STALL RECOVERY AND STALL WARNING INSTRUMENTATION IN A LIGHT AIRPLANE

by

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and

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A report on research conducted by the Educational Research Corporation, under the auspices of the National Research Council Committee on Aviation Psychology, with funds provided by the Civil Aeronautics Administration.

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National Research Council

Committee on Aviation Psychology

Executive Subcommittee

M. S. Viteles, Chairman

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LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

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

Committee on Aviation Psychology

June 13, 1950

Dr. Dean R. Brimhall
Civil Aeronautics Administration, W-2B
Department of Commerce
Washington 25, D. C.

Dear Dr. Brimhall:

The attached report, entitled Stall Recovery and Stall Warning Instrumentation in a Light Airplane, by P. J. Rulon and K. W. Vaughn, is submitted by the Committee on Aviation Psychology with the recommendation that it be included in the series of Technical Reports of the Division of Research, Civil Aeronautics Administration.

The present study was directed toward an evaluation of various stall recovery procedures and the supplementary use of stall warning equipment as a "flight instrument." It was conducted, under the auspices of the Committee, by the Educational Research Corporation, and is the latest in a series devoted to problems of stall recognition and avoidance. The results of this study indicated that "On Horizon" methods of stall recovery, in which the nose was held approximately on the horizon throughout, conserved more altitude than did the more orthodox "Below Horizon" methods, in which the nose is "dumped" below the horizon to regain flying speed. In addition, tests indicated that a stall warning instrument, set to be activated at that angle-of-attack associated with maximum angle of climb, functioned effectively in its primary role of giving notice of an impending stall, and also enabled the pilot, by "bracketing" the signal, to maintain an optimum angle of climb in emergencies, such as short field take-offs. Establishment of this dual role for the stall warner appears an important contribution.

The report is submitted with the suggestion that the findings of this, and of previous investigations in the series, be widely disseminated with a view of more adequately indoctrinating civilian pilots with respect to the problem of stall recognition and avoidance. It also seems appropriate to suggest that the findings which warrant generalization should be considered in the revision of CAA manuals, including such special publications as "Facts of Flight." The preparation, for wide distribution, of special materials dealing with the problems of stall recognition, recovery and avoidance, including instructional films incorporating the research findings, might well also be considered.

Cordially yours,

MSViteles

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Morris S. Viteles, Chairman
Committee on Aviation Psychology
National Research Council

EDITORIAL FOREWORD

This report is the latest in a series of studies on stall recognition and avoidance conducted under the auspices of the Committee on Aviation Psychology. Interest of the Committee in this area arose from findings in systematic studies by D. R. Brimhall and R. Franzen,[1] of CAA accident records, which indicated that many fatal accidents in light planes follow an inadvertent stall. The high incidence of such accidents pointed to the importance of determining experimentally the problems of stall recognition, and of an evaluation of stall recovery procedures.

The first two of these studies[2,3] indicated that typical student pilots, private pilots, and even flight instructors failed generally in recognizing the "edge" of stall when attempts consciously were made to do so; that pilots exhibiting relatively good stall recognition in certain maneuvers do not consistently show good recognition in other maneuvers; and that the typical pilot frequently departs inadvertently from normal flight in the direction of the stall when he has no business doing so. The third study, directed toward determining the stall cues used by experts, revealed the effectiveness of certain cues not usually stressed during flight instruction or in current manuals. However, the results of the second and third study supported the recommendation, made by the Committee on the basis of the earlier study, that "regulations be formulated requiring the installation of approved stall warning devices in all private airplanes, providing that field tests demonstrate that available instruments can be adequately maintained and function properly over a period of time."

In the present study, various methods of stall recovery were evaluated, and the supplementary use of stall warner equipment as a "flight instrument" investigated. In general, it was found that in the light plane employed in this study, recovery methods employing full power, and in which the nose of the plane was held approximately on the horizon during the recovery, conserved much more altitude than did the more orthodox recovery methods in which the nose of the plane was dropped below the horizon. Moreover it was

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[1] Franzen, Raymond, and Brimhall, Dean R. A study of serious and fatal accident records during 1939 and 1940. Washington, D.C.: CAA Division of Research, Report No. 77, May 1948.

[2] Rulon, P. J. A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar airplanes. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

[3] Rulon, P.J. The inconsistency of pilot performance in approaching the stall: Relationship to flight conditions, experience and age. Washington, D.C.: CAA Division of Research, Report No. 79, September 1948.

concluded that stall warner equipment, set to be activated at the angle-of-attack associated with the maximum angle of climb, not only served effectively as a stall warner, but also as a flight instrument which may be extremely useful in aiding the pilot to achieve the maximum climbing angle during emergencies such as short field take-offs.

In considering the results of this study, however, two possible qualifications should be noted, particularly with reference to the conclusions bearing on methods of stall recovery. First, the tests were made utilizing a Piper J-3 plane only. While the investigators felt that the Piper J-3 was representative of many light planes the results of this investigation should be checked in other types of light planes before general recommendations are made. Second, as the investigators emphasize, this study represented tests of a plane rather than tests of pilots. The flight test trials were run by two experienced pilots. It seems necessary to determine the effectiveness with which the "On Horizon" recovery procedures can be employed by typical private pilots in order to establish the applicability of the results to the general population. It is of interest in this connection, that representatives of the Civil Aeronautics Administration visited the project and flight tested the "On Horizon" recovery procedures. The investigators reported that favorable comments on the efficacy of these procedures were made.

This investigation was conducted by the Educational Research Corporation under the direction of Dr. P. J. Rulon and Dr. K. W. Vaughn.

Morris S. Viteles, Chairman
Committee on Aviation Psychology

June 13, 1950

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SUMMARY

This investigation was directed toward two questions; first: <u>What should the pilot do when the airplane stalls</u>? and second: <u>Can a stall warning signal be used effectively in indicating optimum angles of climb and glide</u>?

Tests were conducted in a Piper J-3 airplane. The plane was equipped with special instruments, including a stall warning device, an angle of attack indicator, and a radio altimeter. During the tests on stall recovery procedures the stall warner was, of course, inoperative.

The tests were run by two competent test pilots. During the stall recovery part of the investigation, stalls were executed in 11 maneuvers and the effect of various recovery procedures in each maneuver studied. Two major types of stall recoveries were executed, viz: "On Horizon" recoveries, in which the nose of the plane was held approximately on the horizon during the recovery, and "Below Horizon" recoveries, in which recovery was initiated by letting the nose drop about 15° below the horizon until full control of all control surfaces was achieved and recovery to level flight could be effected. Within these major divisions, variations of recovery methods utilizing various combinations of control uses also were tried. Ten trials were conducted utilizing each recovery method in each maneuver, data being obtained (in terms of means and measures of variability) on angle-of-attack at stall, airspeed at stall, number of feet lost in recovery, and time required for recovery.

The results of this part of the study indicated that:

1. With the exception of steep turns, if a stall occurs in a maneuver in which additional power is used or is available, and if it is necessary to recover with a minimum loss of altitude, the pilot should:

   a. Add full power (if full power is available) and keep the nose of the plane on or close to the horizon, and

   b. return, and/or keep, the plane level through use of rudder and elevator, going easy on the aileron control.

The "On Horizon" recovery will take longer than the more conventional procedure of "dumping" the nose below the horizon -- in some maneuvers it may take as long as 14 seconds. However, by sitting tight through the "On Horizon" recovery the pilot may effect recovery with marked savings in altitude loss, as compared with the "Below Horizon" recovery; savings running up to, and exceeding, 100 feet. In certain maneuvers "On Horizon" recoveries can frequently be made with loss of altitude not exceeding 50 feet.

2. In steep turns it appears that the pilot should effect recovery through coordinated use of all controls without attempting to continue the turn.

3. In stalls from gliding maneuvers, where additional power is not available (such as with engine failure) recovery can in general be made with least loss of altitude by letting the nose of the plane drop below the glide path and utilizing coordinated movements of all controls in effecting recovery.

Investigation of the second question involved experimental determination of the angle-of-attack associated with the maximum angle of climb and the minimum angle of glide, and the use of the stall warner signal as a flight instrument in indicating the achievement of these flight conditions. The results of this part of the study indicated that a stall warner set to indicate the maximum angle of climb did not also indicate the minimum angle of glide. Of the two it was considered that indication of maximum climbing angle was of the greater practical importance. In this connection, it was concluded that:

4. If a stall warner is set to be activated at the angle-of-attack associated with maximum <u>angle</u> of climb it can serve effectively as a flight instrument. By "bracketing" the "on-off" interval[1] the pilot can be assured that the maximum angle of climb is being achieved. This function as a flight instrument can be extremely useful in situations where achievement of maximum angle of climb is critical, such as in short field take-offs over obstacles, or in "recovering" from a stall warning at low altitude.

5. With reference to the setting of the stall warning indicator, the evidence clearly indicates that much is to be gained by setting the stall warner to be activated, as the stall is approached, at that angle-of-attack associated with maximum angle of climb. This setting allows the stall warner to function effectively in its primary role of giving warning of an impending stall well before the point of stall actually is reached, enabling recovery to normal flight to be made readily. Moreover, it also enables the stall warner to assume a secondary role as a valuable flight instrument under special circumstances. Establishment of this dual role for stall warning equipment appears to represent a major contribution.

The research yielded additional material of ancillary interest, such as a distribution of angles-of-attack at the stall in various maneuvers.

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[1]That is, as soon as the stall warning signal comes on the pilot decreases the angle-of-attack until the warning signal goes off. He then increases the angle-of-attack until it goes on, promptly decreases it until the warner goes off, then increases the angle-of-attack until it comes on again, etc.

STALL RECOVERY AND STALL WARNING INSTRUMENTATION
IN A LIGHT AIRPLANE

PART I

INTRODUCTION

A. The Problem

The inadvertent stall in light aircraft has recently become the object of intensive study and research. In 1948, Franzen and Brimhall reported on the basis of extensive surveys and studies that many accidents in light airplanes follow an inadvertent stall.[1] This report revealed particularly the need for systematic studies of stall recognition. The result was a series of investigations aimed at various aspects of this problem.[2] The first question investigated was "How competent are various groups of pilots in recognizing and avoiding the stall?" Another study attempted to answer the question "How do competent pilots recognize the imminence of the stall?"[3] This study was generally concerned with the specific sensory cues employed by experienced pilots in recognizing the approach to the stall.

The logical sequel to points raised in this investigation is "What should the pilot do when the airplane stalls?"

The curricula of flight instruction universally include some consideration of the stall, its recognition, and practice in recovery from a stalled condition. This is taught in connection with the full-stall landing and occasionally also to equip the student with a knowledge of the sensory cues

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[1] Franzen, Raymond, and Brimhall, Dean R. A study of serious and fatal accident records during 1939 and 1940. Washington, D.C.: CAA Division of Research, Report No. 77, May 1948.

[2] Rulon, P. J. A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar planes. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

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The studies reported by Rulon were concerned with flight instructors, private pilots, and student pilots. Two additional studies, one concerned with CAA inspectors and the other with three groups of Naval aviators, have also been conducted. The reports on these investigations are in process of preparation.

[3] Rulon, P. J. Stall recognition in a light airplane. Washington, D.C.: CAA Division of Research, Report No. 86, May 1949.

that characterize the approach of stall conditions so that he may avoid inadvertent stalls in flight. It would seem, therefore, that all licensed pilots know how to recover when a stall occurs.

It is probably true that most licensed pilots do know how to recover from a full-stall condition at a safe altitude. Instruction in stalls during training is conducted at a safe altitude, usually 1,500 to 2,000 feet, and the emphasis is ordinarily placed on recovering safely and in an acceptable manner. Students are taught to approach the stall in a more or less standard procedure, required to recognize it as it occurs, and to recover to straight and level flight after stalling. Unless the pilot later attempts an advanced rating, his practice on stalls probably remains at a minimum.

If the pilot stalls at an altitude of 400-500 feet above the terrain, he absolutely must recover without using up his precious altitude in the process. At low altitude, the pilot's problem in recovering from the full stall is one which requires an accurate answer to the question "How can the aircraft be recovered from the full-stall condition with a minimum loss of altitude?"

B. Purpose of this Investigation

The general purpose of the present study was to determine the relative effectiveness of various methods of recovering from stalls in light aircraft. The general questions investigated were (1) How can the pilot of a light aircraft best recover from a primary stall at low altitude? and (2) How can the pilot best utilize a stall warner in avoiding a primary stall? The answers to these general questions may be expected to vary considerably with the type of aircraft involved, with the various maneuvers of flight, and with other important factors in the flight situation. In seeking solutions to these problems for a single aircraft, the present investigation was primarily concerned with the development of methods and procedures whereby these problems, as they pertain to other aircraft and other flight conditions, can be further investigated.

The work of the project consisted of three principal phases: (1) the instrumentation of the testing aircraft and the calibration of the special instruments installed in it; (2) the testing of methods of recovery from the primary stall; and (3) the testing of methods of recovery from a stall warning. Each of these aspects of the study involved problems pertaining to the tests to be devised, the measures obtained, and the criteria of recovery employed.

The ensuing Part II of this report is concerned with the problems of instrumenting the testing airplane and with the calibration of the instruments installed in it. The basic purpose of instrumenting the testing airplane was to obtain accurate and reliable data on airspeed, altitude, and angle of attack. Before any dependable tests of the behavior of the airplane could be conducted, it was necessary to install sensitive instruments which would provide reliable data. The ordinary light plane is not instrumented to provide highly accurate altitude and airspeed data. Few aircraft of any type are equipped with accurate angle-of-attack indicators. The first principal problem of the present study, therefore, was to instrument a light aircraft so that these data would be available for use in the testing procedures.

The second principal problem was to devise and carry out testing procedures for purposes of determining the relative effectiveness of various methods of recovery from the primary stall in the principal types of flight maneuvers. As reported in Part III, this involved devising test procedures, identifying the maneuvers to be tested, defining the various methods of recovery from the primary stall, setting up measures for a basis of comparison, and establishing criteria of recovery. These steps were of course only preparatory to gathering the data. The data were obtained in a series of tests conducted under well-controlled conditions for the purpose of revealing whatever differences exist among the various methods of recovering from the primary stall condition.

Part IV of this report considers the problem of recovery from a stall warning. Many light aircraft are presently equipped with one of several commercially available types of stall warners. Specific problems pertaining to how such warners may best be used were investigated. The recommendations of manufacturers of these devices were considered, and the problem of the optimum stall warning installation was studied.

This phase of the investigation was also concerned with determining the maximum angle of climb and the minimum angle of glide of the testing aircraft and their application to recommended stall warning installation. This is reported in Part V.

The present study was limited in scope in that only one testing aircraft was used. The problems investigated and the methods devised for testing and evaluation of various methods of recovery from the primary stall are, however, basic to similar studies of other types of aircraft. The present study was further limited by the fact that variation in pilot performance was not considered. Recovery from a full-stall condition depends not only upon the particular aircraft, the maneuver which was being attempted, and the physical conditions of the flight situation, but also upon the performance of the pilot who is making the recovery.

The present study did not attempt to test variation in pilot performance. In the planning stage of the present study, it was proposed that a representative group of pilots be tested under uniform conditions in the same aircraft, each pilot recovering from the primary stall in each of several maneuvers. Such a study may prove to be desirable. It was believed, however, that the initial tests should be focused on the performance of the aircraft so that the variation in performance of the aircraft with respect to various methods of its control could be compared and evaluated. The present study, therefore, sought to determine the most effective methods of recovering from a complete stall, and did not consider the problem from the point of view of the pilot flying the aircraft. That is, this study was essentially a test of the machine and not of the men who fly it. Two test pilots carried out all of the testing procedures discussed in succeeding sections of this report.

C. Sponsorship

The studies reported herein were conducted by the Educational Research Corporation, Cambridge, Massachusetts, under the auspices of the National Research Council Committee on Aviation Psychology, with funds provided by the Civil Aeronautics Administration. The study was developmental in character in that several stages were involved. Each of these stages was reviewed and approved by the Committee on Aviation Psychology.[4]

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[4] While the study was in operation, representatives of the C.A.A. visited the Project Staff, inspected and flew the testing aircraft, and reviewed the procedures used in the study. C.A.A. personnel visiting the project included Dr. Dean R. Brimhall, Director of Research; Mr. R. D. Freeland, New York Regional Office; Mr. William S. Moore, Chief of the Airman Division and members of his technical staff, Mr. J. F. Guilmartin, Mr. George Stathers, Mr. William Richardson, Mr. W. Puril Barclay, and Mr. G. Sidney Stanton.

PART II

THE TESTING AIRCRAFT

The aircraft used in this investigation was a Piper Cub, Model J-3, C.A.A. designation NC41578. This aircraft was loaned to the Educational Research Corporation by the National Research Council Committee on Aviation Psychology to which it had been assigned for research purposes. The testing aircraft was based at Bedford Air Force Base, Bedford, Massachusetts.

The Piper Cub was chosen for use in this study because it represented a commonly-used, tandem, two-place trainer. This type of trainer is to be found on most airfields; it is commonly used in instruction; and it is frequently privately owned for personal use. As a popular light training plane, it may be fairly representative of other light trainers of its approximate weight and horsepower.

At the time the study was undertaken, this aircraft was equipped to meet the minimum requirements for day contact flight as prescribed in Part 43 of the Civil Air Regulations. It contained an engine tachometer, an engine oil pressure gauge, an engine oil temperature gauge, an air-speed indicator, an altimeter, and a magnetic compass. In addition to these basic instruments, a five-vane stall warning device was installed in the left wing. This stall warning device had been mounted at The Ohio State University in accord with procedures previously outlined by Rulon[1] in connection with a previous study of stall recognition.[2]

The tachometer, oil pressure gauge, and engine oil temperature gauge as installed on receipt of the aircraft were the standard factory gauges. On the basis of inspection and use, these instruments were found to be satisfactory for the purposes of the study. The airspeed indicator was the normally low-quality instrument generally installed in light airplanes. The scale markings on this instrument were at five-mile per-hour intervals, with the lowest reading at 40 miles per hour. This instrument was replaced. The altimeter was the standard factory altimeter, with each scale division representing 100 feet, and there was no provision for making an altimeter setting. This instrument was considered unsatisfactory for testing purposes and was replaced. The magnetic compass in the testing aircraft was satisfactory for local flying purposes. Since none of the testing procedures

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[1]Rulon, P. J. A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar planes. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

[2]Melton, A. W. and Baken, O. An investigation of the effect of sensory deprivation on stall perception. Progress report in files of NRC Committee on Aviation Psychology, 1949.

involved compass measurements, the original installation was therefore satisfactory for the purposes of the study.

The five-vane stall recognition device was also retained although modified somewhat from the installation employed in The Ohio State investigation. The equipment consists essentially of five stall warner vanes arranged on the leading edge of the wing in such a way that they are successively triggered as the plane approaches a stall. The five-stall warners are wired into five lamps installed on a clipboard which the check pilot holds in his lap. Descriptions of this and similar stall warning device installations are presented in previous CAA reports.[3]

B. Special Instrumentation

Since the basic data on recovery from the primary stall were to be expressed in terms of airspeed, altitude, angle of attack, and time, it was necessary to provide for the accurate measurement of each of these variables. A sensitive airspeed indicator, a radio altimeter, an angle-of-attack indicator, and a stop-watch supplied these data.

1. The Airspeed Indicator

The standard Piper Cub airspeed indicator was replaced by a sensitive Kollsman airspeed indicator, model #5868K. This type of airspeed indicator is used on helicopters and is graduated to read from 10 miles per hour to 150 miles per hour with scale markings at 1 mile per hour intervals on speeds below 80 miles per hour. The instrument installed in the testing aircraft was obtained directly from the Sikorsky plant in Bridgeport, Connecticut.

The installation of this sensitive airspeed indicator required a redesign of the pitot-static system. An Aeronca-type pitot-static system was installed in the airplane to operate both this instrument and the sensitive altimeter. The pitot-static head was mounted on the left front wing strut, and extended below it approximately eight inches. In designing the pitot-static system a dehydrator consisting of a gascolator bowl, filled with silica gel crystals was installed at the low point in the pressure line to the airspeed indicator. The dehydrator was intended for use under the instrument panel. It was discovered that the dehydrator interfered with the movement of the stick when mounted. It was replaced with a drain so that moisture which accumulated in the pitot-static system could be removed. The indicator's position on the instrument panel is shown in Plate I, following.

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[3] Ibid. See also, Rulon, P. J., op. cit. footnote 1 and Rulon, P. J. Stall recognition in light airplanes, Washington, D. C.: CAA Division of Research, Report No. 86, May 1949, pp. 1-5.

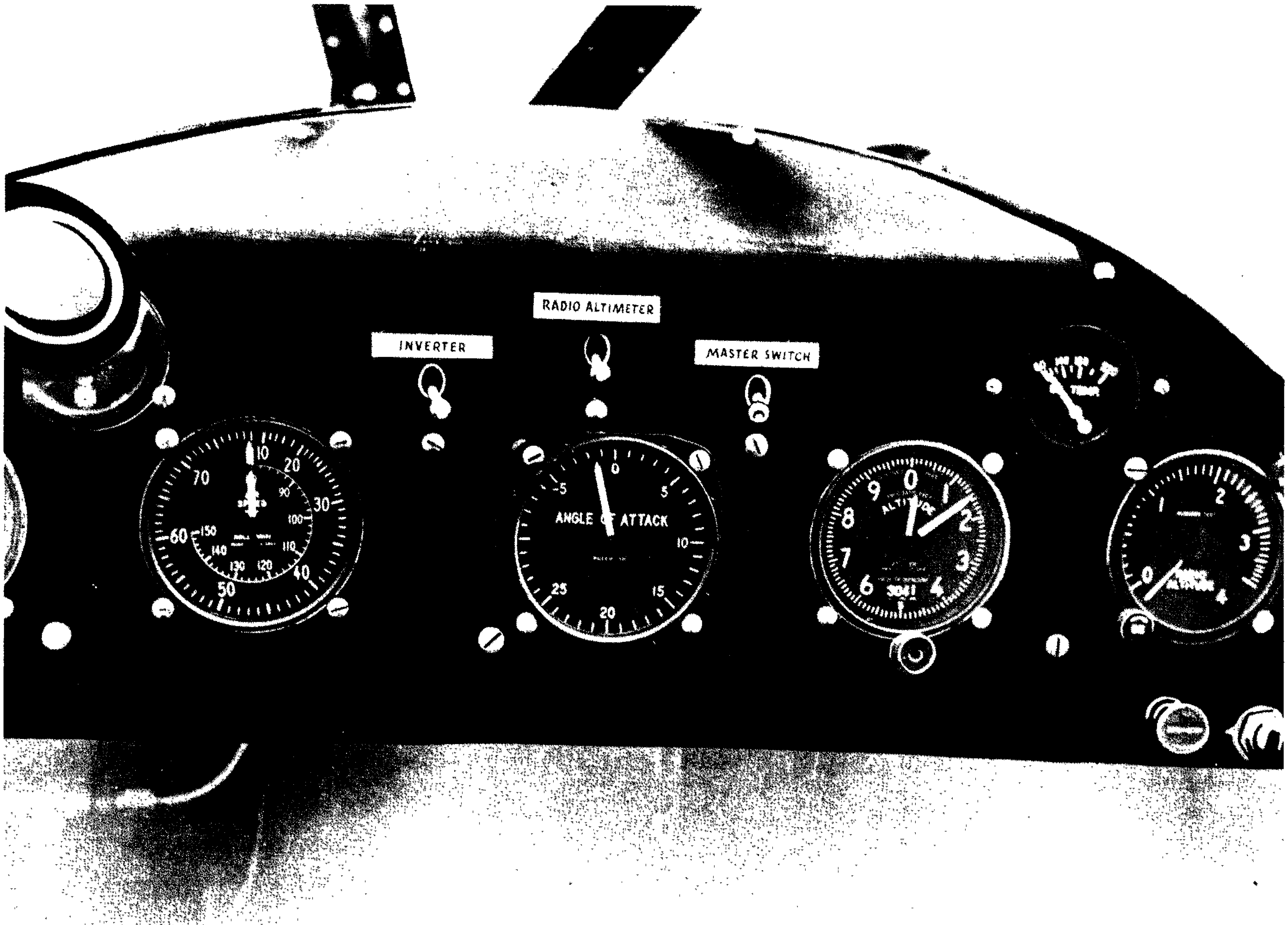

PLATE I

INSTRUMENT PANEL IN TEST PLANE

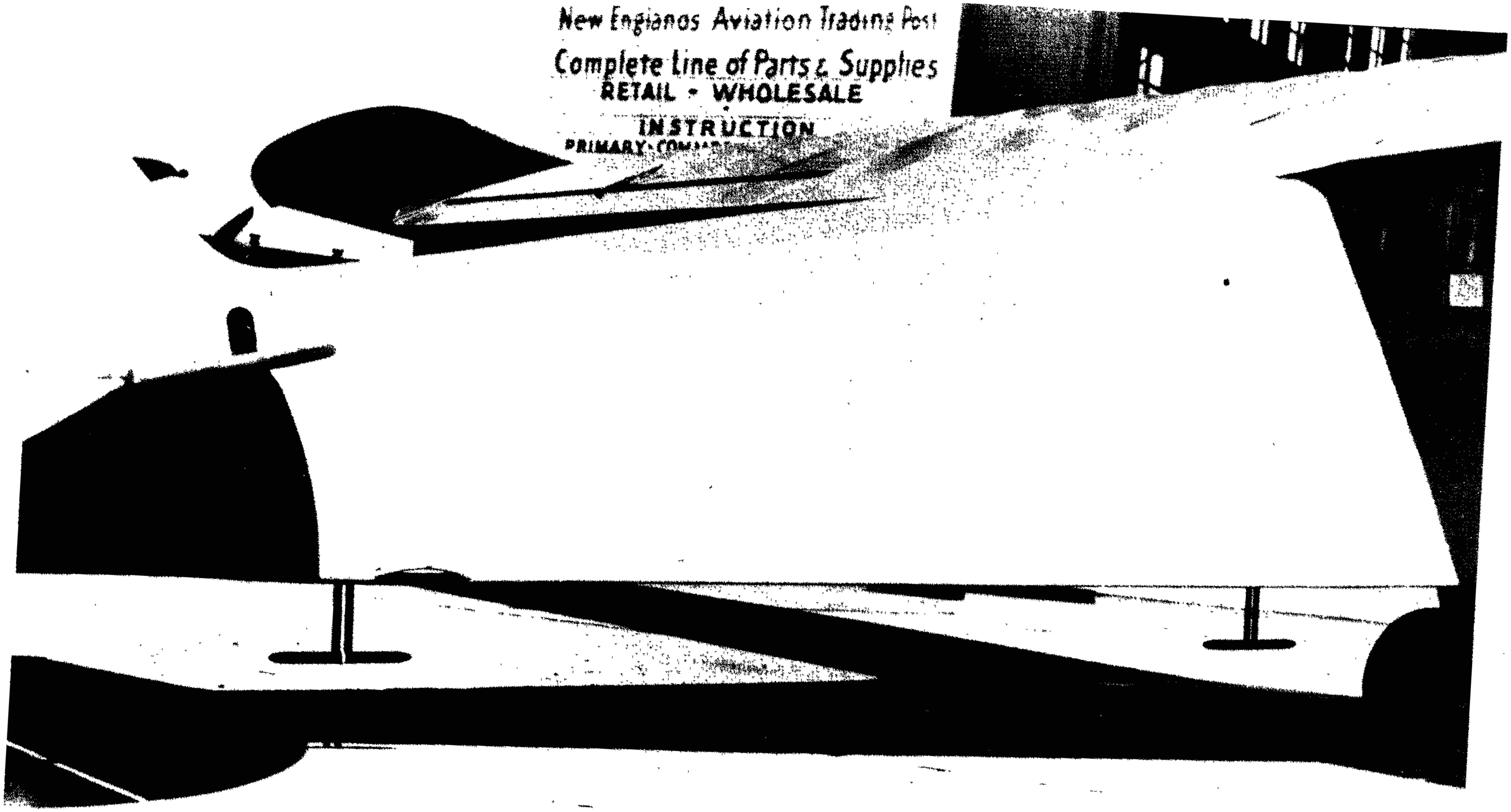

PLATE II

PHOTOGRAPH OF TEST PLANE, SHOWING
DIPOLE ANTENNAE FOR RADIO ALTIMETER

2. Sensitive Altimeter

The Piper Cub altimeter was replaced by a special sensitive altimeter. On this instrument the smallest scale markings are at 10 foot intervals, and altimeter setting is provided. The indicator was mounted in the static line with the airspeed indicator. The indicator's position on the instrument panel was to the right of center as shown in Plate I.

The sensitive altimeter was used primarily for purposes of checking the calibration of the radio altimeter. It was not used in actual testing at low altitude because of the lag which is characteristic of pressure-operated instruments.

3. Radio Altimeter

A standard military-type APN-1 radio altimeter was installed in the testing aircraft. This consisted of a signal transmitter and receiver, an instrument dial, dynamotor, and two dipole antennae. The signal transmitter and receiver were mounted on top of the baggage compartment behind the rear seat on a piece of plywood secured to the air frame. The dynamotor was mounted under the rear right corner of the front seat on the floor. The details of these mountings are shown in Drawings #1 through #4, presented in Appendix A of this report.

The dipole antennae, each mounted in the center of a 2' x 2' section of polished aluminum sheet, were spaced exactly 7 feet apart and were attached to the belly of the testing aircraft. The polished aluminum surfaces proved to be adequate reflecting surfaces for proper operation of the instrument. The antennae extended below the belly of the ship, as shown in Plate II.

As originally obtained, the radio altimeter read true altitude on a low and high scale; the low scale ranged from 0 to 400 feet and the high scale from 0 to 4,000 feet. Since all of the testing was to be done at low altitude, where altimeter readings could be expected to be highly accurate, and since it was desirable to perform the stall tests with a reasonable margin of safety, it was necessary to extend the low scale of this altimeter to read more than 400 feet true altitude. This was done by modifying the electrical circuit and the instrument in such a manner that each unit of the whole scale represented 20 feet rather than 10 feet and, thus, the low scale range became 0 to 800 feet. This procedure permitted fairly accurate readings of true altitude throughout a range sufficient for low altitude testing. It will be noted in Plate I that the scale markings on the radio altimeter (dial on the extreme right) were so spaced that half-scale division readings (10-foot intervals) could be made with good accuracy throughout the scale.

The radio altimeter elements required 24 volts and approximately 6 amperes to operate. A succeeding section explains briefly how the electrical system was installed to accommodate this instrument.

4. Angle-of-Attack Indicator

To obtain angle-of-attack data, a Kollsman angle-of-attack instrument was installed in the testing aircraft. This installation includes a vane which is introduced into the airstream and which activates a small Selsyn master which, in turn, transmits a signal to a Selsyn slave mounted on the instrument panel. The physical displacement of the vane is thus transmitted to an indicator needle. One of the problems of installing an instrument of this type is that of locating the vane ahead of the wing and outside the airstream of the propeller. In the testing aircraft it was necessary to mount a boom under the wing and extending some distance in front of it, so that the vane would not be affected by air flowing over and under the wing.

After extensive experimentation, the boom was installed parallel to the under surface of the left wing at the point where the wing strut and the wing are joined. The leading edge of the vane extended approximately 45 1/2" beyond the leading edge of the left wing. The details of this installation are shown in Drawing No. 3, presented in Appendix A, and the general nature of the boom and position of the vane on it are shown in Plates III and IV following.

It will be noted from Plate I that the angle-of-attack needle swings through a scale ranging from a -5° angle of attack to a $+35^{\circ}$ angle of attack, and that the dial indicator covers the full 360° surface. The particular angle-of-attack indicator used in this study had an amplifying factor of 9, i.e., the movement of the vane was amplified 9 times in the movement of the needle. It was necessary, therefore, to make certain that relatively small displacement of the vane did not result in sizeable errors in angle-of-attack readings.

During the testing and calibration of this instrument, it was discovered that the copper vane which activated the impulse to the indicator was slipping on the small shaft to which it was secured by friction. This shaft is attached to the generator and the slipping of the vane on this shaft necessitated resetting and adjustment. The procedure of resetting the vane to its proper position on the shaft was expedited by the preparation of a template. This template was used regularly to check the vane position on the shaft. Its method of use is illustrated in Plate V following. During the testing procedures it was discovered that the vane position slipped in violent stalling maneuvers. It was therefore necessary to land and reset the vane after particularly violent stalls. To avoid this time-consuming operation, the vane installation was removed and overhauled. A set-screw with a small bronze pressure plate under it was installed for the purpose of securing the vane on the shaft in a constant position. The bronze pressure plate stopped the screw from doing any damage to the shaft and frequent resettings were unnecessary. However, as an additional check, the template was regularly applied to the vane for the purpose of ascertaining whether the vane had retained the same position on the shaft.

