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LANDING PRACTICES OF GENERAL AVIATION PILOTS IN SINGLE-ENGINE LIGHT AIRPLANES

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16. Abstract

The methods and techniques used by a group of general aviation pilots during the landing phase of light airplane operations have been documented. This report contains the results of 616 landings made by 22 pilots in 2 modern, four-place, single-engine, light airplanes (one having a low wing and the other, a high wing). The landings were made on both a long runway (1524 m (5000 ft)) and a short runway (762 m (2500 ft)); both runways were considered typical of those used in general aviation. The results generally show that most of the approaches were fast with considerable floating during the flares and with touchdowns that were relatively flat or nose-low.

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SUMMARY

The methods and techniques used by a group of general aviation pilots during the landing phase of light airplane operations have been documented. This report contains the results of 616 landings made by 22 pilots in 2 modern, four-place, single-engine, light airplanes (one having a low wing and the other, a high wing). The landings were made on both a long runway (1524 m (5000 ft)) and a short runway (762 m (2500 ft)); both runways were considered typical of those used in general aviation. The results generally show that most of the approaches were fast with considerable floating during the flares and with touchdowns that were relatively flat or nose-low.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) has undertaken a research program to document methods and techniques used by general aviation pilots to land airplanes. This effort was prompted by the general aviation safety records included in reference 1. These reports indicate that most accidents under visual flight rules (VFR) occur during the landing phase of single-engine, light airplanes flown for pleasure. In the vast majority of these accidents, the pilot is the cause or at least a contributing factor.

Many factors influence pilot performance to varying degrees; some of these factors are defined in reference 2 with the degree of influence for each factor.

For this study, two modern, four-place, single-engine, light airplanes (one having a low wing and the other, a high wing) were leased from a fixed-base operator (FBO). A cadre of general aviation pilots with various backgrounds and experiences was provided by the FBO to perform a series of landings both on a long runway (1524 m (5000 ft)) and a short runway (762 m (2500 ft)). Approach and landing data were collected for approximately 150 landings on each runway for each airplane with ground-tracking and airborne data systems. A summary of the results of this landing program is presented to characterize typical private pilot performance during the landing phase of flight in daylight VFR conditions. Preliminary results for the low-wing airplane phase of this program are presented in reference 3.

A motion-picture film supplement has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this report.

TEST EQUIPMENT

The airplanes used in this study (fig. 1) were chosen as being representative of the most widely used airplanes in general aviation private flying. Both airplanes were leased from FBO and were used in his flight training and rental programs. The test vehicles were single-engine, four-place airplanes with fixed tricycle landing gear. One of the airplanes had a low wing and the other had a high wing. The details and specifications for each airplane were obtained from the respective airplane owner's manuals and are presented in tables I and II. Other than wing location, there are several basic differences between the two airplanes: (1) the longitudinal control system for the low-wing airplane used a stabilator, whereas the high-wing airplane used a conventional fixed horizontal stabilizer and elevator; (2) the low-wing airplane was equipped with rudder trim and the high-wing one was not; and (3) the low-wing airplane had manually operated flaps with four discrete settings (0°, 10°, 25°, and 40°), whereas the high-airplane had electrically operated flaps with infinite settings between 0° and 40°.

The airplanes were instrumented to measure and record 21 different flight parameters including airspeed, pitch attitude, flap position, and altitude. The instrumentation system consisted of sensors located throughout the airplane, a signal conditioning package, and a central tape recorder. In the low-wing airplane, the instrumentation package was located in the baggage compartment; in the high-wing airplane, the package was located in the rear passenger compartment. The only modification to the instrument panel was the installation of control switches for the recording system; these switches were centrally located in the panel. The only obvious change in the external appearance of the airplanes was the test boom protruding from the left wing tip. This boom was approximately 75 percent of the wing chord in length and was installed to measure airspeed, angle of attack, and angle of sideslip. A weight was added inside the right wing tip to counterbalance the weight of the test boom. The complete airborne data system increased the basic weight of the test airplane approximately 86.2 kg (190 lb).

The flight characteristics of both airplanes were investigated by NASA research pilots before and after the modifications for instrumentation. The qualitative results of these tests indicated that the installation of the instrument systems had negligible effects on the handling characteristics of both airplanes. Airspeed calibrations were conducted to correlate the pilot's indicated airspeed with the recorded indicated airspeed as measured by the test boom. The airspeed calibration curves for each airplane are presented in figure 2. The recorded indicated airspeed was chosen as the common basis for comparison; therefore, unless otherwise stated, all airspeeds referred to in this report are expressed in terms of the recorded indicated airspeed. In addition, the wings-level, power-off, stall speed range of each airplane was documented for various flap settings. These tests were conducted in accordance with the procedures specified in part 23.201 of the Federal Aviation Regulations (ref. 4). The stall speeds used in the figures are the measured stall speeds of the respective airplanes at the nominal test weight, whereas the stall speeds in the tables reflect the manufacturers' specified values.

