined the diagram of each flight in the presence of the field experimenter, who explained the prescriptions and purposes of the flight. Graphic records made by the R-S Ride Recorder and the Friez Cable Control Recorder were obtained for the whole of each flight, including transition maneuvers and taxi in and out. The administering instructor gave the subject verbal directions for each maneuver as the flight progessed and, by means of a signal marker, marked on the record the beginning and end of each maneuver.

During the first two brackets of Standard Flight A and C-1, the administering instructor filled out one University of Pennsylvania "Analysis of General Flying Habits" and one University of Pennsylvania "Evaluation of Flight" sheet[96] for each bracket (i.e., both flights). During the last bracket, the instructor filled in an Ohio State Check List[97] (earliest form) for Standard Flight A and Standard Flight C-1, respectively.

Surface wind velocity and direction, air conditions (presence of bumps), irregularities in procedure, and notes on the subject's attitude toward the experimental situation were recorded. The number of flying hours each subject had at the time of the flight session was also recorded.

4. After the completion of each standard flight session, the following procedure was employed. If the instructor had noted any irregularities in the execution of the flight, the graphic records of the flight session were checked to clear up possible ambiguities. If the instructor had noted no irregularities, the graphic records were checked last.[98]

The instructor checked over her judgments on the several check sheets (in many cases completing them then, because of insufficient time in flight) and filled in rating sheets from the C.P.T. logbook which were included in the Ohio State Check List for each subject. The field experimenter then checked

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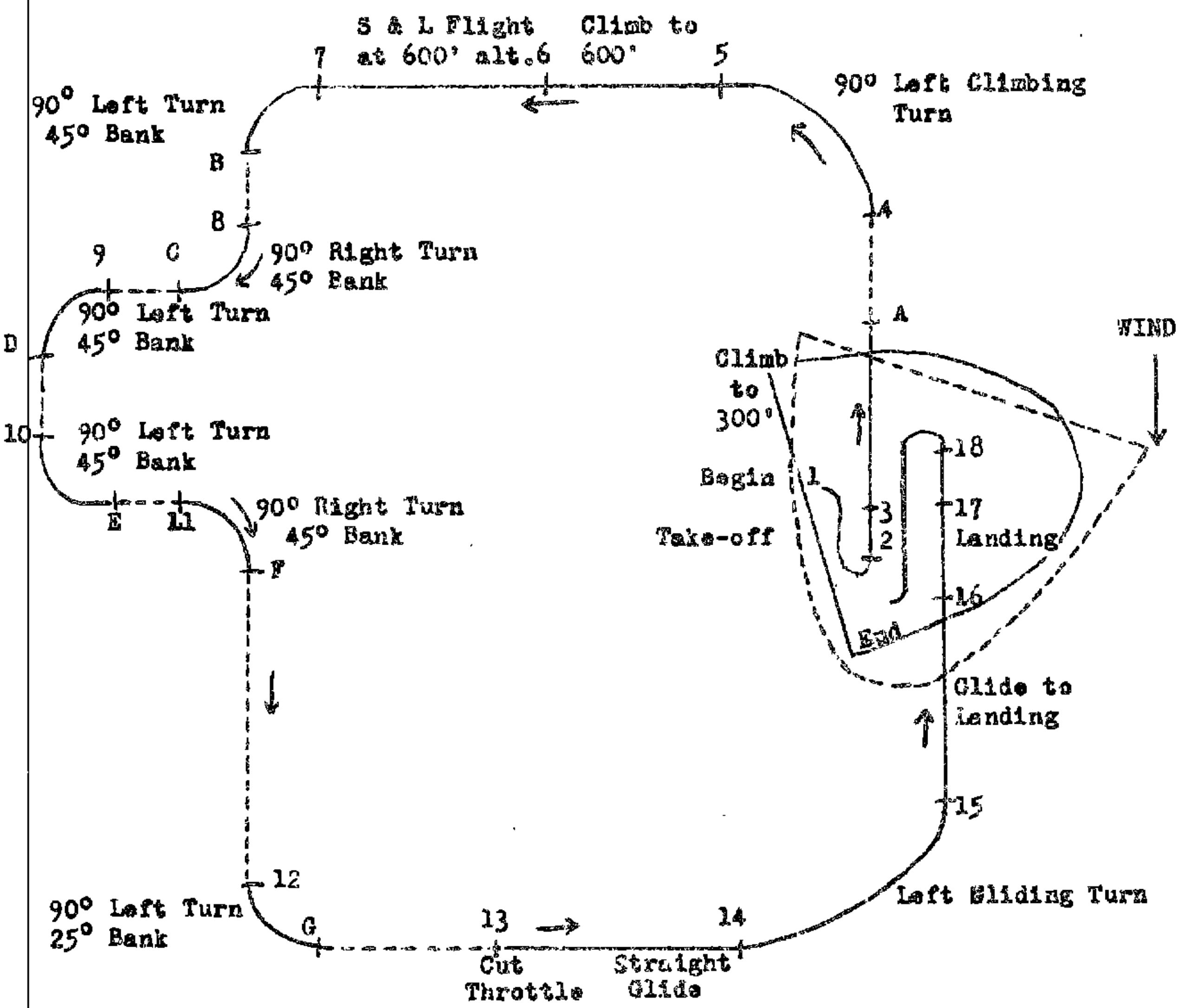
96 See pages 135 and 136, respectively of this <u>Exhibit</u>.

97 The complete Ohio State Check List is too long and too bulky for reproduction. One sheet of this List, however, the check sheet for power turns, is included, page 17. The remaining sheets of this Check List have the same general form as this sheet.

98 Each record was approximately 14 feet long.

DIAGRAM OF STANDARD FLIGHT A

(For use on Runways 2, 3, 4, and 5 at the New Orleans, Louisiana, Airport)



Note: The solid line diagram represents the airport in its approximate position when Runways 2 and 3 are used; the dotted line diagram when Runways 4 and 5 are used.

Prepared by: Morris S. Viteles
University of Pa.

With the assistance of: Vidkunn C. Jarl,
Tulane University.

Date: June 4, 1940

STANDARD FLIGHT A.

June 14, 1940

Standard Flight A represents a flight which should be within the scope of proficiency of student pilots who have completed Stage A of instruction.

The "critical maneuvers," representing those maneuvers which are being studied, are designated by arabic numbers. The intervening maneuvers are "transition maneuvers," representing those maneuvers whose purpose is to get the plane in position for the next critical maneuver. Transition maneuvers are designated by capital letters.

The times were obtained by stop-watch timing of a C.A.A. flight instructor piloting an Aeronca Chief at the S. Davis Wilson Airport, Philadelphia. (The times will vary somewhat from field to field depending upon local conditions.)

Time of Maneuver	Flight Time	Order and Description of Maneuvers	Beginning of Maneuver	End of Maneuver
--	--	1. TAXIING: to take-off line plus turn for observation of approaching aircraft and turn back into wind.	Plane starts to move.	Plane stops at take-off line after observation turn.
10"	10"	2. TAKE-OFF RUN: into wind.	Plane leaves take-off line into wind.	Beginning of next maneuver.
25"	35"	3. STRAIGHT CLIMB: to altitude of 300', followed if necessary by:	Wheels leave ground.	" "
35"	1'10"	Transition Maneuver A: Straight level flight to reach point approximately 1000' beyond field boundary.	Plane levels off at 300'.	" "
25"	1'35"	4. LEFT CLIMBING TURN: to 90° angle from take-off direction. This turn should be a long shallow turn gradual enough to permit turn into wind in case of engine failure.	Plane starts left turn.	" "
10"	1'45"	5. STRAIGHT CLIMB: to altitude of 600'.	Plane straightens out.	" "
15"	2'00"	6 STRAIGHT LEVEL FLIGHT: for 15 seconds at altitude of 600'.	Plane levels off at 600'.	" "
10"	2'10"	7. LEFT TURN: 90° turn at 45° bank, resulting in down-wind direction.	Plane starts left turn.	" "
3"	2'13"	Transition Maneuver B: Short straight flight in preparation for next maneuver.	Plane Straightens out.	" "
10"	2'23"	3. RIGHT TURN: 90° turn at 45° bank.	Plane starts right turn.	" "
10"	2'33"	Transition Maneuver C: Short straight recovery flight.	Plane straightens out.	" "

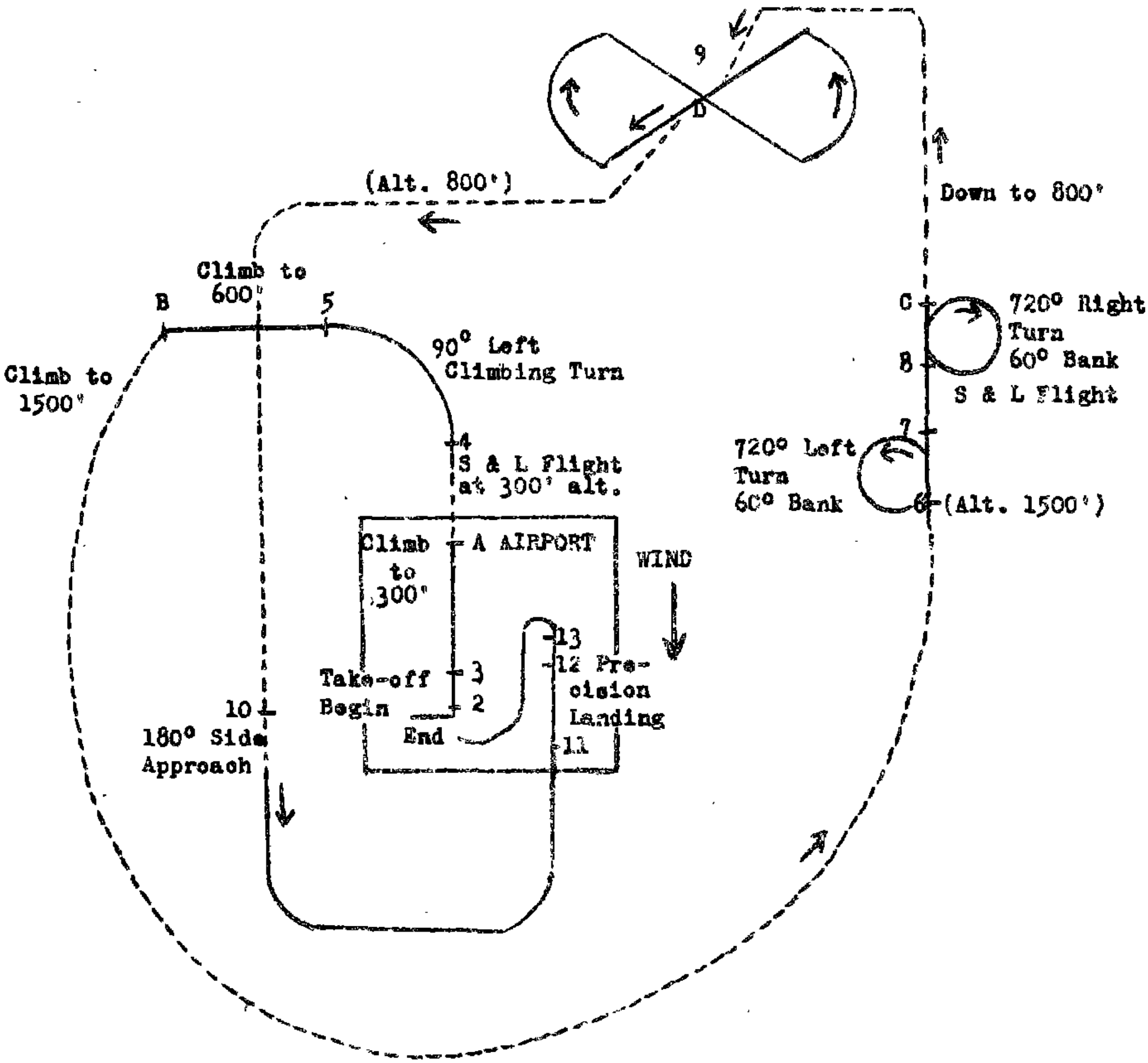
Prepared by: Morris S. Viteles and Albert S. Thompson.

Time of Maneuver	Flight Time	Order and Description of Maneuvers	Beginning of Maneuver	End of Maneuver
10"	2'48"	9. LEFT TURN: 90° turn at 45° bank.	Plane starts left turn.	Beginning of next maneuver.
7"	2'55"	Transition Maneuver D: Short straight recovery flight.	Plane straightens out.	" "
12"	3'07"	10. LEFT TURN: 90° turn at 45° bank.	Plane starts left turn.	" "
6"	3'13"	Transition Maneuver E: Short straight recovery flight.	Plane straightens out.	" "
10"	3'23"	11. RIGHT TURN: 90° turn at 45° bank, resulting in down-wind direction.	Plane starts right turn.	" "
		(Note: Maneuvers 8-11 form three sides of a rectangular course.)		
7"	3'30"	Transition Maneuver F: Straight level flight to point 1500' beyond leeward boundary of field, approaching downwind.	Plane straightens out.	" "
12"	3'42"	12. LEFT TURN: 90° turn with bank at 20° to 25°, resulting in cross-wind direction.	Plane starts left turn.	" "
8"	3'50"	Transition Maneuver G: Straight level flight until operating pilot closes throttle at key position selected as appropriate for successful completion of succeeding maneuvers.	Plane straightens out.	" "
20"	4'10"	13. STRAIGHT GLIDE: until time to turn toward landing area.	Throttle closed.	" "
10"	4'20"	14. LEFT GLIDING TURN: until facing into wind. This turn will be shallow or steep as necessary to properly approach landing area, taking velocity of wind into account.	Plane starts left turn.	" "
20"	4'40"	15. STRAIGHT GLIDE: to landing area.	Plane straightens out.	" "
10"	4'50"	16. LEVEL OFF AND LANDING.	Plane makes final level-off for landing.	" "
10"	5'00"	17. LANDING RUN: of at least 100' without brakes.	**Wheels** touch ground.	" "
---	---	18. TAXI: down-wind to desired position.	Throttle opened.	Plane reaches desired position.

Prepared by: Morris S. Viteles and Albert S. Thompson.

DIAGRAM OF STANDARD FLIGHT C 1

(For use at the New Orleans, Louisiana, Airport)



Note: This diagram serves for all runways used.

Prepared by: Morris S. Viteles
University of Pa.

With the assistance of: Vidkunn C. Jarl
Tulane University

Date: June 4, 1940

STANDARD FLIGHT C. June 14, 1940.

Standard Flight C represents a flight which should be within the scope of proficiency of student pilots nearing completion of Stage C of instruction.

The "critical maneuvers", representing those maneuvers which are being studied, are designated by **Arabic numbers.** The intervening maneuvers are "transition maneuvers", representing those maneuvers whose purpose is to get the plane in position for the next critical maneuver. **Transition maneuvers are designated by capital letters.**

The times were obtained by stop-watch timing of a C.A.A. flight instructor piloting an Aeronca Chief at the S. Davis Wilson Airport, Philadelphia. (The times vary somewhat from field to field depending upon local conditions.)

Standard Flight C.

Time of Maneuver	Flight Time	Order and Description of Maneuvers	Beginning of Maneuver	End of Maneuver
---	---	1. TAXI: to take-off line plus observation turn.	Plane starts to move.	Plane stops at take-off line after observation turn.
10"	10"	2. TAKE-OFF RUN: into wind.	Plane leaves take-off line into wind.	Beginning of next maneuver.
30"	40"	3. STRAIGHT CLIMB: to minimum altitude of 300'.	Wheels leave ground.	" "
10"	50"	Transition Maneuver A: Straight level flight at 300' altitude, if necessary to get beyond field boundary.	Plane levels off at 300'.	" "
35"	1'25"	4. CLIMBING TURN TO LEFT: to 90° angle from take-off direction. This turn to be long and shallow, gradual enough to permit turn into wind in case of engine failure.	Plane starts left turn.	" "
15"	1'40"	5. STRAIGHT CLIMB: to altitude of 600'	Plane straightens out.	" "
3'00"	4'40"	Transition Maneuver B: Climb to 1500' and to appropriate location for succeeding maneuver.	Plane reaches altitude of 600'.	" "
35"	5'15"	6. POWER TURN TO LEFT: 720° at 60° bank.	Plane starts left power turn.	" "
10"	5'25"	7. STRAIGHT LEVEL FLIGHT: Short recovery flight.	Plane recovers from turn.	" "
35"	6'00"	8. POWER TURN TO RIGHT: 720° at 60° bank.	Plane starts right power turn.	" "
1'25"	7'25"	Transition Maneuver C: Proceed to nearest pylon while reducing altitude to 800'.	Plane recovers from turn.	" "

Prepared by: Morris S. Viteles and Albert S. Thompson.

Standard Flight C1 (Continued):

Time of Maneuver	Flight Time	Order and Description of Maneuvers	Beginning of Maneuver	End of Maneuver
		9. FIGURE EIGHTS: three successive shallow figure eights at altitude of 300' around pylons located cross-wind. This maneuver should be entered from down-wind and the first turn made into the wind.		
1'25"	8'50"	(a) First figure eight.	Plane enters 1st Fig. 8 at center-point between pylons.	Beginning of next maneuver.
1'35"	10'25"	(b) Second figure eight.	Plane starts 2nd Fig. 8.	" "
		(c) Third figure eight.	Plane starts 3rd Fig. 8.	" "
1'35"	13'35"	Transition Maneuver D: Proceed to position appropriate for closing throttle for 180° side approach.	Plane reaches original point at end of 3rd Fig. 8.	" "
60"	14'35"	10. 180° SIDE APPROACH: 180° turn to left for precision landing.	Throttle closed for approach.	" "
5"	14'40"	11. LEVEL-OFF AND PRECISION LANDING: within 300' beyond designated point.	Final level-off for landing.	" "
15"	14'55"	12. LANDING RUN:	Wheels touch ground.	" "
---	---	13. TAXI: to take-off position for succeeding flight.	Throttle opened for taxi.	Plane reaches take-off position for next flight.

Prepared by: Morris S. Viteles and Albert S. Thompson.

UNIVERSITY OF PENNSYLVANIA

CIVIL AERONAUTICS AUTHORITY - NATIONAL RESEARCH COUNCIL RESEARCH PROJECT

ANALYSIS OF GENERAL FLYING HABITS

Subject: G. H. H.
Date: 8/28/40
Plane: Aeronca Tandem Trainer NC 26389

Field: New Orleans Airport
Wind: E-4
Time: 12:30 - 2:00

HANDLING OF CONTROLS:

A. Posture: (erect and
Position: (comfortable; whistles while flying
Changes of Position: seldom; leaned forward a couple of times to rest.