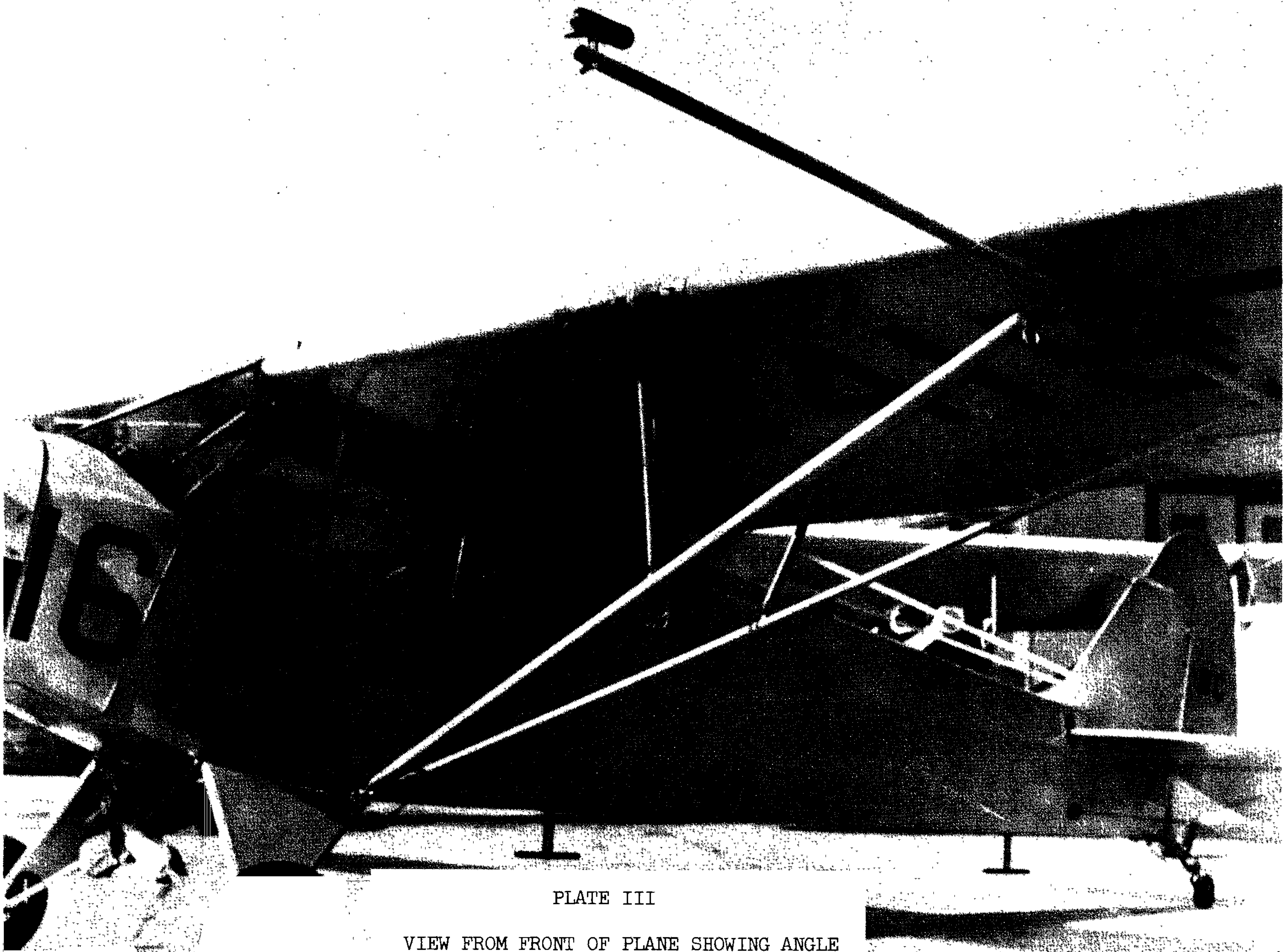

PLATE III

VIEW FROM FRONT OF PLANE SHOWING ANGLE

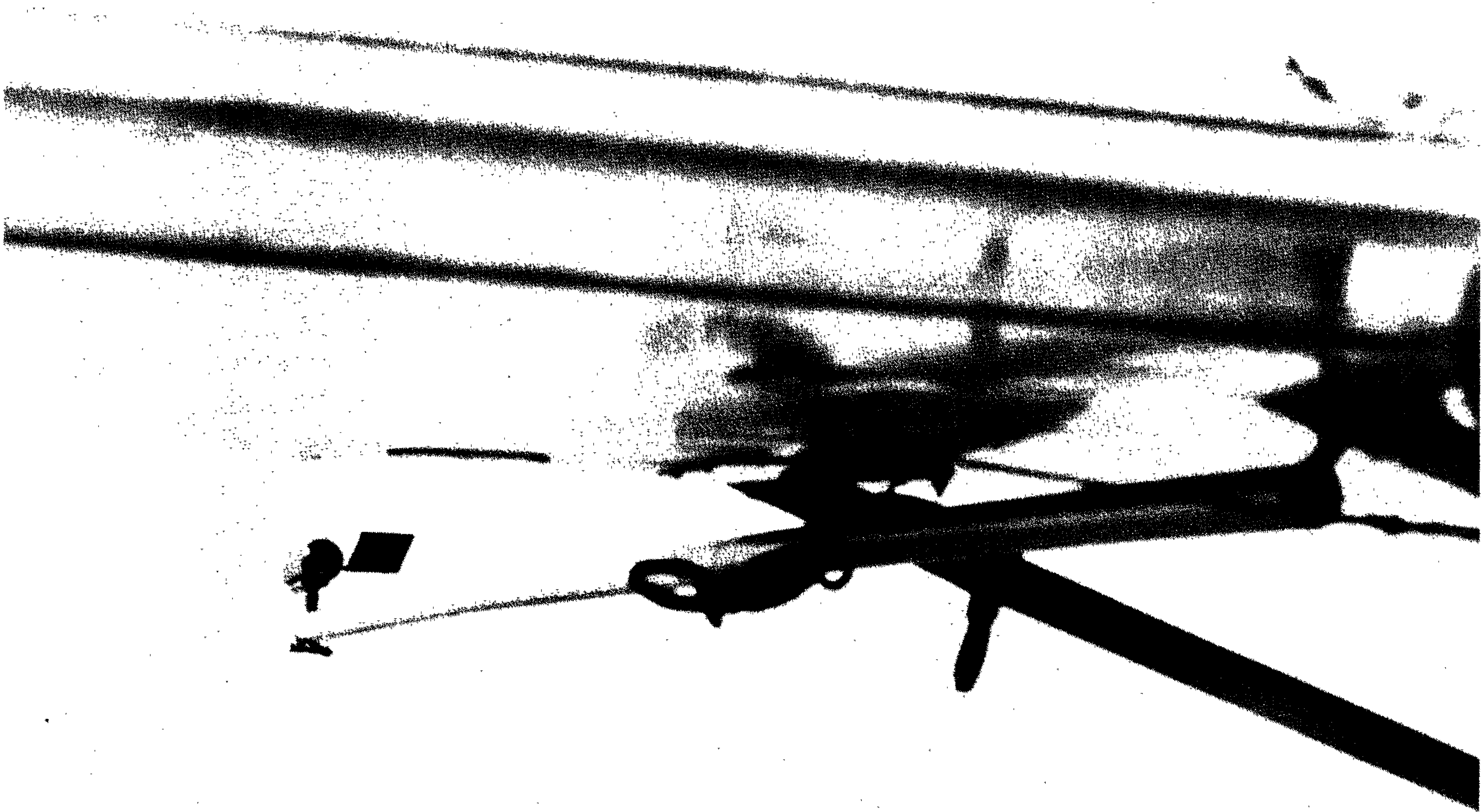

PLATE IV

VIEW FROM TRAILING EDGE OF WING SHOWING
ANGLE OF ATTACK INSTRUMENT INSTALLATION

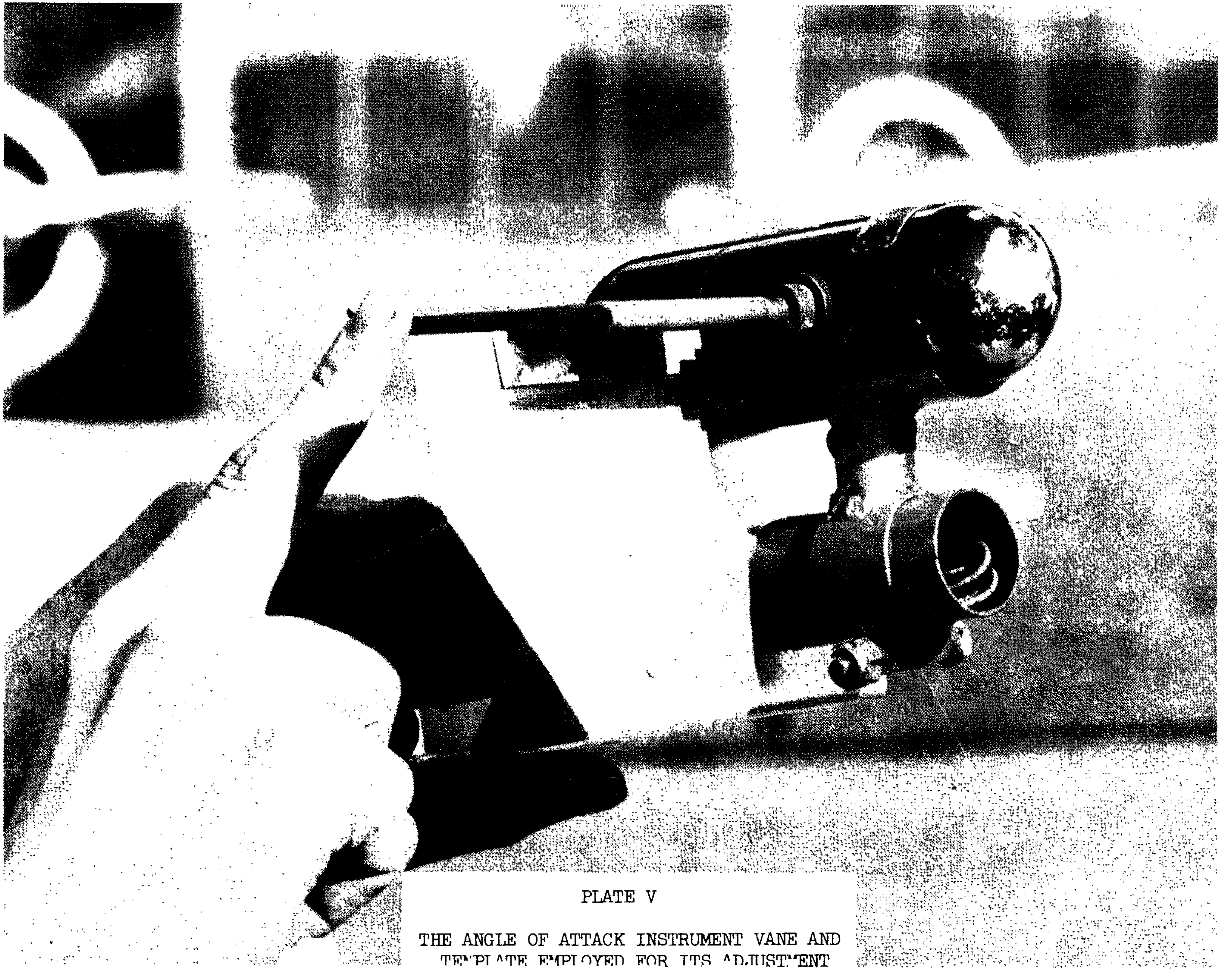

PLATE V

THE ANGLE OF ATTACK INSTRUMENT VANE AND TEMPLATE EMPLOYED FOR ITS ADJUSTMENT

5. Electrical System

In order to provide for the operation of these additional instruments, an electrical system for the testing aircraft was designed. A battery and wind-driven generator were installed as a source of power and wiring and fuse installations were made. The details of these installations are presented briefly in the following paragraphs.

a. Battery. A Willard spill-proof battery, Serial No. NAF 1962-17A, was mounted between the rudders on the floor forward of the front stick. This was a 12-volt, 17 ampere-hour battery at the 5-hour rate. Appendix A, Drawing 1 shows the details of location, and Drawing 6, the details of mounting.

b. Generator. A Champion wind-driven generator, Model 1215, was installed. This generator was a 12-volt, 15-ampere generator, which developed rated power at about 3,000 r.p.m. To conform with C.A.A. regulation, the generator was mounted on top of the landing gear as shown in Plate III and in Drawing 5, presented in Appendix A. This model generator is equipped with a Delco Remy regulating unit, consisting of a voltage regulator, a current limiter, and a reverse current cut-out. The generator was equipped with a hand brake which could be operated from the cockpit to stop it in the event of over-charging or imbalance. The generator, as delivered, utilized a standard two-blade propeller. With this equipment the generator did not develop sufficient power. The hub was re-designed, and a four-blade propeller was fabricated and installed. It was then found that in slow flight the generator did develop sufficient power to operate all of the electrical equipment in the airplane. The four-blade installation was approved by the C.A.A.

c. Wiring System. The electrical system was wired as shown in Drawing 2, Appendix A. This diagram shows the relationship of the invertor and dynamotor to the source of power in the operation of the angle-of-attack instruments and the radio altimeter. In designing this system, the grade of wire and rating of fuses were selected on the basis of C.A.A. requirements. The master switch, the radio altimeter switch, and the angle-of-attack indicator switch, were standard equipment with these instruments.

It may be seen from Drawing 2, Appendix A, that while the source of power was a 12-volt battery and a 12-volt generator, the electrical system used supplied the necessary voltage (24 volts) to operate the radio altimeter and the angle-of-attack transmitter and indicator.

During the installation and testing of the generator, an ammeter was placed in series with the battery to indicate the generator output. The ammeter was taped to the cabane strut as shown in Plate I. Upon the completion and testing of the generator installation, the ammeter was removed as it no longer served a useful function.

6. The Instrument Panel

When the testing aircraft was received, the original instrument panel was torn and patched in several places. On this panel the instruments were located in positions which were unsatisfactory for testing purposes, and also, there was insufficient space for the additional indicators required. A blank instrument panel was obtained and holes were made at points judged to be the easiest to read for testing purposes. An attempt was first made to put the three most important instruments, i.e., the airspeed indicator, the angle-of-attack indicator, and the altimeter on the corners of an equilateral triangle so that the observer could look from any one instrument to another in approximately the same length of time. However, this proved to be impossible when it was discovered that the instruments would not fit in the desired positions.

In designing the instrument panel, it was necessary to mount the radio altimeter at the extreme right of the panel. This was necessitated by the fact that the location of the gas tank interfered with the installation of the indicator mechanism.

The principal details of the instrument panel are shown in Plate I.

In addition to the instruments described above, the testing aircraft was equipped with a free-air temperature gauge mounted in the fixed part of the left side window at the front of the cockpit.

C. Calibration of the Testing Instruments

The second principal step in the instrumentation of the testing aircraft was the calibration of the instruments. There was no attempt to calibrate or test (except by observation) the accuracy of the tachometer, oil pressure gauge, or oil temperature gauge, which were standard equipment on the testing airplane. The calibration activities were confined exclusively to those instruments which provided data for the purposes of the present study. Certain problems encountered in the calibration process were commonplace, while others were quite unique.

1. Airspeed Indicator Calibration

a. Method -- The general procedure used to calibrate the airspeed indicator was to fly the airplane at a constant altitude through a measured distance in a known time period. For this purpose, runway No. 29 at Bedford Air Force Base, Bedford, Massachusetts, was used. This runway is exactly 5,000 feet long and served as the measured distance over which the tests were run. The procedure was to fly the measured distance, both downwind and upwind, on relatively calm days, attempting in both runs to maintain a constant indicated airspeed. During the run, the pilot continuously called off the indicated airspeed readings and every second or third reading was recorded by the observer-pilot. The average of these readings was taken to be the average indicated airspeed over the course for the trial.

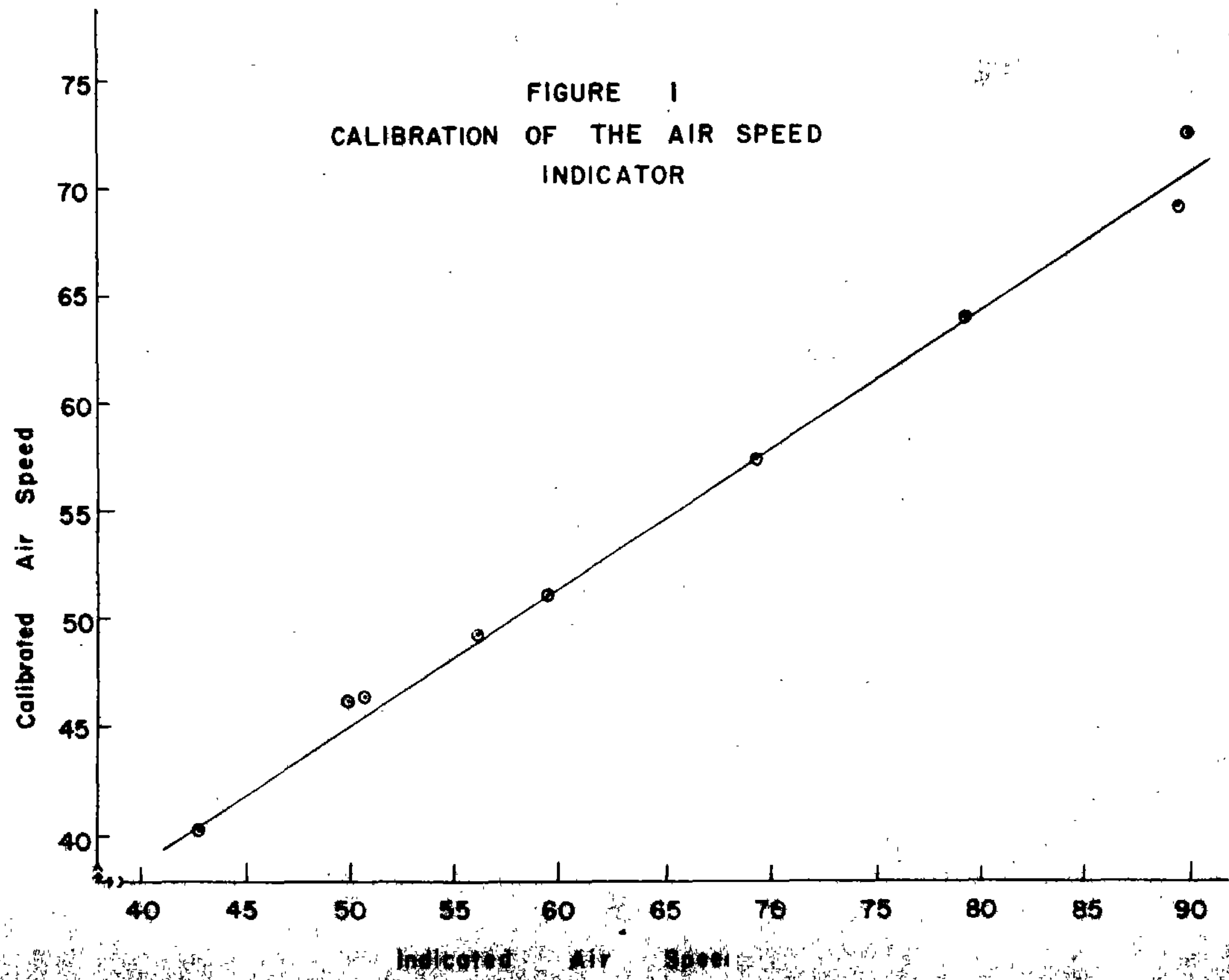

FIGURE 1
CALIBRATION OF THE AIR SPEED INDICATOR

During each run the pilot maintained, insofar as possible, a constant altitude as indicated by the radio altimeter. All flights were made at approximately 150 feet above the runway to increase reliability of timing the flight through the measured distance.

The true airspeed was obtained by determining the average number of seconds required to fly the measured distance. Using the formula for the calculation of true airspeed[4] and making pressure and temperature corrections, a calibrated airspeed was obtained for each indicated airspeed flown during the test. After repeated trials at perfecting the method, discarding trials in which anything went wrong, and running five double (both downwind and upwind) trials for each airspeed, nine indicated airspeeds were equated with their corresponding calibrated airspeeds.

b. Results -- The following tabulation presents the average indicated airspeeds flown and their corresponding calculated calibrated airspeeds.

Point	Indicated Airspeed	Calibrated Airspeed
A	42.9	40.6
B	50.0	46.4
C	50.8	46.6
D	56.2	49.5
E	59.7	51.2
F	69.6	57.7
G	79.6	64.2
H	89.8	69.4
I	90.2	72.9

These data were then graphed and inspected. (See Figure 1.) It was judged that the relationship between indicated and calibrated airspeed was, in general, linear in character. The equation of the curve as determined by calculation was

$$C.A.S = 0.64\ I.A.S. + 13.32$$

From this equation a table listing the calibrated airspeeds for each indicated airspeed ranging from 30 to 90 m.p.h., was prepared. These are presented in Table 1.

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[4] $T.A.S. = \frac{2 \times d}{(T_1 + T_2 \times (1.4667)} = m.p.h.$, in which d is expressed in feet and T is expressed in seconds.

TABLE 1

AIRSPEED CALIBRATION FOR AIRSPEED INDICATOR
INSTALLATION ON AIRCRAFT NC 41578
C.A.S. = 0.64 I.A.S. + 13.32

Indicated Airspeed	Calibrated Airspeed	Indicated Airspeed	Calibrated Airspeed
90	70.9	60	51.7
89	70.3	59	51.1
88	69.6	58	50.4
87	69.0	57	49.8
86	68.4	56	49.2
85	67.7	55	48.5
84	67.1	54	47.9
83	66.4	53	47.2
82	65.8	52	46.6
81	65.2	51	46.0
80	64.5	50	45.3
79	63.9	49	44.7
78	63.2	48	44.0
77	62.6	47	43.4
76	62.0	46	42.8
75	61.3	45	42.1
74	60.7	44	41.5
73	60.0	43	40.8
72	59.4	42	40.2
71	58.8	41	39.6
70	58.1	40	38.9
69	57.5	39	38.3
68	56.8	38	37.6
67	56.2	37	37.0
66	55.6	36	36.4
65	54.9	35	35.7
64	54.3	34	35.1
63	53.6	33	34.4
62	53.0	32	33.8
61	52.4	31	33.2
		30	32.5

2. The Radio Altimeter Calibration

It was noted that the radio altimeter in its normal condition had two scales -- a low scale and a high scale -- and that the low scale read from 0 to 400' and the high scale from 0 to 4,000'. Since the testing work involved recovery from primary stalls at low altitude, the low scale was the only one that could be used. The interest of safety dictated that the testing be done at an altitude of from 500 feet to 700 feet. To obtain radio altimeter readings within this range, the electronic circuit of the amplifier was modified in such a manner that each unit on the indicator scale represented 20 feet rather than 10 feet.

The radio altimeter was equipped with two adjusting set-screws. One of these set-screws adjusts the short end of the low scale. This adjustment is made by landing the airplane and turning the set-screw so that the radio altimeter reads 0 just before the aircraft touches the ground. The 0 adjustment cannot be made with the airplane sitting on the ground. After this initial adjustment has been made, the radio altimeter must be checked carefully during landings. If the needle approaches 0 immediately before the airplane touches the ground, the instrument is properly adjusted.[5]

The second set-screw adjusts the long end of the low scale on the radio altimeter indicator. This adjustment was made as follows: (1) the sensitive altimeter was set with sea-level pressure as given at Bedford Airport; (2) the aircraft was then flown over the ocean at an indicated altitude of 600 feet (the indicated altitude was not corrected for temperature or pressure, as these corrections were negligible); and (3) the set-screw was then adjusted so that the radio altimeter read an indicated 300 feet.[6] It was necessary to make this latter adjustment on a very calm day, and it was necessary to make it over water so that the surface reflecting the altimeter signal did not change significantly during the test runs. After the sensitive altimeter and the radio altimeter agreed when flying at a constant altitude over water for a sufficiently long period of time, the second set-screw was assumed to be properly adjusted. The covers were then secured over the set-screws.

3. Calibration of Angle-of-Attack Indicator

a. Method. The first step in the calibration of the angle-of-attack installation was to determine the angular difference between the assumed wing chord (from the leading edge to the trailing edge of the wing)

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[5]When the ground contact is made, the needle indicates a reading of 50 feet. This phenomenon is explained in technical manuals describing the operation of the radio altimeter.

[6]As noted above, an indicated altitude of 300 feet was an actual altitude of 600 feet, inasmuch as the indicator units which originally represented 10 feet, were made to represent 20 feet by alteration of the electronic circuit.

and the actual wing chord (the bottom surface of the wing). The first setting of the vane on the angle-of-attack indicator was based on the assumption that the wing chord passed through the leading edge of the wing and the trailing end of the wing. The vane was set to read 0 when it was parallel to this assumed chord. It was learned, however, that the wing chord of the J-3-C is assumed to be the bottom surface of the wing.[7]

By a procedure described in some detail in Appendix B, it was determined that the difference between the assumed chord and the true chord of the wing was 1°, 39'.

To calibrate the angle-of-attack installation at various attitudes in flight, a large protractor with a bubble level fixed on a movable indicator was mounted on the left rear window of the testing aircraft. This inclinometer was so fixed that it indicated 0° when the bottom surface of the left wing root was level.

It was then necessary for the test pilots to check angle-of-attack readings in the air. The pilot flew the testing aircraft from the front seat and the observer-recorder sat in the back seat so that he could read the inclinometer accurately. The pilot selected a desired flying attitude. He then adjusted the throttle until the aircraft was neither gaining nor losing altitude. This was cross-checked by a rate of climb indicator and the radio altimeter. The observer-recorder, in the meantime, kept the bubble on the blade of the protractor centered at all times. When the pilot decided that the ship had settled down to stable flight, he called, "NOW," and read the angle-of-attack, airspeed, and r.p.m. The observer stopped adjusting the bubble, leaving the protractor set, while he recorded the instrument readings called out by the pilot as well as the protractor reading. Flight testing was necessarily restricted to times when there was a minimum amount of turbulence. It was necessary for this reason to make many test runs before acceptable data were obtained.

b. Results. After a number of preliminary trials were rejected a series of angle-of-attack indicator and inclinometer readings were obtained. From these readings, five points representing the average readings

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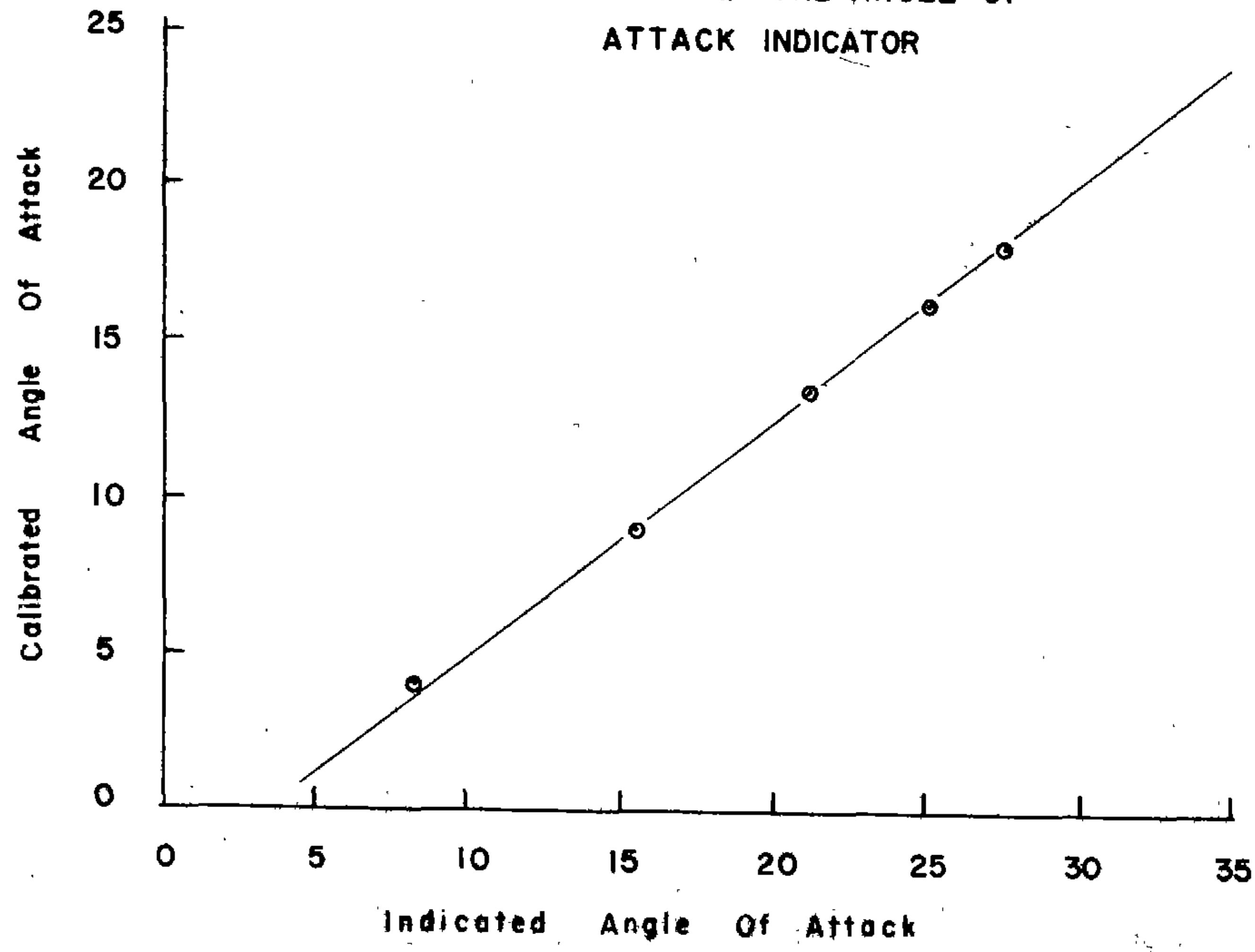
[7]The following information was obtained by telephone from the Piper Aircraft Corporation Engineers at Lockhaven, Pennsylvania:

1. The datum line of the J-3-C to be used for longitudinal leveling is the longeron which runs from the tail and passes under the window on the left side of the ship;
2. The root angle of incidence is +2°30'. Both wings are washed out which decreases the angle of incidence to -41' at the wing rib located at the outboard end of the aileron;
3. The wing chord of the J-3-C is considered to be the bottom surface of the wing, which is nearly flat. The wing used on the ship is a Clark airfoil 35B modified.

FIGURE 2
CALIBRATION OF THE ANGLE OF ATTACK INDICATOR



at selected points on the angle-of-attack scale were obtained. Five runs each were attempted at indicated angle-of-attack readings of approximately 8°, 15°, 20°, and 25°. The following tabulation presents the average angle-of-attack indicated at each of these five points and the corresponding calibrated angle-of-attack values.

Angle-of-Attack Readings

Point	Indicated	Calibrated
A	8.25	4.05
B	15.56	9.00
C	21.12	13.43
D	25.18	16.17
E	27.50	18.05

From graphed data, as indicated in Figure 2, it was judged that the relationship between the indicated angle-of-attack and calibrated angle-of-attack was linear in character, and could be expressed by the following equation:

$$C.A/A = 0.75\ I.A/A - 2.54$$

On the basis of this equation, the calibrated angle of attack for each point on the Kollsman indicator scale was determined. These values are presented in Table 2, following.

D. Summary

Every effort was made to insure the accuracy and reliability of the testing instruments in order that the data obtained might be accurate and dependable. Several months of working time were required to complete this phase of the Project. The design and the size of the testing aircraft complicated the problems of instrumentation for testing purposes. However, all of the necessary instruments were installed and properly calibrated. After this process was completed, the testing aircraft was inspected by the C.A.A., and was approved for flight under the usual Civil Air Regulations for such aircraft. The weight and balance requirements were met, as were all other regulations. It was not, therefore, necessary to register the testing aircraft as an experimental one. In this sense, at least, the plane did not depart significantly from the general characteristics of other Piper Cubs as they are used in flight training and by private pilots.

TABLE 2

ANGLE OF ATTACK CALIBRATION FOR KOLLSMAN
ANGLE-OF-ATTACK INDICATOR INSTALLATION
ON AIRCRAFT NC 41578
C.A/A = 0.75 I.A/A - 2.54

Indicated Angle of Attack	Calibrated Angle of Attack	Indicated Angle of Attack	Calibrated Angle of Attack
1	-1.79	19	11.71
2	-1.04	20	12.46
3	-0.29	21	13.21
4	0.46	22	13.96
5	1.21	23	14.71
6	1.96	24	15.46
7	2.71	25	16.21
8	3.46	26	16.96
9	4.21	27	17.71
10	4.96	28	18.46
11	5.71	29	19.21
12	6.46	30	19.96
13	7.21	31	20.71
14	7.96	32	21.46
15	8.71	33	22.21
16	9.46	34	22.96
17	10.21	35	23.71
18	10.96		

PART III

RECOVERY FROM THE STALL

Eleven practical maneuvers involving climbs, glides, turns, and variations in power settings were investigated. Recoveries were effected by the optimum use of combinations of the following: Power (P), Rudder (R), Ailerons (A), Elevators (E), Nose on Horizon (OH), and Nose below Horizon (BH). The measures of the relative effectiveness of the various methods of recovery from the primary stall were expressed in terms of seconds necessary for complete recovery, and altitude in feet lost during recovery. In the first series of tests of recovery from the full stall, the aircraft was recovered to straight and level flight, and, in a second series of tests, to the normal flight attitude[1] for each maneuver being attempted at the time the stall occurred. In addition to the measurement of altitude lost during recovery and the time required for effecting it, measurements were also made on airspeed and angle-of-attack. These data provide the basis for the evaluation of the recovery methods used in this study.

A. The General Plan of Testing

The general plan of testing was to fly the instrumented airplane over a body of water, advance toward the stall condition in a defined maneuver, stall the aircraft, and measure its performance under various methods of recovery. Since the radio altimeter was especially sensitive to changes in altitude, it was important to conduct all of the tests over a relatively flat surface. It was important, also, to standardize the various methods of recovery so that they could be adequately described and repeated in successive trials. The tests were essentially tests of the performance of the aircraft. It has been noted in preceding sections of this report that only two test pilots were used throughout the study.[2] One test pilot flew the aircraft and made a limited number of instrument readings. Most of the instrument readings, however, were made by an observer. The two test pilots alternated the pilot-observer responsibilities on a systematic basis so that the results for any one maneuver-recovery combination were equalized in terms of pilot performance.

The plan of testing specified that each recovery method be represented by at least ten trials performed under controlled and reproducible conditions. It specified further, that the tests were to be run in relatively calm air so that the effects of turbulence would, insofar as possible, be

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[1]As defined in terms of angle-of-attack and air speed.

[2]These were Philip B. Sampson, E.R.C. Chief Test Pilot, and Leo J. Kerivan.

equalized from trial to trial within the same test, and between various types of recovery in each maneuver tested. The general purposes of these specifications were to obtain data under comparable conditions.

B. The Maneuvers Tested

It was necessary for several reasons to restrict the maneuvers investigated to "typical" flight maneuvers. Primary stalls occur in many complex types of aircraft maneuvers; it was not possible to investigate all such maneuvers. It is believed that the eleven practical maneuvers which were selected for testing are sufficiently inclusive to provide the basic data on stall recovery.

The maneuvers tested were:

1 Straight-Ahead - Climbing Power (Full Throttle);
2 Straight-Ahead - Cruising Power (2,100 r.p.m.);
3. Straight-Ahead - Reduced Power (1,000 r.p.m.);
4. Left Climbing Turn - Climbing Power (Full Throttle);
5. Right Climbing Turn - Climbing Power (Full Throttle);
6. Left Gliding Turn - Reduced Power (1,000 r.p.m.);
7. Right Gliding Turn - Reduced Power (1,000 r.p.m.);
8. Left Steep Turn - (2,100 r.p.m. - 60° Bank);
9. Right Steep Turn - (2,100 r.p.m. - 60° Bank);
10. Left Slow Turn - Reduced Power (1,500 r.p.m. - 30° Bank);
11. Right Slow Turn - Reduced Power (1,500 r.p.m. - 30° Bank).

For testing purposes it was necessary to define these maneuvers and to specify for each the power setting and the degree of bank, where turns were involved. In practice, of course, the pilot of a light aircraft may be one who flies "by the seat of his pants," and his aircraft may not contain the instruments whereby his flight attitudes or maneuvers can be defined so specifically. Nevertheless, the private pilot is concerned with full power climbs, reduced power glides, and level turns. He also engages in slow flight frequently, with reduced or cruising power. These are maneuvers in which the inadvertent stall occurs.

<u>Conditions in which stalls may occur</u>. Stalls occur in full power, climbing maneuvers. In climbing out of a short field, the pilot may attempt to obtain the steepest possible climb, particularly if there is danger from trees, telephone and telegraph wires, or other obstacles in his path. If the runway faces a small hill and the day is windy, the pilot may have an extraordinarily difficult task in climbing over the ridge. Sometimes it is necessary in these climbs to make turns to avoid objects such as a tree or another aircraft. If he turns either right or left and attempts to climb as steeply as possible, then he is bringing about a situation in which the aircraft can easily stall.

Stalls apparently occur frequently under cruising power. The pilot's attention may be distracted by something outside the plane. This is frequently reported as his "girl friend's" house or his own home, the field where he is trying to enter the traffic pattern, or another airplane in the immediate vicinity. The straight-ahead, cruising power maneuver may result in a stall when the pilot is not paying attention to his airplane and pulls the stick back too far. This may happen, also, in the traffic pattern when the pilot attempts to regain traffic altitude without applying power.

The gliding maneuvers may be especially dangerous. In some cases the pilot attempts to stretch his glide to reach the runway or to make a good approach to a small field. The pilot pulls the stick back, attempting to retain as much altitude as possible. He may be caught in a down draft in his glide into the field, or a sharp gliding turn may precipitate the stall.[3]

Stalls in steep turns are likely to occur when the pilot has overshot his course and is attempting to get back on course as soon as possible. This may occur in turning onto the downwind leg of the airfield where the pilot has decided to turn abruptly on the downwind leg, or during the turn to the base leg where he has misjudged the wind velocity. He may find suddenly that he is drifting too far from the airport. In this case he steepens his bank in order to conserve distance. The stall out of the steep turn may also occur on the important turn onto the final, where the pilot has overshot the wind line. Stalls from steep turns may also occur during the performance of the practice maneuver, "On pylon-eight's."

In this study, level turns were performed at reduced power, 1,500 r.p.m. This simulates the turn the pilot makes when he discovers that he is about to overshoot the field on the downwind leg. He may reduce power and start a turn onto the base, or onto the downwind leg, or onto his final leg. In such cases his attention is frequently diverted outside his airplane. The pilot may throttle back so that he can make a small radius turn. In doing this he slows up his airplane to the point where the plane can easily stall.

C. Methods of Recovery

As in the case of maneuvers, it was necessary to define specifically the methods of recovery to be tested. Before this study was undertaken, it was believed that the methods of recovery might be described generally. Preliminary testing revealed the need for more adequate definition and fairly exact specifications to guide the test pilots in the testing work.

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[3]The test pilots flying the testing aircraft reported that those stalls which resulted from a glide may be the most dangerous of all. A stall resulting from a glide, whether it be in the straight-ahead, right or left turning glide, appears to give very little warning. Both test pilots agreed that the straight-ahead glide gives the least warning of any of the stalls performed.

Preliminary interviews. In personal interviews with approximately 40 flight instructors, opinions were obtained as to the optimum methods of recovering a stalled airplane. Five general methods of recovery were recommended by the instructors interviewed. These were:

1. Put the nose toward the ground,
2. Put the nose away from the pilot,
3. Add power,
4. Use rudder only, and
5. Use ailerons.

For experimental purposes, these recommendations for ways in which to recover from the stall were somewhat ambiguous. It will be noted that three of the recommendations pertain to the use of controls, and two pertain to what is done to the airplane; i.e., putting the nose towards the ground and putting the nose away from the pilot. It was evident during early conferences devoted to the problem of defining methods of recovery, that even the test pilots who had interviewed these instructors did not understand exactly what was meant. As a result of these conferences, a more fundamental analysis of the possible methods of stall recovery was developed and tested experimentally.

Methods of describing stall recovery. Recovery of an airplane from a complete stall may be described in either of two ways. In the first place, the description may be concerned only with the particular controls that are used in effecting recovery. Secondly, the recovery may be described in terms of what happened to the airplane in relation to its attitude, airspeed, or other flight variables. The definition of the methods of recovery as used in this study involved both types of description.

Definition in terms of power plant and control surface. Methods of stall recovery were first defined in terms of the power plant and the three control surfaces of the plane; i.e., P- add power, R- use rudder, A- use ailerons, and E- use elevators. This type of definition results in fifteen possible statements of methods of recovery from stalls:

P - add power only,
R - use rudder only,
A - use ailerons only,
E - use elevators only,
PR - add power and use rudder,
PA - add power and use ailerons,
PE - add power and use elevators,
RA - use rudder and ailerons,
RE - use rudder and elevators,
AE - use ailerons and elevators,
PRA - add power, use rudder and ailerons,
PRE - add power, use rudder and elevators,
PAE - add power, use ailerons and elevators,
RAE - use rudder, ailerons, and elevators,
PRAE - add power, use rudder, ailerons, and elevators.

These definitions appeared to be more fruitful for experimental purposes than the suggestions made by the instructors. The instructors' recommendations involved not only the use of certain controls, but also what was accomplished by them. This latter characteristic provided a clue for defining two other variations in methods of recovery. These were the "On Horizon" recovery attitude and the "Below Horizon" recovery attitude.

Definition in terms of visual reference employed. While a pilot uses certain controls and the power plant to effect a recovery from the complete stall, he must also be provided with some visual reference to the attitude of the plane. This reference under visual flight conditions is usually the horizon.[4]

The usual procedure of recovering from a full stall is "to push the nose below the horizon and regain airspeed as soon as possible." This procedure is probably quite satisfactory when the loss of altitude is not the first matter of importance. It is obvious, however, that a pilot who holds the aircraft nose-down toward the ground for any significant length of time may build up excessive air speed or lose excessive altitude or both. At low altitude the pilot is primarily concerned with effecting recovery with the least possible loss of altitude.

"On Horizon" and "Below Horizon" recovery methods. In experimenting with various degrees of "putting the nose toward the ground" the test pilots reported that the testing aircraft would regain straight and level flight if the nose was arrested as it neared the horizon line, and was stopped on it. It was reported that straight and level flight could be achieved more rapidly, however, by putting the nose below the horizon and regaining airspeed more rapidly. These two possibilities of defining the method of recovery were incorporated into the design of the study.[5]

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[4]Under instrument conditions it may be special instrument readings, e.g., air speed, degree of bank, or other measures. This study was primarily concerned with light aircraft in which instruments are ordinarily not available. It was believed desirable to experiment with attitude references that would be readily available to any pilot under day contact-flight rules. When the pilot uses various controls to effect a recovery, he may "put the nose away from him," as in a turn, or he may "put the nose towards the ground," as in a straight-ahead climbing or gliding stall, but he needs more definite instructions than this. The light aircraft stalls in a nose-high attitude and, as he "pushes" the nose toward the ground or away from him, he should have at least some reference point or line which will tell him how far to push it.