A ground-tracking system was used to obtain the flight-path data during the final stages of the approaches and the touchdown data. This system, shown in figure 3, consisted of a 16-mm motion-picture camera and a large photographic grid. The grid was located parallel to the runway and between the camera and the runway so that both the airplane and portions of the grid were photographed simultaneously during the final approach and landing. The exact location of the system was surveyed with respect to the landing end of the runway. The grid consisted of a series of vertical and horizontal plastic strips fastened at the intersections to form squares with sides 0.6 m (2 ft) in length. The total system consisted of ten 6.7-m-long (22-ft-long) sections with rigid aluminum poles between each section. The support poles were adjustable to compensate for uneven terrain and to set the desired elevation of the grid. The overall grid system was 3.05 m (10 ft) high and 67.06 m (220 ft) long.

Normal photogrammetric techniques were used to obtain the trajectory data from the film. All measurements were based on the positions of the tip of the airplane nose and the vertical tail with respect to the position of the photographic grid seen in each picture frame. These measurements were converted to the attitude of the airplane and the location of its center of gravity with respect to the runway threshold. For photographic analysis purposes, all landings were assumed to be on the center line of the runway. Errors resulting from this assumption were found to be negligible for the purpose of this study. A field survey of a typical grid installation indicated a tracking accuracy within ±0.3 m (±1 ft).

Wind direction and velocity at 3.05 m (10 ft) and at 9.14 m (30 ft) above ground level were measured and recorded for each landing. A portable weather station with wind detection equipment was located near the runway for this purpose. (See fig. 4.)

TEST SUBJECTS

A cadre of 22 pilots selected by FBO and approved by NASA performed the landings in this program. The test subjects' experience and background ranged from student pilots with 30 hours flight time to a commercial pilot with about 1000 hours flight time. A complete list of the test subjects with experience, flight time, and number of landings performed is presented in table III. All the subjects were qualified to operate the test airplane in accordance with current Federal Aviation Administration rules and regulations. Ten of the pilots flew in the low-wing airplane phase of the program and 12 flew in the high-wing phase. The original intent was for each pilot to perform landings on both the long and short runways for the phase of the program in which he was involved; however, for various reasons, this intent was not completely met, as can be noted from table III.

AIRPORTS AND RUNWAYS

The airports chosen for this program were selected primarily because they were considered representative of airports used by general aviation pilots, and secondly, because they had a clear area adjacent to the landing runway to accommodate the ground-tracking system.

The airport chosen for the long-runway landings was a large controlled field serving a metropolitan area. A photograph of this field (fig. 5) shows two, hard-surface runways (2-20 and 6-24). All landings were made on runway 2-20 which was 1524 m (5000 ft) long and 45.7 m (150 ft) wide with significant clear areas leading to the thresholds. Field elevation was 12.5 m (41 ft). The airport handled a significant amount of traffic, both civil and military. At times the traffic was heavy; this necessitated modifications of the standard traffic patterns, usually an extended downwind with a long straight-in final.

The short-runway airport was a small uncontrolled field serving a rural area. The photograph of the field (fig. 6) shows a single, hard-surface runway (18-36). All landings were made on runway 18 which was 762 m (2500 ft) long and 15.2 m (50 ft) wide with an elevation of 9.1 m (30 ft). The approach to the runway was over water with a tree line approximately 402 m (1/4 mile) from the threshold. The area between the tree line and the threshold was an open field under cultivation. The airport had very light traffic; consequently, the test subjects could fly the pattern without interference.

TEST PROCEDURES

All the pilots were briefed on the purpose of the study and the operation of the equipment prior to participating in the program. They were asked to make normal landings based on their training and experience. They were also asked to turn the airborne data system on just prior to or just after turning onto the final approach; however, the operation of the airplane and the piloting techniques were left completely to the discretion of the individual pilot. Each pilot was scheduled to make a maximum of six landings in any one day without prior practice on that day. This situation was imposed to minimize practice effects and to obtain data for each pilot under different wind conditions. If for some reason the pilot failed to turn the airborne data system on during some of the landings, the maximum was extended to cover six data landings. In order to help alleviate traffic congestion on the long runway, touch-and-go landings with a significant ground roll were permitted. These landings were permitted on the assumption that this procedure would not significantly affect the normal landing performances. All the landings on the short runway were completed to a full stop.