B. Throttle:
Grasping: rests first two fingers and thumb on ball of throttle
Moving: at times rests both hands on top of stick in straight climb.
Variations: uses to angle of plane (i.e. amount of throttle varied appropriately for variations in longitudinal attitude)

C. Rudder:
Position of Feet: heels on floor feet high on rudder
Changes of Position: seldom
Extent of Leg Movements: 50 % leg, 50 % ankle

D. Stick:
Grasping: five fingers around stick
Variations in Grasping: changes place of hand on stick often

Moving Ailerons: normal

Moving Elevators: normal

E. Comments:

UNIVERSITY OF PENNSYLVANIA

CIVIL AERONAUTICS AUTHORITY - NATIONAL RESEARCH COUNCIL RESEARCH PROJECT

EVALUATION OF FLIGHT

Subject: G. H. H.
Date: 8/28/40
Plane: Aeronca Tandem Trainer

Field: New Orleans Airport
Wind: E-4
Time: 12:30 - 2:00

Over-all rating:
Excellent
<u>Good</u>
Average
Fair
Poor

A. Following Course:
1. Altitude: varied 50 feet or less
2. Maneuvers: well made
3. A pproaches: good
4. Landings: 3-point; caught in prop-wash of airliner on a landing.

B. Turns:
1. Entry: smooth
2. Bank: good
3. Rate: good
4. Recovery: smooth

C. Angle of Climb and Glide: fairly good

D. Straight and Level Flight:
1. Constancy of Attitude: normal
2. Extent of Control Adjustment: normal

E. Throttle Control: almost correctly used

F. Traffic Check: good

G. Comments: good pilot material

POWER TURNS

1st 2d **ENTRY**

() () Simultaneous application of controls
() () Successive application of controls
() () Uses aileron, no rudder, on entry
() () Uses rudder, no aileron, on entry
() () Slips during entry
() () Walks rudder
() () Enters turn in mild dive
() () Enters turn in definite dive and fails to correct
() () Enters turn in mild climb
() () Stalls ship on entry
() () Skids on entry

BANK

() () Accurate angle of bank
() () Bank varies not more than + or -5°
() () Bank varies not more than + or -10°
() () Bank varies more than + or -10°
() () Continuous fluctuation of less than 10° in bank
() () Continuous fluctuation of more than 10° in bank
() () Holds off bank, makes a climbing turn
() () Slips
() () Banks more than 80°
() () Banks less than 60°

TURN

() () Constant rate of turn
() () Varies rate of turn
() () Fluctuation in rate of turn
() () Rides same rudder during turn
() () Rides opposite rudder during turn
() () Rides rudder during turn one direction
() () Rides rudder during turn in both directions
() () Walks rudder during turn
() () No skidding
() () Skids
() () Tends to pull turn too tight, mushes

ALTITUDE

() () No loss or gain of altitude
() () Continuous fluctuation in altitude of less than 50 ft. during turn
() () Changes altitude not more than 50 ft.
() () Changes altitude not more than 100 ft.
() () Changes altitude over 100 ft.
() () Slight dive during turn
() () Dive during turn
() () Stalls ship during turn

(Continued on following page)

POWER TURNS (Continued)

RECOVERY

() () Simultaneous application of controls
() () Successive application of controls
() () Uses aileron, no rudder, on recovery
() () Uses rudder, no aileron, on recovery
() () Recovers with nose high
() () Holds nose level during recovery

PRECISION

() () Recovers from turn "on course"
() () Recovers from turn 5° r. or l. of "on course"
() () Recovers from turn not more than 10° r. or l. of "on course"
() () Recovers from turn more than 10° r. or l. of "on course"
() () R. and l. turns equal in precision
() () R. and l. turns not equal in precision

THROTTLE

() () Increases power and gains speed before starting turn
() () Increases power to gain speed after starting turn
() () Fails to increase power
() () Reduces power on completion of turn
() () Fails to reduce power on completion of turn

with the instructor, as far as possible, the whole pad of check sheets in order: two sets of the University of Pennsylvania "Analysis of General Flying Habits" and "Evaluation of Flight" sheets (one each for the first two brackets), and two Ohio State Check Lists (one for the third Standard Flight A and one for the third Standard Flight C-1, each including a copy of the rating sheet from the C.P.T. logbook.)

This procedure was completed whenever possible. Unfortunately, however, instruction conditions were such that the instructor frequently could not re-check the various check sheets until several hours after the flight, sometimes, in fact, not until the end of the flying day. More often than not the field experimanter and instructor could not do a complete check together, for reasons that are obvious from the above list of things to be checked.

5. Some of the subjects had never flown the Aeronca tandem trainer, since this ship had just been released. Prior to the standard flight session, all the less experienced subjects who had not previously flown the test ship piloted it through a familiarization flight, for which records were also obtained. This flight lasted usually a half-hour, though longer in some instances. Some of the subjects who had been trained on Piper Cubs had flown the Aeronca tandem trainer during the training period when no Cub plane was available; the familiarization flight was ordinarily omitted for these subjects.

IV. <u>Preliminary Analysis of the Instruments and Records.</u>

No formal analysis of the records was undertaken at Tulane University. While the taking of the records proceeded, however, a preliminary informal analysis of the records was carried on and was facilitated by the availability of the advice of expert pilots, and the daily experience at the field.

A. <u>Evaluation of the Instruments and Recommendations for Field Use.</u>

1. Preliminary evaluation of the Friez Cable Control Recorder consisted in observation of its practicability for recording control movements, carried on at the field, and an evaluation of the records obtained by this instrument. The results of this preliminary analysis of the Friez instrument are contained in the <u>Supplemental Report</u>.

2. As the Friez instrument had been designed specifically for recording control movements, its evaluation was a straightforward process. The R-S Ride Recorder, however, had not been designed for airplane use, and little was known about its capabilities, beyond the fact that it offered more possibilities of obtaining useful information than any other

commercial flight recorder available. Evaluation of the R-S instrument consisted in a preliminary analysis of the capabilities of each of the recording systems, and an appraisal of its utility at the field.

The preliminary physical analysis, while not pursued to any great length, provided the basis for the complete analysis later carried out at the University of Pennsylvania. As a matter of record, it should perhaps be mentioned that this preliminary analysis resulted in a statement of the equivocal nature of the pitch-and-longitudinal-acceleration trace[99] and a statement of the relationship between load factor and the angle of bank in laterally balanced horizontal turns.[100]

Recommendations for the field use of the R-S Ride Recorder, derived from the experience of the Tulane Project, are presented in the Supplemental Report, "The Capabilities and Deficiencies of the R-S Ride Recorder and the Friez Cable Control Recorder."

B. Evaluation of the Records Obtained.[101]

The preliminary analysis of the records was concerned chiefly with : (1) discovering characteristic features of either the Friez or R-S records which would aid in distinguishing elementary maneuvers from one another and (2) pointing out ambiguities in the records resulting from incomplete identification of maneuvers and performer.

1. The identification of maneuvers by means of characteristic features of the R-S Ride Recorder and Friez Cable Control Recorder records:

   a. By means of certain characteristic features of either the R-S or Friez records or both, it was found possible to distinguish the following maneuvers from the other maneuvers contained in the C.P.T. primary course.[102]

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99 See Supplemental Report, pages 189-190.

100 See Supplemental Report , pages 160-161.

101 This section presupposes that the reader has read pages 1-17 of the Introduction, Part I of the main Report, which summarize the characteristics of the traces of the R-S Ride Recorder. It is not necessary, however, to have any further information concerning the Friez Cable Control Recorder than is presented in the preceeding pages of this Exhibit.

102 For material dealing with the identification of maneuvers in the C.P.T. advanced training course, the reader is referred to McFarland, R.A., and Holway, A.H., The Measurement of Flight Performance in Relation to Piloting, I, Introduction, to be included in this series of reports.

(1) Taxiing - The taxi can be identified by means of either the R-S or Friez record.

(a) On the R-S Ride Recorder record, when the airplane is traversing rough ground, the jolts transmitted through the wheels to the various recording systems produce rapid scale-length excursions of each wing-low trace and of the load factor trace.[103] The frequency of these scale-length oscillations is very high; the oscillations are packed so tightly together that their frequency cannot be counted at the paper speed at which these records were made (1½ inches per minute). Such traces are characteristic of taxiing over rough ground and occur in no other situation except the landing run.

When the airplane is taxiing along a smooth runway, these characteristic oscillations are very much reduced in extent, or absent. In such cases, it can be known, however, that the airplane is on the ground because the landing and take-off run can be identified on the R-S record (See below). The taxi can then be identified by a process of elimination:

(I) The taxi can be discriminated from the take-off run by its lack of the trace of pitch-and-longitudinal-acceleration characteristic of the take-off run. (See below.)

(II) Even in taxiing along smooth runways, the wings are low rather frequently and irregularly, thus producing frequent irregular traces on the wing-low lines. These traces make it possible to distinguish the taxi from periods of rest, despite the lack of the rapid frequency, scale-length vibrations characteristic of taxiing on the ground.

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103 It is to be noted that the remarks in this section concerning the appearance of the load factor trace on the R-S Ride Recorder records of various maneuvers apply only to an accelerometer, or load factor indicator, of a particular calibration (See Introduction Part I of the main report, page 3). (2) It is also to be noted that the appearance of all traces on the R-S Ride Recorder records of these maneuvers will vary somewhat with the airplane in which the maneuvers are executed and the place of installation of the instrument in the airplane (i.e., baggage compartment, front or rear floor, etc.) Such variations, however, will be of degree and not of kind.

(b) On the Friez Cable Control Recorder record, the elevator trace shows slight irregular oscillations superposed on the traces of the control movements when the airplane is moving across rough ground; frequently these oscillations occur so rapidly that the width of the ink trace of the elevator pen is multiplied two, three, or four times. Such traces occur in no other situation.

As in the case of the R-S record, landings and take-offs may be identified by characteristic traces (see below) and taxiing along a smooth runway can then be identified by a process of elimination:

(I) The taxi can be discriminated from the take-off run by its lack of the elevator adjustments characteristic of the take-off run. (See below.)

(II) By the presence of adjustments of any or all of the controls, the taxi can be discriminated from periods of rest, during which no control adjustments ordinarily occur.

It should also be noted that extensive and somewhat irregular rudder adjustments are characteristic of motion of the airplane on the ground or runway and are usually quite distinct from rudder adjustments in the air. Occasionally, however, fairly wide movements of the rudder occur shortly after take-off or before landing. Moreover, it is not possible to distinguish between taxiing and the take-off run by means of the rudder record alone, since wide and rapid rudder adjustments may occur during either.

(2) Landing

Because of the presence of the oscillations characteristic of moving across the ground, either the R-S or Friez record furnishes an unequivocal means of identifying landings.[104]

(a) On the R-S record, moreover, bounce landings can be distinguished by means of scale-length rapid-frequency vibrations of the load factor trace occuring when the wheels come in contact with the ground, and disappearing when the plane momentarily leaves the ground.

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104 This is true even of landing on runways, because the high speed of the landing run causes more violent jolts than the slow speed of the taxi on the runway.

(b) On the Friez Cable Control Recorder record identification of landings is further aided by a decisive record of the increasing back movement of the stick prior to landing.

(3) Take-off[105]

(a) The take-off run is characterized on the R-S Ride Recorder record by a trace of pitch- and longitudinal-acceleration very much resembling a normal distribution curve. The first section of this trace (from origin to apex) is assumed to correspond to that portion of the take-off run during which the airplane is increasingly accelerating prior to leaving the runway.

The end of the trace (at or near the 0 line) is assumed to indicate that the airplane is in approximately level attitude at approximately constant speed on the runway. Actual departure from the runway (as determined by means of signals for a number of records) takes place at this point or one or two seconds later.

If the take-off is made from the ground rather than a runway, the point of departure from the ground is clearly indicated by cessation of the violent oscillations of the load factor and wing-low traces which occur when the wheels are still in contact with the ground.

(b) On the Friez record, the forward movement of the stick in the take-off run is clear as is the following back movement at the moment of the take-off.

(4) Side-slip to landing

(a) The side-slip to landing is characterized on the R-S record by a fairly prolonged positive trace on one of the wing-low lines shortly before the record of landing. The extent of this trace is nearly always scale-

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105 Since the R-S Ride Recorder record furnishes an unequivocal means of identifying the landing and take-off, it also supplies an unequivocal means of determining the time the airplane spends in the air and on the ground. This feature of the R-S record was utilized to provide a survey of the relation of the time spent in the air to the time spent on the ground during the flight instruction of the ten Delgado students and the two Research Assistants at the New Orleans Airport. A progress report submitted by H. M. Johnson, February 24, 1941, presents the results of this survey.

length or only slightly less. Except in the case of power turns, which may themselves be distinguished on the record (See below), unintentional slips are rarely so prolonged and extensive; hence, the deliberate side-slip to landing cannot be confused with unintentional slips.

(b) A side-slip to landing cannot be discriminated with certainty on the Friez Cable Control Recorder record.

(5) Glides and gliding turns to landing

Glides and gliding turns to landing can be distinguished from other maneuvers but not from each other.

(a) The load factor trace of the R-S instrument frequently shows the beginning of a glide by the cessation or marked reduction of the sine curve of engine and propeller vibrations, occuring when the throttle is closed. In addition, a downward trace of pitch-and-longitudinal-acceleration is present, although in many instances it is not marked and would not by itself serve to identify the maneuver.[106] The end of a glide to landing, of course, is readily identifiable by the characteristic vibratory traces of the recording systems when the airplane comes into contact with the ground. If a glide were terminated in the air, however, the point of its termination could not be read with certainty from the R-S record. Glides and gliding turns cannot be distinguished from each other, for reasons which are presented in the discussion below (page146)on maneuvers which cannot be identified.

(b) These maneuvers cannot be identified by means of the Friez Cable Control Recorder record.

(6) Power turns

(a) Power turns may be distinguished on the R-

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106 Probably occasions on which the pilot interrupted the glide by cracking the throttle can also be identified by a resulting upward trace of pitch-and-longitudinal-acceleration. This effect appears on records of all such occasions noted by the field experimenters which have been subjected to casual examination. It is not known whether there is an invariable and unequivocal correspondence between this event and such a trace, however.

S Ride Recorder record by the characteristic load factor trace exhibited by the records reproduced in <u>Plates IVa - IVj</u>. Although the trace of each of these records differ widely, each would be readily identifiable as the trace of a steep turn (with one qualification discussed in the succeeding paragraph). The characteristics of the load factor trace of a steep turn are:

(I) A substantial positive trace of load factor (that is, a trace higher than the second printed line of the chart) and

(II) In the case of the 720° power turn, persistance of this positive record of load factor for a period of approximately 30 seconds or longer.

The qualification mentioned above is that the load factor trace of the spiral is almost identical with that of the power turn. The spiral will ordinarily be made only to a landing, however, and frequently shows a drop in the pitch-and-longitudinal-acceleration trace.

(b) On the Friez Cable Control Recorder record, the power turn is frequently characterized by fairly extensive aileron adjustments and the prolonged application of back stick. These adjustments vary considerably with the individual pilot, however, and are sometimes not so marked that it is possible to identify the maneuver unequivocally by means of the Friez record alone.

(7) Stall

(a) On the R-S Ride Recorder record, the stall appears as an up-and-down trace on the pitch-and-longitudinal-acceleration line, and a short, sharp, and substantial increase in load factor as the pilot pulls up out of the recovery dive.

(b) On the Friez Cable Control Recorder record, the stall appears as full back stick, accompanied by very wide corrective movements of the rudder as stalling speed is approached.

(8) Spin

(a) On the R-S Ride Recorder record, the spin is identified by a characteristic load factor trace: the trace rises very rapidly from its base-line to the top extreme of the load factor scale, remains at the top extreme for a few seconds, returns rapidly to the base-line, then back to the top extreme as the pilot pulls up out of the recovery dive, and finally to the base-line again as recovery is completed. This characteristic load factor trace is usually, though not invariably, accompanied by a short sharp trace on one of the wing-low lines, or on both in succession. In addition, a pitch-and-longitudinal trace somewhat resembling the trace obtained in a stall (See above) is present, though its form is usually less regular than the trace of the stall.

(b) On the Friez Cable Control Recorder record, the spin may be identified by prolonged application of full or nearly full rudder and increasing back stick, which is held during the process of the spin.

b. More important perhaps than the maneuvers which can be identified from the records of the R-S Ride Recorder and Friez Cable Control Recorder are those which show no characteristic identifying features. With the exception of glides and gliding turns <u>to landing</u>, (see page 144 above), the following maneuvers cannot be unequivocally discriminated from each other (without appropriate signals) by means of either the R-S or Friez record:

(1) climbs,
(2) turns in climbs,
(3) glides,
(4) turns in glides,
(5) shallow turns in the earth horizontal, and
(6) straight and level flight.

In the case of the R-S Ride Recorder record, none of these maneuvers requires a positive trace of load factor, since all may be executed without incurring sufficient load factor to overcome the initial bias of the accelerometer (1.05g). No dependable characteristic record is shown for any by the equivocal pitch-and-longitudinal-acceleration trace. Traces may appear on either of the lateral imbalance lines for any one of the maneuvers, but these would indicate merely that the maneuver was not executed in perfect lateral balance.

The Friez Cable Control Recorder record also presents no characteristic features which would distinguish these maneuvers from one another, inasmuch as the control movements required for the entry, recovery, and execution of each are so slight in extent that they cannot be distinguished from the numerous minor corrective movements which also accompany the execution of the maneuver. In the case of a shallow turn, for example, the initial deflection of the rudder and aileron may be confused with the corrective movements frequently necessary to maintain lateral balance immediately before or during the entry. Thus, from a record of control movements of "air work" consisting of only the maneuvers listed above, it would be impossible to distinguish the maneuvers from one another, or, given knowledge of the maneuvers, to point out the beginning and end of any one.

This preliminary investigation clearly indicates the need for a means of identifying maneuvers other than their appearance on the R-S Ride Recorder and Friez Cable Control Recorder charts. Such a method of identification might be provided by:

(1) A satisfactory system of signalling,
(2) The employment of standard flights, or
(3) The use of a graphic recorder providing records of additional flight functions -- such as altitude, airspeed, and rate of turn -- which might show characteristic traces or, in combination with other functions, characteristic patterns of traces for the non-identifiable maneuvers.

Because, as indicated in the succeeding section, it imposes heavy demands on the instructor or pilot, method (1) is probably the least practical of these three methods. At the time this study was conducted, method (3) was impossible, since extant graphic flight recorders recorded only a few flight functions.[107] The employment of standard flights, method (2), is practical[108] and, moreover, offers the advantages of standardized flight situations.[109]

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107 Appendix A to the Supplemental Report presents recommendations for an improved graphic recorder incorporating systems for recording flight functions not recorded by the R-S Ride Recorder and Friez Cable Control Recorder.

108 See page 140 of this Exhibit.

109 See page 2 of the Introduction, Part I of the main report.

2. <u>Ambiguities in the obtained records resulting from incomplete identification of maneuvers and performer</u>

a. The importance of a practical means of identifying the executed maneuvers was underlined by the results of a preliminary analysis of <u>deficiencies</u> in the obtained records.