[5]The test pilots first experimented gingerly with the test of recovery to "on the horizon." This was done first at an altitude of approximately 1,000 feet. One of the test pilots was skeptical that the recovery could be effected in this way and thought it unnecessary to attempt this type of

More specifically, the "On Horizon" recovery method was described as the one in which the nose of the aircraft was arrested and held on a level with the horizon line. The test pilots held the nose "On Horizon" rather than let it fall below. On the other hand the "Below Horizon" recovery was effected by deliberately "pushing" the nose down below the horizon. In this latter maneuver there were no rigid measurements of the exact extent to which the nose was "pushed" below the horizon, but it was estimated by the test pilots that in the "Below Horizon" recovery the nose of the aircraft was aimed at a point approximately 15° below the horizon line. Both test pilots were also experienced flight instructors. It was their judgment that the "Below Horizon" recovery was the <u>normal</u> recovery used in instruction at safe altitudes where loss in altitude was not in question, but where a safe and efficient recovery to straight and level flight was the principal concern. It was believed unnecessary to define either of these criterion conditions more specifically.

Flight instructors and pilots can easily understand the difference between these two types of recovery and even though the "Below Horizon" recovery may sometimes mean an angle greater than 15° below the horizon, the findings of this study would only be exaggerated by this procedure. The pilot who attempts a very steep "Below Horizon" recovery will regain airspeed in a very short time, but he may have difficulty in recovering the airplane to straight and level flight without precipitating a secondary stall or a consequent spin.

<u>"On path" and "below path" recovery methods</u>. The "On Horizon" and "Below Horizon" methods of recovery were the model also for "On Path" and "Below Path" methods of recovery from gliding maneuvers. As described later, the testing aircraft was, in one series of tests, recovered to the angle-of-attack and airspeed characteristic of straight-ahead glides and left and right gliding turns. In effecting recoveries under "On Path" and "Below Path" conditions, the pilot employed the same general procedures used in recovery "On Horizon" and "Below Horizon" methods.

"On Path" recovery was effected by "pushing" the nose downward or away from the pilot until the criterion of recovery (analogous to the horizon line) was achieved and the aircraft was held in that position until it gained sufficient airspeed characteristic of the maneuver involved. That is, when the recoveries were made from the stall induced from a straight-ahead glide, they were effected with the nose below the

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5(Cont.) experimentation. However, the second test pilot had had a related experience in the Army Air Forces in which, as he stated, certain multi-engine aircraft were recovered from the full stall by the "On Horizon" reference, rather than the "Below Horizon" reference. It may be of interest to report here that the first test pilot, who doubted the feasibility of this method of recovery, was soon convinced of its application and use.

horizon and held on the "On Path" attitude for that maneuver. Just as in the case of the "Below Horizon" recoveries, the "Below Path" recoveries involved greater use of elevators, with the nose held below the normal flight path until flying airspeed was regained, and the nose was then brought up to the criterion attitude.

Definition of recovery methods. These methods of recovery were as carefully defined and executed as possible. In those recovery methods, for example, which involved only rudder and elevators, the stick movement attempted to effect changes in the elevators only. In certain turning maneuvers, it was not possible, of course, to avoid the use of some aileron in an RE (Rudder and Elevator) recovery. This vagueness of definition was of considerable concern to the test pilots in the early stages of the investigation, but after demonstration and explanation, the pilots were able to perform an RE recovery with the introduction of only a minimum aileron effect.

An RE recovery may be defined, generally, as one which was effected by the optimum use of the rudder and optimum use of the elevator and with a minimum of aileron control and no change in power setting. Similarly, an AE recovery involved the optimum use of the aileron and elevators and a minimum of rudder control, and no change in power. In fact, in the AE recovery, the test pilots customarily released the rudders in straight-ahead maneuvers and performed the recovery with their feet off the rudder pedals. In turns, where some rudder was already in use and was necessary to continue the turn, the AE recovery specified that the pilot make optimum use of the ailerons and elevators and move the rudder as little as possible and not at all, if feasible.

Certain of the recovery methods were therefore "purer" than others. All maneuvers involving power (P) can be definitely defined as those in which additional power was applied. All straight-ahead maneuvers not involving rudder were generally performed with the feet off the rudder-control pedals. All turns where R was not specified involved a minimum movement of rudder after the turn was established.

D. Criteria of Recovery

Recovery from a stall implies recovery to some flight attitude. In instruction the student is generally taught to recover to straight and level flight. When the stall occurs under actual flight conditions, the pilot may be less interested in recovering to straight and level flight than he is with full control of the aircraft in the flight attitude characteristic of the maneuver he was attempting at the time the stall occurred. Thus there are at least two usable criteria of recovery: (1) recovery to straight and level flight, and (2) recovery to the flight attitude characteristic of the maneuver being attempted at the time the stall occurs.

1. Recovery to Straight and Level Flight

Recovery to straight and level flight is designated as Case I in this study. It is described as straight and level flight and was defined in terms of angle-of-attack at cruising airspeed. To determine the instrument readings characteristic of straight and level flight, successive tests were run over water with the sensitive altimeter and the radio altimeter in full agreement for an extended period of time (from 3 to 5 minutes), and during this period the observer recorded constantly the angle-of-attack readings throughout the trial. Successive trials were run on several days and an average of all of the angle-of-attack readings taken under these conditions was obtained. This average angle-of-attack reading for straight and level flight in terms of angle-of-attack was 7.0° indicated, 2.71° calibrated.

Recovery to straight and level flight, then, was judged to be effected when, following a stall, the aircraft had returned to 7° indicated angle-of-attack, wing level, straight flight.

2. Characteristic Attitude of Flight Maneuvers

When the aircraft was recovered from the complete stall to the flight attitude characteristic of the maneuver being attempted at the time the stall occurred, this was designated as Case II. Investigations of Case II recoveries were limited to glides: straight-ahead glides and left and right gliding turns. In determining the flight attitude characteristic of a normal glide, the aircraft was glided at 65 m.p.h. indicated airspeed in successive trials similar to those conducted in straight-ahead, level flight, and the observer similarly recorded angles-of-attack during the glide. The result of this test indicated that the angle-of-attack characteristic of the normal glide was approximately 13° indicated, 7.21° calibrated, with a power setting of 1,000 r.p.m.

In effecting recoveries from stalls initiated in gliding maneuvers, the aircraft was recovered to an indicated angle-of-attack of 13° and an indicated airspeed of 65 m.p.h., 54.9 m.p.h. calibrated.

E. General Testing Procedures

1. The Testing Schedule.

Before any final tests were run, the entire testing schedule was outlined. This schedule provided for the staggering of tests of various recovery methods in different maneuvers, so that a particular test would not be adversely affected by variations in the weather, in the condition of the aircraft, or similar factors. Insofar as possible, the tests were conducted so as to equalize the effect of factors likely to affect the performance of the airplane. These included, among others, the day on which the test was flown, turbulence, and the pilot flying the airplane.

2. Preliminary Experimentation and Practice

During the performance of the stall and the recovery, both the pilot and the observer were busy with their several tasks, and each had to perform his tasks smoothly and accurately before the test could be successful. The first stage of experimentation began with agreement on directions for performing maneuvers and recoveries. Several flying days were required to complete this phase of the study. In all, a period of approximately two weeks was spent in conference and experimentation with the various recovery methods. Caution was exercised also in the matter of approach to the stall.[6]

Considerable training was necessary so that the observer and the pilot could read the instruments accurately and efficiently. With the possible exception of the stop watch, all of the indicators read in collecting data were moving at the time readings were made. Several hours of flying were required to provide the necessary training.

3. Tests Were Run Only in Relatively Calm Weather.

The testing procedures required approximately five months to complete. It was necessary for reasons of comparability to fly only when the weather was relatively calm. Many of the tests were made in the early morning hours and in the very late afternoon hours. Tests conducted in turbulent air were re-run under suitable weather conditions.

4. All Tests Were Conducted Over a Body of Water.

Approximately one-third of the tests were conducted over a relatively calm bay, sheltered from the open ocean by a beach off Boston Harbor. Approximately two-thirds of the testing was done over lakes or flooded lowlands in the vicinity of Bedford Air Force Base, Bedford, Massachusetts. These bodies of water provided a flat surface and altitude readings were therefore not subject to even the moderate variations in terrain that might have been encountered had a plain or other relatively "level land" surface been used for testing purposes.

Since all of the tests were conducted at very low altitude (from 400 to 700 feet) and there was the usual possibility of an engine failure, the testing areas were further restricted to bodies of water with a suitable landing beach or, as in one case, a convenient golf course nearby.

5. Instruments Were Checked Daily.

As reported earlier, the angle-of-attack indicator was reset daily by the use of a template. This was necessitated for two reasons. Casual

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[6]The test pilots reported that a stall which was approached gradually, as might occur in flight, possessed characteristics quite different from the "accelerated" stall. There is little reason to doubt that the condition under which the stall is approached will affect its recognition on the part of the pilot and may possibly introduce psychological factors affecting his method of recovery.

visitors to the hangar were intrigued by the novel boom installation and "tested" the vane, despite the warning sign which was left on it during the times when the plane was not in flight. Also, as the testing proceeded, the setting of the vane on its shaft became displaced to some extent so that resetting was necessary.

6. Testing Periods Were Limited to Approximately One and One-Half Hours.

At the end of one and one-half hours, the pilots reported considerable fatigue. There was no way for the pilot and the observer to change positions in flight. The gasoline supply of the testing aircraft was sufficient for about two hours at cruising power, with only a small supply of gas left for safety margin. In view of these facts, the testing periods were generally restricted to approximately one and one-half hours. On many occasions, the period during which tests were being made was only about one hour per flight. It was sometimes necessary to fly from twenty to thirty minutes to reach the testing area.

7. The Pilot Concentrated on Performing the Stall and Recovering the Aircraft.

The pilot's main responsibility was to approach the stall in a particular maneuver in a specified way, to stall the airplane, and to recover in accordance with a strict definition of the recovery method. An important responsibility of the pilot was to shout "Now" when the aircraft stalled.[7] He was required also to read the airspeed at the instant the stall occurred, and at the time the observer shouted "Now," when the recovery had been effected.

The pilot sat in the rear seat, but with the cooperation of the observer, he could easily read the airspeed indicator which was located near the right-hand side of the instrument panel, almost directly in front of him. (See Plate I.)

8. The Observer Was Primarily Responsible for Reading and Recording the Test Data.

Sitting in the front seat, the observer had the instrument panel immediately in front of him. As the pilot proceeded towards the stall, the observer watched the angle-of-attack indicator. At the instant the pilot shouted "Now" the observer made a mental note of the angle-of-attack, started a stop watch, and then read the radio altimeter. The observer then returned to his scrutiny of the angle-of-attack indicator and when the

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[7]In those maneuvers where the stall was "progressive," the pilot began his recovery and said "Now" at a pre-determined angle-of-attack.

needle reached the criterion angle-of-attack,[8] he shouted "Now," stopped the watch, read the angle of attack and then read the altimeter. The observer recorded the initial and final angles-of-attack and the initial and final altitude readings, as he had read and noted them on the indicators. He then secured the initial and final airspeed readings from the pilot and recorded these data.[9]

9. The Pilot and the Observer Alternated Responsibility.

This was done for several reasons: (1) after approximately one and one-half hours of performing stalls the pilot became quite tired, (2) it was desirable to test out directions to the pilot to discover whether a second pilot could repeat the recovery methods, (3) it was important to prevent the possibility of testing one pilot's flying "tricks" which might particularly affect the results of one of the several recovery methods, and (4) valuable criticism and suggestions obtained during the testing period came from both pilot and observer, and each of the two men made good suggestions for improvements in procedures.

10. Each Test of a Recovery Method by Maneuver Involved Ten Acceptable Trials.

In general, five of these trials were performed by one of the two test pilots, and five were performed by the other. Generally, also, the pilot who was flying the plane performed a test of one combination and then went on to a schedule in which a second trial involved a second maneuver or a second recovery procedure.

11. Only Acceptable Trials Were Included in the Data.

Even on relatively calm days, momentary turbulence will sometimes affect the behavior of the airplane. The test pilots were the judges of whether each successive trial was: (1) executed properly in terms of the definition for the maneuver and its recovery, and (2) whether the conditions were proper for the test; that is, whether turbulence or other factors interfered with obtaining accurate data on the trial. When the pilot was not pleased with his approach or recovery as a typical performance, he requested that the trial be re-run. When the observer was

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[8] i.e., the angle-of-attack representing the recovery from the stall under the particular experimental conditions prevailing.

[9] There was no method by which the accuracy of the observer's instrument readings readily could be checked, or for determining the degree to which the pilot's performance met the stated conditions of the respective maneuvers performed. However, both pilot and observer underwent a period of intensive training and it appears reasonable to assume that the observer and the pilot represented negligible, or certainly minor, sources of error.

uncertain about the instrument readings, he requested the pilot to re-run the trial. It might be noted that this procedure represents a potential source of error through introduction of observer or pilot bias. Undoubtedly both observer and pilot, as the testing proceeded, reached at least tentative conclusions regarding the relative merits of the "On Horizon" and "Below Horizon" procedures. It might be argued that the observer and pilot could tend to throw out as "not typical" trials in which the results were out of line with their preconceptions. This might have exaggerated the differences obtained between the two general methods of stall recovery.

On the other hand the two pilots not only were given extensive training, but had experience on previous projects and were unculcated with the "research point of view." Moreover, the pilot was specifically instructed that trials should not be thrown out on the basis of the results of the stall execution and recovery. Although the instrument was in the pilot's field of vision, the observer, rather than the pilot, read the radio altimeter for the record, and the observer "threw out" a trial only if he could not make the required instrument readings.

Furthermore, inspection of the tables following indicates that the mean angle-of-attack and mean airspeed at the point of stall was approximately the same when the "On Horizon" and "Below Horizon" values are compared for the various recovery conditions. There is no marked trend, for example, suggesting that the pilots "eased up" on the "On Horizon" maneuvers and executed a less clean, or a less violent break than under the "Below Horizon" conditions. It will be noted, however, that there are a number of statistically significant differences (in terms of angle-of-attack at the stall) between various recovery methods in certain maneuvers. These resulted from a systematic change in the procedures for reading this instrument part of the way through the investigation, and are of little practical significance.

12. <u>All Original Data Were Recorded in Terms of Indicated Values</u>.

For obvious reasons, the test pilot and the observer were not required to translate original data into calibrated values. The angle-of-attack readings recorded on the data sheets were as read from the indicator. The altimeter readings as indicated were, of course, only half values. The original observation sheets, for example, report an initial altitude of 300 feet when the true altitude was 600 feet.[10]

13. <u>The Observer Was Properly Equipped for Accurate Recordings</u>.

The observer recorded all data on a clipboard to which a standard form was attached. This form was filled out insofar as possible in advance of the flight so that the observer's only task in recording was to select

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[10] See discussion of the calibration of the radio altimeter, page 25.

the proper column and record the information he had read, in addition to that read by the pilot. A copy of the record form used in these flight tests is presented in Appendix C.

14. The Testing Aircraft Was Carefully Maintained During the Testing Period.

For reasons of safety, the testing aircraft was very carefully maintained throughout the testing period. It was checked before each morning and afternoon flight by the Project mechanic and by each of the two test pilots. Several days were spent in maintenance and repair which were necessary not only for purposes of safety and compliance with the C.A.A. regulations, but also for the purpose of keeping the aircraft in near-perfect condition throughout the testing procedure.

15. The Tests Were Performed under Careful Supervision.

The Project Directors and other members of the Project Staff met with the test pilots, generally on a daily basis. These conferences were concerned primarily with the problems of testing and particularly with the execution of recoveries in accordance with the definition of the method.

F. Case I Results -- Recovery to Straight and Level Flight

1. Recovery from a Stall Out of a Straight-Ahead, Full Power Climb.

Seven methods of recovery from a stall out of a straight-ahead, full power climb were tested. These are listed in Table 3 following.[11] It will be noted from this table that four recovery methods utilized "Below Horizon" procedures, while three utilized "On Horizon" procedures.[12]

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[11]The abbreviations used in designating recovery methods in Table 3 and in succeeding tables are as follows:

P = add power
R = use optimum rudder
A = use optimum ailerons
E = use optimum elevators
OH = recover with nose held on horizon
BH = recover with nose held below horizon.

[12]In recovery from the stall occurring as the result of a full power, straight-ahead climb, only seven methods appeared to be worthy of investigation. In the first place, all recovery methods involving change in power were automatically cancelled. Climbing power is full power and, consequently, there is no possibility of adding power. Thus, the "P" recovery methods did not apply to this maneuver. It should also be noted here that the test pilots attempted to recover the aircraft with ailerons only (A) with the nose below horizon (A-BH) and on horizon (A-OH). The behavior of the airplane was so

The results for each of the seven methods of recovery tested are presented in Table 3. In this and in succeeding tables presenting the results of tests the values reported are calibrated values. The exception, of course, is time in seconds required to effect the recovery.[13] This table presents the average data values of ten trials per recovery method. The data include the following: average airspeed at the time of stall and at the time of recovery, the average angle-of-attack at the time of stall, the average loss of altitude in feet resulting from the stall, and the average time in seconds required to recover the aircraft to straight and level flight.[14]

Table 3 may be read as follows: with respect to the E-BH method of recovery, the average true airspeed at the time the stall occurred was 35.87 m.p.h.; at recovery, the average airspeed for the ten trials by this method was 67.07 m.p.h.; at the time of stall the true angle-of-attack was 18.46°. The average number of feet lost in the E-BH recovery method was 108.00 feet and the time required to effect recovery was, on the average, 5.73 seconds. These values are shown in the table in the row opposite the small m (mean). The second row for each recovery method presents the standard deviation (σ) of the calibrated values. For example, in method E-BH the standard deviation of true airspeed at the stall was 0.57 m.p.h., and the standard deviation of the measures of altitude lost in this maneuver was 24.28 feet. The third row under each recovery method presents the standard error of the mean values listed in the same column. That is, in the column listing the calibrated airspeed at the stall, method E-BH, the value 0.19 is the standard error of the mean 35.87.[15]

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12 (Cont.) erratic and the possibility of recovery so remote that there appeared to be no practical utility in attempting to recover the aircraft by using ailerons only. It was occasionally possible to recover to straight and level flight with the use of elevators only and by placing the nose on the horizon (E-OH). However, this recovery method also was far from dependable and occasionally the aircraft could not be recovered by this method. As a consequence, tests also were not run on this recovery method.

13 It will be remembered that airspeed, angle-of-attack, and altitude readings were first recorded on the basic data sheets in terms of indicated values.

14 As indicated above, the criterion of straight and level flight was 7° indicated angle-of-attack, wings level.

15 The standard error of the mean is a statistic which describes the stability of the mean value. It may be used to test statistical differences. It was calculated and presented in these tables so that any who might be interested in determining the statistical significance of the differences between means for different methods could use it in calculation. Evaluation of certain pertinent differences in terms of their standard errors, is presented subsequently in the report. (See pages 124 ff.)

TABLE 3

THE EFFECTIVENESS OF SEVEN METHODS OF RECOVERY TO LEVEL FLIGHT FROM A STRAIGHT-AHEAD, CLIMBING-POWER STALL

Recovery Method**		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. E - BH	m =	35.87	67.07	18.46	108.00	5.73
	σ =	0.57	2.14	0.00*	24.28	0.52
	σm =	0.19	0.71	0.00	8.09	0.17
2. RE - OH	m =	34.90	63.49	18.46	26.00	10.54
	σ =	0.57	2.61	0.95	19.08	1.77
	σm =	0.19	0.87	0.32	6.39	0.59
3. RE - BH (RE-RUN)	m =	33.81	68.73	21.20	130.00	8.34
	σ =	0.22	1.72	1.63	16.73	0.94
	σm =	0.07	0.57	0.54	5.58	0.31
4. AE - OH	m =	34.95	68.42	20.94	49.00	12.75
	σ =	1.13	2.54	0.59	46.57	2.58
	σm =	0.38	0.85	0.20	15.52	0.86
5. AE - BH	m =	34.94	75.01	21.38	164.00	8.39
	σ =	1.26	1.38	0.62	28.71	1.20
	σm =	0.42	0.46	0.21	9.57	0.40
6. RAE - OH	m =	35.21	60.62	18.61	42.00	7.89
	σ =	0.70	0.36	0.57	19.89	0.82
	σm =	0.23	0.12	0.19	6.63	0.27
7. RAE - BH	m =	34.95	67.47	19.44	98.00	6.56
	σ =	0.57	1.62	1.11	33.69	0.57
	σm =	0.19	0.54	0.37	11.23	0.19

*The zero variation was occasioned by the pilot's beginning his recovery at 28° indicated angle of attack and so recording 28° as the A/A at all stalls in this series.

**The abbreviations used in designating recovery methods in Table 3 and in succeeding tables are as follows:

P = add power
R = use optimum rudder
A = use optimum ailerons
E = use optimum elevators
OH = recover with nose held <u>on horizon</u>
BH = recover with nose held <u>below horizon</u>

TABLE 4

THE EFFECTIVENESS OF FOURTEEN METHODS OF RECOVERY TO LEVEL FLIGHT FROM A STRAIGHT-AHEAD, CRUISING-POWER STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. E - OH	m =	35.14	64.70	18.54	58.00	10.47
	σ =	0.45	1.57	0.78	21.82	1.31
	σm =	0.15	0.52	0.26	7.27	0.44
2. E - BH	m =	34.44	69.17	18.31	107.00	6.06
	σ =	0.80	1.62	0.56	32.86	0.28
	σm =	0.27	0.54	0.19	10.95	0.09
3. RE - OH	m =	34.12	63.62	18.54	52.00	11.12
	σ =	0.65	1.04	0.62	21.82	1.89
	σm =	0.22	0.35	0.21	7.27	0.63
4. RE - BH	m =	35.85	71.67	18.54	127.00	5.45
	σ =	0.74	2.06	0.22	26.08	0.54
	σm =	0.25	0.69	0.07	8.69	0.18
5. AE - OH	m =	34.37	65.92	23.86	131.00	14.04
(RE-RUN)	σ =	0.79	1.10	2.41	43.92	2.29
	σm =	0.26	0.37	0.80	14.64	0.76
6. AE - BH	m =	34.68	73.79	22.16	149.00	10.12
	σ =	1.17	2.55	0.10	36.73	1.22
	σm =	0.39	0.85	0.03	12.24	0.41
7. PRE - OH	m =	35.73	66.55	18.46	52.73	8.16
	σ =	0.48	1.22	0.00	23.39	0.77
	σm =	0.16	0.43	0.00	7.80	0.26
8. PRE - BH	m =	35.52	73.53	19.14	158.00	5.02
	σ =	0.91	2.29	0.22	32.49	0.71
	σm =	0.30	0.76	0.07	10.83	0.24
9. PAE - OH	m =	35.21	70.46	21.84	66.00	13.58
	σ =	0.70	1.55	0.66	32.31	2.31
	σm =	0.23	0.52	0.22	10.77	0.77
10. PAE - BH	m =	35.02	69.81	22.13	64.00	17.61
	σ =	1.35	1.76	0.08	36.66	2.71
	σm =	0.45	0.59	0.03	12.22	0.90

TABLE 4 (Continued)

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
11. RAE - OH	m =	34.64	65.72	19.21	58.00	11.82
	σ =	0.71	2.16	0.67	39.19	2.57
	σm =	0.24	0.72	0.22	13.06	0.86
12. RAE - BH	m =	34.53	71.48	19.29	138.00	6.33
	σ =	0.87	2.68	0.97	29.93	0.66
	σm =	0.29	0.89	0.32	9.98	0.22
13. PRAE - OH	m =	36.25	67.65	19.02	56.00	10.94
	σ =	0.69	0.93	0.47	25.77	2.94
	σm =	0.23	0.31	0.16	8.59	0.98
14. PRAE - BH	m =	36.05	72.58	19.21	128.00	6.19
	σ =	0.66	1.51	0.17	24.82	0.77
	σm =	0.22	0.50	0.06	8.27	0.26

The remainder of this table and succeeding tables are read in a similar manner.

As shown in Table 3, the RE-OH method of recovery resulted in an average loss of only 26 feet. Straight and level flight was regained, on the average, in approximately 10.5 seconds. The second most satisfactory method of recovery, from the point of view of altitude lost during recovery, was method RAE-OH with an average altitude loss of 42 feet and a recovery period of approximately 7.9 seconds. Of the seven methods of recovery tested, AE-BH resulted in the greatest loss of altitude, 164 feet.

It will be noted from this table that the "On Horizon" method of recovery was in each case superior to its corresponding "Below Horizon" method of recovery. For example, in the RE-BH recovery an average of 130 feet was lost during recovery to straight and level flight, as contrasted with method RE-OH in which an average of only 26 feet was lost.

These data indicate definitely that the pilot who stalls this airplane in a straight-ahead, full power climb should use the stick to hold the nose on the horizon and use the rudder to level the wings. It may require as long as 13 or 14 seconds to regain straight and level flight, but he can be certain that this method of recovery will result in the least loss of altitude. If he uses the elevator to "push" the nose below the horizon and attempts to level the wings with ailerons, he may lose as much as 150 to 200 feet of altitude (See AE-BH, Table 3).

2. Recovery from a Stall Out of Straight-Ahead, Cruising Power Flight.

Fourteen recovery methods were tested in connection with recovery from stalls out of straight-ahead, cruising power flight. These constitute most of the possible methods whereby the aircraft can be recovered from a stall out of this maneuver.[16]

As shown in Table 4, five methods of recovery produced near equal results in terms of altitude lost during the recovery from the stall: E-OH, RE-OH, PRE-OH, RAE-OH, and PRAE-OH. Of these, the RE-OH recovery resulted in the least loss of altitude, an average of 52 feet. When the criterion of loss of altitude is applied exclusively, all of these methods of recovery resulted in approximately the same average loss of altitude. However, it will be noted in Table 4 that RE-OH and PRE-OH recoveries were more consistent; that is, the variation (standard deviation) was not as large for these recovery methods as for RAE-OH and PRAE-OH.

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[16]The PE-OH and PE-BH recovery methods were flown experimentally, but were not tested. In a stall resulting from a straight-ahead, cruising maneuver, the left wing frequently dropped first. When power and only elevators were used for controls, recovery to straight and level flight was not possible. The use of only power and elevators in recovering from a stall in this maneuver was considered impracticable for the reason that it could not possibly be recommended as an optimum way of recovering.

It is of special interest to note that each of these five recovery methods involved the "On Horizon" procedure. As in the case of recovery from a stall following a straight-ahead, full power climb, the "On Horizon" methods were consistently superior to their corresponding "Below Horizon" methods.

Of the five methods of recovery which appear to be most promising in gaining control of the aircraft after a stall from a straight-ahead, cruising power maneuver, there is little doubt of the two which are of most practical significance. The pilot is generally safer with full power than he is with cruising or reduced power. Thus, his choice of recovery methods is limited to two: PRE-OH and PRAE-OH. That is, in recovery from the stall out of this maneuver the pilot is likely to lose the least amount of altitude if, following the stall, he immediately applies full power, uses rudder and elevator as effectively as possible, and holds the nose on the horizon until full control is regained and the aircraft returns to straight and level flight. This can be accomplished in about 8 to 8.5 seconds, on the average. Again, as in the case of straight-ahead climbs, about the worst thing the pilot can do is to apply full power, to put the nose below the horizon, and attempt to regain straight and level flight as <u>rapidly</u> as possible. This may result in a loss of altitude ranging from 130 to 190 feet, but, if altitude permits, he will be able to recover to straight and level flight in approximately 5 seconds.

3. <u>Recovery from a Stall Out of Straight-Ahead, Reduced Power Flight (Glide)</u>.

As shown in Table 5, ten methods of recovery were investigated in connection with stalls out of a straight-ahead glide. Of these, seven methods of recovery involved "Below Horizon" procedures, and only three involved "On Horizon" procedures.[17] Four of these involved no increase in power. These were tested for purposes of verifying what might happen to the pilot who stalls out of a glide and neglects to apply whatever power he has available. As shown in Table 5, he will undoubtedly live much longer by applying power and getting away from the stall as soon as possible.

Recovery method PRE-OH, with an average loss of 30 feet and time recovery interval of approximately 13 seconds resulted in less loss of altitude than any of the other methods listed in Table 5. The next most satisfactory procedure involved the addition of aileron control to the PRE procedure (add power, use rudders and elevators as effectively as possible). At the other extreme, recovery method RE-BH resulted in an average loss of 319 feet and was fairly consistent in this loss of altitude. The standard deviation of 22.11 feet indicates that even a "lucky" pilot will have little chance of recovering with less than 250 to 260 feet loss of altitude.

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[17]The "On Horizon" recovery procedure was not used in those cases where power was not added in effecting the recovery.

TABLE 5

THE EFFECTIVENESS OF TEN METHODS OF RECOVERY TO LEVEL FLIGHT FROM A STRAIGHT-AHEAD, REDUCED POWER STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. E - BH	m =	40.13	72.00	17.71	206.00	6.57
	σ =	0.52	2.18	0.00*	35.27	0.95
	σm =	0.17	0.73	0.00	11.76	0.32
2. RE - BH	m =	39.43	72.51	17.71	319.00	7.44
	σ =	1.04	1.36	0.00	22.11	1.40
	σm =	0.35	0.45	0.00	7.37	0.47
3. FAE - OH	m =	39.64	68.04	17.71	64.40	11.04
	σ =	0.60	0.96	0.00	15.92	1.33
	σm =	0.20	0.32	0.00	5.31	0.44
4. AE - BH	m =	38.94	70.92	17.71	242.00	9.19
	σ =	1.08	1.52	0.00	32.80	1.50
	σm =	0.36	0.51	0.00	10.93	0.50
5. PRE - OH	m =	40.26	68.16	17.71	38.00	13.25
	σ =	0.41	0.95	0.00	24.90	1.52
	σm =	0.14	0.32	0.00	8.30	0.51
6. PRE - BH	m =	40.19	73.16	17.71	114.00	6.82
	σ =	0.56	1.23	0.00	19.60	0.55
	σm =	0.29	0.41	0.00	6.53	0.18
7. PAE - BH	m =	39.31	71.49	17.71	101.40	6.93
	σ =	0.59	0.82	0.00	14.41	1.78
	σm =	0.20	0.27	0.00	3.42	0.59
8. RAE - BH	m =	39.57	75.01	17.71	173.00	7.37
	σ =	0.51	0.85	0.00	29.34	2.04
	σm =	0.17	0.28	0.00	9.78	0.68
9. PRAE - OH	m =	40.15	70.01	17.71	54.00	11.04
	σ =	0.59	1.70	0.00	30.07	1.69
	σm =	0.20	0.57	0.00	10.02	0.56
10. PRAE - BH	m =	40.25	71.29	17.71	89.00	7.38
	σ =	0.59	1.01	0.00	23.00	0.61
	σm =	0.20	0.34	0.00	7.67	0.20

*The zero variation was occasioned by the pilot's beginning his recovery at 27° indicated angle of attack and so recording 27° as the A/A at all stalls in this series.

The three methods of recovery using "On Horizon" procedures were all superior to any of the "Below Horizon" recovery methods. When all controls were used, the PRAE-BH recovery, and the nose of the aircraft was allowed to drop below the horizon approximately 15°, and recovery was effected as soon as possible, the average loss was 89 feet and recovery was effected in approximately 7.5 seconds. However, this does not compare very favorably with the 38 feet, the 54 feet, and the 64 feet losses for the "On Horizon" recovery methods.

Judging from these data, the optimum method of recovery from the stall out of a straight-ahead glide involves the addition of power, the optimum use of rudder and elevator, and placing the nose on the horizon until straight and level flight is achieved. About the worst thing a pilot can do is to attempt his recovery without adding power and using only rudder and elevators, and also by placing the nose of the aircraft below the horizon. This method of recovery resulted in an average loss of 319 feet. It was effected in the relatively short time of 7.4 seconds; but this time advantage, if any, would be only in the doubtful value which is gained by a rapid dive into the ground from an altitude of less than 318 feet.

4. <u>Recovery from a Stall Out of a Left Climbing Turn</u>.

Only six methods of recovery from a stall out of left and right climbing turns were tested. P (add power) recovery methods were ruled out by the fact that full power was involved in the climb.

As shown in Table 6, recovery method RAE-OH resulted in an average loss of 69 feet and recovery was effected in an average of approximately 14 seconds. The next most satisfactory method of recovery was RE-OH with an average loss of 72 feet and a recovery interval of approximately 10 seconds. Of those recoveries tested, RE-BH resulted in the greatest loss of altitude, 175 feet.

In stalls out of left climbing turns, the "On Horizon" procedures were consistently and systematically superior to the "Below Horizon" procedures.

These data indicate that the best advice to pilots who stall in the left climbing turn is: (1) make optimum use of all of the controls and place the nose of the aircraft on the horizon, (2) do not let it fall below the horizon, and (3) wait. Recovery will not be effected immediately. In fact, it will probably require approximately 14 seconds, but you can expect to get away from a stall out of this maneuver with an average of approximately 70 feet loss of altitude. The worst advice that can be given to the pilot is to attempt his recovery without the use of ailerons and to allow the nose of the aircraft to fall well below the horizon. This is a <u>rapid</u> method of recovery, but it consistently results in a loss of approximately 150 to 160 feet before the aircraft can be regained to straight and level flight.

TABLE 6

THE EFFECTIVENESS OF SIX METHODS OF RECOVERY TO LEVEL FLIGHT
FROM A LEFT CLIMBING TURN STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - OH	m =	33.81	67.20	20.79	72.00	10.26
	σ =	0.51	1.53	1.48	39.70	1.78
	σm =	0.17	0.51	0.49	13.23	0.59
2. RE - BH	m =	34.38	72.26	20.71	175.00	6.84
	σ =	0.78	2.42	1.42	15.00	1.14
	σm =	0.26	0.81	0.47	5.00	0.38
3. AE - OH	m =	34.95	68.43	20.56	99.00	13.27
	σ =	0.69	1.01	1.46	22.11	1.49
	σm =	0.23	0.34	0.49	7.37	0.50
4. AE - BH	m =	34.44	69.96	19.74	104.00	7.15
	σ =	0.71	1.04	0.95	31.69	0.86
	σm =	0.24	0.35	0.32	10.56	0.29
5. RAE - OH	m =	34.68	66.63	18.46	69.00	13.91
	σ =	0.53	1.38	0.75	29.82	2.87
	σm =	0.18	0.46	0.25	9.94	0.96
6. RAE - BH	m =	34.48	72.65	19.29	122.00	6.83
	σ =	0.79	3.27	0.78	24.41	1.21
	σm =	0.26	1.09	0.26	8.14	0.40

5. Recovery from a Stall Out of a Right Climbing Turn.

The results of the tests of methods of recovering from a stall out of a right climbing turn followed the same general pattern as in the case of the left turn. The results of these tests are shown in Table 7.

Recovery method RAE-OH again was superior, with an average loss of 46 feet and a time recovery interval of approximately 12 seconds. The least satisfactory method was RE-BH, as in the case of the left climbing turn.

Tables 6 and 7 both indicate that the "On Horizon" procedures were distinctly and consistently superior to the "Below Horizon" procedures.

These data indicate that advice to pilots on recovery from stalls from right and left climbing turns is essentially the same. In each case, the pilot can conserve the greatest amount of altitude by a coordinated use of rudders, ailerons, and elevators, and by holding the nose on the horizon until the aircraft recovers. In the right turn this recovery may be effected somewhat more rapidly than in the left turn, but the principle of recovery is exactly the same.

6. Recovery from a Stall Out of a Left Gliding Turn.

With respect to recovery from a stall out of gliding turns, nine recovery methods were investigated in both right and left turns.[18] These are listed in Tables 8 and 9.[19]

Three recovery methods produced near equal results. These were PRE-OH with an average loss of altitude of 79 feet; PAE-OH with an average loss of 83.4 feet; and PRAE-OH with an average loss of 82 feet. The time for effecting recovery for each of these methods was approximately 12.6 seconds, 11.8 seconds, and 11.7 seconds, respectively. In contrast with the results of these three methods of recovery, method RE-BH resulted in an average loss of 291 feet with recovery effected on the average of 7.8 seconds.

As with the previous maneuvers in which more than one method of recovery was nearly the same, the three methods of recovering from a stall out

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[18]It will be noted that the "on horizon" recovery procedure was not used in those cases where power was not added in effecting the recovery.

[19]It would have been much more efficient to have tested only those maneuvers which involved the addition of power. However, it was believed important to obtain some evidence on what is likely to happen to the pilot if he does not have power after stalling out of a gliding turn. Also, it will be remembered that the scheduling of testing was such that one maneuver was not completed until virtually all others were.