RESULTS AND DISCUSSION

The results of this landing performance study cover a total of 616 landings made in both airplanes at both runways. A total of 299 landings were made in the low-wing airplane (144 on the long runway and 155 on the short runway) and 317 landings were made in the high-wing airplane (163 on the long runway and 154 on the short runway).

Flight Conditions

All landings were made essentially at sea level with an ambient temperature range from 21° C to 32° C (70° F to 90° F). The wind conditions for each landing are presented in figure 7. The data were recorded at the time of each landing relative to the active runway as measured at 3.05 m (10 ft) above ground level. These data are presented to show that the landings were made with a wide range of wind conditions, including variable winds that resulted in some landings being made with a tail-wind component. The short-runway airport was located a considerable distance from the normal base of operations; consequently, it was more difficult to conduct tests there under favorable wind conditions than it was at the long runway which was the normal base of operations. As a result, more landings with a tail-wind component were made at the short runway than at the long runway. The pilots were informed of the wind conditions at the time, and tests were continued only when the pilots judged that the tail winds did not adversely affect their landing performance.

Traffic Patterns

All the pilots were familiar with the airport used for the long-runway landings since it was their normal base of operation. The approaches were all "left-hand" traffic patterns and entry was nominally 244 m (800 ft) above ground level. Generally, the patterns could be characterized as being standard (ref. 5). However, as mentioned previously, the airport handled a significant amount of traffic which occasionally necessitated modifying the traffic pattern to provide spacing between airplanes. These pattern modifications occurred only about 10 percent of the time.

Most of the pilots were unfamiliar with the airport used for the short-runway landings. The airport was uncontrolled, with an insufficient volume of traffic to affect the landing patterns to any significant degree. Most of the pilots stated that they based their landing pattern geometry on experience in judging distance from the runway without specific reference to ground features. The traffic patterns were all left hand and entered at the standard 244-m (800-ft) altitude. It was noted that the tree line approximately 402 m (1/4 mile) from the threshold usually provided enough turbulence to slightly upset the airplanes on final approach. However, some of the approaches were made inside the tree line and were not subjected to the upset.

Trajectories

Profiles of the approach trajectories measured with the ground-tracking system for all landings of both airplanes at both runways are presented in figure 8. These profiles were obtained from the airplane position data taken in increments of about 67 m (220 ft) along the ground track of the final approach and touchdown. The long-runway data were initiated approximately 305 m (1000 ft) before the runway threshold for both airplanes. The short-runway data for the low-wing airplane were limited to about 61 m (200 ft) before the threshold because of a limited field of view created by a group of trees. However, for the short-runway landings with the high-wing airplane, the ground-tracking system was relocated; thereby, a field of view out to approximately 198 m (650 ft) before the threshold was provided. Shown in figure 8 are the median and the 5- to 95-percentile spread of the data for the height of the airplane at the threshold and for the touchdown distance of the airplane from the threshold. Also included in the figure are 3° and 6° slopes passing through the median height at the threshold; these slopes are included to show the normal range of glide-path angles, as suggested in reference 6.

Generally, the profiles show considerable variation from straight or uniformly curved trajectories denoting considerable jockeying on the part of most pilots during the final approaches. However, certain individual pilots did have uniformly curved trajectories that were relatively consistent. The average flight-path angles used by the pilots in this study were 4.7° on the long runway and 5.9° on the short runway for the low-wing airplane, and 5.1° on the long runway and 6.1° on the short runway for the high-wing airplane. The individual flight paths, however, covered a wide range of values from as low as 1° to as high as 14° during portions of the approaches. The average flight-path angles were about 1° steeper at the short runway than those at the long runway. This is probably a direct result of the increased flap deflection at the short runway.

The median height at the threshold was lower for the low-wing airplane than for the high-wing airplane on both runways. With respect to the runways, both airplanes were brought in lower over the threshold at the short runway than at the long runway.

The median touchdown position was closer to the threshold for the low-wing airplane than for the high-wing airplane on both runways. These touchdown distances from the threshold were in direct relation to the median heights of the respective airplanes at the threshold. The short-runway landings were made closer to the threshold than the long-runway landings. The median touchdown distances for both airplanes on both runways were within the first third of the runway, but well beyond the runway designation numbers just past the threshold, as is recommended in reference 5. These touchdown distances from the threshold were less than 13 percent of the runway length on the long runway and less than 16 percent on the short runway for both airplanes.