(1) It was hoped that, by the inclusion of an appropriate means of signalling, such ambiguities as outlined in the previous section would be anticipated. For obtaining the records of instruction flights, an appropriate signal code was devised which, if it had been faithfully executed, would have eliminated many of the ambiguities discovered to be present in the records. Means were provided in the signal code for determining which of the two occupants of the airplane (student or instructor) was handling the controls at the time of the maneuver, and which maneuver was being executed. Care had been taken in devising this code to make it simple and readily memorizable by both instructor and students, and, in addition, the students and instructor were provided with a copy of the code to be carried in the airplane.

A copy of this code and a full discussion of the difficulties encountered in the signalling procedure may be found in the <u>Supplemental Report</u>, pages 195-199. It need be stated here only that despite conscientious and excellent cooperation by the instructor, and by most of the students, the signalling procedure failed of its purposes. The failure is attributed to:

(a) the slow paper speed at which the records were taken (1-½ inches per minute), which rendered the process of signalling rather longer than desirable, and

(b) the fact that attention of both pilot and instructor was (and should have been) primarily directed to other affairs than signalling.

(2) Owing to the failure of this signalling procedure, many records of students' instruction flights are subject to the following ambiguities:

(a) In dual flight, it may not be known whether the student or the instructor was at the controls during a given maneuver. This ambiguity is not present, of course, in the case of solo flights.

(b) In both dual and solo flight, many of the maneuvers cannot be identified because of the lack of an appropriate identification signal.

(c) In both dual and solo flights, the beginning and end of many maneuvers cannot be discriminated with certainty because of the lack of an appropriate signal.

b. Many of the records which were faithfully signalled lack these ambiguities. Even in the case of these records, however, (as well as in the case of records inadequately signalled) there are ambiguities arising from another deficiency --namely, ignorance of the direction of turns.

(1) In order for most meaningful use to be made of the lateral imbalance traces of the R-S Ride Recorder, it is necessary to know the direction of the turn, so that it may be determined which of these traces represents slipping and which represents skidding.

(2) It has been sought to derive the direction of turns by the inclusion in the R-S Ride Recorder of an apparatus for indicating deflection of the rudder and aileron, but this apparatus proved unsatisfactory. (See page 123, this Exhibit.)

(3) It was then hoped that the Friez Cable Control Recorder record would provide this information. Unfortunately, however, as indicated above, the Friez records do not show the direction of any of the elementary maneuvers, with two exceptions:

(a) The spin, in which records of the lateral imbalance traces supply little if any useful information, and

(b) The steep turn, in which the direction is frequently, but not invariably identifiable. (Whether the direction is identifiable depends upon the extent of the rudder and aileron deflections, and thus upon the individual pilot. If the pilot really executes the turn at a steep bank, the direction is usually identifiable, but many of the pilots in this study actually executed medium banks when a steep bank was specified.)

In turns of medium and shallow banks, as noted above, the extent of rudder and aileron deflections in the entry and recovery is little greater than the extent of the corrective movements which are made throughout the turn and which may be either right or left of neutral in the case of each control, regardless of the direction of the turn. Moreover, the neutral position of each trace could not be accurately determined. (See page 202, Supplemental Report.) The extent of the corrective movements and the ambiguity of the neutral positions made accurate judgment of the direction of shallow and medium turns impossible.

(4) Directions of some of the turns on some flights were obtained by conference with the instructor or pilot after the flight. This procedure was not possible in many instances, however, and moreover could not be considered to be highly dependable.

(5) The direction of turns made in circuits of the airport, is, of course, known because of the traffic rules.

(6) The remainder of the turns in the "progress" records of student's instruction flights, however, are mostly ambiguous as to direction.

3. Absence of these ambiguities in the standard flight records.

This investigation of the deficiencies of the records of student instruction flights resulted in the decision to focus attention on records of the standard flights. In addition to being taken under standardized wind and air conditions, and providing standardized flight situations, the standard flight records lack the ambiguities which the "progress" records contain.

a. It is always known who the performer of the maneuver was, since the subject flew the airplane through the entire flight session. If, for any reason, this procedure had been varied, this fact could have been ascertained readily and quickly upon completion of the flight by a conference with the administering instructor.

b. It is known unequivocally which maneuver was performed, since the maneuvers of the standard flights occur in a prescribed order, and since the provision that the maneuvers follow each other in immediate succession makes possible an easy signalling code which makes few demands on the administering instructor. (See Supplemental Report page 197.)

c. The beginning and end of each maneuver are clearly indicated by signals.

d. The direction of turn is known by prescription. If, for any reason the direction of turns had been varied, this fact could also have been quickly and readily ascertained by conference with the instructor or pilot.

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE
OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION B

SUPPLEMENTAL REPORT

THE CAPABILITIES AND DEFICIENCIES
OF THE
R-S RIDE RECORDER
AND THE
FRIEZ CABLE CONTROL RECORDER

by

Oscar Backstrom, Jr.

University of Pennsylvania
Philadelphia, Pennsylvania
November, 1942

PREFACE

This Supplemental Report was prepared as a unit dealing entirely with the instrumentation of the graphic records project carried on at Tulane University and the University of Pennsylvania. In pages 2-13 of the Introduction to the main report, however, the results of the investigation of the R-S Ride Recorder have been summarized, and the chart and chart traces have been described, for the convenience of readers whose interest in instrumentation is only incidental.

In order to avoid duplication of this summary and description, readers are advised to refer to the above-mentioned pages of the Introduction before reading this Supplemental Report.

ACKNOWLEDGMENTS

The author is especially indebted to Dr. F. W. Cobb, supervisor of the graphic records project carried on at Tulane University, who initiated the analyses reported herein, gave freely of his advice and consultation while they were in progress, and reviewed the preliminary draft of this Supplemental Report.

Special acknowledgment is also due to Professor David L. Webster, Chief Physicist, Ballistic Research Laboratory, Aberdeen Proving Ground, who generously reviewed the preliminary draft and made many helpful contributions and comments.

Mr. R. A. McConnell, formerly physicist at the Aircraft Materials Laboratory, Philadelphia Navy Yard, and now at the Massachusetts Institute of Technology, also reviewed sections of the text in preliminary draft, and made many specific suggestions. The method for appraising the extent of error induced in recorded values of vertical acceleration owing to the recording of simultaneous angular accelerations (pages 175-177) and the rationale of the preference of "proper" bank to actual bank, as an indicator of pilot skill (pages 166-166) are contributions of Mr. McConnell.

Mr. W. S. Redhed of the Impact Register Company, manufacturers of the R-S Ride Recorder, supplied a proof from which Diagram 2 and the relevant discussion (page 162) were adapted and developed.

While the author acknowledges gratefully these contributions, he assumes full responsibility for any errors contained herein.

SUPPLEMENTAL REPORT

THE CAPABILITIES AND DEFICIENCIES OF THE R-S RIDE RECORDER AND THE FRIEZ CABLE CONTROL RECORDER

This Supplemental Report presents the results of an extended inquiry into the capabilities of the two graphic recorders employed in this study, including

(a) the nature and possible uses of the data derivable from the records;
(b) errors in recording;
(c) cautions to be exercised in the use of these instruments; and
(d) recommendations for field use of the instruments and laboratory analysis of the records.

DIVISION A

THE R-S RIDE RECORDER

Following is a detailed discussion, including mathematical and physical proofs, of:

(a) the data derivable from each trace (except the signal marker trace)[110] of the R-S Ride Recorder;
(b) errors in the data due to faulty recording;
(c) deficiencies theoretically inherent in the recording systems;
(d) errors resulting from possible faulty installations of the instrument in the airplane; and
(e) difficulties encountered in treating the data.

I - THE LOAD FACTOR TRACE

A. As indicated in the Introduction, page 8, the chief use made of the load factor trace in this study has been to derive information concerning the bank of the airplane in turns made in the earth horizontal. Although a positive load factor will be produced by a curved flight path in any plane as well as the earth horizontal, the load factor trace has little other use in the evaluation of performance on elementary manoeuvers.

1. In the absence of a means of obtaining the value of the climb or glide angle, the trace cannot be used to derive information about the bank in climbing and gliding turns and spirals. (See footnote 122 page 167 of this Supplemental Report.)

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110 See "Signalling procedure", pages 195-199 of this Supplemental Report.

2. a. A characteristic positive load factor trace accompanies spins and the pull-up recoveries from dives (as in the final portion of a stall and recovery), and may be used in identification of these maneuvers.[111] (See page 145, Exhibit I.) In evaluating performance of these maneuvers, however, the value of the load factor attained in their execution has limited importance. These maneuvers are not prescribed in terms of load factor or in terms which have a simple and constant relation to load factor (as does the bank in horizontal turns). Hence, it is not known what the value of the load factor should be.[112] (Cf. discussion of criterion data, pages 1-2 of the Introduction to the main report.)

b. Considerations of airplane structure and design, of course, set an upper limit to the load factor which may be incurred in these and other maneuvers without danger of structural strain or failure. Likewise, varying with the individual pilot, there is an upper limit to the values of load factor which may be incurred without causing loss of consciousness or "blacking out".

In the evaluation of these maneuvers, therefore, a trace of load factor of suitable range and calibration might be employed to indicate whether the pilot executes them in such a manner that the incurred load factor is within a reasonable margin of safety, or verges on the dangerous.

c. The range of the particular accelerometer, or load factor indicator, employed in this study would render such use of the trace impossible, however, because of the comparatively low top limit of load factor recorded (2.65g).[113]

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111 A trace of load factor is also useful in the identification of acrobatic maneuvers in the C.P.T. advanced training course. See McFarland, R. A. and Holway, A. H., The Measurement of Flight Performance in Relation to Piloting, I, Introduction, to be included in this series of reports.

112 The possibility should be noted, however, that even though these maneuvers are not prescribed in terms of load factor, the performance with respect to load factor might be correlated highly with those aspects of performance in which the maneuvers are prescribed. If, upon investigation, this were found to be so, load factor might be used as an item for evaluating the maneuvers, for it would then be known what the load factor should be.

113 The range of the accelerometer is, of course, a matter of choice (within the limitations of the available chart space) and may be varied by appropriate variation of the restraining spring of the unit. The range employed in this study, subsuming "proper" banks from 18° to 61°, is one of the most suitable (within the limitations of the available chart space of the Ride Recorder) for obtaining the maximum information about elementary maneuvers.

In light airplanes, such as class 1-S and 2-S airplanes, a load factor of between 3 and 4 g may ordinarily be incurred without danger of structural stress, unless the airplane has hidden structural defects or is loaded beyond maximum gross weight. These limits are usually higher for military or aerobatic aircraft.[114]

3. Although the accelerations occasioned by encountering gusts or "bumps" affect the load factor trace, it is of dubious value in appraising the smoothness of the air.

   a. Ordinarily the restraining spring of the accelerometer of the Ride Recorder will have an initial tension greater than 1g. For a bump to produce a positive trace of load factor, it must impose a load factor greater than this initial tension, if the airplane is in level flight. For the calibration of the accelerometer employed in this study, if the airplane were in level flight, the load factor imposed in a bump would have to be greater than 1.05g (the load factor occurring in a horizontal turn of approximately 18°) in order to produce a positive trace. In curved flight, the load factor imposed in the bump will be added to the load factor occasioned by the curved flight path, and depending on the values of both, may or may not be recorded,[115] and depending on the temporal relations of the changes in both, may or may not produce a sizeable change in the trace.

   b. The above considerations do not completely prevent the use of the load factor trace as an indicator of bumpy air, for in the case of either curved or level flight in very bumpy air, the fluctuations in the trace are nevertheless quite marked. The chief objection is the fact that such fluctuations, in the case of this instrument, are characteristic not only of bumpy air, but also of a damping curve which occasionally appears in the trace. This damping curve, denoted the "haywire" effect, is illustrated in <u>Plates Ia</u> and <u>Ib</u> and is discussed in detail in pages 172-175 of this <u>Supplemental Report</u>.

B. <u>Use of the load factor trace to supply information about bank in horizontal turns</u>

   1. In the ensuing discussion it will be necessary to distinguish carefully among the terms prescribed bank, "proper" bank, and actual bank.

      a. The <u>prescribed</u> bank is that bank which the subject is instructed to attain and maintain during the particular maneuver.

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[114] "Load Factor Information for Pilots," C.A.A. Aircraft Airworthiness Section, Report No. 10, Sept., 1939. This report is reproduced in Civil Aeronautics Bulletin No. 23, "Civil Pilot Training Manual," Sept., 1941, pages 311-320.

[115] Gusts may cause <u>negative</u> as well as positive load factors.

b. The "proper" bank is:

(1) that bank at which the airplane, having a given forward velocity, would be in perfect lateral balance for the particular rate of turn the pilot has assumed, or, stated in other terms:

(2) that bank at which the resultant of gravitational and centripetal accelerations would be vertical to the wing span for the particular rate of turn (at the given forward velocity), or,

(3) the appropriate bank for the rate of turn at the given forward velocity.

c. The actual bank is the actual angle of inclination of the wing span to the horizon.

2. In a laterally balanced turn, the actual bank is equal to the "proper" bank. In a turn with slip (overbank), the actual bank is equal to the "proper" bank plus the angle of slip. In a turn with skid (underbank), the actual bank is equal to the "proper" bank minus the angle of skid.

3. In any given horizontal turn with angle α of "proper" bank, the load factor is given by the relation

$$\text{load factor} = g \sec \alpha,$$

subject to an error (discussed in pages 161-166 of this Supplemental Report) in certain situations which may usually be regarded as negligible.

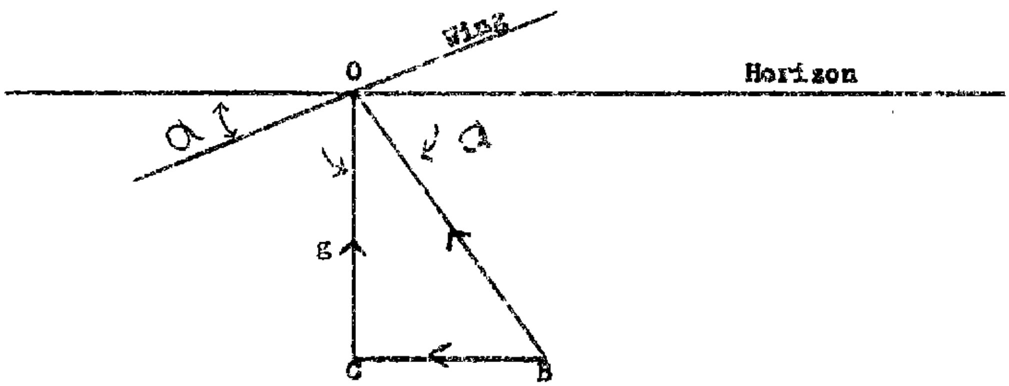

Diagram 1

In any given turn in the earth horizontal the airplane will be laterally balanced when the resultant (BO) of gravitational acceleration (CO) and centripetal acceleration (BC) is perpendicular to the wing-span of the airplane.

a. Laterally balanced turn

In the laterally balanced horizontal turn, as illustrated in Diagram 1,

$$\text{load factor} = BQ = g \sec \phi.$$ [116]

There is no error in this relation in the laterally balanced horizontal turn.

b. Turn with slip

(1) In a turn with slip, however, the resultant of gravitational acceleration and centripetal acceleration is not perpendicular to the wing-span; hence the value of the recorded load factor is somewhat less than the secant of the "proper" bank angle.[117] A slip results when the "centrifugal tendencies" are not great enough to keep the airplane in perfect balance for the particular angle of (actual) bank which the pilot has assumed; i.e., when there is too little "centrifugal force", and the resultant of gravity and centripetal acceleration is not perpendicular to the wing-span of the plane.

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116 The recorded load factor is read from the chart in gravitational units. Since g in gravitational units = 1,

$$\text{load factor} = \sec \phi.$$

117 The same is true of a turn with skid. A skid results when the "centrifugal tendencies" are too great for perfect balance of the airplane for the particular angle of (actual) bank which the pilot has assumed; i.e., when there is too much "centrifugal force", and the resultant of gravity and centripetal acceleration is not perpendicular to the wing-span of the plane. The relations involving the angle σ hold whether σ is the slip or skid angle. The diagrams throughout this Supplemental Report show the slip situation only, for the sake of convenience.

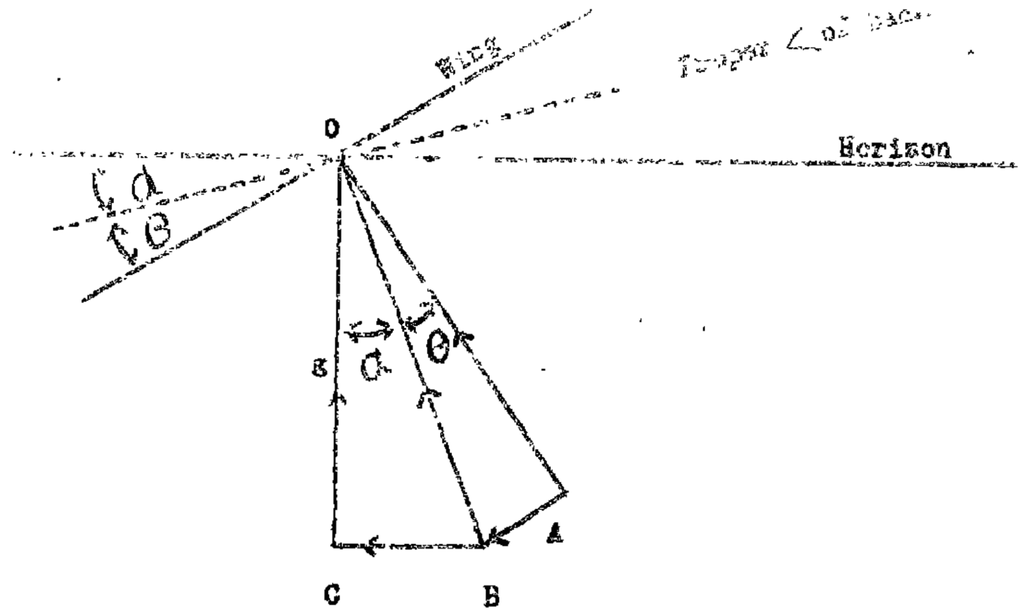

Diagram 2

The dotted line at angle α with respect to the horizon represents the hypothetical position of the wings at which the airplane would be perfectly balanced for the particular rate of turn (at the given forward velocity), i.e., at the angle of "proper" bank. The solid line at angle $(\alpha+\theta)$ with respect to the horizon represents the actual position of the wings, θ being the angle of slip.

(2) Referring to Diagram 2, the resultant (BO) of gravitational acceleration (CO) and centripetal acceleration (BC) is (by definition) vertical to the hypothetical position of the wing-span at which the airplane would be perfectly balanced for the particular rate of turn.

$$BO = \sec \alpha$$

But recorded load factor = AO, and

$$BO = AO \sec \theta$$

If it is desired to determine α from the recorded load factor in this situation, then, θ must be known, or it must be shown that to omit multiplication by the quantity $\sec \theta$ will induce negligible error in the determined value of α.