TABLE 7

THE EFFECTIVENESS OF SIX METHODS OF RECOVERY TO LEVEL FLIGHT FROM A RIGHT CLIMBING TURN STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - OH	m =	35.72	65.73	21.39	70.00	10.32
	σ =	0.91	0.37	0.78	26.83	1.04
	σm =	0.30	0.12	0.26	8.94	0.36
2. RE - BH	m =	36.74	70.91	19.66	169.00	6.31
	σ =	0.69	2.37	1.01	33.75	1.13
	σm =	0.23	0.79	0.34	11.25	0.38
3. AE - OH	m =	35.40	67.78	20.64	99.00	13.01
	σ =	0.67	1.09	1.14	49.69	2.02
	σm =	0.22	0.36	0.38	16.56	0.67
4. AE - BH	m =	35.02	69.24	21.01	137.00	7.64
	σ =	1.01	0.90	1.17	35.23	0.77
	σm =	0.34	0.30	0.28	11.74	0.26
5. RAE - OH	m =	36.80	68.46	18.91	46.00	12.13
	σ =	1.17	1.43	1.07	18.00	2.39
	σm =	0.39	0.48	0.36	6.00	0.80
6. RAE - BH	m =	37.75	73.40	18.54	109.00	6.18
	σ =	1.40	2.67	0.78	35.05	0.85
	σm =	0.47	0.89	0.26	11.68	0.28

TABLE 8

THE EFFECTIVENESS OF NINE METHODS OF RECOVERY TO LEVEL FLIGHT FROM A LEFT GLIDING TURN STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - BH	m =	39.71	69.94	17.71	291.00	7.81
	σ =	0.39	1.57	0.00	45.70	1.38
	σm =	0.13	0.52	0.00	15.23	0.46
2. AE - BH	m =	39.31	70.58	17.71	267.00	8.00
	σ =	2.10	1.52	0.00	58.66	1.02
	σm =	0.70	0.51	0.00	19.55	0.34
3. PRE - OH	m =	39.69	69.61	17.71	79.00	12.63
	σ =	0.57	1.11	0.00	25.87	1.28
	σm =	0.19	0.37	0.00	8.62	0.43
4. PRE - BH	m =	39.37	73.21	17.71	129.00	6.71
	σ =	0.75	1.53	0.00	48.47	0.94
	σm =	0.25	0.51	0.00	16.16	0.31
5. PAE - OH	m =	39.30	67.14	17.71	83.40	11.85
	σ =	1.23	0.92	0.00	30.73	1.56
	σm =	0.41	0.31	0.00	10.24	0.52
6. PAE - BH	m =	40.00	69.05	17.71	127.00	7.90
	σ =	0.69	1.35	0.00	27.59	0.88
	σm =	0.23	0.45	0.00	9.20	0.29
7. RAE - BH	m =	39.25	74.55	17.71	264.00	9.57
	σ =	1.30	2.27	0.00	32.92	1.85
	σm =	0.43	0.76	0.00	10.97	0.62
8. PRAE - OH	m =	39.89	68.16	17.71	82.00	11.72
	σ =	0.57	1.30	0.00	35.97	1.59
	σm =	0.19	0.43	0.00	11.99	0.53
9. PRAE - BH	m =	39.61	72.00	17.71	125.00	7.15
	σ =	0.91	1.48	0.00	32.03	0.66
	σm =	0.30	0.49	0.00	10.68	0.22

TABLE 9

THE EFFECTIVENESS OF NINE METHODS OF RECOVERY TO LEVEL FLIGHT FROM A RIGHT GLIDING TURN STALL

Recovery Method		Calibrated Airspeed at Stall	Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - BH	m =	40.33	71.55	17.71	264.00	7.03
	σ =	1.26	0.91	0.00	33.82	0.85
	σm =	0.42	0.30	0.00	11.27	0.28
2. AE - BH	m =	39.82	68.98	17.71	255.00	8.13
	σ =	0.99	2.29	0.00	60.37	1.26
	σm =	0.33	0.76	0.00	20.12	0.42
3. PRE - OH	m =	40.90	69.55	17.71	67.00	12.73
	σ =	1.04	1.75	0.00	21.93	1.54
	σm =	0.35	0.58	0.00	7.31	0.51
4. PRE - BH	m =	41.60	74.81	17.71	162.00	7.05
	σ =	1.17	2.33	0.00	58.00	0.70
	σm =	0.39	0.78	0.00	19.33	0.23
5. PAE - OH	m =	40.25	67.84	17.71	65.00	12.56
	σ =	0.83	1.01	0.00	39.81	1.82
	σm =	0.28	0.24	0.00	13.27	0.61
6. PAE - BH	m =	40.09	69.82	17.71	141.40	8.14
	σ =	0.86	1.10	0.00	32.71	1.21
	σm =	0.29	0.37	0.00	10.90	0.40
7. RAE - BH	m =	41.68	74.56	17.71	272.00	8.97
	σ =	0.65	1.14	0.00	53.25	1.12
	σm =	0.22	0.38	0.00	17.75	0.37
8. PRAE - OH	m =	41.34	69.11	17.71	60.00	11.85
	σ =	0.49	0.93	0.00	18.97	1.40
	σm =	0.16	0.31	0.00	6.32	0.47
9. PRAE - BH	m =	41.16	73.15	17.71	134.00	7.52
	σ =	0.73	2.17	0.00	16.85	0.76
	σm =	0.24	0.72	0.00	5.62	0.25

of the left climbing turn all used "On Horizon" procedures. The corresponding recovery methods, using the "Below Horizon" procedures resulted in losses from 40 to 60 feet more than the "On Horizon" procedures.

These results indicate that the best thing the pilot can do when he stalls out of a left gliding turn is to add power, drop the nose to the horizon, and hold it there until recovery is effected. It doesn't appear to make much difference whether he uses only rudder and elevator to level the wings and hold the nose on the horizon, or whether he uses only ailerons and elevators, or whether he uses all three. The essential procedures are that he add power immediately, level the wings, and not allow the nose to drop below the horizon. He may expect this to require from 12 to 13 seconds before the aircraft returns to straight and level flight. He is more likely to get away with the least loss of altitude if he minimizes the use of ailerons.

7. Recovery from a Stall Out of a Right Gliding Turn.

The methods of recovery investigated in connection with recovery from a stall out of a right gliding turn were the same as those tested in the left gliding turn. These are listed in Table 9, which presents the results for each of the recovery methods tested.

As may be expected, the optimum method of recovering from a stall out of a right gliding turn is about the same as recovering from a stall out of the left gliding turn. As shown in Table 9, methods of recovery PRE-OH, PAE-OH, and PRAE-OH were again distinctly superior to any of the other methods investigated. It will be noted in comparing Tables 8 and 9, however, that the order of three best recovery methods in the right gliding turn was not the same as in the left gliding turn. As shown in Table 9, recovery method PRAE-OH resulted in an average loss of only 60.00 feet. It will be noted also that this was the most consistent method of on horizon recovery through addition of power (a standard deviation of 18.97 vs. standard deviations of 21.93 and 39.81). Recovery method RAE-BH was the least satisfactory method tested. This method resulted in an average loss of 272.00 feet, but it was effected on an average of approximately 9 seconds.

A comparison of the "On Horizon" and "Below Horizon" recovery methods from a stall out of the right gliding turn reveals essentially the same results as in the case of the left gliding turn. Only methods of recovery which involve the addition of power appeared to be at all feasible when attempting to recover from a stall out of a right gliding turn. The exception to this would be, of course, when one was primarily interested in effecting a rapid recovery without respect to the number of feet of altitude lost in the process. If this were the problem, then recovery methods RE-BH, PRE-BH, or PRAE-BH would be desirable. Of these the addition of power and coordinated use of rudder, ailerons, and elevators, with the nose held below the horizon will result in safe airspeed about as rapidly as any other method of recovery, and will at the same time lose less altitude on the average.

When the pilot is at low altitude and is particularly anxious to conserve as much altitude as possible, and he stalls out of a right gliding turn, his best procedure and also the one likely to be most consistent is the addition of power, the coordinated use of rudder, ailerons, and elevators, and holding the nose on the horizon until he gains full control of the aircraft in straight and level flight. This may require as long as approximately 12 seconds, perhaps one or two seconds more, but he can depend on getting back to straight and level flight by this procedure and, at the same time, lose the least amount of altitude. In this same situation, about the worst thing he can do is to attempt to recover with the coordinated use of rudder, aileron, and elevators, by placing the nose below the horizon, and by not adding power. He may very easily lose as much as 300 feet and his recovery method will not be a particularly rapid one. His best bet all around is to add power and hold the nose on the horizon until level flight is resumed.

Since there is every reason to believe that the tests of recovery methods in the left and right gliding turns were highly comparable, the pilot should perhaps recognize that he is apt to lose more altitude in a stall out of a left gliding turn than out of a right one.[20] It will be noted from a comparison of Tables 8 and 9 that method PRAE-OH resulted in recovery from a stall out of the left gliding turn with an average loss of altitude for the ten trials of 82.00 feet while in the case of the right gliding turn the same recovery method achieved straight and level flight with a loss of only 60.00 feet. It will be noted further that the recovery from the stall out of the right gliding turn was more consistent. That is, the standard deviation of the ten trials was considerably less than that of the ten trials by the same method of recovery in the left gliding turn.

8. Recovery from a Stall Out of Steep Turns.

As reported earlier, the steep turn was performed with full power at a 60° bank, nose on horizon. The test pilots experimented with the use of rudder and elevators only to recover from this stall. They reported that the stall itself was so violent and so unpredictable that it seemed wise only to experiment with the optimum use of rudder, ailerons, and elevators, and recover with the nose below the horizon. No "On Horizon" procedures are possible in recovering from the "stall under" out of a

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[20] In general, pilots make more left turns than right ones. The test pilots used in this investigation did not, however, report any difficulty with performing the right turn, so it may be assumed that the left and right turns were flown with equal ease and coordination of controls. If this is true the recovery from a stall out of a right gliding turn may be accomplished with less loss of altitude than that likely to result from a stall out of a left gliding turn.

steep turn.[21] It was necessary particularly in testing recovery from stalls out of the steep turns to conduct the tests in relatively calm air. The stall itself was so violent under turbulent conditions that it was thought desirable to run tests in turbulent and still air and compare the results for these conditions of recovery. Tables 10 and 11 following present the results of the tests in turbulence and still air for the left steep turn and the right steep turn, respectively. Since only one recovery method was tested, it was not possible to compare the "On Horizon" vs. the "Below Horizon" procedures, but it can be noted from these tables that, in general, stalls in turbulent air resulted in the greatest loss of altitude. This is not particularly significant in the case of the left steep turn but was marked in the case of the right steep turn.

These tables reveal the same tendency found in the case of stalls out of right and left gliding turns. As before, recovery from right steep turns was effected with less loss of altitude than in the case of the left steep turn. The only advice to pilots these tests reveal is that when one "stalls under" out of a left or right steep turn, he can hardly expect to get away with a loss of less than 90 to 150 feet of altitude. Furthermore, as reported by the test pilots, he may definitely expect violent, unpredictable behavior of the aircraft. In effecting his recovery he may expect to achieve the best results with the optimum use of rudder, ailerons, and elevators, and by holding the nose below the horizon until airspeed permits straight and level flight. This will probably take about 7 to 8 seconds, perhaps longer, perhaps less, depending upon turbulence, the pilot's coordination, and the degree of bank.[22]

As in the case of all of the other stalls, the best advice to pilots with respect to the steep turn is "avoid the stall." It is going to be difficult to recover from it. But, if the pilot does stall, he should use all controls to effect recovery.

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[21]With the nose of the aircraft held on the horizon in the approach to the stall out of this maneuver, the turn was gradually tightened until the stall occurred. There are at least three distinct types of stalls out of this maneuver: (1) a "mushing" stall in which the turn is continued while the aircraft shudders and falters in the turn, (2) a "stall over" in which the down wing comes up and the aircraft "slides" out in near wing-level flight and (3) a "stall under" in which the aircraft is momentarily in a near-inverted dive. Of these, the last is the most violent and probably the most dangerous, and it is most likely to be the stall which loses the most altitude. To obtain consistently the "stall under" out of the steep turns, the test pilots "crossed controls," using the rudder in the direction of the turn and opposite aileron.

[22]A 60° bank is a very steep turn. Most pilots will characterize a 45° bank as a steep turn. It is believed, however, that the findings reported for the 60° bank turn will, in the main, hold for "steep" turns with less bank, say from 45° to 60°. There was, in this study, however, no attempt to determine whether or not this assumption holds.

TABLE 10

THE EFFECTIVENESS OF ONE METHOD OF RECOVERY TO LEVEL FLIGHT FROM A LEFT STEEP TURN STALL UNDER TWO CONDITIONS OF TURBULENCE

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RAE - BH	m =	43.45	74.04	21.39	150.00	4.88
(Turbulent	σ =	3.58	3.97	1.32	33.76	0.85
Air)	σm =	1.19	1.32	0.44	11.25	0.28
2. RAE - BH	m =	41.99	69.89	23.19	102.00	7.72
(Still	σ =	1.68	4.05	1.99	48.95	2.67
Air)	σm =	0.56	1.35	0.66	16.32	0.89

TABLE 11

THE EFFECTIVENESS OF ONE METHOD OF RECOVERY TO LEVEL FLIGHT FROM A RIGHT STEEP TURN STALL UNDER TWO CONDITIONS OF TURBULENCE

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RAE - BH	m =	39.49	72.79	17.71	95.00	6.20
(Turbulent	σ =	1.32	3.14	0.75	65.92	0.94
Air)	σm =	0.44	1.05	0.25	21.97	0.31
2. RAE - BH	m =	41.72	68.48	18.09	89.00	8.63
(Still	σ =	1.51	1.69	0.69	27.73	1.51
Air)	σm =	0.50	0.56	0.23	9.24	0.50

9. Recovery from a Stall Out of a Left Slow Turn.

Nine recovery methods were tested in recovering from stalls from this maneuver. These are listed in Table 12. As shown there, three recovery methods involved "On Horizon" procedures [23] and six involved "Below Horizon" procedures.

As in the case of previous maneuvers, the "On Horizon" procedures were distinctly superior to the "Below Horizon" procedures. Method PRE-OH, with an average loss of 63 feet and a time recovery interval of 10.3 seconds, was most satisfactory. Recovery method PAE-OH, with an average loss of 73 feet and 11.2 second recovery interval, and method PRAE-OH, with an average altitude loss of 74 feet and a 9.9 second recovery interval were next most satisfactory. Of those methods tested, RE-BH resulted in the greatest loss of altitude, 199 feet.

On the basis of the results shown in Table 12, the best advice to pilots is to recover from a stall out of a left slow turn by the addition of power and the optimum use of rudder and elevators, and holding the nose of the aircraft on the horizon. A somewhat less effective recovery will be made if ailerons are used instead of rudders or if ailerons are used in addition to rudders. In recovery from a stall out of a left slow turn, the use of ailerons appears to handicap rather than to assist the recovery of the aircraft. About the worst thing a pilot can do is to attempt to recover without adding power, and by using rudder and elevator to level the wings, to put the nose below the horizon, and attempt to get flying speed very rapidly. If he follows this procedure he may lose as much as 200 feet, possibly more, and, although his recovery may be rapid, his loss of altitude will almost certainly be excessive.

10. Recovery from a Stall Out of a Right Slow Turn.

The methods used in recovering from a stall out of a right slow turn were the same as those used in the case of the left slow turn.

The results of tests of recoveries from a stall out of the right slow turn in general follow the same pattern as the left slow turn. There were differences, however, particularly in the case of the recovery method which proved to be most satisfactory. As shown in Table 13, the most satisfactory method of recovering from the right slow turn was method PAE-OH. This method resulted in an average loss of 30 feet and was quite consistent (standard deviation of 18.44). This recovery method was not only distinctly superior to PRE-OH and PRAE-OH, but it was also much more reliable, as will be seen by a comparison of standard deviations of the ten trials for each of these recovery methods.

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[23] The "On Horizon" recovery procedure was not applicable in those recoveries where additional power (i.e., full throttle) was not employed.

TABLE 12

THE EFFECTIVENESS OF NINE METHODS OF RECOVERY TO LEVEL FLIGHT FROM A LEFT SLOW TURN STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - BH	m =	41.55	72.32	17.71	199.00	7.63
	σ =	1.25	2.55	0.00	26.63	0.70
	σm =	0.42	0.85	0.00	8.88	0.23
2. AE - BH	m =	37.89	67.40	19.51	179.00	8.41
	σ =	1.05	1.26	0.69	24.68	1.05
	σm =	0.35	0.42	0.23	8.23	0.35
3. PRE - OH	m =	41.30	67.20	17.71	63.00	10.30
	σ =	1.22	1.90	0.00	24.92	1.06
	σm =	0.41	0.63	0.00	8.31	0.35
4. PRE - BH	m =	41.80	71.81	17.71	149.00	8.22
	σ =	1.85	2.29	0.00	48.05	1.70
	σm =	0.62	0.76	0.00	16.02	0.57
5. PAE - OH	m =	37.51	67.22	20.22	73.00	11.19
	σ =	0.62	1.03	0.94	40.76	2.08
	σm =	0.21	0.34	0.31	13.59	0.69
6. PAE - BH	m =	37.58	70.52	19.44	131.00	6.99
	σ =	0.86	1.19	0.58	33.60	0.73
	σm =	0.29	0.40	0.19	11.20	0.24
7. RAE - BH	m =	41.85	70.32	17.79	171.00	6.77
	σ =	1.49	1.41	0.22	47.85	1.09
	σm =	0.50	0.47	0.07	15.62	0.36
8. PRAE - OH	m =	37.83	67.15	19.66	74.00	9.86
	σ =	0.91	0.78	0.69	24.17	2.15
	σm =	0.30	0.26	0.23	8.06	0.72
9. PRAE - BH	m =	38.12	70.83	19.44	132.00	6.22
	σ =	0.64	1.48	0.58	30.27	0.86
	σm =	0.21	0.39	0.19	10.09	0.29

TABLE 13

THE EFFECTIVENESS OF NINE METHODS OF RECOVERY TO LEVEL FLIGHT FROM A RIGHT SLOW TURN STALL

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - BH	m =	40.45	71.93	17.71	183.00	6.74
	σ =	0.82	2.14	0.00	24.52	0.81
	σm =	0.27	0.71	0.00	8.17	0.27
2. AE - BH	m =	40.47	67.99	20.64	212.00	9.86
	σ =	1.62	0.76	1.28	45.78	1.62
	σm =	0.54	0.25	0.43	15.26	0.54
3. PRE - OH	m =	40.65	67.72	17.71	56.00	9.38
	σ =	0.87	2.27	0.00	24.98	1.07
	σm =	0.29	0.76	0.00	8.33	0.36
4. PRE - BH	m =	40.39	73.72	17.71	152.00	8.42
	σ =	1.25	1.64	0.00	38.94	1.29
	σm =	0.42	0.55	0.00	12.98	0.43
5. PAE - OH	m =	39.63	67.35	21.54	30.00	11.04
	σ =	0.72	0.72	0.55	18.44	1.60
	σm =	0.24	0.24	0.18	6.15	0.53
6. PAE - BH	m =	39.26	68.87	20.49	108.00	7.21
	σ =	0.59	1.30	1.16	32.65	0.89
	σm =	0.20	0.43	0.39	10.88	0.30
7. RAE - BH	m =	41.28	72.96	18.46	146.00	7.10
	σ =	0.32	1.56	0.00	33.53	1.14
	σm =	0.11	0.52	0.00	11.18	0.38
8. PRAE - OH	m =	39.23	66.49	19.96	55.00	10.41
	σ =	1.34	1.36	1.16	39.81	1.27
	σm =	0.45	0.45	0.39	13.27	0.42
9. PRAE - BH	m =	38.97	71.04	19.36	123.00	6.96
	σ =	1.06	1.82	0.45	54.41	0.55
	σm =	0.35	0.61	0.15	18.14	0.18

As in the case of the left slow turn, the "On Horizon" methods were consistently superior to the "Below Horizon" methods. A notable difference, however, pertains to ailerons and rudders. In the case of the left slow turn, ailerons seem to hinder rather than help, whereas in the right slow turn, the use of aileron and elevator with power added and nose held on horizon appears to be the most satisfactory method of recovery.

Judging from these results, the pilot who stalls out of a right slow turn should recover by applying power, using ailerons and elevators, and holding the nose on the horizon. If he employs these practices he may recover with a loss of altitude of approximately only 50 feet; his recovery may require as much as 11 or 13 seconds. If he uses rudder instead of ailerons to level his wings and hold the nose on the horizon, he may expect to lose from 20 to 30 feet more altitude, but he will effect his recovery from 1 to 2 seconds faster. If he adds power and uses coordinated rudder, ailerons and elevators, he may be able to complete his recovery as effectively as in the case where he uses rudder and elevators only. However, when he uses coordinated controls, his recovery is not at all likely to be as consistent as when he uses only ailerons and elevators.

About the worst thing a pilot can do when he stalls out of a right or left slow turn is to drop the nose below the horizon and attempt to level his wings with the ailerons. This may cost him from 175 to 250 feet of altitude.

G. Case II Results -- Recovery to Normal Glide Path

Case II recoveries were defined as those which returned, not to straight and level flight as in Case I, but to the attitude of flight characteristic of the maneuver being attempted at the time the stall occurs. This phase of the study involved tests of recovery from stalls out of the straight-ahead glide and right and left gliding turns only.[24] Tests of the gliding

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[24]It may be possible in climbing maneuvers to recover from the stall by arresting the nose, not on the horizon, but on the angle-of-attack characteristic of the maneuver being attempted. This method of recovery was not tested in the present study, nor was it tried experimentally. Judging from the results of the previous section, it would be possible to test this hypothesis by choosing the optimum method of recovery from the stall out of each maneuver and testing whether or not the airplane can be recovered by arresting the downward sweep of the nose on the "normal" attitude for the maneuver in question. If it is possible to recover the aircraft under these conditions, then it can at least be expected that the recovery interval will be much longer than that required for "On Horizon" procedures. It is possible, also, that if the aircraft can be recovered at all, this procedure would sometimes be erratic, depending upon turbulence and other conditions, including the completeness of the stall.

attitude defined the "normal glide" as 1,000 r.p.m., 65 m.p.h. indicated airspeed, and an indicated angle-of-attack of 13 degrees.[25]

In tests of recoveries reported in this section, "On Path" procedures and "Below Path" procedures replaced those of "On Horizon" and "Below Horizon" procedures. The "On Path" and "Below Path" were determined by testing. The "On Path" procedures were defined as 13° angle-of-attack and "Below Path" procedures involved the use of a guide line taped to the windshield. This guide line was so located that "Below Path" represented a flight path approximately 15° below the normal gliding path.[26]

In designing the recovery methods for return to the Case II criterion, methods of recovery involving the addition of power were not tested. The assumption here was that these recovery procedures were to simulate as nearly as possible the forced landing situation with a dead engine. For obvious reasons it was not at all feasible to experiment with a dead engine.

1. <u>Recovery from a Stall Out of a Straight-Ahead Glide</u>.

Eight methods of recovery from stalls out of a straight-ahead glide were tested in connection with the Case II criterion, return to the normal glide path. Four of these recovery methods involved "On Path" procedures and four "Below Path" procedures. These recovery methods are listed in Table 14.

As shown in Table 14, the "Below Path" methods of recovery were distinctly superior to the "On Path" methods of recovery. Recovery method AE-BP resulted in an average loss of 114 feet and approximately 7.5 seconds were required to effect recovery to a normal glide path. Three other methods, all using "Below Path" procedures, were almost equally effective. These are RE-BP, 127 feet; E-BP, 130 feet; and RAE-BP, 132 feet.

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[25]The indicated airspeed was selected as being typical of good instruction in the normal glide. Since the maneuvers were performed at low altitude, it seemed best not to throttle back below 1,000 r.p.m. To arrive at the 13° angle-of-attack (indicated) the test pilots glided the aircraft in ten successive trials of two minutes each under the conditions of 1,000 r.p.m. and 65 m.p.h., indicated airspeed. The results of these tests averaged approximately 13° indicated angle-of-attack.

[26]After the normal gliding path had been determined, the nose was then lowered approximately 15° below this path to correspond with the 15° "below horizon" procedures reported earlier. The observer then fixed to the windshield a small piece of tape which if placed on the horizon in the gliding maneuver would result in the aircraft following a path approximately 15° below the normal gliding path. In this way "Below Path" and "On Path" were defined fairly objectively, and could be repeated in successive trials.

TABLE 14

THE EFFECTIVENESS OF EIGHT METHODS OF RECOVERY TO CRITERION ATTITUDE OF MANEUVER FROM A STRAIGHT AHEAD GLIDE (1,000 RPM)

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. E - OP	m =	40.02	54.20	17.71	254.00	20.88
	σ =	0.28	1.29	0.00*	109.56	9.79
	σm =	0.09	0.43	0.00	36.52	3.26
2. E - BP	m =	39.95	55.93	17.71	130.00	7.37
	σ =	0.57	1.55	0.00	21.40	0.94
	σm =	0.19	0.52	0.00	7.10	0.31
3. RE - OP	m =	39.05	54.24	17.71	280.00	25.75
	σ =	2.40	1.41	0.00	117.39	11.46
	σm =	0.80	0.47	0.00	39.13	3.82
4. RE - BP	m =	39.83	57.41	17.71	127.00	8.17
	σ =	1.09	1.54	0.00	44.28	1.18
	σm =	0.36	0.51	0.00	14.76	0.39
5. AE - OP	m =	39.19	55.50	17.71	275.00	23.75
	σ =	0.59	0.72	0.00	114.08	12.17
	σm =	0.20	0.24	0.00	38.03	4.06
6. AE - BP	m =	40.39	57.34	17.71	114.00	7.44
	σ =	0.90	1.51	0.00	34.41	0.81
	σm =	0.30	0.50	0.00	11.47	0.27
7. RAE - OP	m =	39.37	54.92	17.71	212.00	17.65
	σ =	0.65	1.24	0.00	93.95	6.20
	σm =	0.22	0.41	0.00	31.31	2.07
8. RAE - BP	m =	39.20	57.03	17.71	132.00	7.15
	σ =	0.78	1.97	0.00	34.87	1.32
	σm =	0.26	0.66	0.00	11.62	0.44

*The zero variation was occasioned by the pilot's beginning his recovery at 27° indicated angle of attack and so recording 27° as the A/A at all stalls in this series.

The method of recovery utilizing "On Path" procedures all resulted in an average altitude loss of more than 200 feet, with method RE-OP being least satisfactory with an average loss of 280 feet and an average recovery interval of nearly 26 seconds.

These results indicate very clearly that the pilot who stalls out of a normal glide and who cannot apply power for one reason or another, can best recover to a normal glide attitude by putting the nose of the aircraft below the normal glide path, leveling his wings with aileron and elevators and resuming a normal glide as soon as possible thereafter. If he uses rudder to assist in leveling his wings, he may expect a somewhat greater loss of altitude before he can establish a normal glide. On the other hand, he must recognize that the aircraft will not regain flying speed by holding the nose on the normal glide path without excessive loss of altitude. If he uses rudder and elevators or ailerons and elevators to level the wings, and attempts to hold the nose on the normal flight path, he may lose as much as 250 to 300 feet before he has regained normal gliding attitude and airspeed. In short, when he is attempting a forced landing without power and stalls out of a glide into the field, his best possible method of recovery involves at least regaining his airspeed as quickly as possible. This he may do by putting the nose of the airplane toward the ground, and when he regains flying speed, he can resume a normal glide path. The glide path will not, of course, be the one he could have flown had he not stalled. The stall will result in forcing him into the field short of where he might have landed, had the first normal glide been maintained.

2. <u>Recovery from a Stall Out of a Left Gliding Turn (1,000 r.p.m.)</u>

Six methods of recovery were tested in connection with recovery from left and right gliding turns, simulating forced landings. These are listed in Table 15 which presents the results for the left gliding turn and in Table 16 which presents the results of tests of the right gliding turn.

When the glide involves a turn and the stall occurs in the turn the recovery cannot be made quite as effectively, in terms of loss of altitude, as in the straight-ahead glide. The results of the six tests of recovery from stalls out of the left gliding turn when the normal glide path was the criterion attitude of recovery are shown in Table 15. Of these methods, RAE-BP was most satisfactory, with an average loss of approximately 149 feet and a recovery interval of approximately 8.5 seconds. The next most satisfactory method of recovery was AE-BP with an altitude loss of approximately 160 feet and a recovery interval of approximately 9 seconds. The most costly method of recovery in loss of altitude was method AE-OP, in which an average of 250 feet was lost and the recovery interval was of approximately 17.5 seconds duration.

Recovery from a stall out of a gliding turn cannot be made very effectively by holding the nose of the aircraft on the normal glide path.

TABLE 15

THE EFFECTIVENESS OF SIX METHODS OF RECOVERY TO CRITERION ATTITUDE OF MANEUVER FROM A LEFT GLIDING TURN (1,000 RPM)

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - OP	m =	40.25	53.82	17.71	212.00	18.75
	σ =	0.65	1.56	0.00	73.59	8.94
	σm =	0.22	0.52	0.00	24.53	2.98
2. RE - BP	m =	40.51	58.21	17.71	178.40	11.30
	σ =	0.64	2.65	0.00	39.18	2.73
	σm =	0.21	0.88	0.00	13.06	0.91
3. AE - OP	m =	40.65	54.52	17.71	258.00	17.51
	σ =	1.49	1.08	0.00	95.06	5.03
	σm =	0.50	0.36	0.00	31.69	1.68
4. AE - BP	m =	40.66	59.38	17.71	160.00	9.11
	σ =	0.71	2.22	0.00	25.30	1.43
	σm =	0.24	0.74	0.00	8.43	0.48
5. RAE - OP	m =	39.56	54.60	17.71	192.00	21.03
	σ =	0.80	1.54	0.00	105.91	11.07
	σm =	0.27	0.51	0.00	35.30	3.69
6. RAE - BP	m =	40.20	58.87	17.71	148.60	8.65
	σ =	0.26	2.48	0.00	45.10	1.74
	σm =	0.09	0.83	0.00	15.03	0.58

TABLE 16

THE EFFECTIVENESS OF SIX METHODS OF RECOVERY TO CRITERION ATTITUDE OF MANEUVER FROM A RIGHT GLIDING TURN (1,000 RPM)

Recovery Method		Calibrated Airspeed at Stall	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Stall	Loss of Altitude In Feet	Time to Recover In Sec.
1. RE - OP	m =	40.95	55.43	17.71	173.00	15.45
	σ =	1.13	1.47	0.00	56.58	4.68
	σm =	0.38	0.49	0.00	18.86	1.56
2. RE - BP	m =	40.59	57.98	17.71	128.00	8.27
	σ =	0.92	1.51	0.00	44.45	1.65
	σm =	0.31	0.50	0.00	14.82	0.55
3. AE - OP	m =	41.40	55.61	17.71	122.00	11.18
	σ =	0.67	0.78	0.00	91.74	4.18
	σm =	0.22	0.26	0.00	30.58	1.39
4. AE - BP	m =	40.89	58.11	17.71	128.60	6.99
	σ =	0.77	1.32	0.00	43.88	0.95
	σm =	0.20	0.44	0.00	14.63	0.32
5. RAE - OP	m =	41.29	55.75	17.71	221.00	17.14
	σ =	0.99	1.40	0.00	81.05	7.18
	σm =	0.33	0.47	0.00	27.02	2.39
6. RAE - BP	m =	41.72	58.69	17.71	138.00	7.47
	σ =	1.82	1.30	0.00	24.82	0.92
	σm =	0.61	0.43	0.00	8.27	0.31

In the left gliding turn the "On Path" procedures were distinctly inferior to the "Below Path" procedures.

These tests indicate that when the pilot is forced to glide without power available to him and stalls out of a left turn, his best procedure is to coordinate the use of rudder, aileron, and elevator, put the nose below the horizon until flying airspeed is regained, then resume the normal glide path. The stall will cost the pilot approximately 150 feet of altitude and will consequently make his landing shorter than had the original glide been maintained. It appears from these results that the higher the nose of the aircraft is held in attempting recovery to the normal glide, the more altitude will be lost in recovery. If the pilot attempts to recover by holding the nose on the normal glide path and uses only ailerons and elevators, he may lose as much as 200 or 300 feet of altitude. During the 17 or 18 seconds that will be required to get back to the normal glide path, he will be "mushing" toward the ground.

3. Recovery from a Stall Out of a Right Gliding Turn (1,000 r.p.m.)

The six recovery methods employed in testing recovery from a stall out of a left gliding turn were repeated in the case of the right gliding turn. The results of the tests, as shown in Table 16, do not entirely agree with those obtained for the left gliding turn.

Method AE-OP resulted in an average loss of 122 feet, whereas method RAE-BP, which was most satisfactory for recovering from a stall out of the left gliding turn, resulted in an average loss of 138 feet. It will be noted in Table 16, however, that procedure AE-OP was highly variable. The standard deviation of the ten trials was 91.74 feet, as contrasted with a standard deviation of 24.82 feet for recovery method RAE-BP. The latter was, therefore, much more consistent than the former, and for this reason is particularly preferred Similarly, method AE-BP, which resulted in an average of approximately 129 feet and standard deviation of 43.88 may generally be less dependable and less effective than method RAE-BP, with an average loss of 138 feet and a standard deviation of only 24.8 feet. At the other extreme, there is very little question as to which is the least effective method of recovery. This is method RAE-OP which resulted in an average loss of approximately 220 feet and a recovery interval of approximately 17 seconds.

These data indicate that when a pilot stalls out of a right gliding turn and must return to a normal glide path, he can get there with the least loss of altitude by the coordinated use of rudder, aileron, and elevator and by holding the nose of the aircraft below the normal flight path until flying speed has been achieved. He will then bring the nose up to the normal glide path and continue the glide. This can be accomplished in approximately 7 or 7.5 seconds. If the pilot holds the nose down below the normal glide path for a longer period of time, he will, of course, build up greater airspeed, but will, consequently, lose more altitude. If he attempts to hold the nose on the normal glide path his

TABLE 17

SUMMARY OF RESULTS FOR OPTIMUM METHODS OF RECOVERY FROM THE FULL STALL TO STRAIGHT AND LEVEL FLIGHT

Maneuver No.	Optimum Controls	"Below Horizon" Loss of Altitude m	σ	Time m	"On Horizon" Loss of Altitude m	σ	Time m
1. Straight Ahead, Climbing Power (Full throttle)	(P)*R E	130	16.7	8.3	26	19.1	10.5
2. Straight Ahead, Cruising Power (2,100 r.p.m.)	P R E	158	32.5	5.0	53	23.4	8.2
3. Straight Ahead, Reduced Power (1,000 r.p.m.)	P R E	114	19.6	6.8	38	24.9	13.5
4. Left Climbing Turn, Climbing Power (Full throttle)	(P) RAE	122	24.4	6.8	69	29.8	13.9
5. Right Climbing Turn, Climbing Power (Full throttle)	(P) RAE	109	35.0	6.2	46	18.0	12.1
6. Left Gliding Turn, Reduced Power (1,000 r.p.m.)	P R E	129	48.5	6.7	79	25.9	12.6
7. Right Gliding Turn, Reduced Power (1,000 r.p.m.)	P RAE	134	16.9	7.5	60	18.9	11.9
8. Left Steep Turn (2,100 r.p.m., 60° bank)	(P) RAE	102	48.9	7.7			
9. Right Steep Turn (2,100 r.p.m., 60° bank)	(P) RAE	89	27.7	8.6			
10. Left Slow Turn, Reduced Power (1,500 r.p.m., 30° bank)	P R E	149	48.0	8.2	63	24.9	10.3
11. Right Slow Turn, Reduced Power (1,500 r.p.m., 30° bank)	P AE	108	32.7	7.2	30	18.4	11.0
Average**		128.1		7.0	51.6		11.6

* (P) indicates full power at the time of stall

** Excluding Maneuvers #8 and #9

recovery will be erratic and dangerous. He may lose from 200 to 250 feet and he will not gain control of the aircraft until after 15 to 20 seconds have elapsed.[27]

B. Summary of Results and Comparisons

1. Results for Optimum Methods of Recovery from the Full Stall to Straight and Level Flight.

In considering the optimum methods of recovery from a full stall, it will be of assistance to recapitulate the results for each of the tests of recovery from stalls out of the eleven maneuvers considered in this study. Table 17 presents criterion data for the optimum methods of recovery from the stall out of each of the eleven maneuvers with recovery to straight and level flight as criterion, and compares the basic data for the "On Horizon" procedures with those for "Below Horizon" procedures. In preparing this table the method of recovery which resulted in the least loss of altitude was listed. For these methods of recovery the average loss of altitude in feet and the average time interval in effecting recovery are listed in the right section of Table 17. In an effort to understand how these optimum methods of recovery compared with their corresponding "Below Horizon" recovery methods, the latter are listed in the central part of Table 17. The "Optimum Controls" column in this table presents the controls which were used in effecting the optimum recovery. It will be noted in this table that maneuvers 1, 4, 5, 8, and 9 involve the use of full power and, consequently, additional power could not be added. The data presented in Table 17 summarize the important findings of this phase of the investigation.

These findings may be further summarized as follows:

a. When the criterion of recovery was straight and level flight, the "On Horizon" method of recovery was distinctly superior to the "Below Horizon" procedure in recovery from a full stall. As shown in Table 17, the average loss of altitude for all optimum "On Horizon" procedures was only 51.6 feet as contrasted with an average loss of 128.1 feet in the case of "Below Horizon" procedures.

b. Recovery using the "On Horizon" procedures cannot be effected as rapidly as the "Below Horizon" procedures. The former required on the average approximately 11.6 seconds to return to straight and level flight, whereas by the "Below Horizon" procedure, recovery to straight and level flight was effected in on the average of 7.0 seconds.

c. All of the optimum or "best" methods of recovery from the stall to level flight as criterion involved the use of full power and the optimum use of elevators.

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[27]Possible causes explaining the different results found for right and left turns, respectively, are discussed on page 73 following.

d. In stalls out of straight-ahead maneuvers (1, 2, and 3) full power and the coordinated use of rudder and elevators produced the best results. The use of ailerons in recovery from a straight-ahead stall resulted in a greater loss of altitude than necessary.

e. Coordinated use of rudder, aileron, and elevators in turns was generally the optimum method of recovery. This did not hold in the case of left turns to quite the same extent it did with right turns. It will be noted in Table 17 that aileron control was involved in both right and left climbing turns, in right gliding turns, and in right slow turns. It appeared necessary, also, to use ailerons to control the aircraft in very steep turns, maneuvers 8 and 9. The use of ailerons in the left gliding turn and the left slow turn appeared to be detrimental.

f. Another striking fact shown in Table 17 was the superiority of recovering out of right turns over left turns. Recovery out of stalls from left turns systematically involved greater loss of altitude than recovery from stalls out of right turns.[28] It is possible that the effect of torque under full power assists the pilot in bringing the wings level out of the right turn, whereas it may handicap him slightly in the left turn.

g. When the criterion of recovery was straight and level flight the stall out of the left steep turn was the most costly stall of any of the eleven. The right steep turn stall was next most costly. The average recovery from stalls out of these maneuvers lost from 90 to 100 feet of altitude. On the other hand, recovery from stalls out of a straight-ahead climb was effected with a loss of from 25 to 30 feet of altitude. This applied also in the case of the right slow turn.

2. <u>Results for Optimum Methods of Recovery from a Full Stall to the Normal Glide Path (1,000 r.p.m.).</u>

The tests summarized in the preceding section assumed that the pilot had full power to apply in the event he stalled. Tests were also conducted in gliding maneuvers with a power setting of 1,000 r.p.m. to simulate landing with a dead engine. The results for the optimum methods of recovering in this situation are presented in Table 18. It will be remembered from a preceding section that the best methods of recovering from glides was the "Below Path" procedure. In Table 18, the optimum methods of recovery to the normal glide path by the "Below Path" procedures are presented in the middle section of the table. The right hand section of the table presents test data for corresponding "On Path" procedures.

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[28] As stated previously, most pilots are best practiced on left turns. They make more of them. The traffic pattern is generally toward the left. Had recovery from the stall out of the left turn resulted in less loss of altitude than recovery from the stall out of the right turn, this difference might have been explained on the basis of practice and coordination of the pilot. The reverse, however, can hardly be explained on this basis.