Final Approach Airspeed

The average final approach airspeeds and the average flap deflections measured at 5-sec intervals for the 60-sec period prior to touchdown, which includes flare and touchdown, are presented in figure 9. Also included in the figures are reference approach speeds, which are interpolated values of the manufacturers' recommended approach speeds using the average flap deployment at each time period, and the measured stall speeds of the respective airplanes at the nominal test weight. These reference speeds were calculated as a means of interpreting the approach speed recommendation and because the manufacturers' published values were not directly applicable to the actual flight conditions. The mean final approach airspeed and the standard deviation are presented in table IV.

The data show that, for the most part, the pilots flew the final approaches with an average speed considerably faster than the reference speeds. The exception to this is for the low-wing airplane on the short runway during the final 40 sec prior to touchdown. Reference 7, an FAA flight test guide for a private pilot applicant, specifies that the final approach speed should be "equal to 1.3 times the stalling speed in landing configuration ($1.3V_{so}$) or the final approach speed prescribed by the manufacturer." The acceptable level of performance is expected to be within ±5 knots of the proper final approach speed. If the manufacturers' recommended approach speeds were selected, the reference approach speeds presented in the figure show the appropriate final approach speeds to be used by the pilots. The solid symbols in figure 9 indicate the time periods at which the average speeds exceeded the tolerance band based on the reference values. These symbols indicate that, in general, the average approach speeds used by the pilots in this study were faster than the ±5-knot tolerance until within 15 sec or less of touchdown. The exception to this result is for the low-wing airplane on the short runway in which case the average speed fell within this tolerance approximately 45 sec prior to touchdown.

The data also show that the pilots generally flew the final approaches with a continuing reduction in airspeed rather than holding a constant speed as is recommended in reference 5. However, reference 8 recommends a "gradual reduction in power setting and airspeed during the final approach in preparation for the round-out or flare for landing."

Another point of interest shown by the data is that the final approach speeds on the short runway were slower than those on the long runway for both airplanes. This correlates directly with the larger average flap deflection used at the short runway. The reduction in average approach speed (6 to 12 knots), however, was much greater than the difference in the reference approach speeds (1 to 2 knots). This difference tends to indicate that the pilots were more concerned about the length of the runway and were paying much closer attention to the airspeed during the approach to the short runway to assure landings with comfortable margins between the stopping point and the end of the runway.

Touchdown Airspeed

The cumulative distributions of airspeed at touchdown are presented in figure 10. Included in the figure are the measured stall speeds of the respective airplanes at the nominal test weight and the reference approach speeds based on the flap settings for the last 10 sec of the approaches.

Reference 8 states that the touchdown speed should be at approximately stalling speed. The data generally show, however, that the pilots landed the airplanes with speeds considerably in excess of the stall airspeed; this is most probably a direct result of the excessive airspeed used during the final approach. The median touchdown speeds ranged from 13 percent to 48 percent above the measured flaps-up stall speed of the respective airplanes, and less than 6 percent of the landings for both airplanes at both runways were within the stall speed ranges of the airplane. Except for the low-wing airplane at the short runway, a rather high percentage of the landings were made at speeds in excess of the reference approach speeds.

The data also show that the touchdown speeds at the short runway were significantly less than those at the long runway for both airplanes. The difference in touchdown speeds between runways was approximately the same as the difference in the final approach speeds of the respective airplanes. Again, this could be indicative of the pilots' general concern for the runway length, although it is evident from the specified landing distances given in tables I and II that the available runway was more than adequate. The designated short runway used in this study was not, in fact, a "short runway" requiring maximum performance from either airplane or pilot to achieve a normal landing in the available distance.

Touchdown Pitch Attitude

The cumulative distributions of pitch attitude at touchdown are presented in figure 11. Also included in the figure is a line which indicates the in-flight three-point touchdown attitude of the respective airplanes and which separates the regions of nose-wheel and main-wheel landing attitudes. In general, the touchdown pitch attitudes show little to no difference with respect to runways, particularly for the high-wing airplane. Normally, one might expect the pitch attitudes at the short runway to be more nose-high than at the long runway since the touchdown speeds were slower. However, the flap deflection was greater for the short runway than for the long runway which would shift the pitch attitude and airspeed relationship to a slower airspeed for the same pitch attitude.

The data generally show that the pitch attitudes at touchdown were relatively flat for both airplanes at both runways. The median touchdown attitude ranged from only 1.4° to 2.6° above the three-point attitude (pitch-up). A significant percentage of the landings was made in which the nose wheel contacted the runway before the main wheels. Approximately 12 percent of the landings were nose wheel first, except for the low-wing airplane at the short runway where the percentage was 22 percent.

Nose-wheel landings are almost invariably a direct result of allowing an airplane to touch down with an excessively high airspeed. This situation can produce unstable airplane motions, referred to as porpoising or wheel-barrowing, which can lead to structural damage of the nose gear. During this study, porpoising was noted during some of the landings, but fortunately the pilots were able to cope with the situation and prevent any catastrophic results.