(3) The precise value of θ, the slip (or skid) angle, unfortunately cannot be derived, for it is not given by the static calibration of the lateral imbalance traces of the instrument, and dynamic calibration of the lateral pendulums to show slip or skid angle is impossible.[118] The actual bank therefore cannot be determined from the data derivable from these records.

(4) It can be demonstrated, however, that if it is desired to derive α, the angle of "proper" bank, from AO, equating AO with BO will ordinarily result in negligible error in the derived value of α. Cases in which such equation would result in substantial error can also be defined. The following tables (pages 164-165) illustrate these facts. Table Ia shows the range of possible errors in taking the approximated value of α equal to the true value when the recorded load factor is the lowest value (1.07g) which could be determined from these records by projection at a magnification of 5. Table Ib shows the range of possible errors when the recorded load factor is the highest value (2.05g) which could be determined from these records by projection. The approximated α values are those values obtained from the approximate relationship

$$AO \text{ (recorded load factor)} = g \sec\alpha,$$

i.e., by equating AO and BO. The error values are all negative, since BO is always larger than AO and represents a secant value corresponding to a larger angle. All angle values are rounded to the nearest degree, since even the projection method of making readings does not warrant finer expression. For the same reason, the value of sec θ is taken only to three decimal places.

Examination of Tables Ia and Ib will reveal that for most purposes, the error involved in equating the recorded load factor to the true load factor will result in negligible error in the value of α, whatever the angle of slip or skid. This generalization does not hold for large values of θ and low values of load factor. In records of shallow turns with much slipping or skidding, a substantial error might be introduced in deriving the values of the "proper" bank from the recorded load factor. In records of medium or steep turns, the error is usually negligible even for readings of α at a single point in time. If indices are to be prepared by statistical treatment of the readings involving the taking of averages, it is quite safe to regard the error as negligible.

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118 See page 188, this Supplemental Report.

TABLE Ia.

Showing possible angular error in approximated values of α, the angle of "proper" bank, (i.e., those values determined by taking the recorded load factor (AO) equal to the resultant (BO) of gravitational acceleration and centripetal acceleration), at various values of θ, the true slip or skid angle, when the recorded load factor is the lowest value derivable from the chart (1.07g) by projection at a magnification of 5.

θ in °	secθ	AO (recorded load factor) in g	Approximated α in °	BO (= AO secθ) in g	True α in °	Error in ° incurred by taking approximated α = true α
0	1.000	1.07	21	1.07	21	0
1	1.000	1.07	21	1.07	21	0
2	1.001	1.07	21	1.071	21	0
3	1.001	1.07	21	1.071	21	0
4	1.002	1.07	21	1.072	21	0
5	1.004	1.07	21	1.074	21	0
6	1.006	1.07	21	1.076	22	-1
7	1.008	1.07	21	1.079	22	-1
8	1.010	1.07	21	1.081	22	-1
9	1.012	1.07	21	1.083	23	-2
10	1.015	1.07	21	1.086	23	-2
11	1.019	1.07	21	1.090	23	-2
12	1.022	1.07	21	1.094	24	-3
13	1.026	1.07	21	1.098	24	-3
14	1.031	1.07	21	1.103	25	-4
15	1.035	1.07	21	1.107	25	-4
16	1.040	1.07	21	1.113	26	-5
17	1.046	1.07	21	1.119	27	-6
18	1.051	1.07	21	1.125	27	-6
19	1.058	1.07	21	1.132	28	-7
20	1.064	1.07	21	1.138	28	-7

Approximated α values are derived from the approximate relation

$$\underline{AO} = g \sec \alpha.$$

True α values are derived from the exact relation

$$\underline{BO} = g \sec \alpha.$$

The true value of BO (= AO secθ) cannot be derived from the instrumental data, since θ cannot be known (See page 188 of this Supplemental Report.) Hence only approximate values of α can be derived from the instrumental data.

TABLE Ib,

Showing possible angular error in approximated values of α, the angle of "proper" bank (i.e., those values determined by taking the recorded load factor (AO) equal to the resultant (BO) of gravitational acceleration and centripetal acceleration), at various values of θ, the true slip or skid angle, when the recorded load factor is the highest value derivable from the chart (2.05g) by projection at a magnification of 5.

θ in °	sec θ	AO recorded load factor in g	Approximated α in °	BO (= AO sec θ) in g	True α in °	Error in ° incurred by taking approximated α=true α
0	1.000	2.05	61	2.05	61	0
1	1.000	2.05	61	2.05	61	0
2	1.001	2.05	61	2.052	61	0
3	1.001	2.05	61	2.052	61	0
4	1.002	2.05	61	2.054	61	0
5	1.004	2.05	61	2.058	61	0
6	1.006	2.05	61	2.062	61	0
7	1.008	2.05	61	2.066	61	0
8	1.010	2.05	61	2.071	61	0
9	1.012	2.05	61	2.075	61	0
10	1.015	2.05	61	2.081	61	0
11	1.019	2.05	61	2.089	61	0
12	1.022	2.05	61	2.095	61	0
13	1.026	2.05	61	2.103	62	-1
14	1.031	2.05	61	2.114	62	-1
15	1.035	2.05	61	2.122	62	-1
16	1.040	2.05	61	2.132	62	-1
17	1.046	2.05	61	2.144	62	-1
18	1.051	2.05	61	2.155	62	-1
19	1.058	2.05	61	2.169	63	-2
20	1.064	2.05	61	2.181	63	-2

Approximated α values are derived from the approximate relation

$$AO = g \sec \alpha.$$

True α values are derived from the exact relation

$$BO = g \sec \alpha.$$

The true value of BO (= AO sec θ) cannot be derived from the instrumental data, since θ cannot be known. (See page 188 of this Supplemental Report.) Hence only approximate values of α can be derived from the instrumental data.

(5) Furthermore, the error in α values can be even further reduced by obtaining a better approximation of BO than that obtained by equating it to AO. Although the true value of θ cannot be known, its value by static calibration can be obtained from the lateral imbalance lines. Equating BO and AO is equivalent to regarding θ as 0, for sec 0° = 1.000. A recorded value of θ greater than 0°, though not the true value, must always be a better approximation of the true value than 0°. (See page 183, this Supplemental Report.) Thus, if BO is determined by multiplying AO by the secant of the recorded θ, and α derived from BO, the error in α values is even further reduced, even though the recorded value of θ is less than the true value.[119]

The load factor trace, then, may be used to obtain values of α, the angle of "proper" bank.[120]

C. Utility of "proper" bank as an indicator of pilot skill

1. The utility of this datum, "proper" bank, may not be readily apparent, especially as it does not represent the actual inclination of the wings to the horizon except in the case of perfect lateral balance. Despite the fact that it need not represent the actual inclination of the wings to the horizon, the datum has a definite and important physical significance. It will be recalled that the "proper" bank has been defined (page 160 of this Supplemental Report) as that bank at which the airplane would be in perfect lateral balance for the particular rate of turn the pilot has assumed. Stated in somewhat impressionistic and teleological terms, it is that bank at which the pilot is "attempting" to fly the turn.

As such the "proper" bank is a simple function of the forward velo-

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119 This procedure was followed in deriving the "proper" bank values in the quantitative analysis to be published at a later date.

120 It is to be noted, however, that it must be known to the reader of the records that the subject was in a turn in order for the datum to be derived. (See page 1 of the Introduction to the main report.) In the case of elementary maneuvers, however, there is comparatively little chance of confusion of records of turns and other maneuvers, with the possible exception of spirals, which will ordinarily be made only to a landing. Spins and stalls produce a characteristic trace; traces of "bumps" and gusts are too short to be confused with turns. Any such ambiguity would, of course, be entirely eliminated by the procedure of employing standard flights. In unstandardized instruction flights it might be eliminated by conference with the pilot in regard to doubtful sections, which would be very few.

city and radius of turn of the airplane.[121] In Diagrams 1 and 2, the centripetal component of acceleration (BC) is equal to $\frac{V^2}{R}$, where V is the linear airplane velocity perpendicular to the radius of turn, R.

$$\frac{V^2}{R} = g \tan \alpha,$$

which may be expressed

$$\alpha = \text{arc tan} \frac{\frac{V^2}{R}}{g},$$

or, since g in gravitational units = 1,

$$\alpha = \text{arc tan} \frac{V^2}{R}$$ [122]

2. The validity of this datum as an indicator of pilot skill may perhaps best be demonstrated by an illustration comparing it with the actual bank, which, of course, represents the actual inclination of the wings to the horizon. Suppose, as in the case of the power turns of Standard Flight C1, a subject has been instructed to make a laterally balanced turn with a bank of 60°. The subject aiming at 60°, "chooses" a rate of turn (by rudder and elevator deflection) for which a bank of 45°

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121 And thus of the rate of turn. In the above equations, the quantity $\frac{V^2}{R}$ may be written $V\omega$, where ω is the rate of turn.

122 The question of direction of V does not arise in this method of analysis. It is assumed that all turns are made in a horizontal plane, (i.e., that the acceleration component perpendicular to the plane's thrust line is composed of a vertical component of 1 g, plus a centripetal component.) The stated relations will not hold if a turn is made in any other plane than the horizontal. Referring to Diagram 1, in a simple helical spiral, either up or down, the attained resultant BO and its radial acceleration BC would not be in the earth's vertical, but in a plane perpendicular to the thrust line of the airplane. Hence CO would equal g cos k, where k is the climb or glide angle.

If the airplane is actually climbing or diving in a supposedly horizontal turn, therefore, the α values derived from the relation

$$BO = g \sec \alpha$$

will be somewhat undervalued. For small values of k, however, CO is a weak function of k, and this error may be neglected, provided the values of α are large. α is a strong function of CO for small α's, but the instrument will not ordinarily be used to determine small α's, because an initial bias somewhat greater than 1g will ordinarily be used for the restraining spring; causing load factors produced in small α's not to be recorded.

The stated relations will hold generally if CO is substituted for g. The value of CO could, of course, be known in a climbing or gliding turn if the value of k, the climb or glide angle, were known. This value cannot be derived from the instrument (See page , this Supplemental Report.)

(the "proper" bank) is appropriate, and furthermore slips at 10°. His actual bank in this situation would be 55° (= 45° "proper" bank + 10° slip). Yet it is obvious that this subject has not made a single error of 5°, merely because he tipped his wings to within 5° of the prescribed bank. He has made two errors: one of 15° (= 60° - 45°) in choosing his rate of turn, and one of 10° in his failure to maintain lateral balance.

3. Thus, even though the actual bank does represent the actual inclination of the wings to the horizon, it is apparently a less useful and less valid datum for deriving indices of the subject's pilot skill than the "proper" bank, which may or may not represent the actual position of the wings to the horizon. This deficiency of the actual bank arises from the fact that it is a compounding of two effects, neither of which it indicates directly or simply:

   a. The pilot's estimate of the proper rate of turn (at a given velocity) to achieve the desired bank (as determined primarily by elevator and rudder).

   b. For the chosen rate of turn, the pilot's success or failure to bank properly (as determined principally by the ailerons).

The "proper" bank indicates <u>effect a</u> simply and directly. A limited indication of <u>effect b</u> is given by the lateral imbalance traces, discussed in pages 179-188 of this <u>Supplemental Report</u>.

D. <u>Effects on the record of hitting the prop-wash</u>

1. a. All traces of the R-3 record may be affected by hitting the prop-wash. Since the problems concerned with identification of prop-wash effects on the record involve chiefly the load factor trace, however, they will be discussed in full in this section.

   b. If a pilot carries through the first 360° of a 720° turn with negligible change in altitude and an approximately constant radius of turn, at the completion of the first 360°, the airplane will encounter the turbulent stream of air caused by its previous passage. Upon this encounter it will be subjected to various accelerations, the effects of which will appear on the record.

   c. It is desirable to identify these prop-wash effects for two purposes:

      (1) In order to credit the pilot with an excellent performance of the first 360° of the turn, and

      (2) In order to discount the irregularities in the traces which hitting the prop-wash, as hitting any other bumpy air, produces.

2. To further such identification, the Tulane field experimenters noted certain "characteristic" effects which sometimes appear on the record when the prop-wash is hit. These effects, illustrated in <u>Plate IVi</u>, consist of a rapid drop of the load factor trace to its base-line, or a point

near the base-line, followed by a rapid return to approximately its previous height, and accompanied by a simultaneous spike-shaped trace of a sudden extensive slip or skid, or traces of both.

3. a. Unfortunately, however, these effects do not invariably accompany hitting the prop-wash. In Plate IVj, for example, the pilot hit his prop-wash,[123] and no such effects appear on the record. It is thus necessary to explain the divergence in records of the same event.

   b. An understanding of the nature of the prop-wash is necessary to a full explanation of its effects upon the records.[124] The "prop-wash" encountered in the air, as distinct from the true propeller stream encountered behind an airplane on the ground, is composed primarily of the down-wash left by the wings, which tends to be perpendicular to the position the wings occupied when it was formed. A second component is the vortices left by the wing tips, one vortex on each side of the down-wash. Each vortex whirls in the manner determined by the down-wash, i.e., with the side nearest the other vortex going downward. The real propeller slip-stream is carried below these vortices by the down-wash.

   c. The entire moving mass, called collectively the prop-wash, expands in diameter and grows less turbulent as time passes. The down-wash from the wings, being originally the most powerful of the three elements, is the most persistent. The real propeller slip-stream disappears more rapidly, and its dissipation is aided by the expansion and divergence of the down-wash.

4. When a pilot encounters any part of this turbulent mass of air, he may be said to have hit his prop-wash. The effects on the airplane, and thus on the record, of hitting various parts of this mass, however, may vary considerably, according to which part is encountered and how it is encountered:

   a. In a turn which is almost perfectly circular, at the moment the wings hit the down-wash, they are inclined in practically the same direction as they were when the down-wash was formed. Consequently the down-wash is almost perpendicular to the wings, the lift is greatly reduced, and the load factor is reduced correspondingly.

   On the emergence of the airplane from the disturbed air mass, the lift and load factor return to approximately their previous values (if the pilot has made no very extensive adjustments of the controls). In such instances, the load factor trace shows a drop to, or nearly to, its base-line and a quick return to its previous value, typified by the record shown in Plate IVi.

   b. If on encountering the down-wash, the wings are inclined in a direction somewhat different from the direction they were when it was formed

123 As witnessed by the accompanying observer.

124 The major portion of the above exposition of the effects of prop-wash on the B-S record is the helpful contribution of Professor David A. Webster.

the full acceleration imparted by the down-wash will not lie along the airplane vertical, but will be resolved into airplane vertical, lateral, and longitudinal components. In such instances, the drop in load factor need not be so pronounced as that shown in Plate IVi. The lateral component in such instances will cause slipping or skidding, as shown in Plate IVi.

c. If on completion of the first 360° of the turn the airplane encounters not the down-wash from the wings, but one of the vortices left by the wing tips, the effect on the load factor will not be very pronounced, but lateral imbalance will result. Because of the form of these vortices (See above), the lateral imbalance will likely consist in a slip quickly followed by a skid, or vice versa.

d. Finally, if the airplane encounters only the outer edge of one of the expanded wing tip vortices, the airplane may receive only a mild "bump", the effects of which are negligible. In such instances, a record such as that produced in Plate IVj may result.

5. Records of all the varying types described above were encountered at the field. The most complex record noted showed both a skid and slip (in succession) accompanying the drop in load factor.

6. To summarize the preceding discussion:

a. Hitting the prop-wash sometimes produces certain "characteristic" effects on the R-S Ride Recorder record of the general form shown in Plate IVi. These effects consist of a rapid drop of the load factor trace, frequently to its base-line or a point near its base-line, followed by a rapid return of the trace to approximately its previous height, and usually accompanied by a simultaneous slip or skid, or both.

b. The effects may vary in magnitude, depending in part on whether the pilot hits the full slip-stream or only its edges, and in part on the relation between the directions of the prop-wash gusts encountered and the attitude of the airplane.

c. The effects may also vary in complexity.

7. Absence of the "characteristic" effects on the record, illustrated in Plate IVi and described in paragraph (1), does not necessarily indicate, therefore, that the pilot failed to hit his prop-wash. Moreover, since the prop-wash is merely a mass of turbulent air and any turbulent air of similar velocity[125] might produce similar effects on the record, it will be well to define the conditions under which presence of the particular effects may be taken to indicate hitting the prop-wash.

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[125] It is to be noted, however, that gusts of sufficient violence to produce effects of the extent shown in Plate IVi will rarely be encountered in weather conditions during which student flying is permitted.

6. In a 720° turn, the effects may be taken to indicate an encounter with the prop-wash, provided:

   a. The effects occur approximately halfway through the maneuver (i.e., at the end of the first 360° of the turn).

   b. The "proper" bank in the first 360° is not very variable; otherwise the pilot's rate of turn would have varied and the flight path would not have approximated a perfect circle.

   c. There is not much slipping or skidding in the first 360° of the turn, resulting in sizeable changes in altitude.[126]

   Applying these provisions, it would seem possible to judge with a reasonable and practical degree of certainty whether the effects represent hitting the prop-wash, or whether they should be suspect.

E. <u>Accuracy of the accelerometer (load factor indicator)</u>

The accelerometer of the R-3 Ride Recorder used in this study consisted of a weight having a mass of 26.75 oz., suspended on, and held up against a stop by, a spring of such tension that it would not deflect under a static load of less than 1.05g; constrained to move only vertically to the base of the instrument; and prevented by a stop from compressing the spring further than the deflection occasioned by a static load of 2.05g. The amplitude of the trace made by the recording stylus is ten times the extent of the actual movement of the weight; i.e., the movement of the weight is mechanically multiplied ten times by the recording system. The recording range is one inch; the range of movement of the weight is 0.10 inch.

1. <u>Errors due to small range of deflection and large ratio of multiplication</u>

   a. The small range of movement of the weight and the comparatively large extent of multiplication of movement cast doubt on the accuracy of the recording of load factor. Very slight irregularities in the response of the weight to the imposed loads would produce relatively large errors in recording. Likewise, comparatively slight maladjustments of the mechanical multiplying system would produce relatively large errors in recording.

   Errors in response of the weight to the imposed loads would consist in errors due to bouncing of the weight against the stops and errors due to friction and sticking. There is comparatively little friction in the system, however.