TABLE 18

SUMMARY OF RESULTS FOR OPTIMUM METHODS OF RECOVERY FROM A FULL STALL TO THE NORMAL GLIDE

Maneuver No.	Optimum Controls	On Path: Loss of Altitude			Below Path: Loss of Altitude		
		m	σ	Time m	m	σ	Time m
3. Straight Ahead, Reduced Power (1,000 r.p.m.)	AE	275	114.1	23.8	114	34.4	7.4
6. Left Gliding Turn, Reduced Power (1,000 r.p.m.)	RAE	192	105.9	21.0	149	45.1	8.7
7. Right Gliding Turn, Reduced Power (1,000 r.p.m.)	RAE	221	81.1	17.0	138	24.8	7.5
Average		133.7		7.9	229.3		20.6

The findings presented in Table 18 may be summarized as follows:

a. The "Below Path" method of recovery was distinctly superior to the "On Path" procedures in recovering to a normal glide path. The "Below Path" procedures resulted in an average loss of altitude of approximately 134 feet, as contrasted with an average of approximately 229 feet for the "On Path" procedures.

b. The "On Path" procedures of recovery from a stall out of a glide can be effected if time and altitude permit. The average time interval necessary for recovery by "Below Path" procedures was approximately 8 seconds, but by "On Path" procedures, approximately 21 seconds.

c. All of the optimum or "best" methods of recovery from the stall out of a glide to the normal glide path as criterion involved the coordinated use of ailerons and elevators.

d. In the stall following a straight-ahead glide, ailerons and elevators alone produced the best results. When rudder was used in recovery from the stall out of this maneuver, the loss of altitude on the average tended to be greater than when it was not used. (See Table 14.)

e. The coordinated use of rudder, ailerons, and elevators in recovery from stalls out of gliding turns was the optimum method of recovery.

f. As in the case of recovery to straight and level flight, stalls out of turns lost more altitude than the stall out of the straight-ahead glide. Furthermore, recoveries from stalls out of right gliding turns were made with less loss of altitude than recoveries from stalls out of left gliding turns.

g. Judging from the data presented in Table 18, the stall out of the left gliding turn is the most costly stall out of glides, as judged by the altitude lost. That is, when the pilot who cannot or does not apply power, stalls in the left turn, he cannot hope to recover the aircraft as rapidly or as effectively as in the case of a stall out of the straight-ahead glide or a right gliding turn. This finding has particular interest when viewed in the light of the infamous "last turn in" to the field.

PART IV

RECOVERY FROM A STALL WARNING

A. General Considerations

The experimentation reported in preceding sections of this report was concerned with the recovery of a light aircraft from a full stall.[1] The results apply to the case in which the aircraft actually stalls and the pilot is faced with making a recovery, either to straight and level flight or to normal glide. The data which have been presented reveal clearly that the stall must be avoided, if at all possible, particularly at low altitudes where the resulting loss of altitude may precipitate an accident.

Within very recent years stall warning devices have become available commercially. Several types of stall warner have been sold in considerable numbers. Private owners of light aircraft have been urged by both popular and technical writers to purchase and install some type of stall warner. Research has shown that the physical and psychological clues whereby the stall may be detected are frequently obscure and difficult to recognize. The findings from research on stall recognition led to the recommendation that some mechanical stall warning device be installed on light aircraft to assist pilots to recognize the imminence of stall conditions.[2] The Civil Aeronautics Administration has considered the possibility of recommending that such devices be installed on training and private planes.

When the pilot is flying an aircraft equipped with a stall warner, his problem will generally be that of recovering from "near stalls" rather than full stalls. That is, until the point of stall, the pilot has control of the aircraft and can resume normal flight by the usual procedures of control. He merely returns to the normal attitude for the maneuver he is attempting. In this process, the aircraft continues without loss of altitude such as inevitably results when the full stall occurs. If he is climbing, he can continue to climb; if he is gliding, he can return almost immediately to a safe glide.

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[1] In maneuvers resulting in "progressive" stalls the recovery was begun when the angle-of-attack indicator read an appropriate value.

[2] Rulon, P. J. <u>A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar airplanes</u>. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

On the basis of the findings of this study the Committee on Aviation Psychology recommended that regulations be formulated requiring the installation of approved stall warning devices in all private airplanes, providing that field tests demonstrate the available instruments can be adequately maintained and function properly over an extended period.

Stall warners have taken a variety of forms, both with respect to the mechanical principle whereby the instrument senses the approach of stalling conditions, and also in the manner of indicating the signal. In this first respect, the stall warner may function as a crude instrument for measuring angle-of-attack, or for sensing flow of air. Its essential element is that when either the angle-of-attack approaches that characteristic of the stall, or when the flow of air is characteristic of some point near the stall where the pilot should be "warned," the instrument initiates a signal which is transmitted to the pilot. This signal may consist of a light flashing on, a buzzer or horn sounding, or indeed it may consist of a "stick-shaker" or some other obvious physical cue. These physical cues "warn" the pilot that the stall is approaching and that he should resume a more nearly normal angle-of-attack or airspeed if he is to escape the full stall.

In view of these considerations, a study of recovery from a stall warning must take a very different line of inquiry from that employed in recovery from the full stall. In the case of the full stall, recovery from the stall was effected to straight and level flight and to the attitude characteristic of a normal glide. When tests of recovery from a stall warning to these criterion conditions are run, the general nature of the results can be predicted on the basis of experience. Experimentation would have been unnecessary except for the purpose of determining, for example, the exact amount of altitude gained in a climb rather than lost in a climbing stall. This type of data is of some value for descriptive and instructional purposes. Data of this type were obtained in the present study and are reported in succeeding sections. The problem of securing these data was, however, secondary to the study of a more general question: "Where can the stall warner be set so that it will be of most assistance to the pilot?" The consideration of this problem involved tests of the stall warning device installed on the testing aircraft, and determining the maximum angle of climb and the minimum angle of glide of the testing aircraft. In addition, flight tests were made of "recoveries" from a stall warning for purposes of describing accurately the amount of altitude that may be gained rather than lost by flying along the path of maximum angle of climb[3] rather than depending upon even the best possible means of recovery in the event of a stall.

B. Testing the Stall Warning Instrument

The testing aircraft was equipped with a five-vane stall warning installation that was originally designed for testing and instructional purposes. This installation consisted of five individual stall warners mounted in such a manner as to trip at various flight attitudes. Similar installations were used in the Rulon studies of stall recognition and avoidance. At the time these studies were conducted, however, the aircraft used was

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[3]Or the minimum altitude lost by flying along the path of the minimum angle of glide.

not equipped with a radio altimeter, an angle-of-attack indicator, or a sensitive airspeed indicator. The vanes were separated from each other on the basis of the "feel" of the aircraft, its attitude with visual reference to the horizon in flight and its behavior with respect to the full stall out of various maneuvers. The fourth vane in the series was set to trip at a flight attitude which was very near the stall, but which could be maintained without actually stalling the aircraft by proper coordination of the controls. The remaining vanes were set at fairly uniform intervals which represented distinguishable differences in flight attitude and graduated toward normal flight from the exaggerated attitude characterized by flight at the fifth vane.

The first step in the investigation of recovery from a stall warning was the testing of these vane settings.

1. Method of Testing.

The method of testing was designed to determine the angle-of-attack and airspeed at which each of the five stall warners came on, and was essentially the same as that employed in the testing procedures described earlier. Testing was facilitated by the fact that the stall warning device included a clipboard on which separate lamps were lighted as each warning vane was tripped. The clipboard could be moved about freely in the cockpit and could be held near the angle-of-attack indicator so that the reading of the angle-of-attack indicator could be taken almost instantaneously following the tripping of the vane and the lighting of the lamps.

During the testing, the pilot concentrated on flying the aircraft and on reading the airspeed as in previous tests. The observer held the clipboard near the angle-of-attack indicator. He read the latter as the lamp came on. When the lamp came on, he called "Now." At that instant the pilot read the airspeed. The indicated angle-of-attack and the indicated airspeed were then recorded by the observer.

Six test trials were run for each of the five lamps for each of nine maneuvers. These maneuvers corresponded to the ones investigated in connection with recovery from the full stall; the slow turns were not run.

2. Results of Testing.

Data obtained in these tests are summarized in Table 19, which presents the average calibrated angle-of-attack and the average calibrated airspeed at the time each of the five lamps was lighted.[4]

a. Average Airspeed. The following Table 20 lists for each signal lamp the range of average airspeeds among maneuvers listed in Table 19.

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[4]Calibration procedures were reported in an earlier section of this report.

TABLE 19

TESTING OF STALL WARNING INSTALLATION ON PIPER J-3-C - NC 41578

Maneuver	Lamp No.	Calibrated Angle of Attack m	Calibrated Angle of Attack σ	Calibrated Airspeed m	Calibrated Airspeed σ
1. Straight Ahead Climbing Power	1	5.21	0.35	51.17	2.73
	2	7.71	0.28	45.65	0.62
	3	10.59	0.38	40.10	0.86
	4	14.09	0.91	35.83	0.68
	5	16.15	0.14	37.72	0.26
2. Straight Ahead Cruising Power (2,100 r.p.m.)	1	4.71	0.35	50.53	0.85
	2	7.16	0.26	45.22	0.71
	3	9.08	0.43	41.80	0.30
	4	13.09	0.80	34.63	0.79
	5	16.34	1.18	33.15	0.65
3. Straight Ahead Reduced Power (1,000 r.p.m.)	1	3.84	0.38	53.93	1.83
	2	6.33	0.47	48.10	0.63
	3	9.08	0.31	44.79	1.01
	4	12.40	0.14	39.45	1.01
	5	17.40	1.31	37.08	1.13
4. Left Climbing Turn (2,100 r.p.m.)	1	3.96	0.35	51.48	0.89
	2	6.58	0.18	47.65	0.49
	3	8.65	0.14	41.91	0.48
	4	11.84	0.28	37.83	0.61
	5	15.21	0.28	38.18	0.26
5. Right Climbing Turn (2,100 r.p.m.)	1	4.52	0.34	52.33	1.17
	2	7.27	0.63	48.83	0.90
	3	8.77	0.43	41.68	0.73
	4	12.34	0.91	38.07	0.97
	5	16.52	0.40	39.35	0.49
6. Left Gliding Turn (1,000 r.p.m.)	1	3.46	0.00	56.71	1.57
	2	6.40	0.26	50.97	0.45
	3	8.96	0.17	45.85	0.85
	4	12.40	0.63	41.90	0.62
	5	15.84	0.57	41.05	1.28
7. Right Gliding Turn (1,000 r.p.m.)	1	3.46	0.00	56.71	0.87
	2	6.83	0.31	51.80	1.20
	3	9.15	0.26	46.27	1.48
	4	13.52	0.40	43.92	0.52
	5	15.59	0.28	42.45	0.62

TABLE 19 (Continued)

Maneuver	Lamp No.	Calibrated Angle of Attack m	σ	Calibrated Airspeed m	σ
8. Left Steep Turn	1	2.71	0.00	65.90	0.54
(2,100 r.p.m.)	2	5.09	0.28	59.40	0.35
(60° bank)	3	7.27	0.14	54.60	0.96
	4	11.58	0.47	46.60	0.83
	5	14.21	0.28	41.68	0.89
9. Right Steep Turn	1	3.02	0.34	66.00	0.80
(2,100 r.p.m.)	2	6.02	0.34	63.97	0.58
(60° bank)	3	7.33	0.17	57.13	1.74
	4	12.21	0.28	52.57	3.81
	5	13.96	0.48	51.82	2.39
Average of all Maneuvers	1	3.88	0.81	56.09	5.85
	2	6.60	0.81	51.29	6.07
	3	8.76	0.97	46.01	5.74
	4	12.61	0.96	41.20	5.62
	5	15.69	1.24	40.28	4.98

TABLE 20

SUMMARY OF RESULTS FOR AIRSPEED

	Range of Averages	Average
Lamp #1	50.53 to 66.00 m.p.h.	56.09
Lamp #2	45.22 to 63.97 m.p.h.	51.29
Lamp #3	40.10 to 57.13 m.p.h.	46.01
Lamp #4	34.63 to 52.57 m.p.h.	41.20
Lamp #5	33.15 to 51.82 m.p.h.	40.28

The average airspeeds at which each of the lamps came on are not particularly meaningful. However, it will be noted in the above table that the averages of all maneuvers show a fairly regular progression from the highest to the lowest, with the exception of the interval between the fourth and fifth lamps. In this particular stall warning installation, the fifth vane was set to come on just as the airplane started "over the top" out of a stall from a left climbing turn. The first vane was set so that it would come on in any improper departure from normal climb or glide. The other vanes were separated by approximately equal intervals in terms of angle and position on the leading edge of the wing.

While there were no reversals in averages for all maneuvers, there were some in the tests of the five vanes in individual maneuvers. It will be noted in Table 19 that, in the case of the straight ahead climb, straight ahead cruising, and the right climbing turn maneuvers, the average airspeed values obtained by testing were less for the fifth vane than for the fourth vane. These reversals could have been due to sampling errors, the techniques of the pilot or the observer, the weather conditions on the days in which these tests were flown, or other factors which affected the performance of the aircraft and the instrumentation employed.

b. Average Angle-of-Attack. The following Table 21 lists for each signal lamp the range of angle-of-attack averages among the maneuvers listed in Table 19.

It could be noted from Table 19 that the signals consistently came on in the left steep turn at the lowest angle-of-attack. On the other hand, the highest angle-of-attack required to turn on each signal lamp occurred in the straight-ahead, full power climb.

These findings indicate a fairly regular progression of increase from the first lamp to the fifth lamp. In general, each lamp was separated from the preceding one by an angle-of-attack ranging from approximately 2.5° to 3.5°.

TABLE 21

SUMMARY OF RESULTS FOR ANGLE-OF-ATTACK

	Range of Averages	Average
Lamp #1	2.71° to 5.21° A/A	3.88°
Lamp #2	5.09° to 7.71° A/A	6.60°
Lamp #3	7.27° to 10.59° A/A	8.76°
Lamp #4	11.58° to 14.09° A/A	12.61°
Lamp #5	14.21° to 16.15° A/A	15.69°

These findings pertain only to the particular five-vane stall-warning installation on the testing aircraft. They illustrate what might have been done to calibrate stall-warning installations used in investigations of stall recognition and avoidance. Had, for example, an angle-of-attack indicator been available in the aircraft used for testing stall recognition and avoidance, one of the measures of stall recognition might have been in terms of angle-of-attack, rather than the number of lamps lighted. However, the vane system employed in previous studies is now seen to be roughly equivalent to the costly angle-of-attack instrument available to the present investigators.

C. Location of the Stall Warner

These data show how troublesome is the problem of locating the stall warner. Where should the warning be given? It is obvious from the above data that the owner of a light aircraft can select either position 3 or 4, or he may select any intermediate point. What constitutes an acceptable basis of selection?

1. Recommendations of Stall Warner Manufacturers.

Conferences were held with representatives of companies manufacturing and installing stall warning devices. In these conferences the investigators attempted to determine the basis upon which the stall warning device manufacturers recommended the location of their device.

The manufacturers of the Greene Safe Flight Stall Warner recommended that their instrument be located to come on at a point from 3 to 5 miles per hour above the stalling speed. This recommendation was not accompanied by a definition of the maneuver in which the stalling speed was to be obtained. It may be assumed, however, that the straight-ahead, cruising power, unaccelerated stall was intended, although this was not specifically stated in the recommendation.

The Beech Stall Warner, which is presently installed on Beechcraft Bonanzas and similar aircraft, was, according to its representatives, generally located to signal at from 6 to 10 m.p.h. above stalling speed. The Beechcraft Corporation did not make a definite recommendation on the installation of its stall warning device; it prefers to leave the exact location of the device up to the owner of the aircraft.

The conferences with representatives of these companies revealed no basic reason why the stall warner should be set to signal at from 3 to 10 m.p.h. above the stalling speed, except that "this is probably the best place to put the warner."

2. Further Considerations.

The present project sought to provide information that would be helpful in teaching and learning about stall conditions in light aircraft. It was therefore believed that a more readily explainable basis for installing the stall warning device should be sought. It may be assumed that a pilot who intentionally brings the aircraft close to stalling conditions does so primarily in the process of seeking maximum performance of the plane. If he stalls out of a climb, he does so because he is attempting to achieve a maximum climb. He may be attempting to get over some obstacle, or avoid another plane, or climb out of a short field. Stalls out of a glide may occur because the pilot is attempting to flatten his glide as much as possible to conserve altitude. In attempting to climb too steeply or to glide too flatly the pilot approaches stalling conditions and may actually stall the airplane. As he approaches these conditions, he should be warned at some point that he has reached either (1) a point beyond which it is not "safe" to go, or (2) a point around which it is desirable to bracket his flight so as to obtain a maximum performance. Both of these possibilities were considered.

a. A Safety Point. It appeared that most stall warning installations have taken the first approach. That is, the warner is installed so that the signal comes on at an attitude close to the stall and indicates "unsafe flight." The pilot knows that his object is to turn off the signal. With this principle operating, the installation may have various effects on different pilots, and the installation, itself, may vary in considerable degrees. One pilot may prefer to have his warning very close to the stall, whereas a second pilot may prefer to have his much closer to normal flight. If the warner is set too near normal flight, then small amounts of turbulence tend to turn the stall warner on. In such cases, the pilot may get in the habit of ignoring the stall warning device and perhaps leaving it on, even though he has almost reached the point of stalling.

If, on the other hand, the stall warning installation is so near the point of stall when the signal comes on that the plane has virtually stalled, then the pilot may delay too long and not be able to recover before the aircraft stalls. In previous studies of stall recognition and performance, it was apparent that many pilots approached the stall, recognized that they were near it, but did not recover in time to avoid it. Thus, if the stall warning device is installed and operated on the principle of psychological "nearness" to the stall, the mechanical device depends for much of its effectiveness upon the psychological idosyncrasies of the pilot, and also upon the relative location of the warner from the point of stall.

b. An Optimum Point. If, on the other hand, it were possible to locate a stall warner at some point of maximum performance, it would be possible to instruct the pilot that this optimum performance could not be exceeded with any favorable results. If such an optimum were sufficiently short of the stall to permit the pilot to "bracket" the optimum, then the pilot would be equipped, not only with a stall warner, but with a flight instrument which permitted him to obtain the maximum results from the maneuver he was attempting.

As previously stated, it is possible that there are two principal reasons for inadvertent stalls. The pilot may be either attempting to climb too steeply or to glide too flatly. Maximum angle of climb and minimum angle of glide, therefore, may be desirable optimal points around which to "bracket" flight in steep climbs and flat glides. It would appear that these represent limiting flight attitudes beyond which the pilot cannot go without defeating his purposes. The principal question to be answered, however, is whether the maximum angle of climb or minimum angle of glide is achieved at such a setting as to permit the use of this optimum for bracketing purposes and also as a stall warning. That is, if the maximum angle of climb is achieved at an angle-of-attack so near the angle-of-attack characteristic of the stall, then it might be "dangerous" to select this flight attitude as an optimum "warning" attitude. Also, if the maximum angle of climb were very close to the angle-of-attack characteristic of normal flight, then it would also be "a nuisance" to use this as an optimum point.

As a next step the present investigation sought to determine the maximum angle of climb and the minimum angle of glide, and to relate these to pertinent data in an effort to determine whether these optimal flight attitudes were sufficiently safe for practical use in operating a light aircraft.

PART V

RECOVERY TO OPTIMUM CLIMBING AND GLIDING ANGLES

In the preceding sections of this report it was hypothesized that the stall warner should be located to "warn" at the point of maximum performance in the climb. In climbing maneuvers this is a flight path lying along the maximum angle of climb. In terms of gliding maneuvers, the optimum flight path is along the minimum angle of glide. In less general terms, the maximum angle of climb is that angle of flight which will result in the most altitude gained per foot of forward progress along the ground. Similarly, the minimum angle of glide is that flight path which will result in the least loss of altitude per foot of forward advance over the ground.

Most pilots know that there is a difference between the airspeed which produces the <u>steepest</u> climb (maximum <u>angle</u> of climb) and the airspeed which achieves the <u>fastest</u> climb (maximum <u>rate</u> of climb). In fact, the maximum <u>rate</u> of climb is frequently specified in manuals obtained from aircraft manufacturers. However, most pilots do not know the airspeed (or angle-of-attack) that represents the maximum <u>angle</u> of climb for their aircraft. Information on this type of aircraft performance is not presented in manufacturers' manuals. Yet the pilot may need this type of information, particularly when he is seeking maximum performance in climbing over some obstacle or in attempting to stretch his glide in the case of a forced landing or in other situations in which he does not have power to apply.

A. <u>The Purpose of This Phase of the Investigation</u>

There were two specific purposes of this phase of the investigation: (1) to determine the maximum angle of climb and the minimum angle of glide for the testing aircraft, and (2) to test various methods of "recovering" from a stall warning set to come on at the maximum angle of climb.

The first purpose involved the testing of gain in altitude under full power at selected airspeeds. From the data thus obtained it was possible to calculate a maximum angle of climb and to translate this into the airspeed at which this maximum angle of climb was achieved under full power. Tests were also run to determine the minimum angle of glide. This involved the gliding of the testing aircraft under conditions of constant 1,000 r.p.m., and varying airspeeds. The second purpose of this phase of the investigation involved the testing of methods of controlling the aircraft in attempting to fly along the flight path prescribed by mechanical signals which came on and went off near the maximum angle of climb of the testing aircraft. These tests were intended to provide information on the amount of altitude that can be conserved by using a stall warner to provide a signal, which when "bracketed" obtains the maximum performance of the aircraft in the climb.

B. The Maximum Angle of Climb

1. Testing Procedures.

The general nature of these testing procedures included the selection of six general airspeeds to be flown under full power conditions, and designing and flying the flight tests necessary to obtain the basic data whereby the maximum angle of climb could be calculated.

a. Six Airspeeds. The six airspeeds selected for testing purposes were 40, 45, 50, 55, 60, and 65 m.p.h. The test design specified that the aircraft was to be flown at each of these airspeeds under full power for at least one minute.

b. Procedures. The testing aircraft was flown low over water until the altimeter read approximately 100 feet. The nose of the aircraft was then slowly pulled up and power was added. When the airspeed settled down to the airspeed for which the run was to be made, the pilot called "Now," and the observer started his stop watch and read the radio altimeter and then the angle-of-attack indicator. The pilot then attempted to climb the airplane at exactly the desired airspeed. At the end of exactly 60 seconds of climb the observer called "Now," and read the radio altimeter and the angle-of-attack indicator. At the signal, the pilot read the airspeed. These data were then recorded and checked.

Six trials were run at each of the six airspeeds. The testing schedule was so designed that the six tests at each of the desired airspeeds were equalized insofar as possible with respect to the changing weight of the aircraft due to gas consumption.

c. Precautions. In preliminary tests it was discovered that even slight turbulence resulted in considerable variation in the data. In view of this fact, all tests were conducted in very calm air.

It was believed that the change in the weight of the aircraft due to gas consumption might also affect the results. A systematic study of this factor was made, but it was discovered that the variations in results obtained with a near-empty tank and near-full tank of gas were such that these variations might have been explained on the basis of differences in sampling, rather than on the basis of a consistent difference in performance of the testing aircraft under these two conditions. Nevertheless, the testing schedule was arranged so as to avoid the possibility of having one or more of the altitude measures for the selected airspeeds being adversely affected by either a near-full tank of gas or a near-empty one.

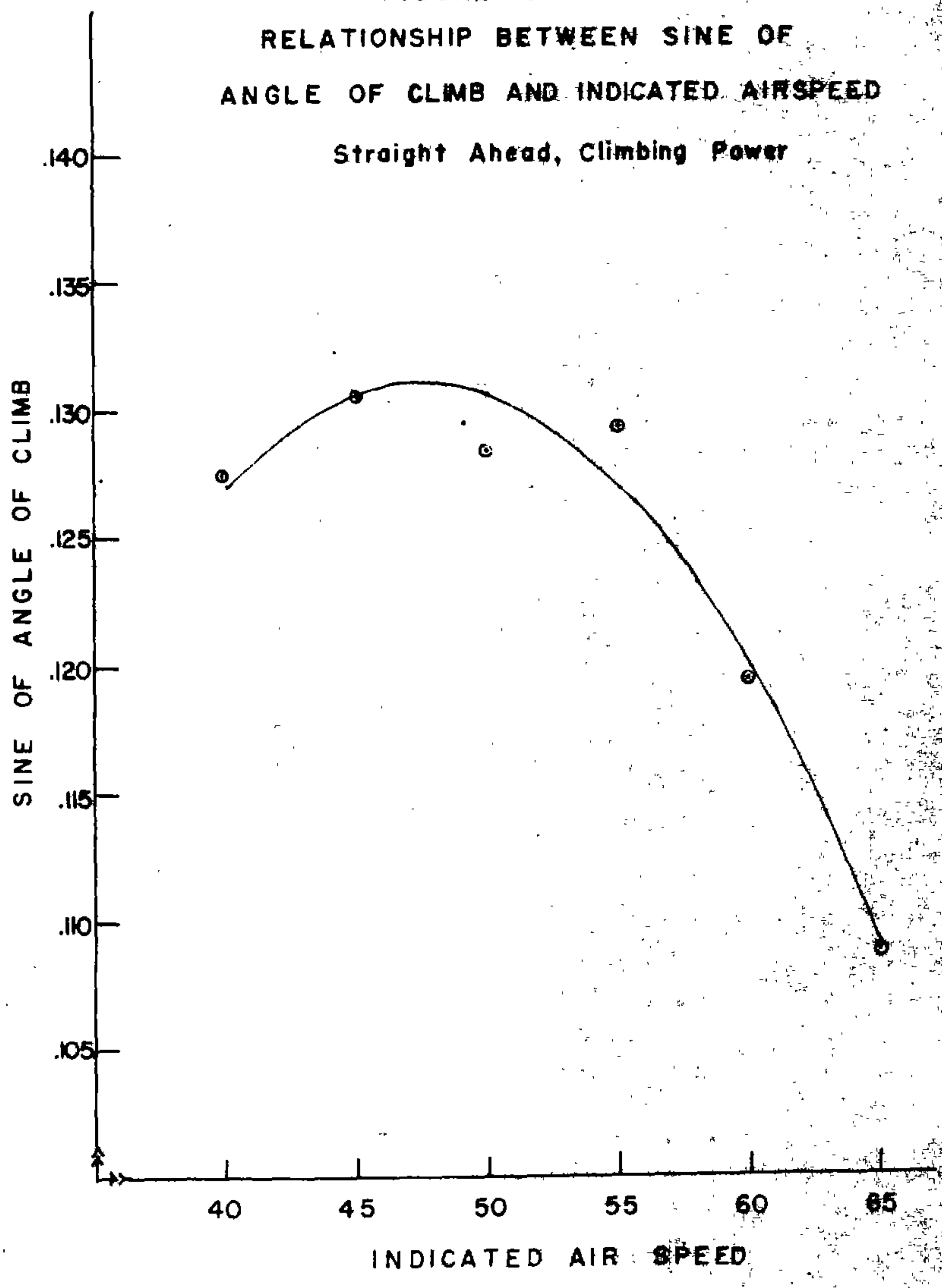
2. Results.

The maximum angle of climb was determined for three climbing maneuvers -- straight-ahead climb, right and left climbing turns.

FIGURE 3

RELATIONSHIP BETWEEN SINE OF ANGLE OF CLIMB AND INDICATED AIRSPEED

Straight Ahead, Climbing Power



a. Straight-Ahead, Climbing Power. A summary of the test results for each of the six airspeeds flown in this maneuver is presented in Table 22. The distance along the flight path was calculated in terms of calibrated airspeed of one minute duration. The altitude gained was calculated directly from the radio altimeter readings and the sine of the angle of climb was calculated by dividing the distance on path by the altitude gained. These tests provided the basic data for the calculation of the curve of best fit.

TABLE 22

MAXIMUM ANGLE OF CLIMB DATA -- AVERAGE OF SIX TRIALS
STRAIGHT-AHEAD CLIMB

Indicated Airspeed	Calibrated Airspeed	Distance On Path	Altitude Gained	Sine of Angle of Climb
40	38.9	3423.2	436.0	.1274
45	42.1	3704.8	483.3	.1305
50	45.3	3986.4	511.7	.1284
55	48.5	4268.0	551.7	.1293
60	51.7	4549.6	543.3	.1195
65	54.9	4831.2	525.0	.1087

These data were graphed as shown in Figure 3 and it was judged that a second-order curve would be a curve of best fit.

Using the usual method of calculating a curve of the second order and using the coordinates of the five points shown on Figure 3 as basic data, the following equation of the curve was obtained:

$$\text{Sine } \alpha = -.0303 + .006795\,(\text{IAS}) - .00007157\,(\text{IAS})^2$$

This equation was differentiated to find its maximum. The obtained maximum was 47.47 m.p.h., indicated. In terms of calibrated airspeed this was 43.7 m.p.h.[1]

[1]The data on determining maximum angle of climb and minimum angle of glide are presented in terms of indicated airspeed, rather than calibrated airspeeds or in terms of angle-of-attack. This procedure was used primarily because pilots of light aircraft will not ordinarily have calibrated airspeed values with which to work. It will probably be necessary also for such pilots to use a slightly different method of obtaining the sine value in testing their own aircraft. It was, of course, possible to have flown a known distance along a path on the ground, such as a 5,000 ft. runway, or a 3,000 ft. runway. However, because of the availability of the radio altimeter, these tests were run over water, where the distance flown "On Path" was easier to obtain than a known distance on the surface of the testing area.

These results indicate that, under full power, the testing aircraft on the average achieved its maximum angle of climb at a calibrated airspeed of approximately 43.7 m.p.h. This was approximately 8.7 m.p.h. in advance of the stall out of the same maneuver.

b. Left Climbing Turn. In tests of maximum angle of climb in the left climbing turn, airspeeds of 45, 50, 55, 60, 65, and 70 m.p.h. were flown. The sines of the angle of climb at each of these indicated airspeeds are presented in Table 23. Using the same method of calculating the equation of the curve of best fit, the following equation was obtained:

$$\text{Sine } \alpha = -.027523 + .0063436\ (\text{IAS}) + .00006729\ (\text{IAS})^2$$

This equation was differentiated to find the maximum, and the value obtained was 47.14 m.p.h., indicated airspeed. This was equivalent to a calibrated airspeed of 43.48 m.p.h.

It will be noted that the maximum angle of climb in the left climbing turn was approximately the same as that obtained in the straight-ahead climb.

TABLE 23

MAXIMUM ANGLE OF CLIMB DATA -- AVERAGE OF SIX TRIALS
LEFT AND RIGHT CLIMBING TURNS

Indicated Airspeed	Calibrated Airspeed	Sine of Angle of Climb Left turn	Sine of Angle of Climb Right turn
45	42.1	.1217	.1260
50	54.3	.1214	.1298
55	48.5	.1178	.1265
60	51.7	.1108	.1189
65	54.9	.1005	.1081
70	58.1	.0833	----

c. Right Climbing Turn. Similar tests were run for the purpose of determining the maximum angle of climb in the right climbing turn. Since these tests were conducted after the left climbing turn tests, it was believed unnecessary to run tests at 70 m.p.h. Tests were run at five-mile per hour intervals from 45 to 65 m.p.h., inclusive. The obtained sines of the angle of climb at these indicated airspeeds are presented in the right hand column of Table 23.

From these data the equation of a second-order curve of best fit was calculated with the following result:

$$\text{Sine } \alpha = -.13395 + .010465\ (\text{IAS}) - .00010419\ (\text{IAS})^2$$

By differentiating this equation to determine the maximum, the value of 50.22 m.p.h. indicated airspeed was obtained. This was equivalent to a calibrated airspeed of 45.45 m.p.h.

It may be noted that the calibrated airspeed characteristic of the maximum angle of climb in the right climbing turn was approximately 1.9 m.p.h. above that in the left climbing turn, and approximately 2.7 m.p.h. above the indicated airspeed characteristic of the maximum angle of climb in a straight-ahead maneuver. This variation in maximum angle of climb among climbing maneuvers is of little practical significance in terms of number of feet climbed per thousand feet of forward advance. Furthermore, the difference may be due to the instrumentation of the airplane. Airspeed calibrations were necessarily accomplished only for straight and level flight.

TABLE 24

MAXIMUM ANGLE OF CLIMB -- SUMMARY OF RESULTS

Maneuver	Airspeed		Maximum	
	Ind.	Cal.	Sine	Angle
1. Straight-Ahead - Climbing Power (Full Throttle)	47.5	43.7	.1310	7°32'
4. Left Climbing Turn (Full Power)	47.1	43.5	.1220	7°01'
5. Right Climbing Turn (Full Power)	50.2	45.4	.1298	7°28'
Average	48.3	44.2	.1276	7°20'

d. Summary. The results of tests to determine the maximum angle of climb are summarized in Table 24. It will be noted from this table that the indicated airspeeds characteristic of the maximum angle of climb in the straight-ahead climbing maneuver and in the left climbing turn were approximately the same. The indicated airspeed for the right climbing turn was approximately 2.7 to 1.9 m.p.h. higher.

With respect to the actual flight angle, the maximum angle of climb possible in the left climbing turn was 7°01', while in the straight-ahead maneuver it was 7°32'. For all practical purposes the maximum angle of climb for each of these maneuvers is approximately the same. It was achieved in the straight-ahead and left climbing turn maneuvers at a slightly lower airspeed than in the right climbing maneuver.

C. Minimum Angle of Glide

Tests similar to those involved in determining the maximum angle of climb were run for the purpose of determining the minimum angle of glide. Three maneuvers were tested: straight-ahead glide, and the left and right gliding turns.

1. Testing Procedures.

As in the tests of maximum angle of climb, selected airspeeds were chosen for testing purposes. Six trials were run at each airspeed, and the average values of these six trials were used in determining the coordinates of the points used in calculating the equation of the sine of the minimum angle of glide.

In the testing process, the aircraft was climbed to an altitude of approximately 900 feet over the water. A glide was set up at one of the selected airspeeds, and as soon as the airplane was gliding in stable condition at that airspeed, the observer started his stop watch, read the radio altimeter, and the angle-of-attack indicator simultaneously. At the end of 60 seconds, the observer called "Now," and again read the radio altimeter and angle-of-attack indicator. These data were then recorded and the trial repeated. Since the range of the radio altimeter was from 0 to 800 feet it was necessary to climb back to about 900 feet before the next trial could be run. For this reason, the trials were distributed over a range of airspeeds so that no one airspeed would be tested with a near-full tank of gas and another airspeed with a near-empty tank of gas. While the change of weight in an hour's testing was not more than 50 or 60 pounds, it was, nevertheless, believed desirable to equalize insofar as possible the effect of loss of weight in gasoline among the various airspeeds.

2. Results.

a. Straight-Ahead Glide. Tests to determine the minimum angle of glide in straight-ahead flight were made at five airspeeds, ranging from 45 to 65 m.p.h., at 5 m.p.h. intervals. The values of the sine of the angle of glide as obtained in these tests are presented in Table 25. From these values the following equation of a curve of best fit was obtained:

$$\text{Sine } \alpha = .66846 - .019779\,(\text{IAS}) + .000174\,(\text{IAS})^2$$

Differentiating this question to determine its minimum, the value of 56.84 was obtained. Thus, the minimum angle of glide was achieved at an indicated airspeed of approximately 56.8 m.p.h. or a calibrated airspeed of approximately 49.7 m.p.h.

b. Left Gliding Turn. The results of similar tests of the minimum angle of glide in the left gliding turn are summarized in the middle column of Table 25. The equation based on these five points was found to be

$$\text{Sine } \measuredangle = .32116 - .0069103 \text{ (IAS)} + .00006132 \text{ (IAS)}^2$$

The minimum as obtained by differentiating this equation was 56.35 m.p.h. In terms of calibrated airspeed, this was 49.4 m.p.h., or almost exactly the same as the airspeed characteristic of the minimum angle of glide in the straight-ahead gliding maneuver.

TABLE 25

MINIMUM ANGLE OF GLIDE DATA -- STRAIGHT-AHEAD, LEFT TURN AND RIGHT TURN

Indicated Airspeed	True (Cal.) Airspeed	Sine of Angle of Glide		
		Straight-Ahead	Left Turn	Right Turn
45	42.1	.1301		
50	45.3	.1129	.1289	.1263
55	48.5	.1099	.1266	.1195
60	51.7	.1092	.1273	.1186
65	54.9	.1163	.1311	.1236
70	58.1		.1379	.1345

c. Right Gliding Turn. As shown in Table 25, the five airspeeds chosen for testing the left and right gliding turns involved airspeeds ranged by 5 m.p.h. intervals from 50 to 70 m.p.h., inclusive. The obtained sines of angle of climb characteristic of each of these five airspeeds as obtained for the right gliding turn are presented in the extreme right hand column of Table 25.

From these data, the equation of the curve of best fit was found to be as follows:

$$\text{Sine } \measuredangle = .51691 - .0136879 \text{ (IAS)} + .0001175 \text{ (IAS)}^2$$

The minimum as determined by differentiating this equation was 55.25 m.p.h., indicated airspeed, or 50.5 m.p.h., calibrated airspeed.

d. Summary. Table 26, following, presents a summary of the results of testing the aircraft to determine the minimum angle of glide in each of three gliding maneuvers. It will be seen from this table that minimum angle of glide was achieved at calibrated airspeeds ranging from approximately 49.5 m.p.h. to 50.5 m.p.h. These results indicate that the

TABLE 26

MINIMUM ANGLE OF GLIDE -- SUMMARY OF RESULTS

Maneuver	Airspeed Ind.	Airspeed Cal.	Minimum Sine	Minimum Angle
3. Straight-Ahead Glide (1,000 r.p.m.)	56.8	49.7	.1064	6°07'
6. Left Gliding Turn (1,000 r.p.m., 15° bank)	56.4	49.4	.1265	7°16'
7. Right Gliding Turn (1,000 r.p.m., 15° bank)	58.2	50.5	.1182	6°47'
Average	57.1	49.9	.1170	6°43'

testing aircraft did not vary with respect to minimum angle of glide with individual maneuvers to quite the same extent as in the case of the maximum angle of climb. It will be remembered from a preceding section that the difference in airspeed at which the maximum angle of climb was achieved in the left climbing turn was approximately 2 m.p.h. less than in the case of the right climbing turn. In the case of the gliding maneuvers this difference was only approximately 1 m.p.h.