References 7 and 8 state that in nose-wheel type airplanes, the touchdown should be made on the main wheels with little to no weight on the nose wheel. Reference 8 also states that the touchdown speed should be at approximately stalling speed. For the airplanes used in this study, the pitch attitude for touchdown at approximately stalling speed would be sufficiently high that the nose wheel would be well clear of the runway. If the pilots in this study were landing the airplanes in a pitch attitude which would permit some weight on the nose wheel, as stated above, it is apparent that the touchdown speeds would be considerably higher than the stalling speed.

Analysis of Individual Approaches and Landings

Two individual approaches and landings were selected to exemplify some desirable and undesirable piloting practices. These approaches and landings were made by two different pilots on the long runway with the high-wing airplane. The final approach trajectories are presented in figure 12. Included in the figure are the mean and the 5- to 95-percentile spread of the data for the altitude or horizontal position of the airplane at entry into the ground-tracking grid and the altitude of the airplane at the threshold for all the landings performed by each pilot. A mean approach is presented by a line drawn between the two respective mean data points for each pilot. This information is included to give a perspective of the individual approaches with respect to that pilot's general performance. The final approach airspeed and flap position for each of the selected landings are presented in figure 13. Included in the figure are the reference approach speeds and the measured stall speed range of the airplane.

Approach A.- Approach A (fig. 12) had a flight path that was essentially the same as the mean approach for that pilot. The approach was a straight, uniform glide with a flight-path angle of approximately 3.5°. The pilot began the flare near the threshold at an altitude of approximately 2.1 m (7 ft) and touched down about 50.3 m (165 ft) from the threshold. At touchdown, the airspeed was approximately 10 knots above the stall speed, and the pitch attitude, not shown, was 5.9° above the three-point attitude. The wind during this approach and landing was approximately a 30° left cross wind of 7 knots.

This approach and landing show a well-planned and well-executed approach. The final approach speed (fig. 13), although higher than the reference approach speed, was smooth and relatively constant between the transitions associated with flap deflection and flare. The approach leading to the flare was a stabilized, steady flight path during which the pilot was reducing his airspeed in preparation for the flare and landing. There were no necessary last-minute corrections to distract the pilot from the business of flaring and landing the airplane. The touchdown was made with a pitch attitude well above the three-point attitude at a relatively slow airspeed. In general, this approach and landing was considered to be good.

Approach B.- Approach B (fig. 12) had a flight-path angle of approximately 7°, which was about 1° steeper than the mean slope for that pilot. The approach was considerably higher than the mean approach with an altitude of 20.4 m (67 ft) at the threshold. The pilot altered his flight path several times during the approach.

Touchdown occurred approximately 300.2 m (985 ft) from the threshold in a flat pitch attitude, about 0.5° above the three-point attitude, with a high sink rate followed by three bounces that bordered on porpoising. The first bounce is shown in the trajectory trace just before the airplane left the ground-tracking grid. The final approach speed (fig. 13) was well above the reference speed and varied through several oscillations. The touchdown speed was considerably above the stall speed of the airplane and only 4 knots slower than the reference approach speed. The wind during this approach and landing was approximately an 80° left cross wind of 7 knots.

This approach shows several discrepancies resulting from apparent poor planning and poor execution. The approach was high and steep with an excessively high airspeed. The pilot did not appear to have the airspeed under control. The increase in flap deflection about 40 sec before touchdown initiated a transient condition that appeared to leave the pilot "behind the airplane." The high sink rate associated with the fast, steep approach apparently left the pilot undecided as to when to flare the airplane. The rate of descent was not successfully arrested prior to touchdown and the airspeed at touchdown was so fast that the nose wheel almost contacted the runway first. This series of events caused the airplane to bounce down the runway. Although this approach and landing culminated without damage to the airplane, there was certainly much room for improvement in the pilot's landing performance.

Qualitative Evaluation of Landings

The quantitative data obtained from the ground-tracking and flight-instrumentation systems have provided considerable detail about the approaches and landings made by the pilots during this study. However, some qualitative evaluations were desired to provide better insight as to the general quality of the landings.

For these evaluations, the ground-tracking motion pictures were reviewed by an NASA research pilot who holds a certified flight instructor's rating and by one of the project engineers who is a former military aviator. In preparing their evaluations, the reviewers screened many landings and documented discrepancies to look for during the evaluations. A list of the primary discrepancies with an explanation of each is given in table V. Other discrepancies such as slow and porpoising were noted less than 2 percent of the time and have not been included.