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126 Altitude changes resulting from slipping or skidding might be offset by climbing or diving in some instances. In such instances provision (c) would not hold, i.e., the effects might actually be prop-wash effects despite extensive slipping or skidding. Failure to attribute the effects to prop-wash in such instances, however, would not seem to be a serious error.

b. Since no calibrations of the system were performed at the field, it is impossible to state the extent of these possible errors, and thus only the possibility of their presence can be noted.[127]

It was not practical to perform calibrations (either static or dynamic) of the accelerometer at the field owing to the demands on the use of the test airplane and the impracticality of disturbing the installation. Since in almost any use to be made of flight recorders in problems of pilot selection, classification, and training, it will be impractical to have frequent field checks and service of of the instrument, it is apparent that the load factor indicator should be designed to have such a deflection range that possible frictional errors will induce a relatively slight proportionate error of recording; and that, moreover, the ratio of mechanical multiplication should be relatively small in order to reduce the magnitude of possible errors due to maladjustments of the mechanical transmission system. Inasmuch as the accelerometer of the Ride Recorder does not meet these requirements, it must be judged relatively unsatisfactory for field use.[128]

2. <u>Errors due to limited damping and the recording of high-frequency effects.</u>

a. The accelerometer is pseudo-damped by means of stops placed in positions corresponding to the extremes of the scale of the chart. This stop-damping is, of course, inoperative when the weight is in a position between the extreme ranges. Thus, in the greater part of the range of load factor recorded, the device is undamped except as the dry friction in the system serves as a damping factor. The damping induced by this dry friction is relatively slight.

b. The consequence of this limited damping and the high natural frequency of the system is that the system is affected by, and the stylus will record, other effects than load factor. These effects are the high-frequency vibrations of the propeller, engine, and frame. Since the frequency of these vibrations is much higher than the frequency of changes in load factor, there is no "interference" (i.e., summation) between these two effects, except in possible very isolated instances. The vibrations trace is thus superposed on the trace of load factor, and appears on the record as a complex of sine curves, whose form is very nearly that of a simple sine curve. (See <u>Plates II</u>, <u>III</u>, and <u>IVa-IVj</u>.)

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127 See page 128 this <u>Supplemental Report</u>.

128 It should be borne in mind that this accelerometer was designed for use in railway cars, and not in airplanes; hence this deficiency is no reflection on the design and craftsmanship of the manufacturer. The manufacturer has recently developed an air-damped low-frequency accelerometer, available in several recording ranges, which may have eliminated these and other deficiencies. The writer has not examined any of these newer recording units.

The fact that the vibrations trace has this simple form despite the supposed complexity of the vibrations themselves may be attributed to the presence of a regular simple dominant vibration which is so powerful as to obscure the form of the other vibrations. This dominant vibration is identified as that of the propeller and propeller shaft.

c. Since this superposed trace may be taken to be a simple sine curve, the true reading of load factor at any point is obtained by taking the height of its mid-point from the base-line.

Certain instances appear, however, in which this procedure is both impractical and inaccurate. These instances are records of occasions on which there occur engine, frame, and propeller vibrations of a frequency approaching the natural frequency of the weight-and-spring device. Whenever a vibration of such frequency occurs, the vibrations trace recorded is not a true trace. The weight is set swinging in its natural frequency, and the resulting trace is a "haywire" effect. (See Plates Ia and Ib).

In such instances, readings of load factor are very dubious. See especially the first section of Maneuver 8, Plate Ia. Maneuver 8, Plate Ib, shows a much milder form of this effect, but it will be apparent that even here, load factor readings in certain sections are open to considerable doubt. The proportion of Maneuver 6 containing the effect is somewhat less than the proportion of Maneuver 8 in the case of both plates.

d. In handling the records, the effect can easily be identified. (Contrast Plates Ia and Ib with Plates II, III, and IVa-IVj.) The disposition to be made of such records will depend upon the purpose for which they are used. In "clinical" estimates of the excellence of the performance, the effect can be discounted in making the qualitative judgment, unless it is very pronounced and persists through a large proportion of the maneuver. In exact quantitative treatment, the best course would seem to be to discard at least the extreme cases.[129]

e. The cause of this effect was identified in the following manner. A record was obtained of the engine, propeller, and frame vibrations of the test airplane throughout the total range of throttle settings. The engine was run with the airplane on the ground with the wheels blocked. Throttle settings at intervals of about 100 revolutions per minute were used, beginning at 475 r.p.m., the lowest setting obtainable, and ending at 2100 r.p.m., full open throttle. The resulting trace showed two distinct sections which resembled traces

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[129] Such cases were discarded in the sample quantitative analysis.

of natural frequencies, one at 700 r.p.m., and one at 1500 r.p.m.[130] The trace also appeared to be approaching another such section at the top setting. The fact was thus established that at certain throttle settings of the test airplane, the engine, propeller, and frame vibrations approached the natural frequency of the accelerometer.

The rest of the procedure was inference from this fact and the appearance of the effect on the record. It is impossible, of course, to state under exactly what dynamic conditions a vibration frequency approaching the natural frequency of the device will occur. The engine, propeller, and frame vibrations in flight will depend not only on throttle setting, as on the ground, but also on flight attitude. Given the appearance of the trace, however, and the fact that there occur (determined by throttle setting alone) engine, propeller, and frame vibrations of a frequency approaching the natural frequency of the device, it is logical to infer that such traces as presented

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130 The calculated natural frequency of the system is approximately 10 per sec. or 593 per min. Errors in the tachometer of the airplane and errors in measuring the deflection of the spring of the instrument under the static loads used in calibration could account for the difference in the calculated and experimentally determined natural frequencies.

The natural frequency of a weight-and-spring accelerometer is given by the formula

$$N.f. = \frac{1}{2\pi}\sqrt{\frac{E}{m}}$$

where E = spring constant = $\dfrac{\text{applied force in poundals (or dynes)}}{\text{deflection of spring in ft. (or cm.)}}$

and m = mass of the moving parts in lbs. (or grams).

Since a static load of 1g (32.17 ft./sec.^{2}) acting on a mass of $\frac{26.75}{16}$ lb. deflected the spring $\frac{0.10}{12}$ ft., (see page 15):

$$N.f. = \frac{1}{2\pi}\sqrt{\frac{\dfrac{\frac{(26.75)(32.17)}{16}}{\frac{0.10}{12}}}{\frac{26.75}{16}}}$$

$$= \frac{1}{6.2832}\sqrt{\frac{\frac{(26.75)(32.17)(12)}{(16)(0.10)}}{\frac{26.75}{16}}}$$

$$= \frac{1}{6.2832}\sqrt{(32.17)(12)(10)}$$

$$= \frac{1}{6.2832}\sqrt{3860.40}$$

$$= \frac{62.13}{6.2832}$$

$$= 9.89 \text{ sec., or } 593/\text{min.}$$

in Plates Ia and Ib are the result of the recording of a vibration frequency in the vicinity of the natural frequency of the system.

f. As mentioned earlier, it is the presence of this effect which makes it dubious procedure to utilize the trace as an indicator of the smoothness of the air. Small sections of this effect would resemble traces of "bumps". Conversely, it is not possible to attribute "haywire" traces to the "haywire" effect unless they persist for a fair length of time. The cause of a section showing only one or two such oscillations of the form shown in Plates Ia and Ib would be equivocal. It would be possible, of course, to discount such a section, whatever its cause; and thus, the practical purpose of utilizing the trace as an indicator of bumpy air would be served nevertheless.[131]

3. Errors due to faulty installation

a. A certain error may occur in the recording of load factor when the instrument is mounted in a position other than the vertical axis of the airplane. If the accelerometer is mounted to one side of the longitudinal axis, it will be affected by angular accelerations of roll; if it is mounted to one side of the lateral axis, it will be affected by angular accelerations of pitch. Thus, if it is mounted in any position other than the vertical axis, it must be affected by one or both. The recorded effect is then the algebraic sum of the effects of angular accelerations and load factor. In most of the feasible mounting places in the various Class 1 primary training airplanes, the effect of these angular accelerations will not be great, especially that of angular acceleration of roll. It is important, however, to consider the possible effect of angular acceleration of pitch.

b. The instrument in this particular project was installed in the baggage compartment of the test airplane (an Aeronca Tandem Trainer, Model 50-TL) at a position approximately 4½ feet behind the vertical axis.

In order to determine to what extent the values of load factor were affected by the error, it is necessary to "work back" from an assumed chart-value error. (Since all the records contain the error, its extent cannot be isolated by comparison of the records at hand.)

Assuming, for example, that the load factor trace is affected by an angular acceleration of pitch causing an error of 0.10g for 1 second, the arc which the instrument would describe about the center of

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131 There is no relation between the presence of this effect and the notation of bumpy air by field experimenters or administering instructor; some instances occur when the presence of bumpy air is noted, many occur when its presence is not noted.

gravity is given by the general equation

$$S = \frac{1}{2} \frac{a}{g} t^2$$

where $\frac{a}{g}$ is tangential linear acceleration (the recorded error) in feet/sec.^{2} and t is time in seconds.

$$S = (\tfrac{1}{2}) \ (0.10) \ (32.17) \ (1.0)^2$$

$$= \frac{3.217}{2}$$

$$= 1.6085 \text{ feet.}$$

The angle, ω, of rotation is given in degrees by the general equation

$$\omega = \frac{S}{R} (57.2958)$$

where

S = the arc in feet (or inches),

R = the radius of the arc in feet (or inches)[132]

= approximately 57.5 inches,[133] and

1 radian in degrees = 57.2958

$$\omega = \frac{(1.6085)\ (12)\ (57.2958)}{57.5}$$

$$= 19.3^\circ$$

Thus, in order for an angular acceleration of pitch to produce an error of 0.10g in the load factor record for 1 second, the pitch angle of the airplane would have to be changed 19.3° in that second. This displacement within this time would seem to correspond to fairly extensive and sudden elevator adjustments which will rarely be encountered in elementary maneuvers.

In order for an angular acceleration of pitch to produce an error of

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132 That is, the distance along the longitudinal axis between the vertical axis and the projection of the accelerometer on the longitudinal axis.

133 The values are given in inches to permit cancellation of a pair of quantities; hence the value 12 in the numerator in the calculation of the value of ω. The approximate value of $R = 57.5$ inches was obtained by actual measurement, being the distance taken on a line parallel to the airplane's horizontal and longitudinal from the leading edge of the wing to the center of the baggage compartment of an Aeronca Tandem Trainer. Since the center of gravity (and thus the vertical axis) lies several inches to the rear of the leading edge of the wing, this value is probably excessive by several inches.

0.05g in the load factor trace for 1 second, the pitch angle of the airplane would have to be changed about 9.65° within that second. Even this order of change in pitch angle would seem not to occur so often in the elementary maneuvers as to prohibit treatment of the records.

c. It may be stated then, that though the error in the load factor trace in this set of records due to the recording of angular accelerations may operate to produce occasional readings with an objectionably large error, the total load factor curve of a given turn will closely approach the true curve. Furthermore, since the error may be plus or minus, if values of load factor or "proper" bank, derived from the values of load factor, are to be averaged, partial cancellation of the error would be expected.

d. The possible error is nevertheless toolarge to admit statement of values of load factor or "proper" bank to as high a degree of accuracy as might be desirable.[134] In possible future uses of the instrument, or other instruments containing a load factor indicator, particularly in the case of airplanes with greater maneuverability than the Aeronca Tandem Trainer, somewhat more care should be exercised in selecting a position for mounting, with more thought given to accuracy of the records and less to convenience.

E. <u>Use of the static calibration to derive values of load factor from the chart</u>

1. Throughout this study, the static calibration of the accelerometer was applied to obtain values of load factor from the chart. Since the loads recorded in flight are dynamic loads, a dynamic calibration should properly have been employed for highest precision, but it was believed that the possible differences in the static and dynamic calibrations of the accelerometer were too small to justify the labor necessary to calibrate it dynamically. (A dynamic calibration was not furnished by the manufacturer.)

2. It was not thought necessary to perform a dymanic calibration of the accelerameter for the following reasons:

a. The weight may compress or stretch the spring only within a limited range of loads (1.05-2.05g). Since the weight is prevented by the upper stop from stretching the spring beyond its original tension, there is no tendency to plastic deformation of the spring.

b. The natural frequency of the accelerometer is several times the frequency of the imposed dynamic acceleration; thus, the system can record the imposed acceleration correctly as to dynamic frequency in all situations in which the "haywire" effect is absent.

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[134] See page 178, this <u>Supplemental Report</u>.

c. Since conditions (a) and (b) exist, there would be little difference in the static and dynamic calibrations of this particular unit. Although the dynamic calibration might show a logarithmic or other nonlinear curve, the deviation from linearity in each chart division of 0.10 inch would hardly exceed the possible deviation owing to errors of recording.

d. In view of the possible magnitude of errors discussed above, it would seem to be false precision to insist upon the use of a dynamic rather than static calibration of the accelerometer.

e. The bank values derived by application of the static calibration to the trace in both the qualitative and quantitative studies of the main Report are reasonable and conform to expectation.

F. <u>Policy followed in this study with regard to accuracy of the accelerometer</u>

1. In view of the number of possible errors in the bank values derived from the values of load factor, it is impossible to phrase an accurate estimate of the extent of such errors.

2. One fact deserves special mention, however: relatively large errors in the values of load factor in the upper part of the chart scale will produce relatively small errors in the values of "proper" bank. This fact is illustrated by <u>Table 1</u>, page 28 of <u>Part I</u> of the main Report, or by the duplicate <u>Table A</u>, page 99 of <u>Appendix B</u> to <u>Part I</u>. The nature of the secant relation between the value of load factor and the "proper" bank angle is such that in the upper part of the chart scale, relatively large increments of load factor represent relatively small increments of "proper" bank.

3. The bank values important in this study of steep-banked power turns correspond to load factor values in the upper part of the chart scale. Therefore, it would be expected that, apart from possible physical cancellation of the errors (as when one error offsets another in the recorded trace) and apart from algebraic cancellation in the preparation of indices by averaging values, the magnitude of the possible errors in load factor would not seriously affect the bank values, except in isolated instances.

4. The data derived from the load factor trace were thus deemed to be adequate for the purposes of this exploratory study. Greater precision in such data, however, is recommended for future studies. It is to be noted that the treatments applied to these records in the qualitative and quantitative analyses reported in <u>Parts I</u> and <u>II</u> of the main Report anticipate many problems which might be encountered in treating more accurate records of an improved instrument.

II - THE LATERAL IMBALANCE TRACES

A. The calibration of the lateral imbalance pendulums

It will be recalled that two pendulums, each stopped at the mid-point, are employed to indicate deviations from the position of lateral balance. The following discussion applies to each pendulum, and the singular "pendulum" is employed throughout. Each of Diagrams 3-5 applies equally well to either. If the observer imagines himself to be viewing the plane from the rear, the diagram applies to the left pendulum; if he imagines himself to be viewing the plane from the front, the diagram applies to the right pendulum. The two traces produced by these pendulums were calibrated statically, and the scale is such that each 0.10 inch in height of trace represents 2° additional deviation from the level position under static conditions. The limit of the scale for each trace is 14°.

This static calibration fails to give accurate results under conditions of flight, however. The following material is a resumé of the investigations to determine the capabilities of the pendulum as an indicator of angular deviations from perfect lateral balance.

1. Nature of the error of the pendulum in showing slip or skid angle

   a. Under static conditions the lateral pendulum indicates the true angle of inclination of the instrument from the horizontal.

STATIC CONDITIONS

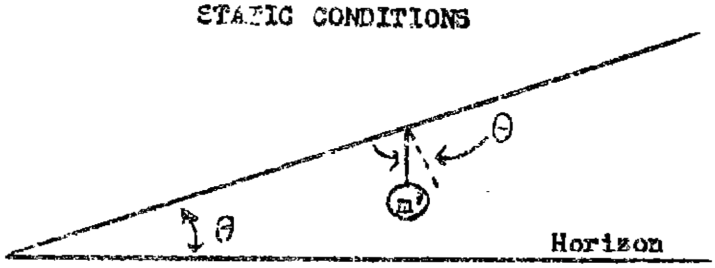
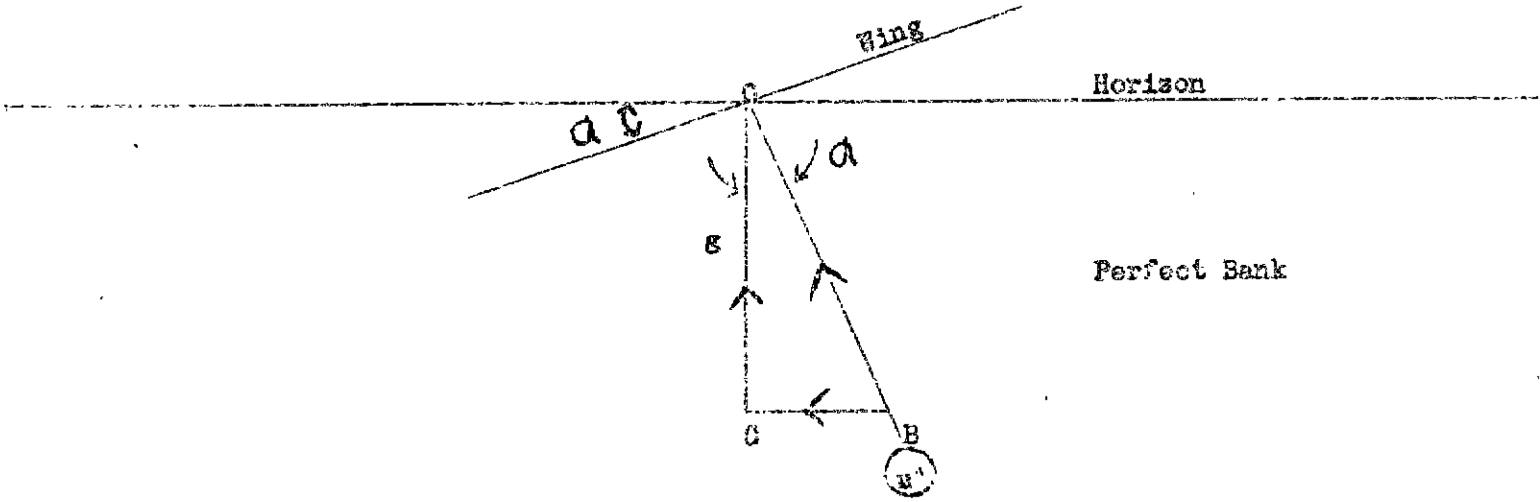


Diagram 3

[Here the tension on the shaft of the pendulum will be simply $m'g$, m' being the mass of the bob, and g being gravitational acceleration.]

Diagram 4



b. Under conditions of flight, however, the pendulum may or may not indicate the true angle of inclination from the position of perfect lateral balance.

(1) As illustrated in Diagram 4, in any given turn in the earth horizontal with angle of bank, ϕ, the airplane will be laterally balanced when the resultant (BO) of gravitational acceleration (CO) and the centripetal acceleration (BC) is perpendicular to the wing span of the airplane. In the perfectly balanced turn, the tension of the shaft of the pendulum will be m' times the resultant (BO), and the pendulum will hang in the airplane vertical along line OB, indicating no deviation from lateral balance.

(2) In a turn with slip, however, the above Diagram 4 does not hold.[135] A slip results when the "centrifugal tendencies" are not great enough to keep the airplane in perfect balance for the particular angle of bank the pilot has assumed; i.e., when there is too little "centrifugal force," and the resultant of gravity and centripetal acceleration is not perpendicular to the wing span of the airplane.

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135 The same is true of a turn with skid. The derived relations involving the angle θ hold whether θ is the slip or skid angle. The diagrams throughout this Supplemental Report show the slip situation only, for the sake of convenience.