The fact that the airspeed characteristic of the minimum angle of glide did not differ to any appreciable extent by maneuver suggests the possibility of a single stall warning unit which may be set to come on at minimum angle of glide in one gliding maneuver, and at the same time serve equally well in other gliding maneuvers. Had a wide range of airspeeds been found within the gliding maneuvers, then the exact location of a stall warning apparatus would have to be determined in relation to the maneuver in which the stall was of most interest or importance.

D. Locating a Stall Warner to Signal at Optimum Climbing Attitude

Once the optimum airspeeds of flight in climbing and gliding maneuvers (with a particular power setting) had been obtained, the next step was to locate a stall warner to signal at a flight attitude on or very near the optimum attitude. In this study the stall warner was located at an optimum point determined by the climbing maneuvers. Tests were run on both climbing maneuvers and gliding maneuvers with the stall warner located in this position.

A reinspection of Table 19 will indicate that the original stall warner in the Number 3 position lighted the signal at an average of 40.1 to 46.3 m.p.h., depending upon the maneuver involved (and exluding steep turns). This range was approximately the same calibrated airspeed as that characteristic of the maximum angle of climb.[2] It was, therefore, decided to run preliminary tests of the stall warner in the Number 3 position to ascertain whether this might be used in its original location for tests of flight along the flight path described by the maximum angle of climb and the minimum angle of glide.

Before these tests were run, an improved stall warning vane was installed in the Number 3 position. This new-type warner was of the same general design as the original, but the vane itself was shorter and more sturdy. All testing was done with this improved vane rather than the original Number 3 vane. The characteristics of the new-type vane appeared to differ somewhat from those of the original vane. This, however, in no way affects the results obtained in determining the maximum angle of climb or the minimum angle of glide. The only difference pertained to the "on-off" interval[3] and in this respect the new-type vane was better suited to the testing aircraft than the original type vane, having a shorter interval.[4]

1. Testing Procedures.

The purpose of this series of tests was to determine the airspeed interval over which the stall warner operated. It was known that the warner came on at a fairly consistent airspeed, but that it was not turned off until after a higher airspeed was achieved. Before the lamp would go off, it was necessary to initiate recovery to level flight.

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[2]The average calibrated airspeed at which the warner in the Number 3 position came on was 41.2, as compared with an airspeed of 43.7 for the maximum angle of climb in the straight-ahead climbing maneuver, and an average of 44.2 m.p.h. for all climbing maneuvers.

[3]As noted following, when the stall was approached from normal flight the stall warner came on at a relatively consistent airspeed. However, when recovery was instituted, the stall warner did not turn off until a considerably higher airspeed (and lower angle-of-attack) was achieved than that which represented the original onset of the warning as the stall was approached. The "on-off interval," then, is the difference (in airspeed or angle-of-attack) between (1) the value at which the warning first comes when the stall is being approached from normal flight, and (2) the value during recovery to normal flight at which the signal ceases. In terms of airspeed, the latter value is greater than the former. In terms of angle-of-attack the latter value is less than the former.

[4]It will be noted, however, that approximately the same results, relative to "bracketing" the stall warner signal, would have been obtained had the regular vane been employed. An examination of the curve in Figure 3 will indicate that bracketing a vane with a slightly wider "on-off" interval would still keep the flight path near the maximum angle of climb.

A total of ten test trials were run. Signal lamps 1, 2, 4 and 5 were removed from the apparatus so that only lamp Number 3 would light in a stall approach. In the flight tests, the pilot continued to read the airspeed, as in previous tests, and the observer read the airspeed and the angle-of-attack at which the lamp came on. By putting the clipboard containing the lamp between the angle-of-attack indicator and the airspeed indicator, the observer was also able to check the readings provided by the pilot.

Tests were run for both full power, straight-ahead climbs and straight ahead gliding maneuvers.

2. Results.

a. Straight-Ahead Climb. Table 27 presents the results obtained in these tests. Both indicated and calibrated airspeeds and angle-of-attack values are given for the "on" and "off" characteristics of the new-type stall warner in the Number 3 position. This warner came on at an average indicated airspeed of 46.6 m.p.h., and an indicated angle-of-attack of approximately 21.0°. In terms of calibrated values, these were 43.2 m.p.h. and 13.2°, respectively. The warning lamp was turned off at an average indicated airspeed of 49.1 m.p.h. (44.8 m.p.h., calibrated) and an average indicated angle-of-attack of 19.6° (12.1° calibrated).

TABLE 27

RESULTS OF TESTS OF WARNER IN #3 POSITION
STRAIGHT-AHEAD, FULL POWER CLIMB

Data As	Airspeed		Angle-of-Attack*	
	ON Mean*	OFF Mean*	ON Mean*	OFF Mean*
Indicated	46.6	49.1	21.0	19.6
Calibrated	43.2	44.8	13.2	12.1

*Of ten trials

As shown previously in Table 24, the maximum angle of climb was achieved with an indicated airspeed of 47.5 m.p.h. (43.7 m.p.h., calibrated) in the full power, straight-ahead climbing maneuver. This airspeed lies almost exactly in the middle of the "on-off" interval (indicated airspeed values). The average indicated airspeed for all climbing maneuvers, as shown in Table 24, was 48.3 m.p.h. This average airspeed characteristic of the maximum angle of climb in the three principal climbing maneuvers also was well within the 49.1 - 46.6 m.p.h. interval "bracketed" by the stall warner in the Number 3 position.

In other words, when the improved vane was installed in the third vane position it came on and went off over an airspeed range which was almost equally distributed on either side of the optimum airspeed for obtaining maximum angle of climb at full power. Had the Number 3 vane been set to come on at a lower airspeed or a higher airspeed, it would have been necessary to have adjusted its position on the wing, so that the "on" and "off" airspeeds "bracketed" the optimum airspeed.

It may be of some interest to note from Table 27 that the average angle-of-attack characterizing this "on-off" interval ranged from approximately 12.1° to approximately 13.2°. The optimum angle-of-attack was approximately 12.6° and this lies almost exactly in the middle of the "on-off" interval. The testing aircraft stalled fairly uniformly at a calibrated angle-of-attack of approximately 19.0°. The optimum angle-of-attack under full power was, therefore, approximately 6.4° less than the stalling angle-of-attack.

This last fact was of considerable importance. As discussed earlier, had the maximum angle of climb represented an angle-of-attack very close to the stall, the procedure of "bracketing" the warning signal would be dangerous. By attempting to achieve maximum performance the pilot would be constantly on the verge of the stall. In this aircraft, however, maximum angle of climb was achieved at an angle-of-attack far short of the stall, and therefore the procedure of "bracketing" the maximum angle of climb warning was perfectly "safe."

b. Straight-Ahead Glide. The results of similar tests for the straight-ahead, gliding maneuver are presented in Table 28. In the straight-ahead glide the vane in the Number 3 position came on at an average of 52.6 m.p.h., indicated airspeed, and was turned off at an average indicated airspeed of 53.1 m.p.h. In terms of calibrated airspeeds, this range was from 47.0 to 47.3 m.p.h. In terms of angle-of-attack, the Number 3 vane came on at 19.9° indicated, 12.4° calibrated, and was turned off at an angle-of-attack of 20.0° indicated, 12.5° calibrated.

TABLE 28

RESULTS OF TESTS OF WARNER IN #3 POSITION
STRAIGHT-AHEAD GLIDE (1,000 r.p.m.)

Data As	Airspeed		Angle of Attack	
	ON Mean*	OFF Mean*	ON Mean*	OFF Mean*
Indicated	52.6	53.1	19.9	20.0
Calibrated	47.0	47.3	12.4	12.5

*Of ten trials

The "on-off" airspeed of the Number 3 vane in the straight-ahead glide, however, did not "bracket" the optimum gliding airspeed of any of the gliding maneuvers. As shown in Table 26, the minimum angle of glide was achieved at an indicated airspeed of 56.8 m.p.h. This value lies outside the "on-off" interval by approximately 4 m.p.h. indicated and approximately 2.5 m.p.h., calibrated. In other words, the stall warner which was set almost exactly in the middle of the "on-off" interval pertaining to the climbing maneuvers, was set at too low an airspeed for equally effective application in "bracketing" the minimum angle of glide.

Two other findings are worthy of note. As may be determined from Tables 27 and 28, the "on-off" interval in terms of calibrated airspeed was 1.4 m.p.h. for the straight-ahead climb, whereas in the straight-ahead glide, the "on-off" interval was only 0.3 m.p.h. A similar result was obtained with respect to angle-of-attack. In the full power climb, the "on-off" interval in terms of calibrated angle-of-attack was 1.1°, and in the case of the gliding maneuver only 0.1°. These results indicate that the "on-off" position for the stall warner in the glide must be set within a very restricted interval if the minimum angle of glide is to be achieved. On the other hand, the "on-off" interval for climbing power may be somewhat less precise in the exact position of the warner.

E. Tests Along Optimum Flight Path

The final step in this part of the investigation was to test out in actual flight the general hypotheses concerning flight along an optimum flight path as defined in terms of maximum angle of climb. Flight tests were run with various methods of "recovery" used in each of seven maneuvers. In these tests, the pilot recovered from the stall warning signal in the maneuver in question into a straight-ahead climb. These tests may hardly be described as tests of recovery. Yet, in a very real sense, they are. A pilot who is advancing toward the stall generally does so fairly gradually. He pulls the stick back and the aircraft gradually assumes an exaggerated angle-of-attack as airspeed decreases. When the stall warning comes on, the pilot, in one sense, begins a recovery. That is, he returns toward normal flight. His behavior is, in another sense, not recovery, since he has not entered into the full stall. However, for purposes of description, in this section of the report the terms "recovery from a stall warning" and "use of the stall warner in achieving an optimum flight path" are in general used synonymously.[5]

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[5]As noted in the introduction to Part IV of this report (See page 78) the "recovery" from the stall warner to an optimum flight path is given primary emphasis because of the relatively greater practical implications yielded by such data, as compared with data on recovery from the stall warner to straight and level flight, or to a normal glide.

Within each of the seven maneuvers the methods of recovery to be tested were selected on the basis of results obtained in testing recoveries from the full stall. The particular recovery methods used in this phase of the testing are listed in the tables which present the results for each maneuver.

1. <u>Testing Procedures</u>.

In flying the tests for "recovery" from a stall warner, certain departures from previous methods of testing were employed. In the first place, the pilot was not required to recognize and recover from the full stall. He began his "recovery" as soon as possible after the stall warner came on. His procedure was to turn off the stall warner, and then turn it on again, turn it off, and thus "bracket" the stall warning signal.[6] It was assumed that by "bracketing" this signal (or by "bracketing" the "on-off interval") he would advance along the optimum flight path as far as climbs were concerned.

In these tests the pilot began a stall approach and then watched the stall warning indicator. When it came on, he signaled by calling out "Now." The observer read three values -- indicated airspeed, indicated angle-of-attack, and altitude in feet -- and he also started a stop watch at this signal. At the end of a specified time interval, depending upon the maneuver, the observer called out "Now," and read the angle-of-attack indicator and the altimeter. At this point, the pilot read the airspeed. These data were then recorded by the observer and, when there was any doubt of the accuracy of the readings, the test trial was rerun.

In these tests, the time interval flown along the optimum path was determined generally by the time interval necessary to effect recovery by the most effective method to straight and level flight from a full stall. For example, in the tests of recovery from the stall out of the straight-ahead, climbing power maneuver the optimum method effected recovery in an average interval of 10.54 seconds (shown in Table 3). A flight interval of 11 seconds was selected for testing this maneuver in recovery from a stall warning. Through selecting the time interval in terms of the amount of time taken for recovery from a full stall a clearer picture of the effectiveness of this use of the stall warner could be obtained.

2. <u>Results</u>.

a. <u>Straight-Ahead Climb</u>. Four methods of controlling the aircraft in flight along the optimum angle of climb were tested. These are

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[6]The pilot brackets the stall warning signal in the same sense that a pilot "brackets the A signal" in an approach to a low frequency range station. He does not, of course, bracket the signal by flying "on both sides of it," since once the stall warner is activated it remains "on" during any further increase in angle-of-attack until the plane stalls and well into the recovery. In this sense he brackets the "on-off interval", as defined on page 97 of this report, footnote 3.

listed in Table 29.[7] In evaluating recovery from a stall warning the altitude gained is the criterion rather than the altitude lost. Again, however, it is desirable to consider the variability or consistency of each method as shown by the standard deviation of the individual measures.

As shown in Table 29, the use of elevators in "bracketing" the stall warning resulted in the most consistent performance. However, two other procedures using ailerons and elevators and rudder, ailerons and elevators gained more altitude but did not do so as consistently as the use of elevators only.

It will be noted in Table 29 in the column listing the calibrated airspeeds at signal and recovery, that the airspeed at recovery was consistently higher than that at the time of signal. This is to be expected. In approaching the stall, the test pilot was using full power and his airspeed was gradually decreasing. Under full power conditions with the stick held all the way back, the aircraft progresses from a normal angle of climb to an exaggerated flight attitude. In this progression, airspeed is lost and, consequently, the airspeed at the time recovery began will be read a fraction of a second after the signal comes on. For this reason, the airspeed at signal was generally a little lower than the airspeed at the time the warner came on. On the other hand, when recovery is started and the stall warner is "bracketed" the airspeed increases, and at the time of recovery, then, was consistently higher than that at the time of signal. Had the signal been "bracketed" for a minute or so, the average airspeed over the course would have settled down to approximately the airspeed of the maximum angle of climb. The measures of airspeed over the 11-second interval, however, reveal variations that occur in that time interval.

As shown in the column at the extreme right of Table 29, the observer was not always able to stop the stop watch at the end of exactly 11 seconds. This variation in amount of time, however, was relatively small and may for all practical purposes be ignored in comparing the gain in altitude over the time interval.

b. Straight-Ahead, Cruising Power. Eight methods of recovery from a stall warning were tested in connection with the straight-ahead, cruising power maneuver. These are listed and the data reported in Table

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[7]The designation "SW" refers to recovery method from a stall warning signal. E-SW indicates that in straight and level flight, the pilot used only elevators to lower the nose below the point where the stall warner went off, and to raise the nose again so that the stall warner would come on. This "bracketing" procedure permitted the pilot to approximate the optimum climbing path.

TABLE 29

THE EFFECTIVENESS OF FOUR METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A STRAIGHT AHEAD FULL POWER MANEUVER

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack At Signal	Change of Altitude In Feet	Time to Recover In Sec.
1. E - SW	m =	43.13	45.44	12.61	+63.00	11.00
	σ =	0.71	1.45	0.94	14.18	0.00
	σm =	0.24	0.48	0.31	4.73	0.00
2. RE - SW	m =	42.31	45.00	12.38	+61.40	11.04
	σ =	1.66	1.86	0.71	18.47	0.06
	σm =	0.55	0.62	0.24	6.16	0.02
3. AE - SW	m =	43.14	45.45	12.23	+70.40	11.09
	σ =	1.28	1.50	0.58	55.55	0.50
	σm =	0.43	0.50	0.19	18.52	0.17
4. RAE - SW	m =	40.97	45.05	12.31	+68.00	10.96
	σ =	1.44	1.00	0.93	42.38	0.26
	σm =	0.48	0.33	0.31	14.13	0.09

NOTE: Recovery made by bracketing the stall warning signal for 11 seconds.

TABLE 30

THE EFFECTIVENESS OF EIGHT METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A STRAIGHT AHEAD MANEUVER WITH CRUISING POWER (2100 RPM)

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack at Signal	Change of Altitude in Feet	Time to Recover in Sec.
1. E - SW	m =	41.72	45.37	13.21	+24.00	11.00
	σ =	0.95	1.96	1.01	18.00	0.00
	σm =	0.32	0.65	0.34	6.00	0.00
2. PE - SW	m =	43.15	44.23	12.98	+66.00	11.00
	σ =	1.39	1.29	0.75	14.97	0.00
	σm =	0.46	0.43	0.25	4.99	0.00
3. RE - SW	m =	42.69	46.60	12.38	+20.00	11.01
	σ =	1.48	1.24	0.92	19.49	0.10
	σm =	0.49	0.41	0.31	6.48	0.03
4. AE - SW	m =	42.83	44.61	12.38	+45.40	11.08
	σ =	2.82	1.56	1.08	23.29	0.28
	σm =	0.94	0.52	0.36	7.76	0.09
5. PRE - SW	m =	43.51	45.05	12.46	+74.00	11.04
	σ =	1.57	1.57	0.67	81.40	0.10
	σm =	0.52	0.52	0.22	27.13	0.03
6. PAE - SW	m =	43.98	45.38	12.01	+64.00	11.00
	σ =	1.41	1.30	0.90	26.91	0.00
	σm =	0.47	0.43	0.30	8.97	0.00
7. RAE - SW	m =	41.99	44.10	12.08	+26.00	11.07
	σ =	1.41	1.94	0.84	24.16	0.17
	σm =	0.47	0.65	0.28	8.05	0.06
8. PRAE - SW	m =	42.44	45.06	12.01	+62.00	11.00
	σ =	1.83	1.62	0.69	29.93	0.00
	σm =	0.61	0.54	0.23	9.98	0.00

NOTE: Recovery made by bracketing the stall warning signal for 11 seconds.

30.[8] It will be noted from this table that the methods of recovery which involved the addition of power generally resulted in the largest altitude gains. Of these, method PRE gained an average of 74 feet in approximately 11 seconds. The most consistent method of flying along the optimum flight path was again the method using elevators only (PE) to "bracket" the stall warner.

Some of the tests reported in Table 30 are apparently mere academic investigations. These results indicate very definitely that when the pilot can fly along the optimum flight path with the use of only elevators and a minimum of rudder and aileron controls, he will consistently gain the most altitude. However, it is sometimes necessary to apply rudder or aileron in order to keep the aircraft from skidding or turning. A skid or a turn will, of course, impair the recovery and will result in less gain in altitude in a given time interval. From a practical point of view, recovery PRAE, with an average gain of altitude of 62 feet and a standard deviation of approximately 30 feet, is probably the best method of "bracketing" the stall warner. This means merely that when the stall warner comes on the pilot adds power and coordinates the controls in flying along the optimum path of climb. If momentary turbulence hits him, he may find it impossible to effect a PE recovery (add power and use elevators only).[9]

c. <u>Straight-Ahead Glides</u>. The six recovery methods tested in connection with a stall warning out of a straight-ahead glide are listed in Table 31, which presents the results for each of these methods of flying the optimum climbing path. A time interval of 13 seconds was used in these tests.

In recovering from a stall warning in the glide, the pilot has two choices. He can recover to an optimum glide path, or he can pull up and go around again. If he continues his glide into the field, method RAE, that is, coordinated use of rudder, ailerons, and elevators and flying along the

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[8]The utility of recovering from a stall warning in straight and level flight into a maximum climb might, at first thought, be questioned. However, discussion with experienced pilots indicated that if the stall warner sounded during straight and level flight the pilot might well be in a tough spot, such as in traffic during an approach, where the most intelligent thing to do would be to get up and away as soon and as rapidly as possible.

[9]The <u>elevators only</u> and <u>power and elevators only</u> methods of flying along the optimum climbing path were in general run on very calm days. When there was even moderate turbulence, the use of elevators only in flying along any flight path would be an unwise practice. The pilot has full use of all of his controls in the optimum climb and it is sensible to use them.

TABLE 31

THE EFFECTIVENESS OF SIX METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A STRAIGHT AHEAD GLIDE (1,000 RPM)

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack at Signal	Change of Altitude in Feet	Time to Recover in Sec.
1. RE - SW	m =	46.73	46.66	12.84	-134.00	13.00
	σ =	1.17	1.78	0.69	37.20	0.00
	σm =	0.39	0.59	0.23	12.40	0.00
2. AE - SW	m =	46.34	46.28	12.61	-121.00	13.00
	σ =	1.55	1.08	0.45	37.80	0.00
	σm =	0.52	0.36	0.15	12.60	0.00
3. PRE - SW	m =	43.38	43.27	12.54	+ 81.00	13.00
	σ =	0.99	2.55	0.71	17.00	0.00
	σm =	0.33	0.85	0.24	5.67	0.00
4. PAE - SW	m =	44.10	44.99	12.24	+ 70.00	13.03
	σ =	1.64	1.62	0.67	34.93	0.14
	σm =	0.55	0.54	0.22	11.64	0.04
5. RAE - SW	m =	45.83	46.35	12.84	-118.00	13.05
	σ =	0.81	1.24	0.60	34.87	0.10
	σm =	0.27	0.41	0.20	11.62	0.03
6. PRAE - SW	m =	45.12	45.82	12.01	+ 84.00	13.02
	σ =	1.91	1.73	0.50	16.85	0.06
	σm =	0.64	0.58	0.17	5.61	0.02

NOTE: Recovery made by bracketing the stall warning signal for 13 seconds.

optimum glide path, is his best choice, provided it does not overshoot or undershoot the field. If he wants to pull up and go around again, his best choice is the addition of power and the coordinated use of controls and "bracketing" the stall warner. As he adds power, it will be necessary to pull the nose up in order to keep the light "bracketed" and as power begins its effect, the aircraft will enter into a climb. Under full power and coordinated use of controls and "bracketing" the stall warner, he will climb out of the field at a maximum angle of climb, and thus get away safely for a return to the traffic pattern, if this is his intention.

As shown in Table 31, he will lose the least altitude in the glide by the coordinated use of all controls and he will gain the most altitude in the climb by the addition of power and coordinated use of controls.

d. Left Climbing Turn. Three methods of recovery from a stall warning to flight along the optimum path of climb were tested. These are listed in Table 32, which presents the results of these tests. A time interval of 14 seconds was used in these tests.

As shown in this table, the method of recovery utilizing rudder and elevators was generally the most effective in the left climbing turn. It is not, of course, always possible to use only these controls. When aileron control was necessary, its use appeared to inhibit the amount of altitude gained in a given amount of time.[10]

e. Right Climbing Turn. The recovery methods used in testing recovery at the stall warning out of the left climbing turn were repeated in the right climbing turn. However, in these tests the criterion time interval was 12 seconds rather than 14 seconds.

The test results for the right climbing turn do not agree, either in magnitude or in order, with those obtained for the left climbing turn. It will be noted in Table 33 that coordinated use of ailerons and elevators, with a minimum of rudder control, resulted in an average increase in altitude of 102 feet, as opposed to 85 feet when optimum rudder was used, and contrasted with an average gain of 69 feet when optimum aileron was not used. When the pilot is attempting to "bracket" the stall warner in a right climbing turn, his climb may be more effective if rudder is held fairly constant and the turn is regulated by the use of ailerons and elevators. This does not mean that the controls are actually crossed; they are coordinated, but the coordination is effected primarily with the use of ailerons rather than with the movement of rudder. This may be possible only in the right turn because of the effect of torque resulting from the full power setting typical of the turn.

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[10]This may mean that the motion of the plane slowed down by the use of ailerons, and that while the same general climbing path was followed, the aircraft did not progress as far in fourteen seconds as it did when the use of ailerons was not necessary.

TABLE 32

THE EFFECTIVENESS OF THREE METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A LEFT CLIMBING TURN (FULL THROTTLE)

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack at Signal	Change of Altitude in Feet	Time to Recover in Sec.
1. RE - SW	m =	43.14	45.51	11.34	+81.00	14.00
	σ =	1.48	1.95	1.02	35.90	0.00
	σm =	0.49	0.65	0.34	11.97	0.00
2. AE - SW	m =	44.61	45.58	12.09	+78.00	14.00
	σ =	1.37	1.01	0.60	33.99	0.00
	σm =	0.46	0.34	0.20	11.33	0.00
3. RAE - SW	m =	43.97	44.86	11.64	+61.00	14.00
	σ =	0.93	1.35	0.53	21.19	0.00
	σm =	0.31	0.45	0.18	7.06	0.00

NOTE: Recovery made by bracketing the stall warning signal for 14 seconds.

TABLE 33

THE EFFECTIVENESS OF THREE METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A RIGHT CLIMBING TURN (FULL THROTTLE)

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack at Signal	Change of Altitude in Feet	Time to Recover in Sec.
1. RE - SW	m =	44.10	46.65	12.39	+69.00	12.00
	σ =	1.93	3.33	0.40	47.32	0.00
	σm =	0.64	1.11	0.13	15.77	0.00
2. AE - SW	m =	45.51	46.34	12.01	+102.00	12.00
	σ =	1.62	1.14	0.84	30.92	0.04
	σm =	0.54	0.38	0.28	10.31	0.01
3. RAE - SW	m =	44.61	45.70	12.24	+85.00	12.00
	σ =	1.66	0.95	0.89	46.53	0.00
	σm =	0.55	0.32	0.30	15.51	0.00

NOTE: Recovery made by bracketing the stall warning signal for 12 seconds.

f. Left Gliding Turn. Three methods of flying along the optimum gliding path were tested in both right and left turns. These methods are listed in Tables 34 and 35. It will be noted from these tables that the only case considered in these glides was the situation in which the pilot pulls up in order to leave the glide and begin a steep climb. As a consequence, only power-added methods of recovery were tested. A time interval of 12.5 seconds was used in both cases.

Results of the methods of recovering from a left gliding turn to a maximum angle of climb are shown in Table 34. Of these methods the addition of power and the coordinated use of all controls was somewhat less satisfactory than the method whereby rudder was held fairly constant and coordinated control was effected with ailerons.

These results indicate that a pilot who wishes to pull up out of a glide into the field may, in the same time it would take him to recover from a full stall, actually gain 70 to 80 feet of altitude by adding power and "bracketing" the stall warner. His performance is not unlike that involved in a similar recovery from the straight-ahead glide. As he adds power and continues to "bracket" the stall warning, the aircraft goes through a transition from a glide into a maximum climb. He can maintain his bank by coordinated use of ailerons and rudders and use elevators to "bracket" the flight path described by the stall warner. This will be a perfectly safe method of pulling up, and it will provide the pilot with the maximum performance his aircraft is capable of accomplishing.

g. Right Gliding Turn. Table 35 presents the results of the tests of recovery from a right gliding turn to a right climbing turn. A recovery interval of 12.5 seconds was utilized.

Results of the two tests reported in Table 35 confirm what has already been shown generally in previous tables. When the pilot decides to pull up into a climb out of a right gliding turn, he adds power and coordinates the use of all of his controls. When he "brackets" the stall warner he may expect a gain of approximately 77 feet in approximately the same amount of time that would be involved in recovering from the stall in the event that it occurred out of the glide.

The results of the tests reported in this section are of primary interest in comparing what may happen to the pilot at a critical point in flight. That is, he may stall or he may begin recovery from a stall warning. If he stalls, the inevitable result is loss of altitude. If the stall warner signals at the proper flight attitude, then he may begin and effect his recovery along an optimum flight path.

TABLE 34

THE EFFECTIVENESS OF THREE METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A LEFT GLIDING TURN (1,000 RPM)

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack at Signal	Change of Altitude in Feet	Time to Recover in Sec.
1. PRE - SW	m =	45.51	44.54	12.54	+70.00	12.50
	σ =	0.96	2.67	0.62	40.50	0.00
	σm =	0.32	0.89	0.21	13.50	0.00
2. PAE - SW	m =	45.19	42.69	12.39	+76.00	12.50
	σ =	1.16	1.59	0.62	32.55	0.00
	σm =	0.39	0.53	0.21	10.85	0.00
3. PRAE - SW	m =	45.94	44.48	11.56	+51.00	12.50
	σ =	1.41	2.22	0.81	29.14	0.00
	σm =	0.47	0.74	0.27	9.71	0.00

NOTE: Recovery made by bracketing the stall warning signal for 12.5 seconds.

TABLE 35

THE EFFECTIVENESS OF TWO METHODS OF RECOVERY AT STALL WARNING SIGNAL FROM A RIGHT GLIDING TURN (1,000 RPM)

Recovery Method		Calibrated Airspeed at Signal	Calibrated Airspeed at Recovery	Calibrated Angle of Attack at Signal	Change of Altitude in Feet	Time to Recover in Sec.
1. PRE - SW	m =	47.09	46.33	12.84	+45.00	12.50
	σ =	2.25	1.89	0.69	23.88	0.00
	σm =	0.75	0.63	0.23	7.96	0.00
2. PRAE - SW	m =	45.37	46.93	11.86	+77.00	12.50
	σ =	1.06	1.77	0.56	33.78	0.00
	σm =	0.35	0.59	0.19	11.26	0.00

NOTE: Recovery made by bracketing the stall warning signal for 12.5 seconds.

PART VI

COMPARISONS OF RECOVERY FROM THE FULL STALL WITH OPTIMUM FLIGHT PERFORMANCE

The tests conducted in this study had two general purposes: (1) determining the relative effectiveness of various methods of recovering from the full stall, and (2) testing "recoveries" by "bracketing" a stall warning set to come on at or near the maximum angle of climb. The detailed results are presented in parts IV and V. The purpose of this section is to bring together the most pertinent results of each of these general types of tests for purposes of comparison. No new data are introduced, but various data from tables presented previously are assembled and presented as simply as possible. These comparisons are intended to assist in showing what may be accomplished when a stall warning instrument is properly located and used in various flight maneuvers, as compared with the best recovery the pilot can hope to make if he stalls.

Comparative data are available for seven of the eleven maneuvers investigated in connection with recovery from the full stall. The slow turns and the steep turns were not tested in connection with recovery from the stall warning.[1]

In the comparisons considered in this part of the report, the climbing maneuvers are considered together and the gliding maneuvers are considered together. Straight-ahead, cruising power is considered separately.

A. The Climbing Maneuvers

1. Situations Conducive to the Stall.

A pilot may find himself in a situation where he must climb out of a field as steeply as possible. In this climb, he may be forced to make right or left turns. He may appreciate the fact that stalls out of turns are typically more dangerous than stalls out of straight-ahead flight, but this fact may not be uppermost in the pilot's mind when he is attempting to avoid some obstacle in his flight path. Stalls might be precipitated out of climbs in the landing process as well as in take-offs. If,

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[1]If the pilot is attempting to perform a level turn and approaches a stalling point, he will be warned by the warner. His object then is to turn the warner off, and he may do this by decreasing the rate of turn. That is, he pushes the nose of the aircraft away from him. If he does this and his bank remains fairly constant, he may lose no altitude, nor gain any.

near the end of his approach to the field, the pilot judges that he cannot make a landing, he may be forced to go from a glide to a steep climb very rapidly. This transition may result in a stall.

2. Comparative Results.

The pilot who attempts a very steep climbing maneuver is presented with three general possibilities: (1) his flight attitude may gradually be increased in steepness until the aircraft stalls, (2) he may fly at some angle-of-attack or along some flight path which will achieve for him less than optimum performance of the aircraft, or (3) he may have some device or instrument which permits him to fly along a flight path which obtains the best results in the climb.

Of these three general possibilities offered to the pilot, the present study collected data on the first and third; that is, on what happens to the pilot when he stalls and what happens to him when he flies along an optimum flight path in terms of maximum angle of climb. Table 36 summarizes data pertaining to the climbing maneuvers.

a. Straight-Ahead Climb. When the aircraft stalls out of the straight-ahead climb, the wing loses lift very rapidly. The test pilots employed in this study were not able to effect recovery to straight and level flight with less than an average loss of altitude of 26 feet, and this was possible only by the "best" method of recovery. As shown in Table 36, the optimum method of recovery from a full stall out of the straight-ahead climbing maneuver was -26 ± 13 feet.

To effect this optimum recovery required on the average approximately 10.5 seconds, as shown in Column 3. On the other hand, when the test pilot began his recovery at the stall warning and "bracketed" the stall warning signal which was set to come on at maximum angle of climb, an average of 61 feet was gained in 11 seconds. As shown in Column 4, this performance resulted in an estimated distance of approximately 84 feet between the altitude lost by the optimum recovery from the full stall and the altitude gained from "bracketing" the maximum angle of climb.[2]

As shown in Table 3, the RE-OH recovery method was considerably superior to any other method of recovery. Recovery method RE-BH, for example, lost on an average of 130 feet of altitude. Other recovery methods were still more expensive of altitude. In other words, the pilot can hardly escape the loss of from 20 to 30 feet of altitude by the full stall, no

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[2]The obtained difference between averages was 89. However, this was corrected for the difference in the time interval. It will be noted that recovery method RE-OH required an average of 10.5 seconds. In the stall warning tests the aircraft was flown for 11 seconds. When the time intervals are equalized, the average gain in altitude for the stall warning procedure was 58, not 61.

TABLE 36

COMPARISONS OF TESTS IN CLIMBING MANEUVERS: OPTIMUM METHODS OF RECOVERY FROM FULL STALL VERSUS FLIGHT ALONG PATH OF MAXIMUM ANGLE OF CLIMB

Maneuvers Recovery from	By Procedures	Altitude Change in ft. Average	Required Time in sec. Average	Better by Average of (feet)[1]
1. Straight Ahead Climb (Full throttle)				
Full Stall	RE-OH	-26 ± 13	10.5 ± 1.2	
Stall Warning	E-SW	+63 ± 10	11	+84*
4. Left Climbing Turn (Full throttle)				
Full Stall	RAE-OH	-69 ± 20	14 ± 1.9	
Stall Warning	RE-SW	+81 ± 24	14	+150
5. Right Climbing Turn (Full throttle)				
Full Stall	RAE-OH	-46 + 12	12 ± 1.6	
Stall Warning	AE-SW	+102 ± 21	12	+148

[1]Difference between altitude gained by SW procedure and altitude lost by recovery from stall.

*Estimated by correcting for differences in time intervals.

matter how good his recovery. By the simple procedure of "bracketing" the stall warner he can in the same amount of time it takes him to recover from the full stall better himself by as much as 80 to 90 feet of altitude.

b. Left Climbing Turn. The optimum method of recovery from a full stall out of a left climbing turn, method RAE-OH, resulted in an average loss of approximately 69 feet, and required a recovery interval of approximately 14 seconds. Contrasted with this is the gain of 81 feet obtained by the RE-SW method. Thus, the difference between the optimum method of recovering from the full stall and the optimum method of flying the stall warning signal was 150 feet difference in favor of the stall warning performance. Table 36 also reveals that the optimum method of recovering from the full stall did not apply in the stall warning recovery. Method RAE-OH, which conserved the most altitude following the stall out of the left climbing turn, -69 feet, gained only 61 feet in its corresponding method RAE-SW. But even here the difference between the optimum method of recovery from the full stall and a less than optimum method of flying the stall warning signal resulted in a difference of 130 feet in favor of the stall warning procedure.

c. Right Climbing Turn. As shown in Table 36, the difference between the optimum method of recovery from the full stall out of the right climbing turn and the optimum method of flying the stall warner in this same maneuver was a difference of 148 feet in favor of the stall warning procedure. Here, as in the case of the left climbing turn, the optimum method of flying the stall warning signal was not the counterpart of the optimum method of recovery from the full stall.

The data presented in Table 36 show conclusively that in the climbing maneuvers the procedure of recovery at a stall warning and "bracketing" a signal set to come on at maximum angle of climb resulted in altitudes from 80 to 150 feet more than was possible under even the best methods of recovering from the stalls out of these maneuvers.

B. Straight-Ahead, Cruising Power

1. Situations Conducive to the Stall.

The pilot sometimes slows down his airspeed without change of power setting. This may occur when the pilot is distracted by something outside the plane. This may be a friend's house, the airfield where he is trying to fly a good traffic pattern, or another airplane in the immediate vicinity. When his attention is distracted from flying his own airplane he may unknowingly exert greater back pressure on the stick and ignore the physical cues which otherwise would warn him of the impending stall. A stall sometimes occurs in the traffic pattern where the pilot has attempted to regain traffic altitude without applying power properly.

2. Comparison of Results.

The comparative results pertaining to stalls out of the straight-ahead, cruising power maneuver are summarized in Table 37. The summary data presented in this table pertain to two situations: (1) where the recovery is attempted without the addition of power, and (2) where the recovery involves the addition of power to effect it.

a. Cruising power (2,100 r.p.m.). As shown in the upper half of Table 37, the difference between the optimum recovery from a full stall out of straight-ahead, cruising power and the recovery method for flying the maximum angle of climb path was 97 feet. The best of the various methods of recovery from the full stall resulted in an average loss of 52 feet, whereas the best of the methods of "bracketing" the stall warner resulted in an average gain of 45 feet. Recovery procedure RE-OH, which was the best method of recovering from the full stall, required approximately 11 seconds to effect a recovery to straight and level flight. In this same 11 seconds, had the pilot not stalled, he might have flown the maximum angle of climb path by method AE-SW and have gained an average of 45 feet. As shown in Table 4, there were several other procedures in recovering from the stall out of cruising power maneuvers which resulted in losses of altitude of more than 100 feet. As compared to such recoveries, the stall warner recovery has an advantage of at least 150 feet.

b. Full Power. Tests of methods of recovery involving the addition of power revealed similar differences between optimum methods of recovery from the full stall and optimum methods of flying the maximum angle of climb path. As shown in the lower half of Table 37, method PRE-OH in recovery from the full stall resulted in an average loss of 53 feet in 8.2 seconds, whereas recovery method PRE-SW resulted in a gain of 74 feet in 11 seconds (55 feet in 8.2 seconds). When adjusted for time interval the difference gained by the stall warner procedure was estimated at 108 feet. This is approximately the same as the 97 feet obtained in the cruising power recovery. The only significant difference between these methods of recovery was that the full power recovery was effected in approximately 8.2 seconds while the cruising power recovery methods required approximately 11 seconds for recovery.

These data show that the addition of full power may do little to improve upon the loss of altitude in the straight-ahead cruising power maneuvers, but it does effect recovery more rapidly.

The data pertaining to the straight-ahead cruising power maneuver re-enforce the data previously reported on comparisons in the climbing maneuvers. With reduced power (2,100 vs. 2,300 or 2,400 r.p.m.) the advantage of the stall warning procedure over recovery from the full stall is somewhat less than in the full power manouvers. The significance of the advantage, however, is in no way impaired.

TABLE 37

COMPARISONS OF TESTS OF STRAIGHT-AHEAD CRUISING POWER: OPTIMUM METHODS OF RECOVERY FROM THE STALL VERSUS FLIGHT ALONG PATH OF MAXIMUM ANGLE OF CLIMB

Maneuvers Recovery from	By Procedures	Altitude Change in ft. Average	Required Time in sec. Average	Better by Average of (feet)
2. Straight Ahead, Cruising Power (1,000 r.p.m.)				
Full Stall	RE-OH	-52 ± 15	11.1 ± 1.3	+97
Stall Warning	AE-SW	+45 ± 16	11	
Full Stall	PRE-OH	-53 ± 16	8.2 ± 0.5	+101*
Stall Warning	PAE-SW	+64 ± 18	11	

*Estimated by correction for differences in time intervals.