The results of the qualitative evaluations given in terms of the percentage of landings in which each of the discrepancies was noted by each reviewer were averaged and are presented in figure 14. The short-runway landings with the low-wing airplane were not evaluated since the limited field of view did not afford the reviewers sufficient time to evaluate the approaches to the landings.

The qualitative evaluations show that the majority of the approaches was fast, regardless of the airplane or the runway. This was followed by considerable floating during the flare and by touchdowns that were relatively flat or nose-low. These results are in direct agreement with the analysis of the quantitative data.

The floating, nose-low touchdown tendencies were most probably a direct result of the fast approaches. Although not specifically shown by the data in figure 14, 30 to 40 percent of the fast approaches were also high, steep approaches. The flare discrepancies may very well have also been associated with the fast approaches but were more probably associated with both the deviations from a stabilized, steady flight path and the high, steep approaches. Quite obviously, flight-path deviations during the last portion of an approach prior to the flare will distract the pilot and will impair his judgment as to when to flare the airplane. High, steep approaches with high rates of descent are also difficult to flare with consistency since a considerable flare is required to arrest the rate of descent.

General Comments

The reviewers who evaluated the landings from the ground-tracking films made certain points about the observed piloting practices. These views are expressed in the following comments:

(1) Although several pilots consistently achieved "good" landings, there were numerous deficiencies noted in a major portion of the approaches and landings made by the other pilots. The deficiencies appear to be primarily associated with piloting techniques rather than with the airplanes; the category of the pilots did not seem to have any bearing on performance.

(2) The normal operating environment may have had a definite bearing on pilot performance. The pilots normally operated out of the large metropolitan airport with the long runway used during these tests. At such an airport, with long, wide runways and obstruction-free approaches, there is no requirement to land at a precise point on the runway to prevent overrunning the runway as may be necessary on a short, narrow runway where the margin for error would be reduced or almost nonexistent. This situation may lead to complacency and may permit the acceptance of less than optimum performance.

(3) Failure of most of the pilots to fly the airplanes slowly is quite apparent. This may be attributed to several factors. It could be assumed that those pilots were fearful of stalling the airplanes and were overcompensating with excess speed. While excess speed may preclude the stall, it obviously introduces other undesirable characteristics such as floating, nose-low touchdowns, and bouncing tendencies. Another explanation could be that the pilots were attempting to make extremely smooth landings and thought that the excess speed would help "grease" the airplanes on the runway. It could also be assumed that the pilots were reluctant to accept the reduced airplane response characteristics associated with reduced airspeeds.

(4) Even though most of the landings observed under the conditions of this study were judged to be adequate, they were not

considered desirable. If the pilots exhibited the same piloting techniques under other operating conditions such as - moderate to heavy turbulence, gusting cross winds, less than ideal runway conditions, and higher performance - less tolerant airplanes, many of the observed landings could have resulted in unsafe situations necessitating a "go-around" or possibly resulting in a landing accident.

CONCLUDING REMARKS

The results of 616 landings made by 22 pilots in 2 modern, four-place, single-engine, light airplanes (one having a low wing and the other, a high wing) have been documented. The landings were made on both a long runway (1524 m (5000 ft)) and a short runway (762 m (2500 ft)); both runways were considered typical of runways used in general aviation. The following comments are based on the data collected during the study:

(1) The final approach trajectories showed considerable variations from stabilized, steady flight paths.

(2) The average approach speeds were generally higher than the recommended speeds for the respective airplanes.

(3) The pilots tended to fly decelerating approaches during the final approach rather than maintaining a stabilized speed.

(4) Considerable floating during the flare was noted.

(5) The average touchdown speeds were well above the measured stall speed ranges of the respective airplanes, and a large percentage of the touchdowns were made at speeds in excess of the recommended approach speeds.

(6) The touchdown pitch attitudes of the airplanes were generally flat or nose-low.

(7) Runway length appeared to influence the approach and landing techniques of the pilots of both airplanes.

(8) The landings generally were considered to be adequate and all were completed without damage to the airplanes. However,

many of the landings exhibited characteristics that reduced the margin of safety and presented the potential for an accident.