ACCELERATIONS DURING SLIP AT CONSTANT ANGLE AND CONSTANT RATE OF TURN

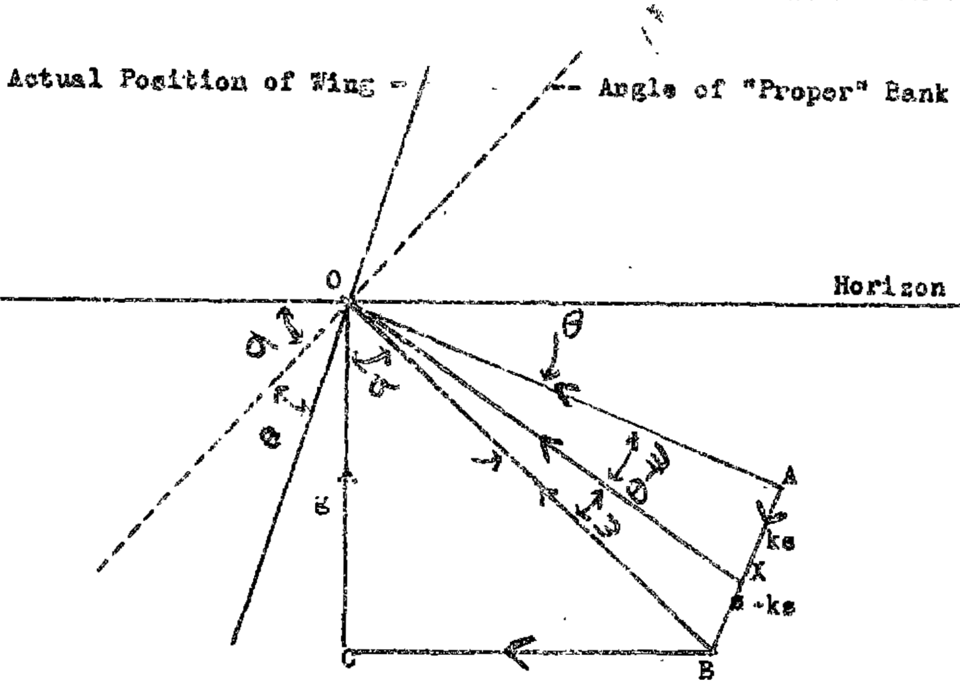

DIAGRAM 5

In this diagram it is assumed that the airplane was in lateral balance at angle of bank ϑ with respect to the horizon until suddenly overbanked by angle θ.

The dotted line at angle ϑ with respect to the horizon therefore represents the position of the wings at which the airplane would be perfectly balanced for the particular radius of turn at the particular velocity. The solid line at angle $(\vartheta + \theta)$ with respect to the horizon represents the actual position of the wings after overbanking, θ being the angle of slip.

With no air resistance,

lateral acceleration $= s = AB$,

and pendulum will hang in airplane vertical in line $\underline{OA}$, showing no deflection.

With no lateral acceleration, --- i.e., when

lateral acceleration $= s - ks = 0$,

pendulum will hang in line $\underline{OB}$, indicating true angle of slip (θ').

With diminishing lateral acceleration (lateral velocity not yet constant),

Lateral acceleration $= s - ks = XB$,

and pendulum will hang in line $\underline{OX}$, indicating angle of slip (θ) with a negative angular error (ω).

See text, pages 180 - 185.

(3) Referring to Diagram 5, during the initial moments of a slip resulting from sudden overbanking, the only external force acting upon the airplane is the aerodynamic lift force along AO perpendicular to the wing span. Hence the overall resultant acceleration must lie in the same direction. But the resultant of centripetal acceleration (BC) and gravitational acceleration (CO) lies along BO. Hence the airplane immediately begins a slip acceleration in the direction of the wing span and of such magnitude, (AB) that the sum of AB and BO will lie in the line AO. As indicated, the sum of AB and BO is AO. This initial slip, or lateral, acceleration (AB) will be designated as s.

(4) The above diagram of accelerations (Diagram 5) applies to the pendulum as well as to the airplane. At the beginning of the slip, the pendulum is hanging perpendicular to the wing span. As long as the net acceleration of the pendulum remains perpendicular to the wing span, i.e., in the direction AO, the pendulum will show no deflection. (The situation is analogous to the effects upon a pendulum suspended in a car which is rolled down an inclined plane. When the car is stationary, the pendulum hangs in the earth vertical and indicates the angle of the incline. But if the pendulum is brought to a position such that it hangs in the car's vertical and the car is allowed to roll down the incline, both car and pendulum are subject to a uniform acceleration, and the pendulum will continue to hang in the car's vertical, so long as the accelerations are uniform.)

(5) This situation will not be realized completely in the air, but will be approximated in the first moments of a slip resulting from sudden overbanking. Air resistance on the side surface of the airplane increases rapidly with the lateral velocity of the airplane; this resistance opposes the lateral motion of the airplane. The resultant of this lateral wind resistance and the aerodynamic lift is a net external force which is no longer perpendicular to the wing span, but which leaves the direction of AO and approaches that of BO as the lateral velocity increases. But the lateral acceleration occurred only by reason of the deviation of the net external force from the line BO. Hence as the lateral velocity and, with it, the lateral wind force, increases, the lateral acceleration decreases. After an infinitely long time the net external airplane force will lie along BO, the lateral acceleration will be zero,

and the lateral velocity will be constant. At this time the lateral wind force will be of such magnitude as to bring the airplane net external force vector into line with BQ, i.e., the lateral wind force will be equal to the mass of the airplane times the initial lateral acceleration, s. At this time, also, the pendulum comes to hang in line OB, since that is the position in which it is subjected to no lateral acceleration. The pendulum then indicates the true angle of slip.[136]

(6) Between these two points (i.e., between the time when the air resistance is negligible and lateral acceleration is a maximum, and the time when the air resistance causes the plane to move at a constant velocity without lateral acceleration) the pendulum will hang in a line OX between OA and OB, and indicate a deflection from lateral balance which will always be less than the true angle. The reading given by the trace will be $\Theta - \omega$, where ω is the angular error. (OX may be anywhere between OA and OB, and ω may have any value from 0 up to the value of Θ.)

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[136] It should be understood that the slip situation shown in Diagram 5 is not universal, and that there will in fact, occur instances in which the pendulum indicates the slip angle immediately.

In Diagram 5, it is assumed that the airplane was in perfect lateral balance until suddenly overbanked, and therefore the lateral (slip) velocity was 0 at the beginning of the slip. In such an instance, it will be noted, the actual bank in the slip situation is greater than it was before the slip originated. Another general case is one in which the actual bank remains constant, but at the moment of origin of slip, the rate of turn is suddenly made "improper" for the particular actual bank (i.e., is decreased). In this case, the slip velocity acquires its full value as suddenly as the rate of turn acquires its new value, so that the pendulum indicates the true slip angle immediately.

Slips originating in the latter manner (i.e., by the establishment of an "improper" rate of turn) undoubtedly constitute a fairly large proportion of the total number of slips, and in such instances the pendulum is subject to no lag in indicating the slip angle. Unfortunately, however, there is no satisfactory way to discriminate such slips from the perhaps equally large number which result from sudden overbanking, or the number which result from a combination of sudden overbanking and establishment of an "improper" rate of turn. The record of any slip must therefore be suspected of being subject to the above-described error.

(7) To summarize, as long as the lateral acceleration which accompanies a given slip or skid is unopposed, the given lateral pendulum will hang in the vertical of the airplane and show no deflection. This situation cannot be fully realized in the air, but will be approximated in the first moments of a slip resulting from sudden overbanking (or a skid resulting from sudden underbanking). During this initial period, the lateral velocity of the airplane is very low, and in consequence the air-resistance to its lateral motion is negligible. When the air-resistance increases to a substantial quantity, the proper pendulum shows a deflection toward the wing which is too low. This deflection is not the true angle of slip or skid, until the air-resistence increases to such a value that the lateral velocity of the plane is constant. Then and only then does the deflection of the pendulum indicate the angle of slip or skid. It then does this directly, as it would under static conditions.

(8) It will be noted that the effects to which the lateral pendulum are subject are much the same as those to which the ball of the ordinary ball-bank indicator is subject, since the particular effects are independent of the masses of the pendulum bob and of the ball. A trace on one of the lateral lines of the instrument, then, is analogous to a curve of the movement of the ball "plotted" against time. 137

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137 There are, of course, certain differences in the effects to which the pendulums and the ball are subject, owing to differences in damping. Except for stops placed at the extremes, the pendulums have no damping, ignoring slight dry frictional factors. The natural frequency of the pendulums is much higher than that of the applied acceleration. Consequently, the only errors to which each pendulum is subject in indicating the applied acceleration (not the slip or skid angle) are those of vibration, which may be identified on the record and discounted. The ball indicator, however, is heavily damped; in many such instruments the extent of this damping exceeds the critical value. For this reason the ball will fail to follow any imposed acceleration by an error whose magnitude will depend on the frequencies of that acceleration, although the ball will not be subject to errors of vibration. Moreover, the extent of this error of insensitiveness to the imposed acceleration cannot be presumed to be negligible, since the ball bank indicator is designed to be a static indicator and not for quantitative dynamic measurements. A trace on one of the lateral imbalance lines of the instrument, then, represents a curve of the movement of an "idealized" (i.e., undamped and therefore more sensitive) ball, "plotted" against time, rather than a curve of the movement of the actual ball.

Thus, the lateral imbalance traces of the instrument represent an objective record of data analogous to those by which instructor and pilot appraise the extent and importance of lateral imbalance.

(9) If, however, the magnitude of the above-described error were negligible, i.e., if the height of a given trace at a given point represented the angular magnitude of slip or skid, further quantitative treatment could also be made of the data afforded by the traces. Obviously, the data may be quantified as they stand by measuring in the arbitrary chart units the extent of motion of the pendulums from zero position. Quantifying the data by measuring the angular magnitude of the slips and skids would increase the scope of quantitative treatment, however.

(10) It is important to note that the above-described error, when present, must always be a negative error. That is, the pendulum can never show a deflection <u>greater</u> than the actual angle of slip or skid, although it may show a deflection which is <u>less</u>. Likewise, a positive trace on one of the lateral imbalance lines must indicate that the particular wing was low, although the absence of a positive trace on either line does not necessarily indicate that no slipping or skidding had occurred. (The angular magnitude and duration of the slip or skid might have been so slight that the air resistance built up was negligible; hence <u>no</u> positive trace occurred.) It would appear that the latter defect is not serious, and that any slip or skid which is so slight and so short that no trace is produced may be safely ignored.

2. <u>Extent of error of the lateral pendulums in showing slip or skid angle</u>

Two methods of examining the error[138] described in the preceding section will be considered here: Method (I) -- Calculation of corrections to be applied to the instrument record to give true slip or skid angle; and Method (II) -- Demonstration that the record error after a time, <u>t</u>, is less than some specified angle when the plane is subjected to a constant slip or skid angle at any given bank angle.

a. (1) Unfortunately, to express the error as in Method (I) requires a knowledge of the time history of the true slip or skid angle, and this knowledge cannot be derived from the present data.

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[138] It should be understood that this error is theoretically inherent in this type of instrument and does not result from an improper construction.

(2) Moreover, the indicated magnitude of a given slip or skid cannot be made to show the true magnitude by adding a correction which would be applicable to all readings of the same indicated magnitude. Some of the indicated magnitudes would be correct readings (See footnote, page 138); the remainder would be erroneous by varying amounts, depending in part on the true magnitude of the slip (or skid), the time elapsed since its origin, and the corrective movements of the pilot.

(3) The practical consequence of this situation is that the lateral imbalance traces cannot be dynamically calibrated by such a process as, e.g., comparing records of the instrument with simultaneous records made by means of a gyroscopic device and deriving a set of general values to correct the instrumental readings. There is no such set of generally applicable correction values.[139]

Each individual reading would have to be corrected individually.

b. (1) Method II -- i.e., to determine, for various slip and bank angles, the time within which the pendulum will show the slip angle minus an arbitrarily specified "negligible" error -- is obviously the more practical method of dealing with the error. If it were found, for example, that the pendulum attained a large proportion of its final readings within a very short time, the error might be regarded as negligible. Or, if situations could be identified in which the error were excessive, and others in which the error were negligible, the pendulum might be employed to show slip or skid angle in certain situations only, in accordance with this knowledge.[140]

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139 The range of the time lag of the pendulum in various situations might be determined empirically, however. See pages 187-188.

140 The time within which the pendulum attains an approximately true indication of slip angle depends on the rate at which the air-resistance on the side-surface is built up to overcome the lateral acceleration of the airplane. The rate of increase of air resistance varies with both the angle of slip and the angle of "proper" bank (that angle at which the wings would be properly balanced for the particular rate of turn).

(2) To determine the magnitude of the time "lag" in various situations by calculation, however, requires the use of formulas which contain empirical constants referring to the aerodynamic characteristics of the side surface (the fuselage) of the test airplane. These empirical constants are not available, since they are not customarily determined in the testing of airplane types. Approximations of these constants might, however, be employed for rough estimates of the time required for the pendulum to reach a satisfactorily accurate reading in various situations.

(3) Empirical determination of the magnitude of the time lag is also possible. The following is an outline of a method for such empirical determination:

(a) An expert pilot would be required to execute a series of slips from the attitude of level flight. Each slip would be held at as nearly constant a magnitude as possible, but slips over a range of magnitudes would be recorded with the R-S Ride Recorder.

(b) At a given moment, which would be noted on the record by a signal marker, the pilot would bank suddenly and maintain the desired inclination of the wings to the horizon while using rudder to prevent turning. The airplane would be held in this attitude until several seconds after the ball-bank indicator had reached its final position, at which time the pilot would reassume level flight.

(c) From the R-S record the time required for the slip trace to reach its final height (or its final height with an arbitrarily specified "negligible" error) could then be determined for slips of various magnitudes, and an estimate of the magnitude of the time "lag" in the pendulum could be derived.

(d) This procedure would, of course, require fine coordination on the part of the pilot, particularly in the maintenance of a straight course and in preventing steepening of the established slip angle. To determine whether the pilot prevented turning and whether the respective slip angles remained constant, simultaneous motion photographs might be made of an artificial horizon[141] and turn indicator.

(4) The above method is the formalization of a method outlined by Professor David L. Webster. Professor Webster tentatively estimates from rough preliminary tests employing direct observation of the ball-bank indicator and using a pocket watch for timing, that the ball-bank indicator reaches 90% of its final readings within a maximum of two to five seconds.[142]

3. To summarize the capabilities of the lateral imbalance traces:

a. They will show the angle of slip or skid under dynamic conditions only with a time lag of unknown magnitude. Moreover, this lag varies with the slip angle and the "proper" bank, so that it is not constant in all situations. It would not, therefore, be possible to synchronize the lateral imbalance traces with the other traces by the determination of a single value of this lag, to be applied in reading the chart.

b. During the period of lag, the <u>angular</u> error in the trace of a given slip or skid may vary from a negligible finite amount to approximately the full true magnitude of the slip or skid. Readings of slip or skid taken during the period of lag will, therefore, have varying amounts of error. It seems likely, from the rough estimates cited above, however, that the time lag does not exceed several seconds in any case. It might, therefore, be expected that <u>averages</u> of readings of slip over a period of time might approximate the true angular average fairly closely, especially in cases of prolonged slipping.

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141 The artificial horizon shows directly the angle of inclination of the wings to the horizon, and thus when the wings are banked without turning, shows directly the angle of slip.

142 Employing as constants approximations suggested by Mr. R. A. McConnell, formerly physicist at the Aircraft Materials Laboratory, Philadelphia Navy Yard, the writer calculated, for "proper" bank angles of 21° and 60°, respectively, the time within which the pendulum would show slip angles ranging from 1° to 14° with angular errors of 1°, 2°, and 3°, respectively. In each case, the slip angle was assumed to be held constant. Considering 3° as an acceptable "negligible" error, the calculations showed that in all the above cases, the pendulum reached an acceptably accurate reading within a range of 6-10 seconds. Owing to the lack of a suitable approximation for one constant, however, the formulas employed failed to take account of the component of force on the side surface of the airplane due to the forward velocity of the airplane, and the calculated times are consequently considerably overvalued.

c. Because the amount of error may vary, and because traces of equal height may represent various values of slip or skid, a dynamic calibration of the pendulums in terms of slip and skid <u>angle</u> is impossible.

d. In the absence of definitive tests of the magnitude of the time lag of the pendulums in showing slip or skid angle, the more conservative procedure would seem to be to regard such errors as excessive. A positive trace on either line, however, may be regarded for practical purposes, as a curve of the deviation, during a slip or skid, of the ball of the ball-bank indicator from its midposition, "plotted" against time. Viewed in this manner, the traces may be quantified by means of an arbitrary scale, and may otherwise be treated as a datum commonly used by instructor and student to appraise the extent and importance of lateral imbalance: namely, the deviation of the ball from its center position.

B. <u>Difficulty in reading the lateral imbalance traces</u>

The only difficulty encountered in obtaining readings of lateral imbalance from the chart is the occasional presence of vibrations traces. These are easily identified and discounted. The solid "spike" traces seen on several of the plates are examples: See especially the left-wing-low line, <u>Plates Ia</u>, <u>Ib</u>, and <u>II</u>. Other examples are seen in the traces on the right-wing-low line of <u>Plates IVe</u> and <u>IVf</u>, in which a slight vibrations trace is superposed on the slip trace. The amplitude of these vibration traces is always much less than that of the vibrations traces of the load factor line, except in the case of taxiing.

III - THE PITCH-AND-LONGITUDINAL-ACCELERATION TRACE

The pitch-and-longitudinal-acceleration trace, it will be recalled, is produced by a stylus attached to an undamped pendulum free to move only in the longitudinal plane.

A. This pendulum is subject to at least two effects:

1. A sudden change in the longitudinal pitch of the airplane causes the pendulum bob to move relative to the longitudinal axis either forward or backward. Raising the nose of the airplane causes relative backward motion of the pendulum bob; lowering the nose of the airplane causes relative forward motion of the bob. Nosing up tends to produce an upward trace on the chart; nosing down, a downward trace.

2. Positive longitudinal acceleration causes the pendulum bob to move backward, tending to produce an upward trace;

negative longitudinal acceleration (longitudinal deceleration) causes the bob to move forward, tending to produce a downward trace.

B. The trace actually produced represents the algebraic sum of the two effects of longitudinal acceleration and sudden change in longitudinal pitch. Moreover, it will be noted, in many situations these two effects occur in conjunction, and will tend to cancel each other in the recorded trace; for, usually, nosing down is accompanied by positive longitudinal acceleration and nosing up is accompanied by negative longitudinal acceleration.

C. Unless the magnitude of one of these two effects is known, the magnitude of the other cannot be known. Since there are no data at hand which can be utilized to give the magnitude of either effect, neither can be isolated. Moreover, in view of the facts that the trace is not explicit as to either effect, and that the effects will ordinarily partially offset each other in the trace, little meaningful use can be made of this trace in connection with either quantitative or qualitative analysis of the elementary maneuvers contained in Standard Flights A and C1.