C. The Gliding Maneuvers

1. Situations Conducive to the Stall.

There are two general applications of the tests conducted in this study as they pertain to glides. The first of these is a situation in which the pilot is in a straight-ahead or a right or left turning glide, and for some reason must apply full power and climb out of the field. The second simulates the dead engine in which the pilot is forced to glide all of the way into the field. These are considered separately in the present section of this report.

a. Full Power Recovery. When the stall warner is set to signal at the maximum angle of climb, and this comes on in a glide, the pilot who recovers by "bracketing" the stall warner under full power will find himself climbing in a few seconds after full power has been applied. In other words, "bracketing" the stall warner results in a transition from a glide to a climbing maneuver.

If the pilot stalls out of a glide in an attempt to begin a climb without applying power, he may expect results similar to those presented in Table 38. The data presented in this table are concerned only with full power recoveries. These data show that an average of approximately 140 feet difference existed between the stall warning procedure and the recovery from the full stall out of the straight-ahead glide. In the case of the left gliding turn, the difference was 155 feet, and in the case of the right gliding turn, 133 feet. Optimum methods of recovery from stalls out of the glide resulted in losses ranging from 38 feet to 79 feet in the case of the straight-ahead glide and the left gliding turn, respectively. Contrasted with these were average gains of 84 feet and 76 feet possible with the stall warning "bracketing" procedure.

While these specific data apply only to the testing aircraft, it may be assumed that other light aircraft would behave in a similar manner. That is, if the glide is to be abandoned in favor of a full power climb, the pilot may expect to obtain the best results by "bracketing" a signal set to come on at the maximum angle of climb. Even though he does not stall, he cannot employ any procedure which will effect for him a greater gain in altitude than that represented by the maximum angle of climb.

b. Gliding Power Recovery. It was not deemed wise in this investigation to attempt tests of gliding maneuvers with a dead engine. A power setting of 1,000 r.p.m. is not a dead engine and the aircraft does not behave in quite the same way with this power setting as it does with a dead engine. Nevertheless, the results presented in Table 39 are of considerable interest. These data pertain to the situation in which the pilot stalls out of a glide, and effects recovery without adding power to the 1,000 r.p.m. used in setting up the glide. Without adding power the pilot's choice in recovering from a stall out of a glide at 1,000 r.p.m. is to return to the normal glide path and proceed down it as efficiently as possi-- Therefore, the data in Table 39 were assembled from the Case II tests with

TABLE 38

COMPARISON OF TESTS IN GLIDING MANEUVERS: OPTIMUM METHODS OF RECOVERY WITH POWER ADDED FROM THE FULL STALL VERSUS FLIGHT ALONG THE MAXIMUM ANGLE OF CLIMB

Maneuvers Recovery from	By Procedures	Altitude Change in ft. Average	Required Time in sec. Average	Better by Average of (feet)
3. Straight Ahead Glide (1,000 r.p.m.)				
Full Stall	PRE-OH	-38 ± 17	13 ± 1.0	
Stall Warning	PRAE-SW	+84 ± 11	11	+140*
6. Left Gliding Turn (1,000 r.p.m.)				
Full Stall	PRE-OH	-79 ± 17	12.6 ± 0.9	
Stall Warning	PAE-SW	+76 ± 22	12.5	+155
7. Right Gliding Turn (1,000 r.p.m.)				
Full Stall	PRAE-OH	-60 ± 13	11.8 ± 0.9	
Stall Warning	PRAE-SW	+77 ± 23	12.5	+133*

*Estimated by correction for differences in time intervals.

the criterion of return to the normal glide path. These data have one defect that should be noted. It is shown in Part V that, when the stall warner was set to come on at the maximum angle of climb, the calibrated airspeed at which the stall warner came on was approximately 2.5 m.p.h., lower than that airspeed which achieves the minimum angle of glide. In other words, the stall warner which was "bracketed" in the tests reported in the lower half of Table 39 were not run by "bracketing" the minimum angle of glide. They were run by "bracketing" an airspeed for which the angle of glide was somewhat greater than the minimum angle of glide.

The recovery method which resulted in the least altitude loss from the stall out of a gliding maneuver to the glide path recovery was AE-BP, with an average loss of 114 feet. Contrasted with this was the stall warning procedure RAE-SW, in which the average loss of altitude was only 67 feet in the same time interval. As shown in Table 39, this resulted in a difference of 47 feet in favor of the stall warning procedure. It may be assumed that this difference would be even greater had the aircraft been equipped with a warner which came on at the minimum angle of glide, rather than the maximum angle of climb.

D. General Summary of Comparisons

The data presented in this part of the report reveal the striking difference between the best method of recovery from a full stall, and the performance of the aircraft when recovery was started at the stall warner and was effected by "bracketing" this signal. The stall warner was set at maximum angle of climb, and, consequently, the results for the gliding maneuvers had special application in the case of the gliding situations. However, in all maneuvers, including the glides, the tests of the stall warning procedures resulted in altitudes from 50 to 150 feet better. Altitude differences of this magnitude have little or no significance at 1,500 or 2,000 feet, but they are of crucial importance at the low altitudes.

Instruction and information programs can impart to the pilot knowledge on the best method of recovery from a stall in any maneuver. However effective such a program of instruction and information may be, it cannot overlook the fact that the stall is expensive of altitude and is dangerous. When the pilot cannot recognize the impending stall, he can, as shown by the results of this part of the study, turn to a flight device which will not only prevent him from stalling, but will also permit him to achieve the maximum performance that the aircraft can produce.

TABLE 39

COMPARISONS OF TESTS OF STRAIGHT AHEAD GLIDING POWER: OPTIMUM METHOD OF RECOVERY TO NORMAL GLIDE FROM FULL STALL VERSUS "BRACKETING" STALL WARNER

Maneuvers Recovery from	By Procedures	Altitude Change in ft. Average	Required Time in sec. Average	Better by Average of (feet)
3. Straight Ahead Glide (1,000 r.p.m.)				
Full Stall	AE-BP	-114 ± 23	7.4 ± 0.9	
Stall Warning	RAE-SW	-118 ± 24	13	47*

*Estimated by correction for differences in time intervals.

PART III

SUMMARY

The results of this study may be summarized under three general headings: (1) the characteristics of the testing aircraft, (2) the results of tests of methods of recovery from the full stall, and (3) results of tests of flight along an optimum flight path defined as the maximum angle of climb. The testing aircraft was equipped with instruments to obtain accurate data on airspeed, altitude, and angle-of-attack. The flight tests pertaining to recovery from the full stall involved its recognition by the pilot and an observer.[1] The second set of flight tests involved the use of a stall warning device by means of which the pilot regulated his recovery by "bracketing" a signal set to come on at maximum angle of climb.

A. Characteristics of the Testing Aircraft

1. The Aircraft.

The testing aircraft was a Piper J-3, NC 41578. Its weight and balance characteristics conformed to C.A.A. standards, and it was properly licensed and approved by the C.A.A.

2. Instrumentation.

This aircraft was equipped with a factory-grade engine tachometer, oil pressure gauge, oil temperature gauge, and magnetic compass. These instruments were checked, but were not calibrated. For testing purposes, a sensitive Kollsman airspeed indicator, Model No. 5868 K, of the type used on helicopters, was installed and calibrated. A special sensitive altimeter replaced the factory-grade altimeter. A standard military-type APN-1 radio altimeter was installed and calibrated. The testing aircraft was also equipped with a Kollsman angle-of-attack instrument which was installed and calibrated. A specially designed electrical system involved the use of a Willard spill-proof 12-volt battery (17 ampere hour at 5-hour rate), a Champion winddriven generator, Model 1215 (mounted on the undercarriage), and an inverter and dynamotor. The inverter and dynamotor were necessary to operate the angle-of-attack instruments and the radio altimeter. The indicators for these instruments were conveniently located on an instrument panel, specially designed for purposes of testing.

All of these installations of special testing instruments were inspected by the C.A.A. representatives and approved by them. Each of the testing instruments was inspected frequently and maintained continuously.

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[1]With the exception of gliding maneuvers in which a criterion angle-of-attack was used as point of stall.

3. Stalling Speeds.

The stalling airspeeds (calibrated) of the testing aircraft ranged from approximately 35 m.p.h. in the straight-ahead, climbing power maneuver to approximately 42.7 m.p.h. in the left steep turn (2100 r.p.m., 60° bank). The average stalling speed of three full power, climbing maneuvers (straight-ahead, left and right turns) was approximately 35 m.p.h. The stalling speed of three gliding maneuvers (straight-ahead, left and right gliding turns) was approximately 40 m.p.h.

4. Angle-of-Attack.

The calibrated angle-of-attack in straight and level flight of this aircraft as obtained by testing was 2.71°.

In a "normal" gliding attitude -- 1,000 r.p.m., 54 m.p.h. calibrated airspeed -- the average calibrated angle-of-attack as obtained by testing was 7.21°.

Tests of angle-of-attack at stall produced results ranging from approximately 18° to approximately 22°, with an average of all tests of approximately 19°.

5. Maximum Angle of Climb.

Tests were run to determine the aircraft's maximum angle of climb at low altitude. This was found to be 7°01' in the case of the left climbing turn, 7°28' in the right climbing turn, and 7°32' in the straight-ahead climb. The average of these was found to be 7°20'.

At maximum angle of climb, the calibrated airspeed ranged from 43.5 to 45.4 m.p.h., with an average of 44.2 m.p.h.

6. Minimum Angle of Glide.

Tests were run to determine the minimum angle of glide in three gliding maneuvers. The results obtained ranged from 6°07' in the straight-ahead glide to 7°16' in the left gliding turn. The minimum angle of glide for the right gliding turn was 6°47', and the average for all gliding maneuvers was 6°43'.

The calibrated airspeed at 1,000 r.p.m. and the minimum angle of glide ranged from 49.4 m.p.h. in the left gliding turn, 15° bank, to 50.5 m.p.h. in the right gliding turn, 15° bank. The airspeed in the straight-ahead glide at minimum angle of glide was 49.7 m.p.h., and the average for all three maneuvers was 49.9 m.p.h.

7. Stall Warning Apparatus.

The testing aircraft was equipped with a special stall warning apparatus with a lamp as signal. The signal vane was set to trigger at a calibrated airspeed of approximately 43.2 m.p.h., and to release at a calibrated airspeed of 44.8 m.p.h. in the full power climb. At these airspeeds, the calibrated angle-of-attack was 13.2° for the "on" and 12.1° for the "off." With a calibrated angle-of-attack of approximately 12.6° at maximum angle of climb, this setting was considered adequate for testing purposes. The angle-of-attack range over the "on-off" interval was almost equally distributed on either side of the angle-of-attack at maximum angle of climb. These values were approximately 6.5° angle-of-attack below the average stalling angle. (See A-4, above.)

B. Tests of Recovery from the Full Stall

Various methods of recovery of the aircraft from the full stall were investigated in 11 maneuvers. The first set of tests involved the problem of recovering from a full stall to the criterion of straight and level flight, 2.71° angle-of-attack (7°, indicated). This was designated Case I. Case II tests were restricted to the gliding maneuvers only, and involved recovering from the full stall to the criterion of a normal glide, 13° indicated angle-of-attack, approximately 7.2° calibrated angle-of-attack. A total of 84 recovery methods applying to 11 maneuvers were tested in Case I, and 20 methods of recovery pertaining to the three gliding maneuvers were tested in Case II. These results are summarized by maneuvers below.

The methods of recovery involved combinations of the optimum use of power, rudder, ailerons, and elevators and a refinement in recovery procedures with reference to the attitude of the aircraft during the recovery process. Two attitudes during recovery were tested: the "On Horizon" and "Below Horizon" procedures. The "On Horizon" procedure involved arresting the nose of the aircraft just above the horizon line and not permitting it to go below the horizon. The "Below Horizon" procedure involved pushing the nose of the aircraft approximately 15° below the horizon line until full control of all control surfaces was again achieved, and recovery to level flight was then effected.

In Case II this comparison became "On Path" versus "Below Path," in which attempts to recover the aircraft were made by dropping the nose to the normal glide path in the "On Path" recovery. In the "Below Path" recovery, the nose was dropped approximately 15° below the normal glide path and held there until flying airspeed was regained.

In evaluating the effectiveness of the various recovery procedures two criteria were employed (1) the loss of altitude in feet, and (2) the consistency of the recovery (standard deviation of altitude losses). The time required to effect recovery was considered secondary to these criteria. Testing was done only in relatively calm air; all tests were conducted over water where radio altimeter readings were highly accurate; and all unacceptable trials were rerun. Results were based on 10 acceptable trials per recovery method.

Case I -- Recovery to Straight and Level Flight

Altitude loss, best and poorest methods in all maneuvers except steep turns. In Figure 4, is presented graphically in summary form the information regarding altitude loss in recovery to straight and level for the best and poorest "On Horizon" and "Below Horizon" recovery methods, for all maneuvers except steep turns. It is evident that for each of these nine maneuvers the best "On Horizon" method was superior to the best "Below Horizon" method. Moreover, the differences between the best and poorest values[2] under each of the two general procedures were statistically significant at a very acceptable level of confidence[3] for seven of the nine maneuvers. Critical ratios of less than 2.00 were yielded, however, for the left climbing turn, and the straight-ahead cruising maneuvers.

Moreover, and in general, the poorest "On Horizon" recovery method was superior to the best "Below Horizon" method, the single exception to this trend being in the case of the straight-ahead cruising maneuver. Even these differences showed some trend toward statistical significance, six of the nine yielding critical ratios greater than 2.50. Clearly, when the consistency of the trend is considered, the possibility that the superiority of the "On Horizon" procedures is a chance affair can be considered so extremely remote as to be disregarded. Direct statistical evaluation of the probability of these cumulative differences occurring by chance is not readily possible, however.

For all maneuvers where the "On Horizon" recovery procedure was possible, and considering the control use methods yielding least loss of altitude, the average altitude loss was 51.6 feet, as contrasted with an average loss of 128.1 feet for the "Below Horizon" procedures. For some maneuvers the difference in number of feet lost by the two procedures was markedly greater. The "On Horizon" procedures resulting in the least loss of altitude were effected on the average in approximately 11.6 seconds, a considerably longer period than for the "Below Horizon" procedures the average time for which was about 7.0 seconds. However, the longer time is more than compensated for by the altitude saved.

There seems, therefore, eminent justification for the conclusion that through use of the "On Horizon" recovery procedures, recovery from a stall to level flight was accomplished with markedly, and in general significantly, less loss of altitude than when the "Below Horizon" recovery procedures were employed.

Evaluation of various "On Horizon" recovery methods. Having established that the "On Horizon" recovery procedures best conserve altitude in stall recovery, the next question is which of the control use methods effects the

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[2] i.e., the altitude losses for the best and poorest methods of control use.

[3] A critical ratio greater than 3.00 being yielded.

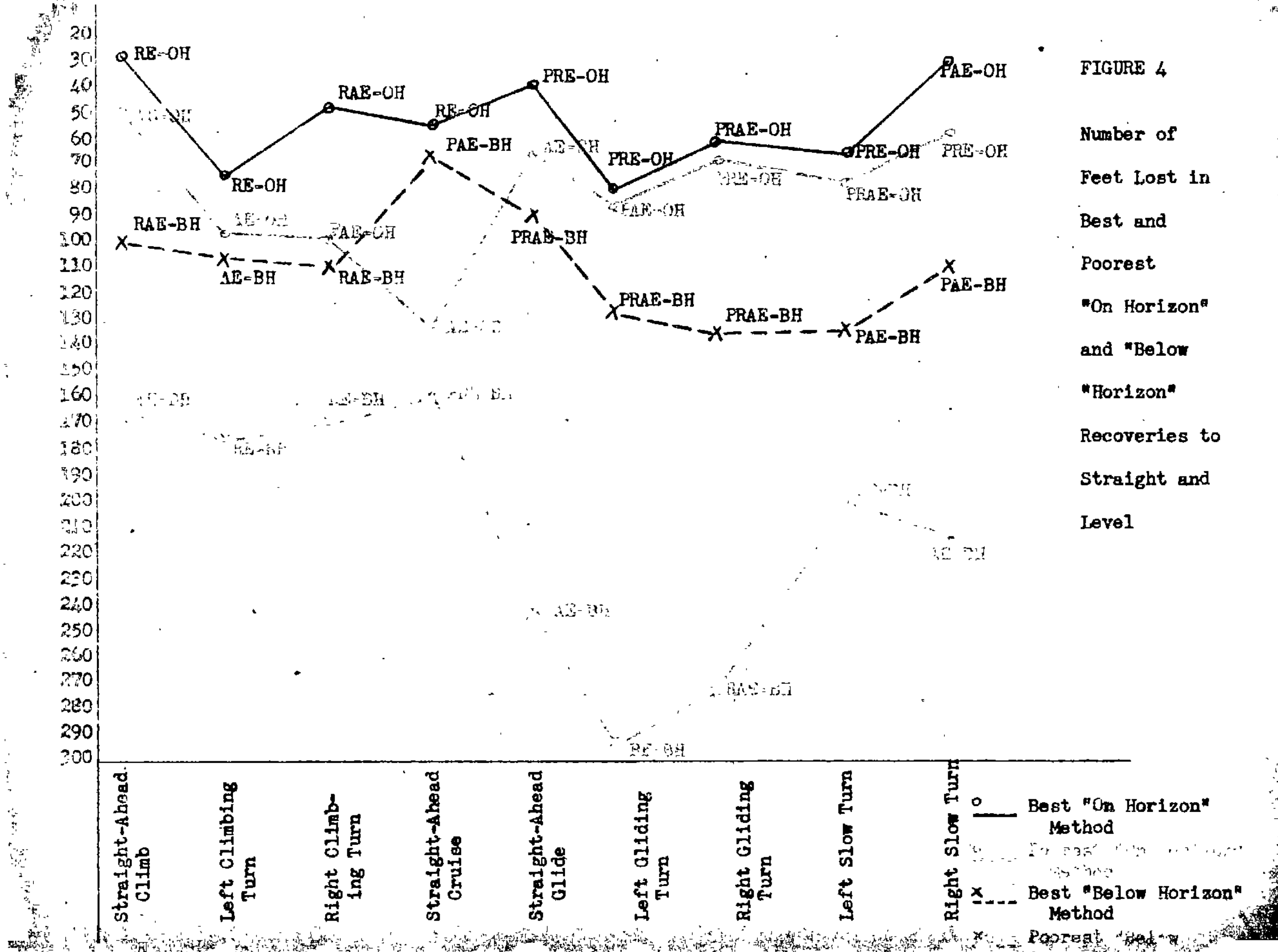

FIGURE 4

Number of Feet Lost in Best and Poorest "On Horizon" and "Below "Horizon" Recoveries to Straight and Level most satisfactory "On Horizon" recovery. Data pertinent to this question are summarized graphically in Figure 5. In this figure the number of feet lost through use of the various control movement methods, with and without use of additional power are plotted. The standard deviations for the various methods also are entered in the figure.*

Available experimental evidence (although incomplete) together with logical considerations indicates that to effect an optimum recovery, additional power, if available, should be used. On the other hand evidence regarding the specific control movements yielding best results is not consistent maneuver to maneuver. However, the differences in altitude loss values for at least the two best methods in each maneuver are in general not large or significant statistically. Moreover, it appears unrealistic to expect a pilot to remember, for example, to use aileron and elevator in recovery from a stall in a right slow turn, but to use rudder and elevator if the stall is from a slow turn to the left.

In general, it would appear that the pilot, in recovery from a stall by the "On Horizon" procedures, will not go far wrong if he remembers to use elevator and rudder to control the plane, and to go easy on the ailerons. The "Aileron-Elevator" (AE) method gave best results only in the right slow turn, and this might well represent an artefact.

Steep turns. It will be recalled that in steep turns the stall under appeared particularly vicious, and the only effective recovery method appeared to be to put the nose below the horizon, and to use all controls to an optimum degree in effecting recovery. Under these conditions a considerable loss of altitude appears unavoidable, although the evidence indicated that the loss would not be so great under conditions of smooth air as under conditions of turbulence. The lack of applicability of the "Below Horizon" methods in the steep turn seems not of great import. If a stall occurs out of this maneuver it may well carry the nose below the horizon before the pilot can begin his recovery.

Case II -- Recovery to the Normal Gliding Angle

Altitude loss for best and poorest methods. Procedures and methods of recovery to the normal gliding angle, without addition of extra power[4] were tested following stalls from a straight-ahead glide, a left gliding turn, and a right gliding turn. The two general procedures were "On Path" recoveries, where the nose was held on the normal glide path during the recovery, and "Below Path" where the nose was allowed to drop below the normal glide path in the course of the recovery.

In Figure 6 is presented graphically the summary information for the best and poorest methods under the "On Path" and "Below Path" procedures.

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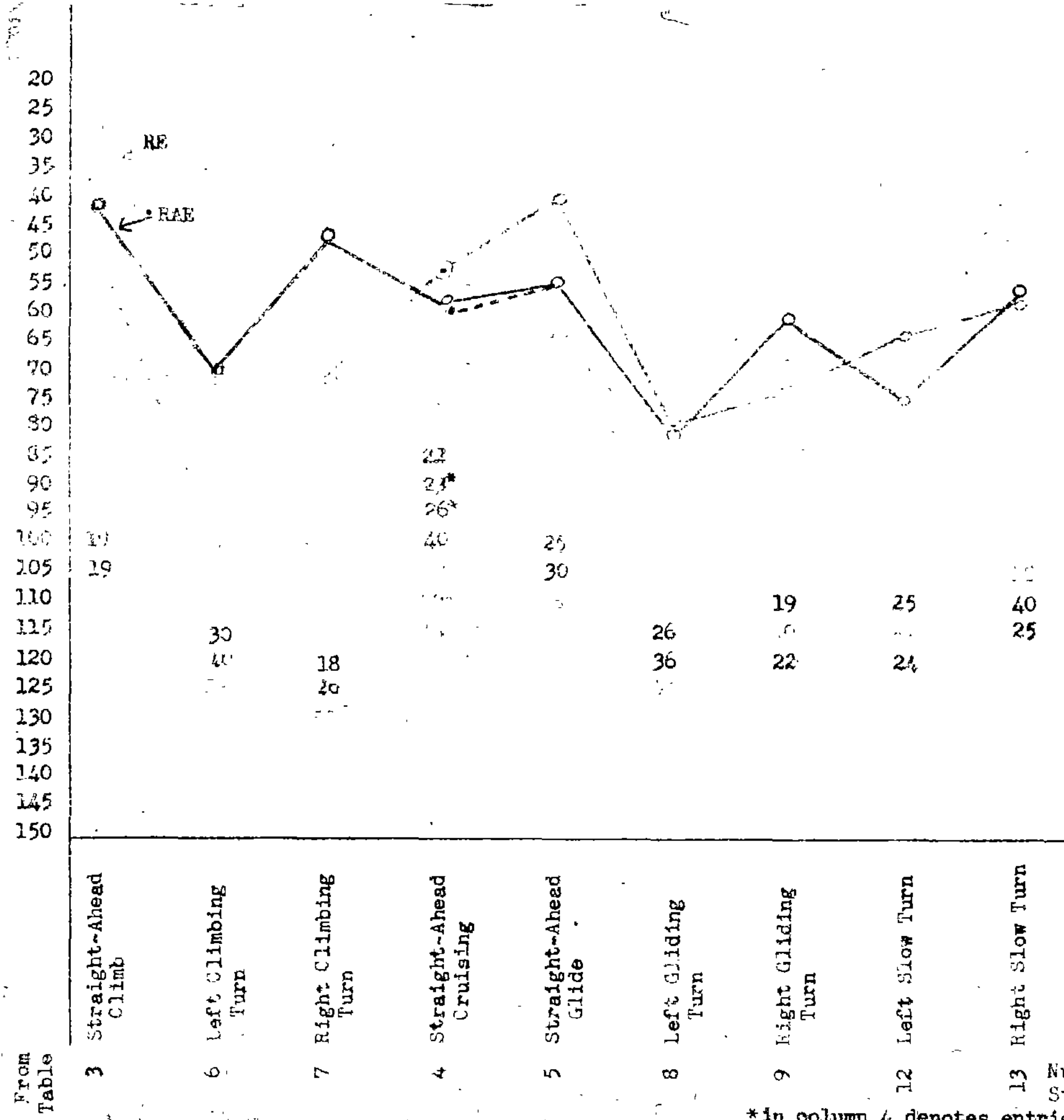
*Editor's note: In this figure, circles and solid lines denote recoveries utilizing full power, dots and dotted lines the recovery utilizing cruising power. It should be noted that the recoveries for the climbing maneuvers are denoted by solid lines even though their letter designations in Tables 3, 6, and 7 (RE-OH, AE-OH, and RAE-OH) do not include the prefix "P". It was not considered that these recoveries included addition of full power (P) since full climbing power was employed to begin with.

[4]Glides were executed with 1,000 r.p.m.

FIGURE 5

Graphic Representation of Number of Feet Lost in "On Horizon" Recovery with Various Control Use Methods

(All maneuvers involving recovery to level flight except Steep Turn)



Controls used

RE

RAE

full power used in recovery

cruising power used in recovery

Numerals represent respective Standard deviation values

*in column 4 denotes entries for "with added power"

It will be noted that for two of the three maneuvers the "On Path" recovery resulted in greater loss of altitude than did the "Below Path," although for the right gliding turn there is very little difference between the altitude loss values for the best "On Path" and the best and poorest "Below Path" procedures. The standard deviations for these values are relatively large, indicating considerable trial to trial variation for all of the procedures, and in general the differences between altitude loss values cannot be considered highly significant statistically, although for the straight-ahead glide the difference between the best "Below Path" and the best "On Path" recovery procedure yielded a critical ratio of 2.74.

Although evidence for the superiority of the "Below Path" recovery procedure is not unequivocal with reference to all three gliding maneuvers, certainly it can be stated that the pilot, recovering from a stall in a gliding maneuver, where additional power is not available, will in general be better off if he lets the nose drop below the glide path during recovery, rather than attempting to hold the nose on the glide path. Even in the right turn, the standard deviation for the best "On Path" recovery is markedly larger than for any of the below path recoveries, indicating that while on the average the best "On Path" recovery yielded about the same results as the best "Below Path" procedure, performance from trial to trial was much less consistent.

<u>Evaluation of various "Below Path" recovery methods</u>. A summary of the altitude loss data for the various recovery methods using the "Below Path" procedures is presented in Figure 7. It should be noted that there is no consistent trend over all maneuvers; furthermore, none of the differences between methods in any maneuver is statistically significant. It appears unrealistic to expect a pilot to remember that he should use rudder, aileron and elevator in a stall recovery from a left gliding turn, but only aileron and elevator in recovering from a stall in a right gliding turn or in a straight-ahead glide. It would seem that the pilot will not go too far wrong, in recovering from a stall in a gliding maneuver, when additional power is not available, if he recovers by letting the nose drop below the glide path to pick up flying speed, <u>and utilizes coordinated movement of all controls</u>, i.e., the "RAE" recovery method.

True, as is evident from Figure 7, the "RAE" recovery resulted in a somewhat greater mean loss of altitude in the straight-ahead glide and in the right gliding turn. However, in the latter maneuver while the mean altitude loss was slightly greater than for the other two methods, the two best methods yielded markedly more variable performance, i.e., yielded markedly larger standard deviations. Therefore, on the whole, in gliding maneuvers where no additional power is available, the Below Horizon "RAE" recovery appears best.

C. <u>Tests of Flight Along an Optimum Flight Path</u>

Various methods of recovery of the aircraft from a stall warning to flight along an optimum flight path were investigated in 7 maneuvers. The

FIGURE 6

Number of Feet Lost in Best and Poorest "On Path" and "Below Path" Stall Recoveries Without Additional Power in Gliding Maneuvers

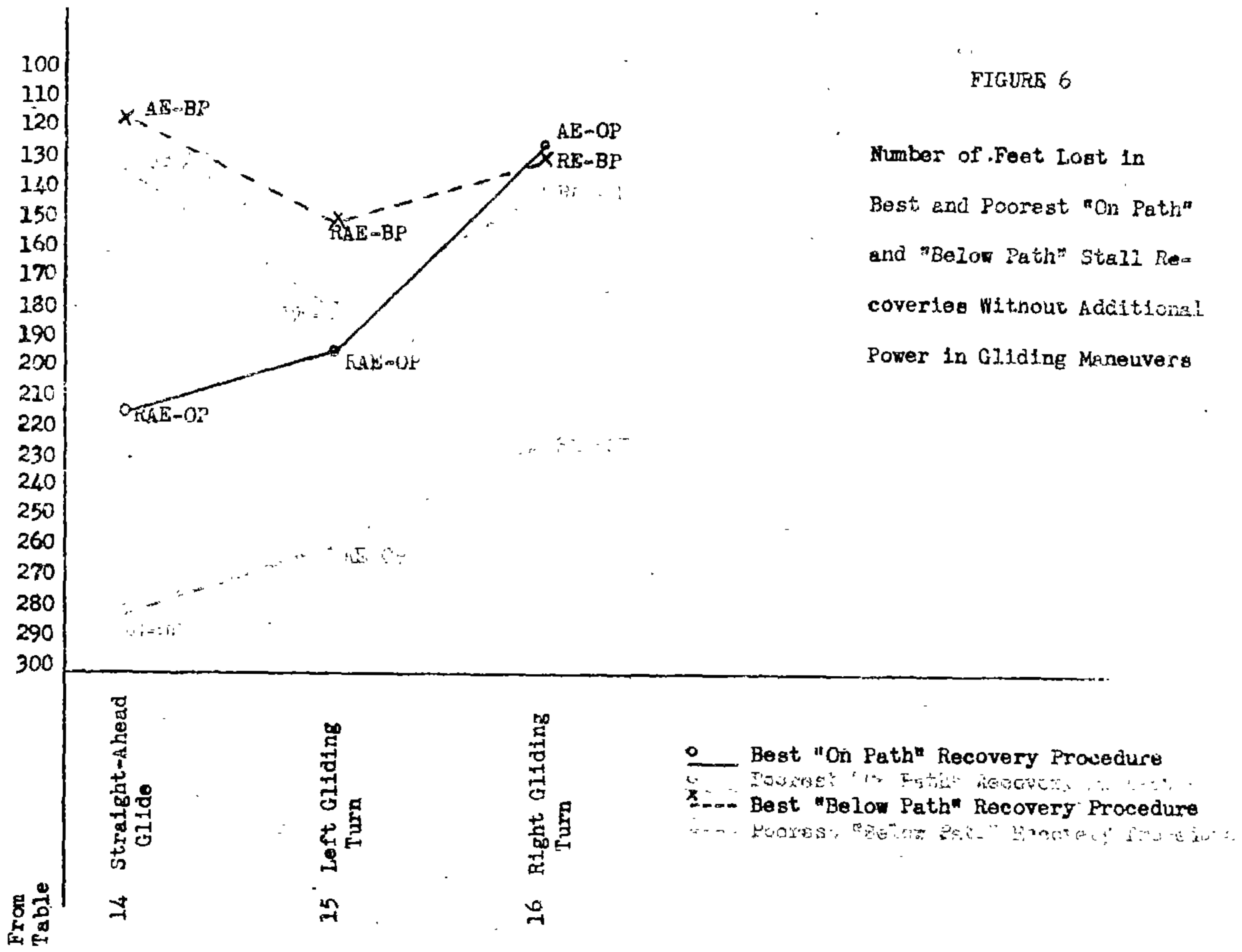
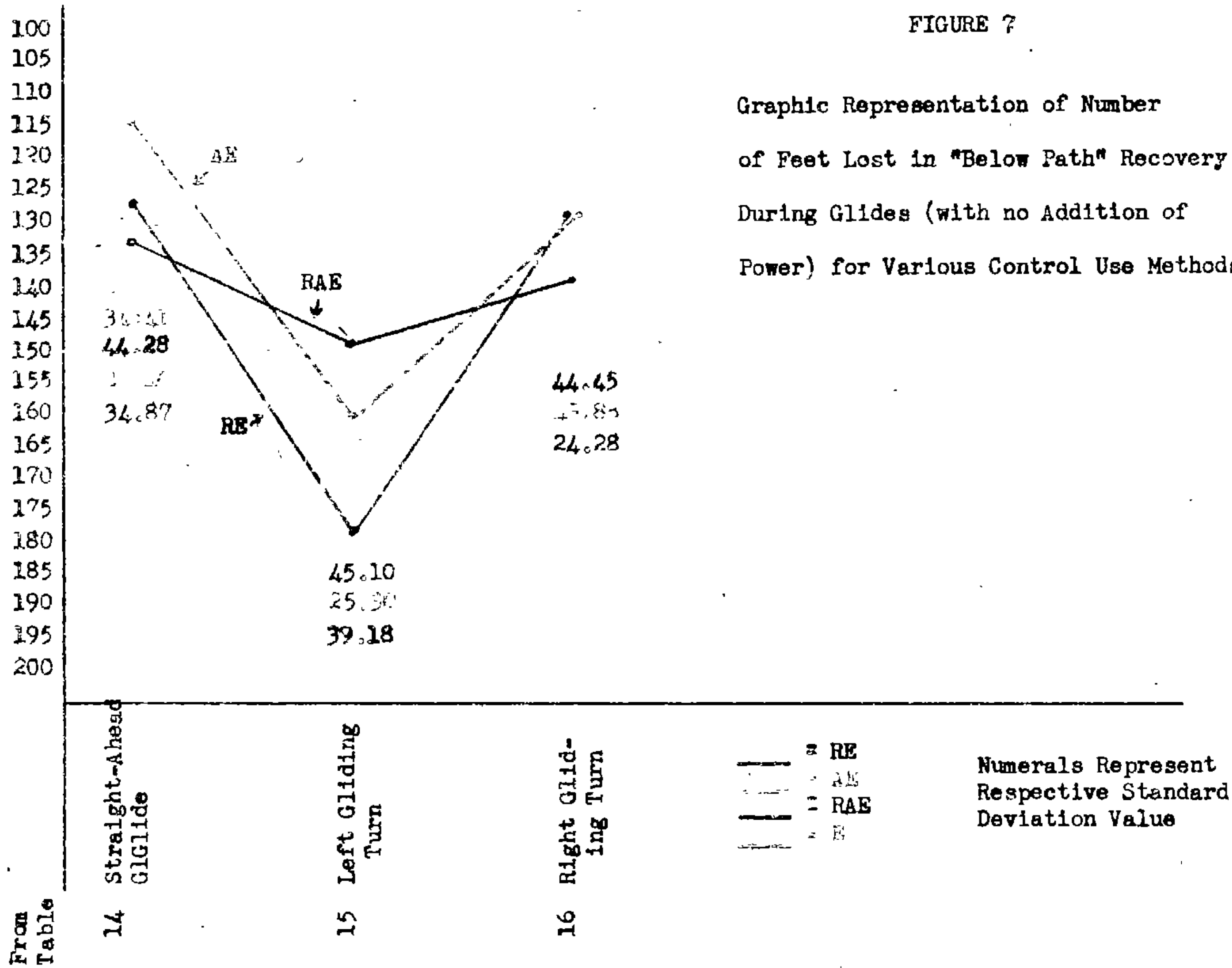


FIGURE 7

Graphic Representation of Number of Feet Lost in "Below Path" Recovery During Glides (with no Addition of Power) for Various Control Use Methods



optimum flight path was defined as that involving the maximum <u>angle</u> of climb. It was found that the number 3 vane of the stall warner installation was activated at about the angle-of-attack associated with the maximum angle of climb, and that the maximum angle of climb could be achieved through "bracketing" the stall warner signal. Of the 11 maneuvers tested in connection with recovery from the full stall, the left and right slow turns and the left and right steep turns were not considered in this phase of the study. The procedure in these tests was to enter and continue the approach to the stall until stall warner signal came on. The pilot then "bracketed" this signal. That is, as soon as the stall warner signal came on he reduced the angle-of-attack until it went off. He then increased the angle-of-attack until it came on again, decreased the angle-of-attack until it went off, and so on, thus "bracketing" the signal in the sense a pilot "brackets" the "A" during an approach to a low frequency range station. (In another sense the pilot "brackets" the "on-off" interval.) He continued the "bracketing" procedure until the observer called "Now" ending the test. The amount of altitude gained (or lost) during a specified period of time was determined, the period of time for any maneuver being that number of seconds required for <u>recovery from a full stall</u> by the optimum method, as determined in a previous part of the research.

A summary presentation of the results of this part of the study is given in Figure 8. In this figure the number of feet of altitude gained (or lost) during recovery along the optimum flight path is presented for the various recovery methods (i.e., control uses) in the seven maneuvers under investigation. First, inspection of this figure indicates that maximum altitude along the optimum flight path is achieved when full power is used in bracketing the stall warner signal. In the straight-ahead climb at full power, and in the climbing turn, execution was at full throttle. In the straight-ahead cruising power maneuver, addition of full power resulted in much greater altitude gain than when no power was added.[5] In the straight-ahead glide there was a marked loss of altitude if power was not added, a finding, of course, altogether in line with expectation.[6]

The question of which combination of control uses yields the best results is less clear cut. Obviously it is unrealistic to expect a pilot to remember a different set of control uses for optimum execution in different maneuvers. For example, the normal pilot could hardly be expected to remember that he should use aileron and elevator in the right climbing turn, but coordinated controls (rudder, aileron and elevator) in the right gliding turn. In any event, the differences in altitude gained with various control movement methods and utilizing full power are not very significant statistically, critical ratios less than 2.00 in general being yielded.