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July 14, 1976

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TABLE I.- LOW-WING AIRPLANE CHARACTERISTICS

[Airplane Owner's Manual]

Wing area, m^2 (ft^2)	14.9 (160)
Wing span, m (ft)	9.1 (30)
Length, m (ft)	7.2 (23.5)
Height, m (ft)	2.2 (7.3)
Power, kw (hp)	134.3 (180)
Empty weight, kg (lb)	591 (1303)
Gross weight, kg (lb)	1089 (2400)
Nominal test weight,[a] kg (lb)	925 (2040)
Never exceed speed, knots (mph)	149 (171)
Approach speed for -	
Flaps up, knots (mph)	74 (85)
Flaps 10°, knots (mph)	71 (82)
Flaps 25°, knots (mph)	69 (79)
Flaps 40°, knots (mph)	66 (76)
Stall speed for -	
Flaps up, gross weight, power off, knots (mph)	57 (66)
Flaps 40°, gross weight, power off, knots (mph)	50 (57)
Take-off ground run at sea level for -	
Flaps 25°, gross weight, maximum effort, m (ft)	219.5 (720)
Landing ground roll at sea level for -	
Gross weight, m (ft)	182.9 (600)
Single engine	
Four place	
Tricycle landing gear (fixed)	
Basic metal construction	
Fixed pitch propeller	

[a]Not Handbook value.

TABLE II.- HIGH-WING AIRPLANE CHARACTERISTICS

[Airplane Owner's Manual]

Wing area, m^2 (ft^2)	16.2 (174)
Wing span, m (ft)	11 (36)
Length, m (ft)	8.2 (27)
Height, m (ft)	2.7 (8.75)
Power, kw (hp)	111.9 (150)
Empty weight, kg (lb)	592 (1305)
Gross weight, kg (lb)	1043 (2300)
Nominal test weight[a], kg (lb)	894 (1970)
Never exceed speed (calibrated airspeed), knots (mph)	151 (174)
Approach speed for -	
Flaps up, knots (mph)	61 to 70 (70 to 80)
Flaps down, knots (mph)	56 to 65 (65 to 75)
Stall speed for -	
Flaps up, gross weight, power off, aft c.g., calibrated airspeed, knots (mph)	50 (57)
Flaps 40°, gross weight, power off, aft c.g., calibrated airspeed, knots (mph)	43 (49)
Take-off ground run at sea level for -	
Flaps up, gross weight, m (ft)	263.7 (865)
Landing ground roll at sea level for -	
Flaps 40°, gross weight, m (ft)	158.5 (520)
Single engine	
Four place	
Tricycle landing gear (fixed)	
Basic metal construction	
Fixed pitch propeller	

[a]Not Handbook value.

TABLE III.- TEST SUBJECTS

(a) Low-wing airplane

Pilot	Total flight hours at beginning of program	License held	Number of landings made on long runway	Number of landings made on short runway
1	115	Private	20	18
2	300	Private	18	18
3	87	Private	22	18
4	92	Private	7	---
5	55	Private	19	18
6	240	Private	27	23
7	560	Private	18	18
8	30	Student	13	---
9	100	Private	---	24
10	40	Student	---	18
		Total	144	155

(b) High-wing airplane

Pilot	Total flight hours at beginning of program	License held	Number of landings made on long runway	Number of landings made on short runway
1	30	Student	18	17
2	240	Private	18	---
3	45	Student	20	---
4	75	Private	20	---
5	330	Private	18	18
6	105	Private	19	17
7	30	Student	17	17
8	100	Private	16	17
9	900 to 1000	Commercial	17	18
10	145	Private	---	14
11	33	Student	---	18
12	100	Private	---	18
		Total	163	154

TABLE IV.- MEAN FINAL APPROACH AIRSPEED AND STANDARD DEVIATION

Time before touchdown, sec	Final approach airspeed, knots, for -							
	Low-wing airplane on -				High-wing airplane on -			
	Long runway		Short runway		Long runway		Short runway	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
60	85.3	8.4	83.6	8.9	77.0	8.0	67.8	6.6
55	84.6	7.2	81.3	9.7	77.4	7.6	68.6	6.8
50	84.8	6.6	80.3	9.3	77.8	7.6	67.8	7.2
45	83.8	6.8	77.6	11.5	77.8	8.2	66.9	7.2
40	83.0	6.2	76.4	9.7	77.4	8.2	66.7	7.4
35	81.6	5.6	75.4	9.1	77.0	8.0	67.1	7.4
30	81.6	5.8	74.6	8.2	76.4	7.6	66.9	7.2
25	81.5	5.1	74.8	7.8	75.2	7.4	66.1	7.0
20	80.3	4.9	74.1	7.0	74.5	6.6	65.9	6.8
15	79.1	4.3	72.9	6.6	73.3	6.6	65.3	6.6
10	78.9	5.3	71.9	6.0	71.1	6.8	64.0	5.8
5	74.8	5.4	68.8	5.4	67.3	6.6	60.3	6.4
0	66.3	6.2	60.5	5.6	58.7	7.8	49.6	7.0