D. It has been suggested by the Harvard investigation that the trace may be useful in identifying certain acrobatic maneuvers by supplying elements in a characteristic pattern.[143] The results of the preliminary investigation carried on at Tulane University indicate that the trace is of relatively slight value in identifying the elementary maneuvers recorded in these records.[144]

IV - TRACES FOR RECORDING CONTROL MOVEMENTS

A. Not shown on any of the plates is a trace indicating aileron movements, which, if present, would lie in about the center of the chart, and a trace indicating rudder movements, which would lie below the pitch-and-longitudinal-acceleration trace at the bottom of the chart. The control movements recording systems of the Ride Recorder were discarded in the first week at the field in this study, having been judged to be less desirable than the Friez Cable Control Recorder, which was then installed and employed in conjunction with the Ride Recorder.

B. The control movements recording systems were electrical, and operated by means of switches so placed that a circuit was made when the par-

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143 McFarland, R.A. and Holway, A. H, op. cit.

144 The pitch-and-longitudinal-acceleration trace is useful in identifying glides, stalls, and take-offs. See Exhibit I, pages 143-145.

ticular control was moved out of the neutral range.[145] Each of the traces was produced by a stylus attached to the armature of a double solenoid magnet which deflected the armature in one direction when the left switch was closed and in the other when the right switch was closed. Thus, each trace indicated the particular side of neutral to which the control was moved.

C. Neither trace, however, gave an indication of the extent of the control movement; neither recorded all movements; and neither indicated the direction of all movements; (for the particular control might be, e.g., to the left of neutral and might be moving to the right, yet until it reached the no-contact point, the direction of movement would not be indicated.) The traces were, in fact, signal traces indicating only the particular range within which the control was held.

This situation indicates no fault in construction, for the control movements recording systems were designed only for this purpose. The primary object of their inclusion was to identify the direction of turns, so that it might be known whether given positive traces on the wing-low lines represented slipping or skidding.[146]

D. The switch systems, apart from the deficiencies in the form of information they were not designed to show, were found at the field to be somewhat unsatisfactory owing to difficulty in obtaining a good adjustment of the neutral range. This range was undesirably large. Either control might be moved several inches to either side of neutral[147] before contact was made with the switch. Thus, even in fairly steep turns, the traces might not indicate that either control had been moved away from neutral. In the light of information provided by inspection of the Friez Cable Control Recorder records, this situation is not surprising; for control movements in most of the elementary maneuvers are in the main sub-

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145 The newer Redhed Flight Recorders (Models A-2 and A-3) employ mechanical cable systems for recording control movements. The chart has been widened to accommodate the three traces. Model A-2 was employed in the Harvard project. Photographs of the instrument and chart are to be included in the Introduction to the report of that project (McFarland, R. A., and Holway, A. H., op.cit.)

146 It was found, however, that even with the use of the superior Friez Cable Control Recorder, it was impossible to identify the direction of many turns because the initiating rudder and aileron movements were frequently indistinguishable from corrective movements, which may be in either direction. See Exhibit I, page 148.

147 "Streamline neutral"--i.e., determined on the ground. See page 203 of this Supplemental Report.

sumed by a comparatively small range on either side of neutral.[148]

V - DEFICIENCIES OF A DIFFERENT TYPE[149]

The previous discussion has been confined to the capabilities and deficiencies of those devices which the R-S Ride Recorder actually embodies. Nothing has been said of the desirability of obtaining several other data not supplied at all by the instrument.

Apart from the incapabilities of several of the recording units, the data supplied by the instrument are incomplete, for even a complete record of the attitude of the airplane would not be sufficient for a convenient evaluation of the performance. Records of at least two further items seem desirable: airspeed and altitude.

The airspeed record would be useful in many situations, perhaps most notably so in the cases of climbs, glides, climbing turns, and gliding turns. In these maneuvers, the airspeed is the conventional (and the most convenient) indicator of the pilot's maintenance of the proper climbing and gliding angle.

A record of absolute altitude, or of changes in altitude relative to a given altitude, would perhaps be even more directly applicable. Such a record could provide definite and presumably quantitative information about a very important aspect of pilot performance.

VI - RECOMMENDATIONS FOR THE USE OF THE R-S RIDE RECORDER

The following discussion is an outline of suggestions for the use of the R-S Ride Recorder growing out of the experience of the present project.

A. Synchronization of the traces

1. In order to synchronize the traces of the R-S Ride Recorder chart, it is necessary to employ a transparent synchronizing scale. A vertical line down the chart will not intersect all traces at chart positions representing the same point in time. This situation arises in part from the fact that the styluses are constrained to move in arcs rather than vertically to their base-lines, and in part from the fact that the position of each attitude-recording stylus at its base-line does not fall into the same vertical line as the position of the signal stylus at its base-line. (It was impractical to adjust the signal stylus so that its position at its base-line would be in the same vertical line as the positions of the other styluses at their respective base-lines. The space between the possible extreme excursion

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[148] See page 201 of this Supplemental Report.

[149] See also page 205 of this Supplemental Report.

of the load factor stylus and the signal base-line is so small that in certain situations the styluses would touch.)

2. Synchronization is easily effected mechanically by the use of a transparent scale, constructed as follows: With the chart at rest, each of the systems is operated by hand to obtain a complete excursion of the corresponding recording stylus. The record thus obtained represents all possible positions of each trace with respect to the other traces at the same instant. This record, including the base-line of each trace, may then be reproduced on a piece of catalin plastic, to provide the above-mentioned scale. As each arc on the scale represents all possible positions of the particular trace with respect to the other traces at the same time, if the scale be laid on a record such that the scale base-lines are aligned with the chart base-lines, scale arcs will intersect their respective chart traces at the positions they occupied at the same instant.

3. In view of the similarity of the recording systems, possible differential lag among the systems may be safely assumed to be negligible. The transparent scale, then, which is directly designed to provide synchronization of traces, also provides synchronization of the recorded effects.

4. The magnitude of the error which it is possible to incur by simply "ruling down" the chart is illustrated in Plate II. A vertical dotted line has been dropped from signal 6. The barred arcs indicate the true beginning of the maneuver. This error may not at first glance appear large; but it must not be considered simply in terms of horizontal chart length, rather, in terms of time. The position of the signal stylus at its base-line is 0.10 inch chart left of the position of the other styluses at their respective base-lines. This chart error corresponds to a time error of 4 sec. at the particular paper speed employed (1-1/2 inches per minute). The pure arcing error is slightly less. Drastic changes in flight attitude could occur within the space of 4 sec.

5. The relative magnitude of this possible error is, of course, decreased as the paper speed is increased. Even at a paper speed of 6 inches per minute, however, it would amount to 1 sec.

6. In certain uses of the records, such as qualitative rating of performances by direct inspection, little use will be made of this scale. For example, in order to derive the seven qualitative items considered significant in the Sample Qualitative

Analysis of right 720° power turns,[150] it is necessary to use the scale only to determine the beginning and end of the maneuver for each trace (by synchronizing each trace with the initial and terminal signal).[151] Its use is necessary only when a more accurate synchronization of traces is desired than can be obtained by simple direct inspection.

7. A similar scale, however, is imperative for making synchronous fine measurements by means of projecting the records, its size being determined by the particular magnification chosen for projection. It may be constructed by projecting the above-described record onto a suitable piece of plastic at the desired magnification and reproducing the magnified images of the traces and the base-lines on the plastic.[152]

B. Paper speed

Selection of a suitable paper speed will be governed by the fineness of the analysis to which the records are to be subjected, the character of the signalling system, and considerations of administration.

1. At even the low paper speed of 1½ inches per minute, the record of a 30-minute flight -- allowing a suitable length of chart for separation of subjects' records, identification, and removal -- is 4 feet and several inches long. If a fairly large number of records are to be accumulated, their bulk must be considered. In the actual examination of a given flight record, it is rarely desirable to cut it and handle it in small sections. Also, the cost of the paper is to be considered.

2. Despite these objections to a high paper speed, it seems desirable that the paper speed be at least 6 inches per minute and perhaps even greater. First among the advantages of a higher paper speed is the possibility to record the given effects with less compression of detail. This possibility is of the utmost importance if the records are to be subjected to a detailed analysis, for readings can then be made at smaller time intervals.

150See Part I of the main report, pages 21-23.

151Provided that bank items are derived, as recommended (page 168 of this Supplemental Report), from the "proper" bank.

152Such a scale was used in making the quantitative readings of power turns in the Sample Quantitative Analysis.

Some notion of the amount of this compression at a paper speed of 1½ inches per minute may be derived from the various plates, which are full-size. Each turn is longer than 30 seconds and several exceed one minute. The 720° turn was one of the longest maneuvers included in the elementary course.[153] Such maneuvers as 90° medium turns, take-off run, and 90° gliding turns may require no longer than 10 seconds for execution. Ten seconds corresponds to a chart length of ¼ inch at a paper speed of 1½ inches per minute, a chart length of ½ inch at a rate of 3 inches per minute, and a chart length of 1 inch at a paper speed of 6 inches per minute.

3. Another advantage is the reduction of the error in making time measurements (along the chart horizontal). At an increased paper speed, given errors (in terms of horizontal chart length) in setting off the intervals at which readings are taken represent smaller time errors. This is true whether the records are measured or examined directly, or by projection.[154]

4. Another advantage which alone would justify a fairly high paper speed is the facilitation of accurate and adequate signalling. This point is discussed more fully under the next heading.

C. Signalling procedure

1. Signals may serve any or all of three functions: identification of the maneuver, identification of the points at which it begins and ends, and grading of the performance by the instructor.

2. Simplicity in the code is desirable not only for the sake of ease in memorizing it, but also for the sake of convenience in the actual process of signalling, especially if the paper speed is low. Even a fairly simple system of signals is difficult to use at a paper speed of 1½ inches per minute, because the signal key must be released for nearly a second between dots or dashes for them to be discriminated as separate.

   In the Tulane study, a fairly simple code (shown on page 196) was found to be unwieldy at this paper speed even for the instructor

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[153] 360° turns have recently been substituted for 720° turns in the C.P.T. course.

[154] It is to be noted that an increase in paper speed will make no difference in the relative error of measurement of vertical chart distance. It is primarily for this reason that the records must be projected for accurate fine measurements, no matter what paper speed is used.

CODE OF SIGNALS

<u>Grades.</u> A grade is signalled only after a student performance.

A grade should be signalled after take-off and landing, and after all maneuvers called for and signalled as below.

. . .	Very good performance for student at present stage. (dot, dot, dot)
. .	Satisfactory performance for student at present stage. (dot, dot)
.	Poor performance for student at present stage. (dot)

<u>Maneuvers.</u>

-	Straight and level flight. (dash)
--	Medium horizontal turn. (dash, dash)
---	Steep horizontal turn. (dash, dash, dash)
- .	Climb, straight. (dash, dot)
- . .	Climbing turn. (dash, dot, dot)
. -	Glide, straight. (dot, dash)
.. -	Gliding turn. (dot, dot, dash)
- . -	Stall. (dash, dot, dash)
. - .	Spin. (dot, dash, dot)
-- .	Figure eight, medium bank. (dash, dash, dot)
-- . .	Figure eight, steep bank. (dash, dash, dot, dot)

<u>Instructor Handling Plane</u>

Prior to demonstration of correct maneuver: signal for maneuver. (No grading signal.)

Demonstration of incorrect maneuver and emergency, no signals at all.

accompanying the student pilot. Soloing students, who were provided with a signalling push-button inserted into the rear stick, naturally experienced even greater difficulty. Yet, if the instrument is to be used in the primary course in any other way than obtaining records of a pre-arranged course, i.e., a standard flight, some feasible means of identifying the maneuvers must be found, for many of the elementary maneuvers produce no characteristic individual pattern on the record.[155]

A fairly high paper speed will help greatly in this connection.

3. A further aid in providing a workable code would be to omit identification signals for those elementary maneuvers which do produce a characteristic pattern on the records (stalls, spins, steep turns) and have these marked only with a single dot or dash at the beginning and end.

4. The difficulty of complexity of signals, as indicated in <u>Exhibit I</u>, page150, does not arise in the case of standard flights, for the order of maneuvers is pre-arranged and it is therefore not necessary to identify them by specific characteristic signals. All that is needed for identification is a signal indicating the beginning of the maneuver. Since one maneuver is immediately succeeded by another, the initial signal of a succeeding maneuver serves also as the final signal of the preceding maneuver.

5. The need of initial and terminal signals in order to make a detailed analysis of the records arises from two considerations. The first is the lack of distinctive individual patterns in the case of some of the elementary maneuvers, mentioned above. The second is a consideration of experimental technique. Even in the case of those maneuvers which do present a characteristic record pattern, the exact beginning and end of the maneuver cannot be discriminated by means of the attitude traces. If it is desired to consider in the analysis those sections of the maneuver in the vicinity of its beginning and end, -- i.e., the entry and the recovery, signals are especially needed.

It is important to note that in investigations of coordination of pilot response the record of control movements cannot be

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155 For example, a record of a shallow turn of a bank less than 21°, which is the approximate lower extreme of "proper" bank derivable from the instrument, cannot be distinguished from the records of straight and level flight, climbs, or shallow climbing turns. See <u>Exhibit I</u>, pages 146-147.

utilized for this purpose. For example, with reference to flight attitude, a turn begins only after the airplane departs from straight flight. With reference to pilot response, however, the entry to a turn begins when the pilot makes the first control adjustment preparatory to the turn. This adjustment might be any adjustment or combination of adjustments, depending on the flight situation and also on the pilot. Thus, if it is desired to compare pilots' methods of manipulating the controls during the entry to a turn, to utilize the record of control movements to indicate the beginning of the maneuver is obviously begging the question.

6. Plate II illustrates possible ambiguities arising from the lack of an initial and final signal for a maneuver. The left turn, Maneuver 6, is fully delimited by signals. The right turn has neither an initial or terminal signal, owing to a failure of the dry cell. Although the identity of the maneuver is known because the order was pre-arranged,[156] its exact end and beginning are not. The assumed initial and terminal points are given by the arcs on which are superposed small circles. The possible error in the case of the beginning point is somewhat less than in the case of the final point. The beginning point must lie between the initial signal for Maneuver 7 (short straight and level recovery flight) and the next positive trace on the load factor line. In the case of the end point, however, the return of the load factor trace to the base-line does not necessarily indicate a return to level attitude, since the plane might still have a bank of about 18 to 20°, although the trace had returned to the base-line, or so near it that a positive trace would be indiscriminable. Furthermore, a positive trace of load factor appears a few seconds later. This section might well be part of the turn. The selected point seemed more likely to be the end than a later point, however, considering several clues: the length of time the load factor trace was on the base-line, the length of the maneuver, assuming each likely terminating point, and the fact that the pitch-and-longitudinal-acceleration trace gives an indication of a glide shortly after the selected terminal point.[157] Obviously, the selected point is nevertheless very dubious.

7. Signals are liable to error as indicators of the true initial and terminal points of a maneuver, whether those points be defined

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156 The maneuver could be identified as a steep turn without this knowledge, but its direction would not be known.

157 In the succeeding transition maneuver, the subject was required to reduce altitude to that suitable for executing medium-banked figure 8's.

with reference to flight attitude or pilot response, since:

(a) Signals must be made by an observer, and

(b) The observer has to make a judgment as to those points. Such judgments on the part of the signaller are difficult to make, and it is probably as unjustifiable to consider such judgments "true" points as to determine the points from records of control movements.

It would therefore seem wise to avoid, insofar as possible, the introduction of an observer's judgment into the signalling procedure. For example, in the standard flight records taken in this study, the signals represent only the point immediately following the administering instructor's direction to the subject to execute the maneuver; the instructor called for the required maneuver and immediately afterward pressed the signal key. Even with this scheme, however, the factor of observer's judgment is not entirely eliminated, for the observer can give directions for the succeeding maneuver only when, in his judgment, the end of the current maneuver has been reached. Thus, as each signal is taken to represent a beginning point, the factor of observer's judgment does not enter; as it is taken to represent a terminating point, the observer's judgment is involved.

D. Revision of Chart

1. One revision of the chart of the R-S Ride Recorder would be highly desirable if it were to be employed in the actual task of training. The scale of the load factor trace would serve certain purposes better if it were graduated to show, not load factor values in g, but the angle of "proper" bank in degrees. To derive the "proper" bank from the load factor values is both troublesome and unnecessary in view of the fact that such a scale is entirely feasible. Such a revision is almost imperative if the instrument is to be used by an instructor unfamiliar with its characteristics to derive information about students' performance with respect to bank.

2. The load factor trace has, of course, uses other than to supply data for derivation of the "proper" bank. A scale of "proper" bank values would be entirely inapplicable in the case of a stall or a spin. In the case of these maneuvers, however, as indicated on page 158 there seems to be little need for deriving the actual value of the load imposed on the airplane. Measurement of this trace, in the case of the elementary maneuvers at least, will ordinarily be confined to measurement directed toward obtaining bank values. A dual scale showing both values of "proper" bank and values of load factor is an alternative possibility, provided the chart space be increased.

3. The actual construction of such a scale would, of course, depend upon the initial tension of the restraining spring of the accelerometer. A scale of "proper" bank for an accelerometer having a spring of initial tension of 1.05 g will differ from such a scale for an accelerometer having a spring of initial tension of, say, 1.25 or 1.50 g.[158]

E. Recommendations for installation and field use

Recommendations for installation are provided by the manufacturer. Several items arising out of experience on the present project, however, might be valuable to record.

1. Assurance that the instrument is level with respect to the airplane's transverse horizontal is the most difficult part of the installation. It is important to remember that the level provided on the instrument will indicate true level and not level with the airplane's horizontal. For this reason the airplane itself must be on a level surface at the time of the installation.

2. The use of a sponge rubber cushion beneath the instrument is recommended in order to lessen the extent of shocks and vibrations transmitted to it. These will inevitably be somewhat larger than desirable because the attachment at the side pieces must be rigid.

3. In the case of the R-S Ride Recorder (old model) it may be found possible to use one of the controls-recording solenoid keys as a signal key in place of the signal marker, if the controls-recording system is not to be employed. These keys work both ways from the base-line, and a signalling code will thereby be made easier than by placing entire dependence on the single-acting signal marker.

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158 The initial tension of the spring will, of course, depend upon what ranges of load factor one wishes to record. In the case of elementary maneuvers, a range of -1.0 - -2.0 g would seem to be ample. This value allows the recording of load factor corresponding to a range of banks from 0° to 60°. This range would seem to include nearly all significant bank values. Higher values of bias will ordinarily be used only to record load factor occurring in maneuvers whose banks could not be determined from the instrument, viz., acrobatics.