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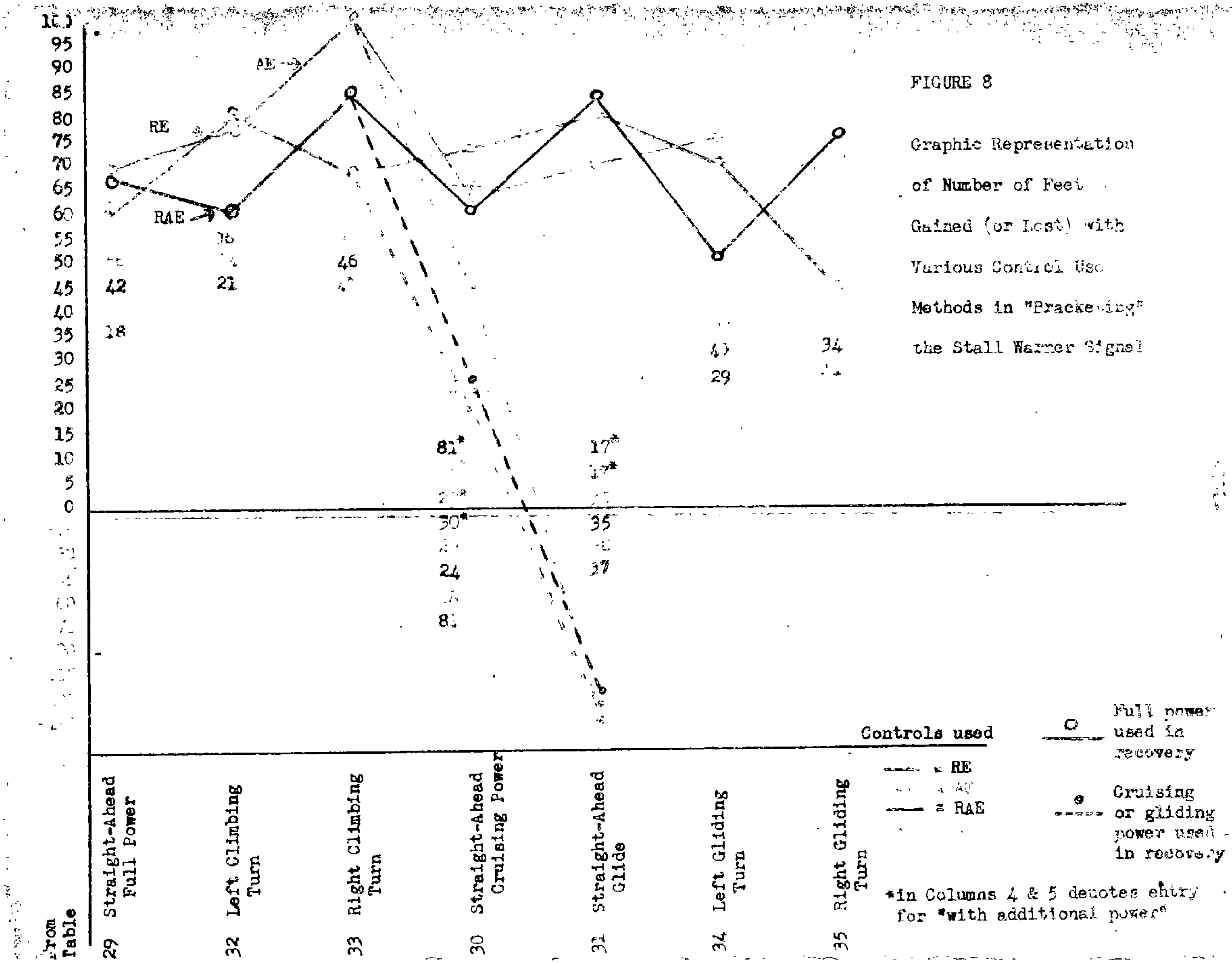
[5]The differences for "additional power" and "no additional power" executions with given control movements approached statistical significance, yielding critical ratios of between 2.0 and 3.0 for this maneuver.

[6]The differences were, incidentally, highly significant statistically.

FIGURE 8

Graphic Representation of Number of Feet Gained (or Lost) with Various Control Use Methods in "Bracketing" the Stall Warner Signal



Reference to Figure 8 suggests that the pilot will probably achieve a reasonable approach to the optimum flight path if he utilizes coordinated movement of all controls (the RAE method) along with full power in "bracketing" the stall warner signal since all the controls are effective at the airspeed resulting from bracketing the stall warner. In this part of the investigation, it will be remembered, attention was centered on achieving maximum angle of climb, rather than maximum rate of climb.

D. Advantage of the Stall Warner

In the following tabulation, Column 1 lists the average time in seconds required to effect the optimum, or best, method of recovery from the full stall out of the maneuver involved. Column 2 reports the average loss in feet which occurred in the recovery by this best method. Column 3 lists the average number of feet of altitude gained by "bracketing" a stall warner set at maximum angle of climb. Finally, Column 4 presents for each maneuver the number of feet of altitude advantage in using the stall warner system versus recovery by the best recovery method from the full stall tested in this investigation.

Maneuver	Recovery Time In Sec.	Loss from Point of Stall In Feet	Gain from Point of Warning In Feet	Advantage In Feet
1. Straight-ahead climb	10.5	26	60	84
2. Straight-ahead cruise	8	53	48	101
3. Straight-ahead glide	13	38	102	140
4. Left climbing turn	14	69	81	150
5. Right climbing turn	12	46	102	148
6. Left gliding turn	12.5	79	76	155
7. Right gliding turn	12	60	73	133

It is assumed with reference to these data that in a glide when the stall warner comes on the pilot goes from a glide to a climb. If, however, he recovers from a stall to a glide, and does so in the best possible manner, he may expect a minimum loss of approximately 50 feet of altitude, as compared to avoiding the stall by bracketing the stall warner.

These data show that a flight instrument set to come on at, or near, the maximum angle of climb, and which "warns" the pilot to begin recovery action, indicates for him a path of flight that will consistently be to his advantage in terms of altitude saved.

Data were presented to show that the point of warning was sufficiently far from the point of stall to permit adequate control of the airplane. Furthermore, the point of warning was sufficiently far from normal flight as to constitute a genuine stall warning.

E. In Summary

On the basis of the analyses of data collected in this investigation certain generalizations regarding optimum procedures for stall recovery, for execution of maximum climbs,[7] and for setting of the stall warner installation appear warranted.

1. With the exception of steep turns, if a stall occurs in a maneuver in which full power is used or is available, and if it is necessary to recover with a minimum loss of altitude, the pilot should:

a. Add full power (if full power is available) and keep the nose of the plane on or close to the horizon, and

b. return, and/or keep, the plane level through use of rudder and elevator, going easy on the aileron control.

The "On Horizon" recovery will take longer than the more conventional procedure of "dumping" the nose below the horizon -- in some maneuvers it may take as long as 14 seconds. However, by sitting tight through the "On Horizon" recovery the pilot may effect recovery with marked savings in altitude loss, as compared with the "Below Horizon" recovery; savings running up to, and exceeding, 100 feet. In certain maneuvers "On Horizon" recoveries can frequently be made with loss of altitude not exceeding 50 feet.

2. In steep turns it appears that the pilot should effect recovery through coordinated use of all controls without attempting to continue the turn.

3. In stalls from gliding maneuvers, where additional power is not available (such as with engine failure) recovery can in general be made with

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[7] in terms of maximum angle of climb, rather than maximum rate of climb.

least loss of altitude by letting the nose of the plane drop below the glide path and utilizing coordinated movements of all controls in effecting recovery.

4. If a stall warner is set to be activated at the angle-of-attack associated with maximum angle of climb it can serve effectively as a flight instrument. By "bracketing" the signal[8] the pilot can be assured that the maximum angle of climb is being achieved. This function as a flight instrument can be extremely useful in situations where achievement of maximum angle of climb is critical, such as in short field take-offs over obstacles, or in "recovering" from a stall warning at low altitude.

5. With reference to the setting of the stall warning indicator, the evidence clearly indicates that much is to be gained by setting the stall warner to be activated, as the stall is approached, at that angle-of-attack associated with maximum angle of climb.[9] This setting allows the stall warner to function effectively in its primary role of giving warning of an impending stall well before the point of stall actually is reached, enabling recovery to normal flight to be made readily. Moreover, it also enables the stall warner to assume a secondary role as a valuable flight instrument under special circumstances. Establishment of this dual role for stall warning equipment appears to represent a major contribution.

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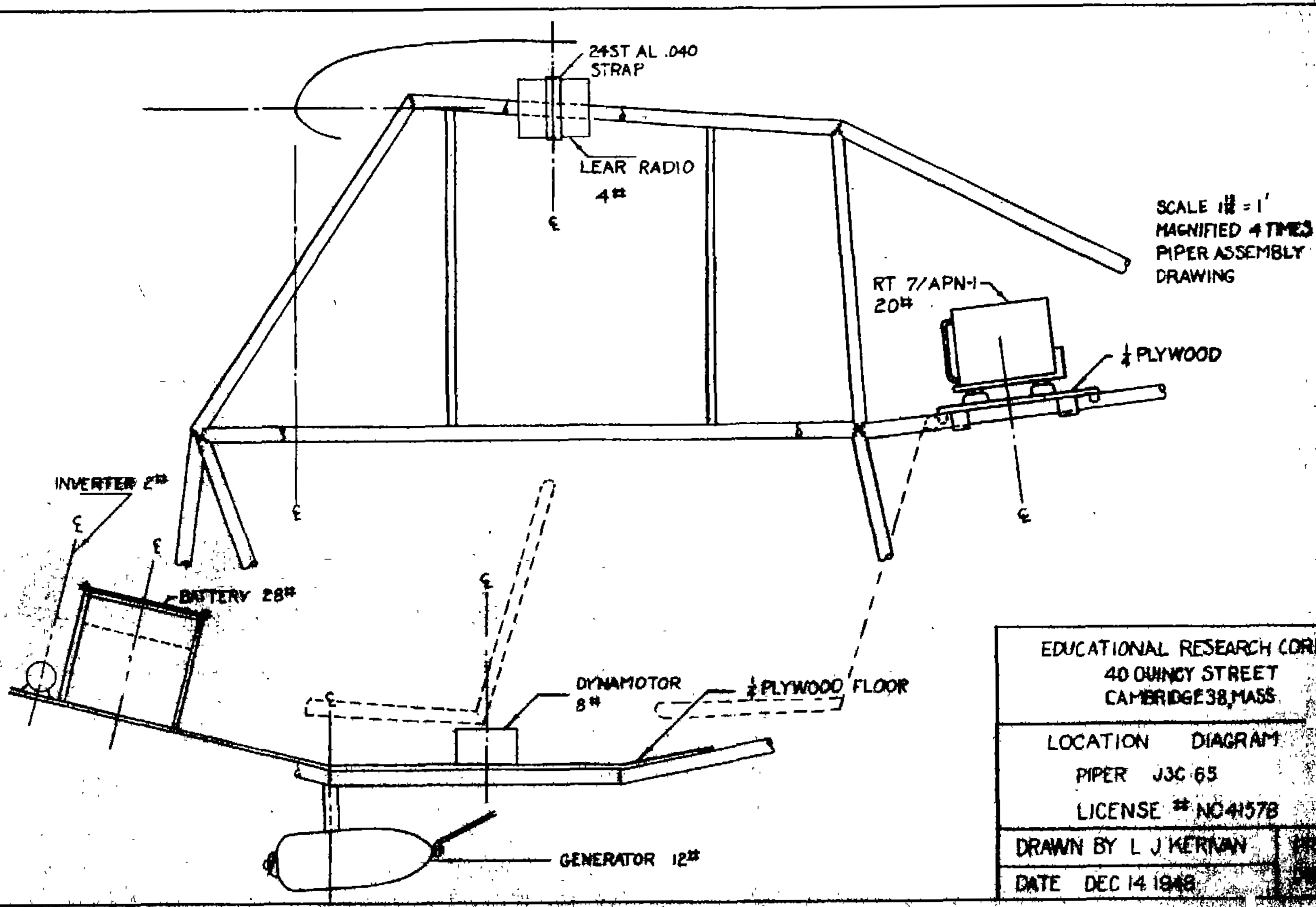
[8]That is, as soon as the stall warning signal comes on the pilot decreases the angle-of-attack until the warning signal goes off. He then increases the angle-of-attack until it goes on, promptly decreases it until the warner goes off, then increases the angle-of-attack until it comes on again, etc.

[9]It is noteworthy, in this regard, that review of the specifications of stall warner manufacturers revealed no clear or consistent practice with respect to the setting of stall warning indicators.

APPENDIX A

DIAGRAMS OF EQUIPMENT INSTALLATIONS*

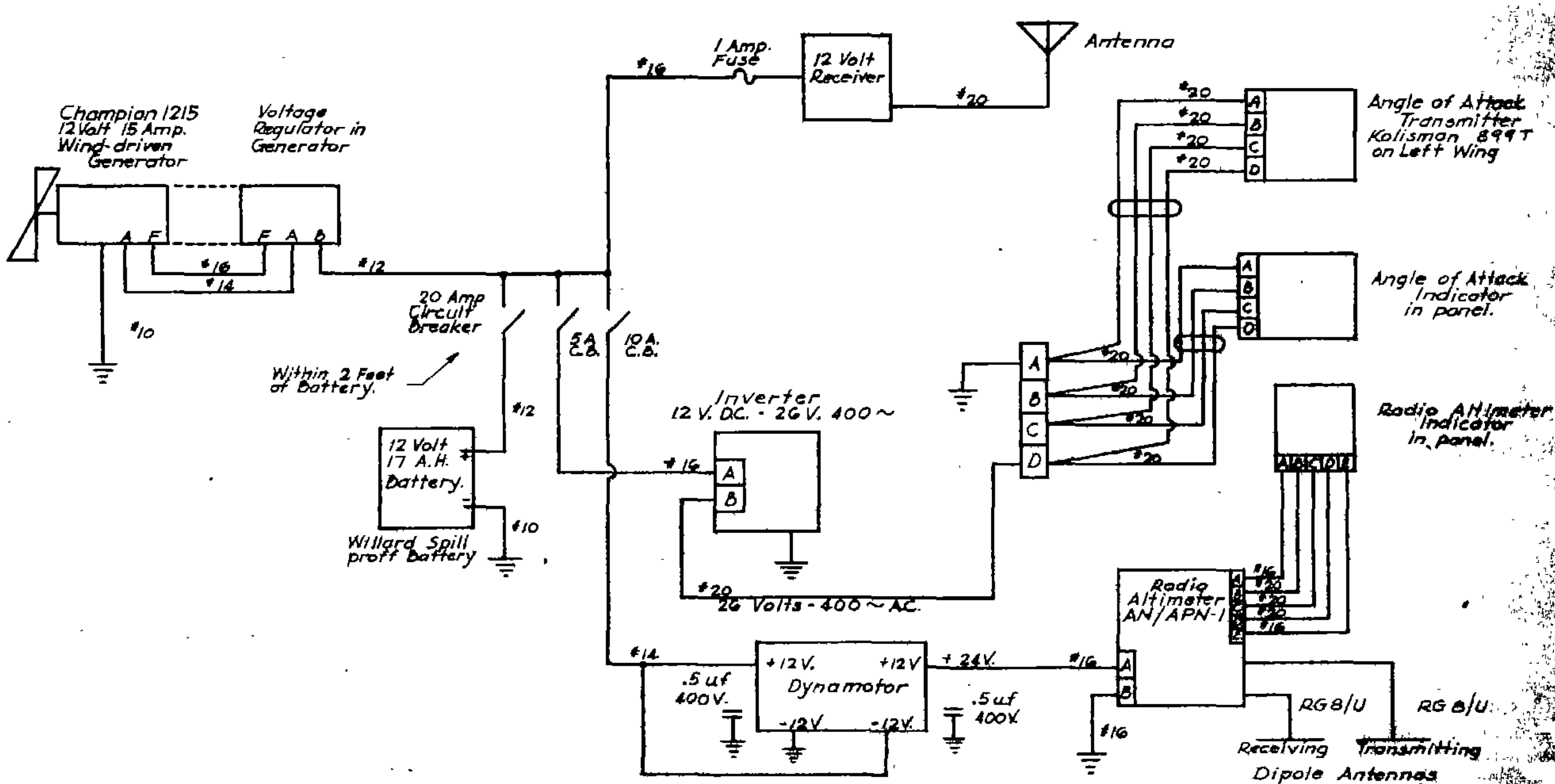
*Original blueprints are in the files of the Committee on Aviation Psychology and can be inspected upon request.



EDUCATIONAL RESEARCH CORP.
40 QUINCY STREET
CAMBRIDGE 38, MASS.

LOCATION DIAGRAM
PIPER J3C 65
LICENSE # NC41578

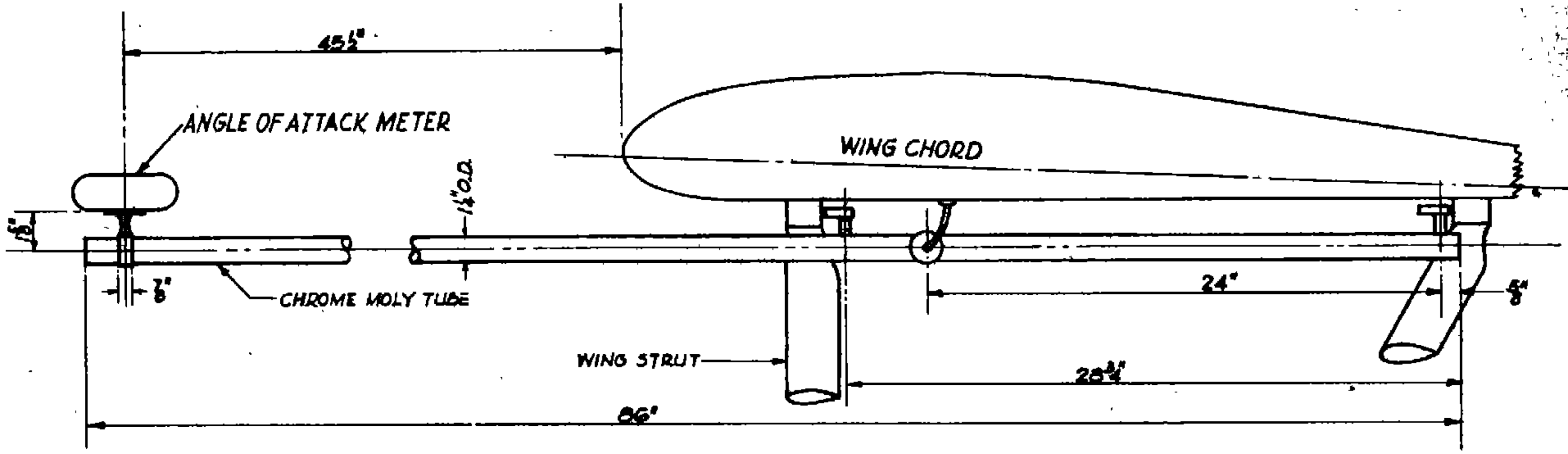
DRAWN BY L J KERNAN
DATE DEC 14 1948



EDUCATIONAL RESEARCH CORPORATION
40 QUINCY ST.
CAMBRIDGE (38) MASS.

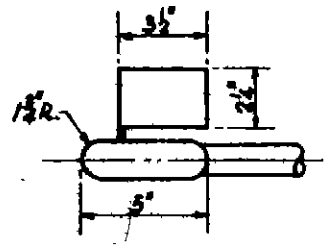
TITLE: Wiring Diagram

FOR C. J. C.

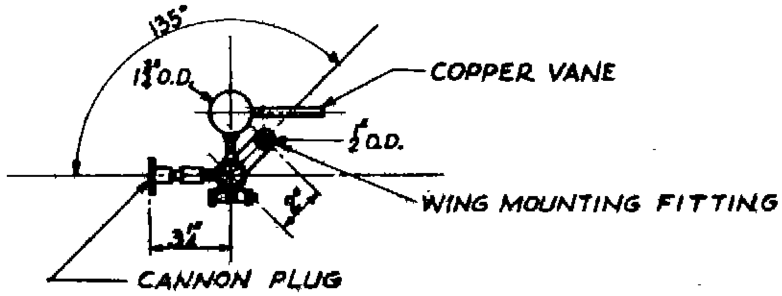


LEFT SIDE VIEW

SCALE: 1" = 5"



PLAN VIEW



REAR VIEW

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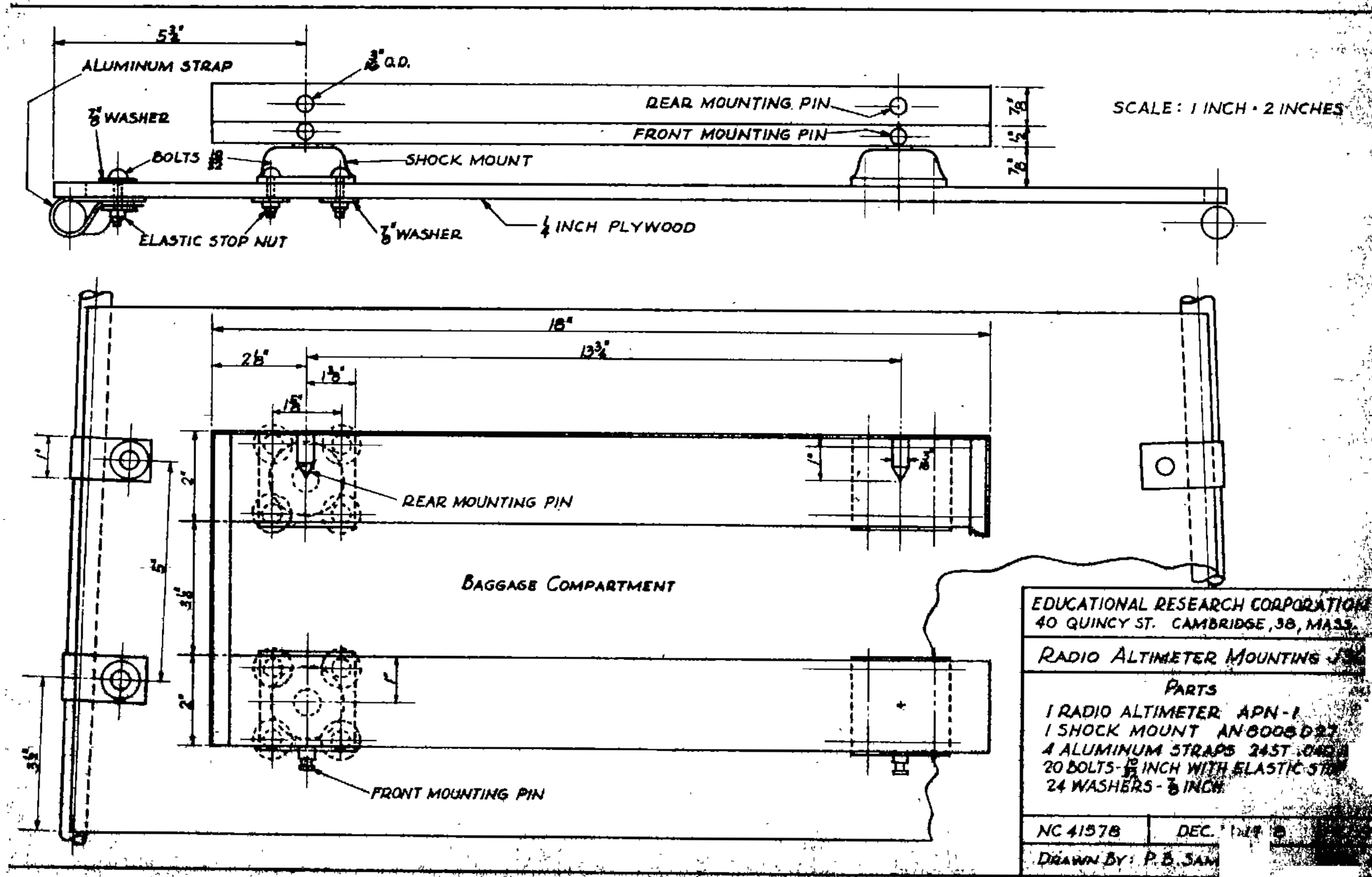
40 QUINCY ST.
CAMBRIDGE 38, MASS.

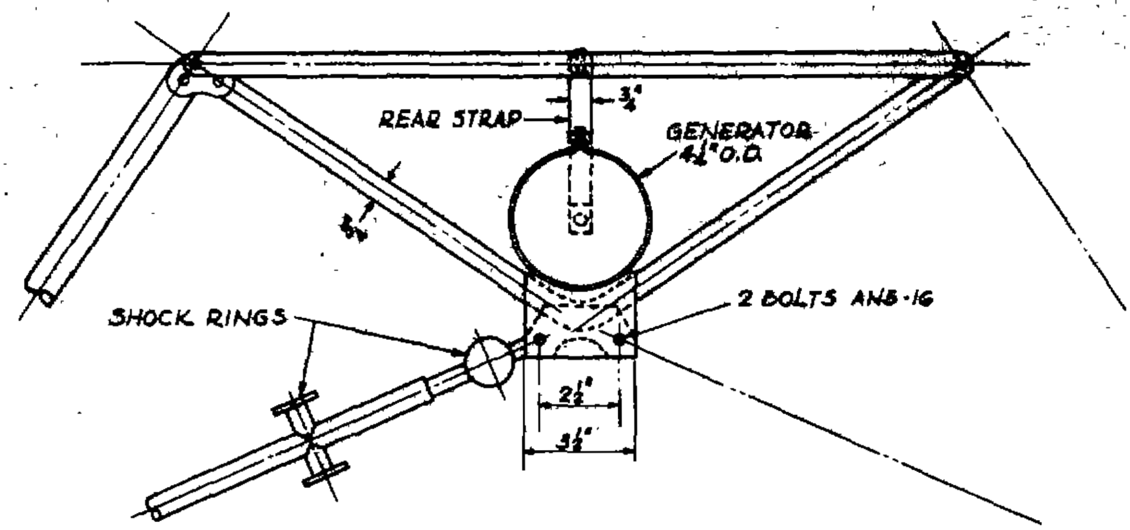
KOLLSMAN ANGLE OF ATTACK INDICATOR

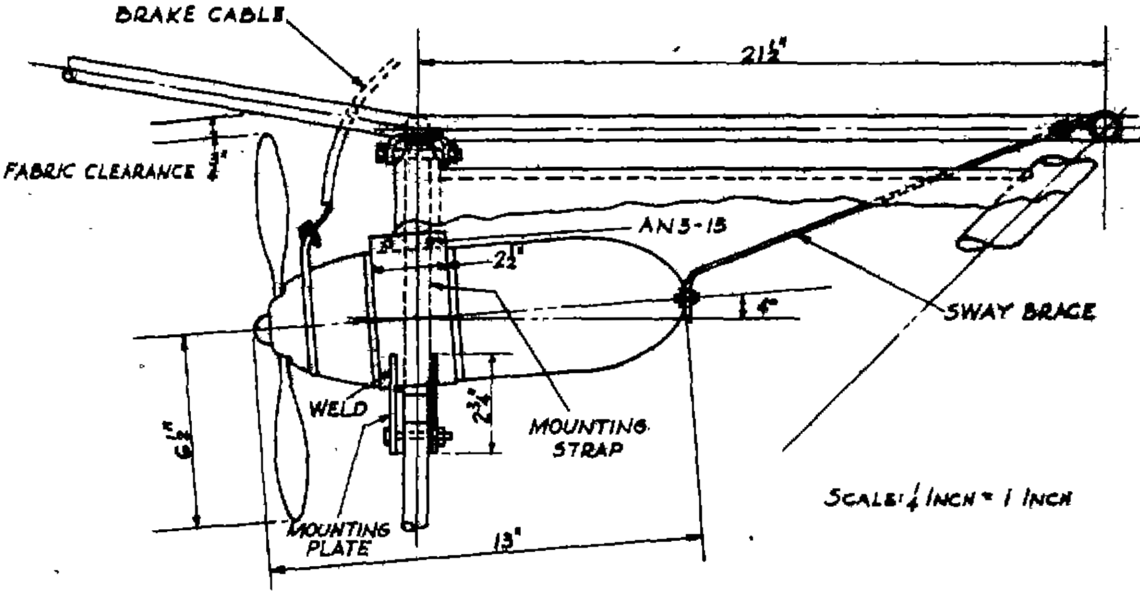
PARTS

1¼" CHROME MOLYBDENUM STEEL TUBE
1 SELSYN TRANSMITTER & HOUSING
1 COPPER VANE
1 BOLT AN5-30 1 BOLT AN5-35

DRAWN BY: PHILIP B. SAMPSON	PROJECT [illegible]
DATE: JAN. 18, 1949	DRAWING [illegible]


SCALE: 1 INCH = 2 INCHES
ALUMINUM STRAP
WASHER
BOLTS
SHOCK MOUNT
ELASTIC STOP NUT
WASHER
1/4 INCH PLYWOOD
O.D.
REAR MOUNTING PIN
FRONT MOUNTING PIN
18"
13 3/4"
REAR MOUNTING PIN
BAGGAGE COMPARTMENT
FRONT MOUNTING PIN
EDUCATIONAL RESEARCH CORPORATION
40 QUINCY ST. CAMBRIDGE, 38, MASS.
RADIO ALTIMETER MOUNTING
PARTS
1 RADIO ALTIMETER APN-1
1 SHOCK MOUNT
4 ALUMINUM STRAPS
20 BOLTS
24 WASHERS
NC 41578
DEC.
DRAWN BY: P. B.





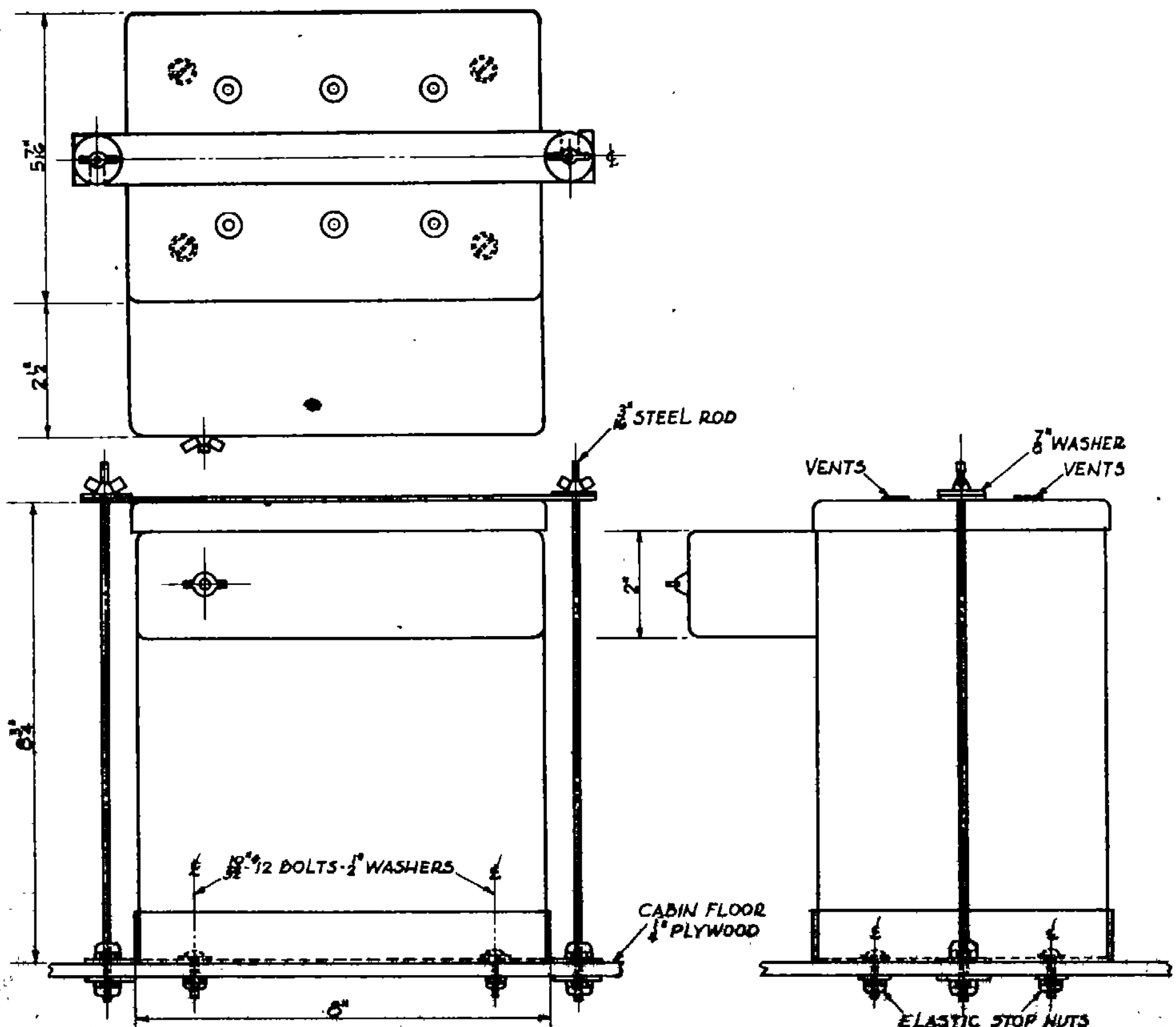
EDUCATIONAL RESEARCH CORPORATION
40 QUINCY ST.
CAMBRIDGE, 38, MASS.

GENERATOR MOUNTING ON LANDING GEAR PIPER J3C

PARTS

1 GENERATOR - 12 LBS. - 12 VOLTS - MODEL № 1215
2 BOLTS - AN5-16
2 BOLTS - AN3-15
2 BOLTS - AN3-10
2 MOUNTING PLATES - .062" - CHROME MOLYBDENUM
1 MOUNTING STRAP - .040" CHROME MOLYBDENUM
1 SWAY BRACE

NC 41578	DATE: DEC. 15, 1948	PRJ. 9



EDUCATIONAL RESEARCH CORP.
40 QUINCY STREET
CAMBRIDGE, 38, MASS.

BATTERY MOUNT
WILLARD SPILL PROOF NAFI
12 V-17 AMP/HR. @ 5 HR RATE

PIPER J3C 65 NC41578
DRAWN BY: LEO J. KERIVAN
SCALE: 1"= 2" DATE:

APPENDIX B

DETERMINATION OF THE ANGULAR DIFFERENCE BETWEEN THE "ASSUMED" CHORD AND THE TRUE CHORD

APPENDIX B

DETERMINATION OF THE ANGULAR DIFFERENCES BETWEEN THE "ASSUMED" CHORD AND THE TRUE CHORD

At the time that the angle-of-attack instrument and mounting boom were installed on the testing aircraft it was assumed that the wing chord ran from the leading edge to the trailing edge of the wing. This imaginary line would by this definition pass inside the wing making it difficult to work with. To avoid this difficulty, a line was constructed below the wing on the side of the fuselage, which was parallel to the assumed wing chord. The construction of this line was accomplished by first drawing two lines which were perpendicular to the assumed chord down the side of the fuselage; one from the leading and one from the trailing edge of the wing. Then equal distances were laid off along each of these lines thus determining two points which were equidistant from the assumed wing chord. When these two points were connected, the resulting line was parallel to the assumed wing chord.

Angle-of-attack is defined as being the angle between the "relative wind" and the wing chord.[1] To be properly calibrated, then, the angle-of-attack instrument must read zero when the copper vane aligns itself with the assumed wing chord. To achieve this calibration the tail of the aircraft was raised until the line on the fuselage which was parallel to the assumed chord was level. This leveling was checked with a conventional bubble level. Next, the angle-of-attack indicator was set at zero and then the copper vane was twisted so that it slipped on its shaft until it was also in a level position and checked with the bubble level. Then with the assumed wing chord and the vane both level and the indicator reading zero, the set-screw was tightened and the vane made secure to its shaft. The instrument now measured the angle between the position of the vane as it streamlined itself with the airstream and the assumed wing chord.

It has been pointed out in Part II of this report that the Engineering Department of the Piper Aircraft Corporation supplied the information that the True chord of the wing is the flat bottom surface of the wing. This meant that the angle-of-attack indicator was reading in error by the angular difference between the assumed wing chord and the true chord. This angular difference between the two chords was determined mathematically so that it could be applied to the indicator readings as a constant calibration correction. The method used for determining this angular difference will be shown in the following steps. First, the distance between the center line of the main gear and the center of the tail wheel was measured. This measurement is designated by the letter "z". Next,

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[1]Jones, Bradley. Aerodynamics for pilots. Civil Aeronautics Bulletin No. 26, U. S. Department of Commerce, Washington, D.C.: September 1940, page 30.

the tail was raised in three successive stages, and the vertical distance between the tail wheel and the ground was measured. The first measurement "y" was made after the longitudinal axis of the aircraft had been leveled. The next measurement "w" was made when the bottom of the wing or true chord had been leveled. The last measurement "x" was made when the tail was raised so that the assumed wing chord was level. By the use of trignometric tables the angles "A", "B", and "C" were determined. The difference between angle "B" and "A" gives the wing root angle of incidence. The difference between angle "C" and "B" gives the angular difference between the true chord and the assumed chord.

Data:

x	54.75 inches
w	49.0 inches
y	43.25 inches
z	207.0 inches

Calculations:

To find angle "A"

$$\text{Sine A} = \frac{y}{z} = \frac{43.25}{207} = .2089 = 12^\circ\ 4'$$

To find angle "B"

$$\text{Sine B} = \frac{w}{z} = \frac{49}{207} = .2367 = 13^\circ\ 41'$$

To find angle "C"

$$\text{Sine C} = \frac{x}{z} = \frac{54.75}{207} = .2645 = 15^\circ\ 20'$$

Root Angle of Incidence	Angular Difference between Assumed chord and True chord
$13^\circ\ 41'$	$14^\circ\ 80'$
$\underline{12^\circ\ \ 4'}$	$\underline{13^\circ\ 41'}$
$1^\circ\ 37'$	$1^\circ\ 39'$

After the copper vane had been set by this leveling method, a template was made and the reading of the indicator taken when the vane was fitted on the template. All subsequent checks of the calibration of the angle-of-attack indicator were made by placing the vane on the template and checking to see that the indicator reading was the same as the original one. If they were not the same, the vane was adjusted by sliding it on its mounting shaft until the correct reading was obtained on the indicator. Plate No. 5 shows the manner in which the vane was adjusted using the template.

APPENDIX C

FORM USED BY OBSERVER IN RECORDING DATA DURING FLIGHT TESTS

APPENDIX C

Educational Research Corporation
40 Quincy Street
Cambridge, Massachusetts

PROJECT NO. 9

Effectiveness of Recommended Methods of Stall Recovery

Date: Time: Temp. Pressure:

Method of Recovery No. ________

Maneuver No. ________

Trial	Air Speed		Angle-of-Attack		Altitude		Ti
	Stall	Recovery	Stall	Recovery	Stall	Recovery	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
Mean							
P.E.							