DIVISION B

THE FRIEZ CABLE CONTROL RECORDER

I. The Friez Cable Control Recorder chart (not shown in any plate) is plain white paper, 7 and 5/16 inches wide. The instrument has four recording capillary pens: a signal marker and one each for the aileron, elevator, and rudder. Movements of a control are transmitted to a pen as follows: a string cable attached to the control moves a spring-restrained reel which in turn transmits the action to the lever operating the pen. Each controls trace shows the magnitude and number of control movements in linear fashion.

II. The recording pens, as the recording styluses of the R-S Ride Recorder, describe arcs. These records are thus also subject to an arcing error, which may be corrected mechanically by the use of a transparent scale constructed in a manner similar to the construction of the scale for the R-S chart.[159] In the case of the Friez instrument, the magnitude of this arcing error will vary somewhat from installation to installation, depending on the range of chart utilized by the installation. The range of any control movement trace is thus limited in practice, though the possible range is, of course, limited by the construction of the instrument.

III. Several outstanding deficiencies, all of which can be overcome, have been noted in casual inspection of these records.

A. The first is concerned with the range of a given control movement trace. If the installation is such that the total range of the movement of a given control is to be recorded, the sensitivity of the trace is undesirably low in the case of elementary maneuvers.

1. With a few notable exceptions, such as taxiing, landing, and spins, extreme control adjustments are rarely encountered in the case of elementary maneuvers. Casual inspection reveals the great majority of control adjustments to lie within the middle third of the range, and a large portion of these to lie within the middle fifth. If the total range of movement of each control is recorded, the chart range occupied by the middle fifth of the total range of movement is too small for accurate discrimination and measurement of these fine movements.

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159 See pages 193-194 of this <u>Supplemental Report</u>.

2. The installation may be arranged, however, such that the total range of the movement of a given control is not recorded, and the effective chart range is devoted to the middle section of the range of control movement. Such an arrangement could be effected in the following manner: The cable would be attached to a position on the particular control such that the entire range of movement would not be recorded. A spring would now be included in the cable system of such tension that it would not be stretched until the pen had reached the chart extreme.[160]

3. In some airplanes, it may not be feasible to attach the cable at such a point on the control that its range of movement will be greater than (or as great as) the range which the instrument can record. This situation may be encountered particularly in the elevator attachment in stick-type airplanes. The elevator cable must be attached at the bottom of the stick, for otherwise the elevator record would include aileron movements. This position of attachment will ordinarily result in a very small chart range of fore-and-aft stick motion. In such instances, a mechanical multiplying device must be included in the system. This may be true in the case of some airplanes even when it is desired to record the total range of elevator movement.

4. The above recommendations are obviously not to be regarded as general recommendations applicable to every use to be made of the instrument. For some purposes it may be desirable to record the total range of movement and ignore fine movements; for others it may be desirable to record the middle range of one or two controls, and the total range of the others or other. It is doubtful that even in an investigation of these elementary maneuvers it would be desirable to preclude records of the total range of elevator movements. The choice must be made in the light of the purposes of the investigation, bearing in mind that the more of the total range of movement represented by the chart range, the less is the accuracy with which fine movements can be discriminated and measured.

B. The second deficiency in the instrument is the difficulty of adjusting

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160 Another alternative would be adaptation of the instrument for non-linear recording, providing for enlarged trace response in the vicinity of neutral and reduced trace response in the extremes of the range.

the installation such that a pen will record neutral[161] when the corresponding control is in neutral position. A slight loosening or stretching of the cable connection will serve to produce an error in the chart neutral position as great as many of the recorded movements.

1. The relative magnitude of such an error would, of course, be reduced by a larger chart range.

2. With the present chart this difficulty must be met mechanically by the inclusion in each cable system of a device permitting easy and frequent adjustment of chart neutral to streamline control neutral, such as a light turnbuckle[162] or a slip screw at the point of attachment to the control.[163]

C. In connection with this difficulty and with others, the observation must be made that the lack of a printed chart gives rise to both great annoyance and major deficiencies.

1. Even if the neutral position is accurately recorded, there is considerable opportunity for error in reading it from a plain chart. Measurement of any sort is rendered inconvenient, whether of the movement traces, or of time (along the chart horizontal).

2. The inconvenience in treatment is matched by inconvenience at the field. Without a ready indication of the length of chart remaining (such as that given by the horizontal scale of the R-S Ride Recorder chart), the operator of an instrument in regular use is confronted frequently with the choice between delaying a flight, perhaps unnecessarily,

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161 The neutral spoken of here is "streamline neutral," determined on the ground. "Streamline neutral" position of the ailerons is that position flush with the wings; of the elevators, that position in the same plane as the stabilizer; and of the rudder, that position in the same vertical plane as the fin. The <u>dynamic</u> neutral position of each control will usually vary from its streamline neutral position, and will vary from time to time with load, air condition, etc.

162 Provided these can be conveniently located, and the air is fairly smooth, adjustment to <u>dynamic</u> neutral position can also be made in straight and level flight.

163 The latter is the device incorporated in the control movements recording systems of the new models (A-2 and A-3) of the R-S instrument.

to insert a new roll, or proceeding with the hope, perhaps vain, that the amount remaining will be sufficient to record the flight period.[164] Even otation of the time of each flight and the estimated amount of chart wastage -- an inconvenient procedure in itself -- did not prevent such occurrences at the field.

D. While the capillary pens were found to work fairly well and to stand up under wear, this method of recording must be pronounced somewhat inferior to the stylus-on-waxed-paper method of the R-S instruments.

1. One inconvenience which was magnified under the conditions of instruction was the necessity for refilling the inkwells and occasionally cleaning them.

2. The open inkwells are, of course, impractical in recording certain acrobatic maneuvers. No difficulty was experienced with these in the elementary maneuvers, however.

3. A relatively minor fault is the width of the pen trace itself. In projection of the records it is objectionably large.

IV. In addition to such recommendations for field use as have been included in the above discussion, several incidental facts which may be of help to those unfamiliar with the instrument are given below.

A. In the case of the elevator and aileron traces, particular care must be exercised in selecting the points on the stick to which the cables are to be attached, in order to avoid recording movements of both controls on one trace. In stick-type airplanes, the elevator cable should be attached at the bottom of the stick. The aileron cable should be attached on or near the "U" arm in which the stick is pivoted. The cable may ordinarily be attached fairly high on the stick, at least as high as possible without interfering with the freedom of movement of the pilot, without danger of the trace's being affected by fore-and-aft motion. A test record made on the ground will indicate whether the installation is satisfactory in this respect. In wheel-type airplanes, the cables to the instrument will ordinarily be attached to the cables which lead from the controls to the control surfaces.

B. The position of pulleys in the cable system must be determined with care, in order that the cable length will not be affected differentially on the two sides of neutral. Pulley friction should be as small as possible.

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164 Some of these plain charts were stamped at the 10 ft. mark with a notation indicating that only 10 ft. of chart were left. This single notation does not satisfactorily overcome this difficulty.

C. Much care in attaching the chart to the take-up roll is necessary in order to avoid fouling of the paper.

D. Because the take-up roll cannot be removed and the chart must therefore be unwound in the airplane, these records should be removed in as short lengths as possible.

E. Several extra pens should be kept on hand so that replacement or repair of defective pens is facilitated.

F. Several extra springs for the pens (to adjust pressure on the chart) are most convenient. These springs have a short life in field use and must be replaced rather frequently.

CONSTRUCTION OF AN IMPROVED GRAPHIC RECORDER

Out of the experience of the various projects of the Committee on Selection and Training of Aircraft Pilots which have employed graphic records have come various recommendations for the design and construction of an improved graphic recorder. These recommendations are embodied in a memorandum transmitted to C. S. Draper, project director of the Committee project at the Massachusetts Institute of Technology for the design and construction of an improved graphic flight recorder. This memorandum, prepared by J. G. Jenkins and M. S. Viteles, with the assistance of Oscar Backstrom, Jr., is attached to this Supplemental Report as Appendix A.

AN ANALYSIS OF GRAPHIC RECORDS OF PILOT PERFORMANCE
OBTAINED BY MEANS OF THE R-S RIDE RECORDER

SECTION B

APPENDIX A

MEMORANDUM TO THE EXECUTIVE SUB-COMMITTEE OF THE COMMITTEE ON SELECTION AND TRAINING OF AIRCRAFT PILOTS CONCERNING SPECIFICATIONS FOR AN IMPROVED GRAPHIC RECORDER

by

J. G. Jenkins
and

Morris S. Viteles

(with the assistance of
Oscar Beckstrom, Jr.)

November, 1942

FROM: J. G. Jenkins
M. S. Viteles

December 12, 1941

TO: Executive Subcommittee - Selection and Training of Aircraft Pilots

SUBJECT: Proposal for a Graphic Recorder

I. In accordance with the request of the Executive Subcommittee, we are submitting below recommendations on instructions to be given to Professor Draper, M. I. T., with respect to the construction of an improved graphic recorder. These recommendations are the outcome of considerable discussion, in which much assistance was rendered by Oscar Backstrom, Jr., formerly of Tulane University, now working with Viteles at the University of Pennsylvania.

II. These recommendations assume that it is necessary to distinguish between a graphic recorder designed primarily for "research" and one designed primarily for "clinical" or "field" use. In the construction of the "research" instrument, the objective would necessarily be that of building an instrument which could supply objective data suitable for detailed quantitative treatment. In the construction of a "clinical" or field instrument, the objective would be that of perfecting an instrument supplying unequivocal data on plane attitude and pilot performance, useful to an instructor, inspector, or reviewing board, in evaluating flight performance and progress during training. The "clinical" or "field" instrument would not be expected to furnish data of the type needed to satisfy completely the requirements of an objective research criterion. A "clinical" or "field" instrument might, of course, incidentally supply certain types of quantitative data but, in the construction of the instrument, the collection of quantitative criterion data would be considered secondary and the latter would be viewed, when obtainable, as useful and highly acceptable by-products of an instrument designed essentially for a "clinical" or "field" instrument. Where there is a choice of units, an effort would naturally be made to use those which will both provide data immediately useful to the instructor, inspector, etc, and at the same time furnish data suitable for detailed quantitative research, but suitability for field use would be the primary objective in the design and construction of the instrument.

III. It is suggested that the immediate needs of C.P.T.P. and of the services can best be met by requesting Professor Draper to prepare a graphic recorder suitable for "clinical" or "field" use rather than to undertake the construction of a "research" instrument. Following are the general specifications for this proposed graphic recorder:-

1. The instrument should be designed to provide a record which will enable an instructor or inspector to determine, by inspection, the attitude of the plane during various maneuvers and the control movements made by the pilot to achieve or correct the observed plane attitude. The instrument should be specifically designed for use in the Civilian Pilot Training Program and in connection with elementary instruction given in basic training courses of the Army

and Navy. This implies that provisions for recording will be limited essentially to the more elementary training maneuvers and will not cover acrobatic maneuvers of the type employed in the intermediate and advanced Army and Navy training.

2. The instrument will, in general, be used in connection with standard flights so that no elaborate means of identifying maneuvers need be incorporated, with the following exceptions:

   a. The instrument should include a signal marker to be operated electrically by the pilot or observer.

   b. If possible, it should include a trace showing automatically the beginning, direction, and end of each turn.

3. The instrument should record all traces on one chart to avoid the need of synchronizing charts. If possible, each of the recording styluses and pens should maintain a uniform horizontal position on the chart to avoid the need of transparent scales or other devices for synchronizing traces on the same chart. Arcing error should be minimized, and, if at all possible, excluded.

4. The instrument should give an immediately visible and interpretable record which may be examined immediately upon the conclusion of flight. The effects recorded should not require computation for interpretation in the field. It is acceptable that computations be employed in the case of such data as are to be used for quantitative purposes; but no computation whatsoever is acceptable for field use.

5. The cost of reproducing the instrument in large numbers for field use; convenience of installation; ease and cost of maintenance; etc., should be given every consideration in the design of the instrument and in the selection of its constituent units.

IV. Apart from the general principles noted above, it seems desirable to place before Professor Draper the following specific requirements and related suggestions with respect to the proposed recorder:

1. The instrument must provide 3 traces showing the number, extent, and duration of movements of each of the 3 air controls, viz., stick (or wheel) right and left; stick (or wheel column) forward and back; pedal (right and left). CONTROL MOVEMENTS

2. There must be included a solenoid signal marker, to be operated by the observer or pilot by means of an appropriate switch, for use in indicating the beginning and end of each maneuver. This trace should be made by a double solenoid to facilitate construction of a signal code in case it should seem desirable to identify and grade maneuvers by code signals. SIGNAL MARKER

3.a. The instrument must provide a trace (or traces) to record each slip and each skid during flight. This trace (or traces) may be obtained through the use of (1) a recording ball bank indicator operating by electric contacts or (2) 2 pendulums free to swing only in the lateral plane of the airplane.[165]

The recording ball bank indicator would consist essentially of a facsimile of the ball bank indicator or lateral inclinometer commonly used in airplanes, with the addition of electrical contacts placed at suitable intervals in the glass tube. The number and location of these contacts would be decided on the basis of advice from instructors and other qualified persons and on the basis of such experimental findings as may be useful in this connection. It is certain that the minimum number would be four; 2 on each side of the mid-position of the inclinometer. If only 2 were used, one would indicate a position of the ball corresponding to "a little imbalance"; the other would indicate "considerable imbalance" or mark the position corresponding to the amount of imbalance sufficient to endanger the airplane and its occupants.

The unit involving the 2 pendulums free to swing only in the lateral plane of the airplane is that now used on the Redhed Flight Recorder.

bb It is suggested that the final choice between the two instruments be left to Professor Draper, who, however, may be interested in considering the relative advantages of each as outlined in the course of our discussion of the proposed recorder.[166] The advantages of the recording ball bank indicator appear as follows:

(1) It would provide a trace giving directly categorized information enabling the instructor to tell at a glance whether the student slipped or skidded "not at all", a "little", or to a "considerable" or "dangerous" degree.

(2) Damping could easily be varied by a change of fluid in the glass tube.

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165 One of these pendulums would be free to swing only left of center, and the other would be free to swing only right of center; each would be stopped at its mid-position. The purpose of employing two pendulums each stopped at the mid-point, instead of a single pendulum free to swing both right and left of center, is to minimize error due to limited damping. Such error would be excessive in an unstopped single pendulum. If a feasible means of damping (specifically, some means other than dry friction) exists, a single pendulum free to swing both right and left of center in the lateral plane might be employed.

166 There will also be made available to Professor Draper a copy of a "Memorandum Concerning Projected Graphic Recorder", prepared by Oscar Backstrom, Jr., University of Pennsylvania and, later, of a report, now being completed by the University of Pennsylvania group, on the qualitative and quantitative treatment of flight recorder data.

(3) The recording ball bank indicator would probably possess a certain advantage over the lateral pendulums in that the lay instructor is familiar with the ball bank indicator. Although the ball and the pendulums are subject to the same effects in the same amounts, certain instructors might be reluctant to accept the lateral pendulums as substantially a ball bank indicator.

(4) Since the trace of this device would be to all intents and purposes a signal trace indicating certain ranges in which the ball has moved, the trace might be designed to take up less chart space than the trace of the lateral pendulums which records actual extent of deflection.

c. The advantages of the lateral pendulums may be summarized as follows:

(1) The pendulums provide traces of a continuous variable. From these traces, categorized information, such as the recording ball bank indicator will furnish, can be obtained, but in addition, other information can be derived. The chart can be marked with lines indicating the limits of the electric contacts proposed in the recording ball bank indicator, to furnish the data available for that instrument. In addition, since the trace records lateral imbalance continuously, more information on extent and pattern of lateral imbalance will also become available.

(2) The lateral pendulums represent a mechanical unit, as opposed to the recording ball bank as an electric unit. As such, the pendulums may possess certain advantages in field operation, in terms of the need of a source of electric power as well as possibly greater stability under constant use.

(3) With the present Redhed instrument, no damping is necessary for the pendulums, provided a suitable place of installation and suitable cushioning against engine shock are provided for the instrument. In the set of records made at Tulane University and examined at the University of Pennsylvania, no difficulty was experienced with vibrations traces in the lateral imbalance lines. Such vibrations traces are few, and where they occur, can easily be discounted. The fact that no damping was necessary probably results from the location of the instrument in the baggage compartment and to the construction of the pendulums, which employ a very short shaft, minimizing the extent of damping motion.

In addition relatively little chart space need be consumed by the lateral pendulums trace inasmuch as the extent of multiplication can be cut down if desired. The Redhed units have also the obvious advantage that they are already in existence, obviating the expenditure of funds for the development of such an instrument.

(4) A <u>sensitive trace of air speed</u> must be included in the graphic recorder. AIR SPEED

(5) The graphic recorder must provide a trace of load factor to supply information concerning bank in elementary maneuvers. The chart space occupied by this trace should be calibrated in a trigonometric scale of degrees of "proper" bank, in accordance with the approximate relation load factor = g sec φ, where φ is the angle of "proper" bank.[167] (See <u>Supplemental Report</u>, pages 160-166 LOAD FACTOR

(6) The instrument must include a trace providing information on maintenance of altitude. Such information will ordinarily be used not to show the attainment and maintenance of any specific altitude in feet but variations in altitude during prescribed maneuvers, i.e., to show whether the subject maintained a recorded altitude X $\pm$ n feet. This trace can probably be provided by a recording sensitive altimeter, with maximum topmost reading not exceeding 4,000 feet.[168] The trace should be readable within the most refined limits of the instrument, i.e., the smallest quantity recorded accurately by the instrument should be easily derivable from the chart.[169] ALTIMETER

(7) It is highly desirable that the instrument include a unit indicating unequivocally the beginning, direction and close of each turn about the <u>z</u> axis. The trace indicating turn should only be included if the instrument is sufficiently sensitive to provide this information with respect to shallow turns since analogous information for medium and tight turns can be derived from the traces of movements of the 3 air controls. TURN INDICATOR

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167 It is to be recognized that this relation will not hold in these portions of a turn in which the angular extent of climbing or diving, or slipping or skidding is great. Units 3 and 4 will provide a rough indication of whether these conditions exist. Furthermore, the greatest error in the relation occurs when the above conditions exist in the case of shallow banks.

168 If such an altimeter were provided with a means of adjustment to 0 feet at ground level, it might also be used to show whether the subject attained and maintained a <u>specific</u> altitude. The only deterrent to such a use would be the fact that reliance would have to be placed on the instructor or other field personnel to make this adjustment for each flight, whereas, whether the adjustment to 0 feet is correct or not, the instrument can always show variations in feet from any given unknown altitude.

169 A recording rate-of-climb device was rejected because of the existence of an undesirable lag in such an instrument. Moreover, the extent of this lag is variable from time to time and situation to situation.

V. The items described above indicate the essential requirements of the clinical or field instrument. The recommendations are made on the assumption that there is need for a perfected clinical instrument and that the members of the Executive Subcommittee of the Committee on Selection and Training of Aircraft Pilots are satisfied to have an amount up to Four Thousand Dollars ($4,000) expended on the construction of such an instrument. If the mandate is for a "research" instrument, additional preliminary research and a considerably larger grant will probably be required.

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