TABLE V.- DISCREPANCIES SCORED DURING LANDINGS

Discrepancy	Explanation
Flight-path deviations	Changes in flight path and/or airspeed during approach
Fast approach	Determined primarily by pitch attitude during approach
High, steep approach	Airplane too high when entering camera field of view - flight-path angle steep
High flare	Flare occurred too high above runway
Multiple flare	More than one flare prior to touchdown
Over flare	Airplane pitch rotation during flare too much; aircraft starts to climb
Late flare	Airplane pitch rotation during flare incomplete before touchdown
No flare	No pitch rotation before touchdown
Float	Excessive distance covered after flare and before touchdown
Nose-low touchdown	Airplane pitch attitude too low at touchdown
Bounce	Landing gear clears runway after initial contact during touchdown

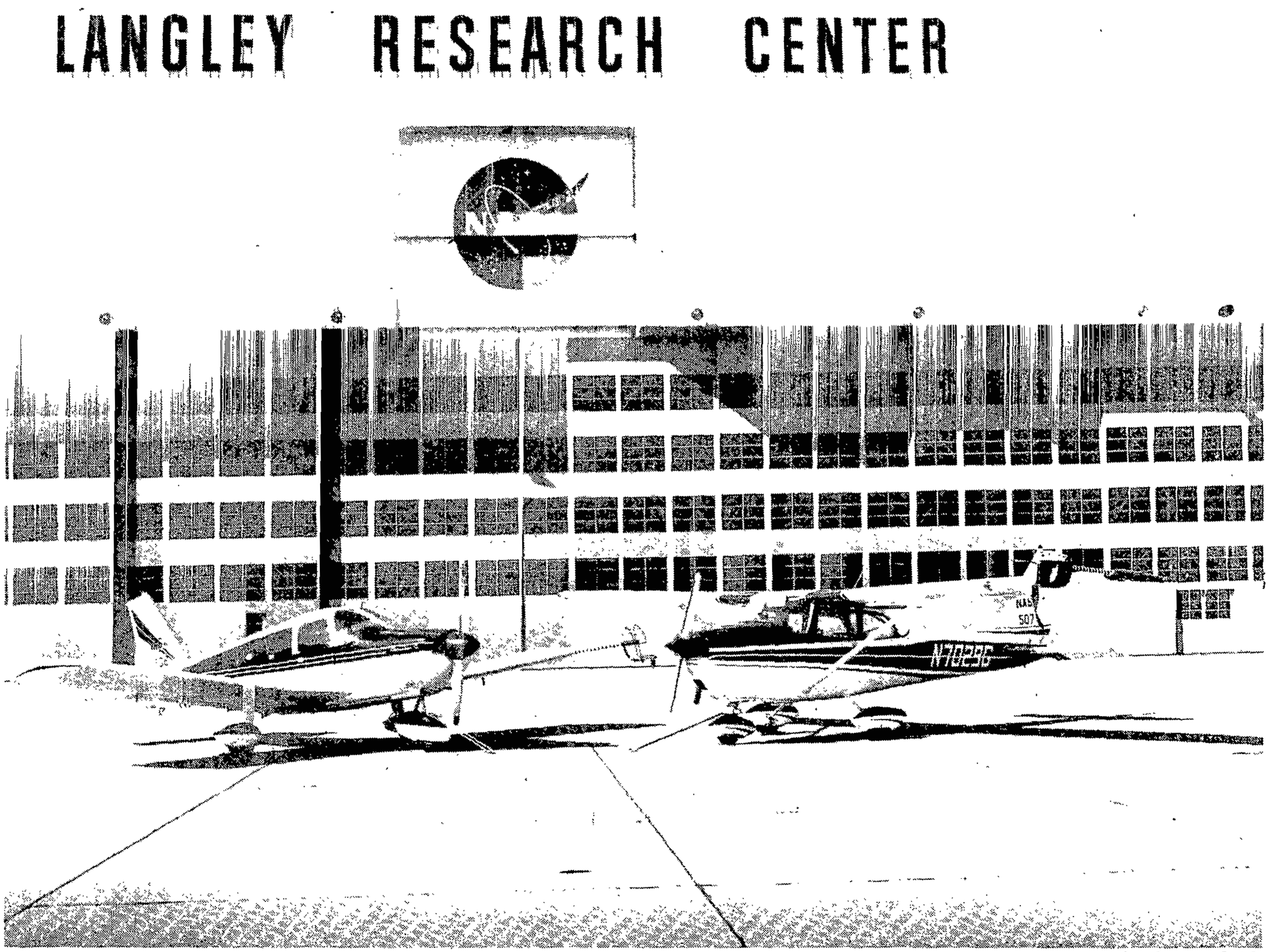

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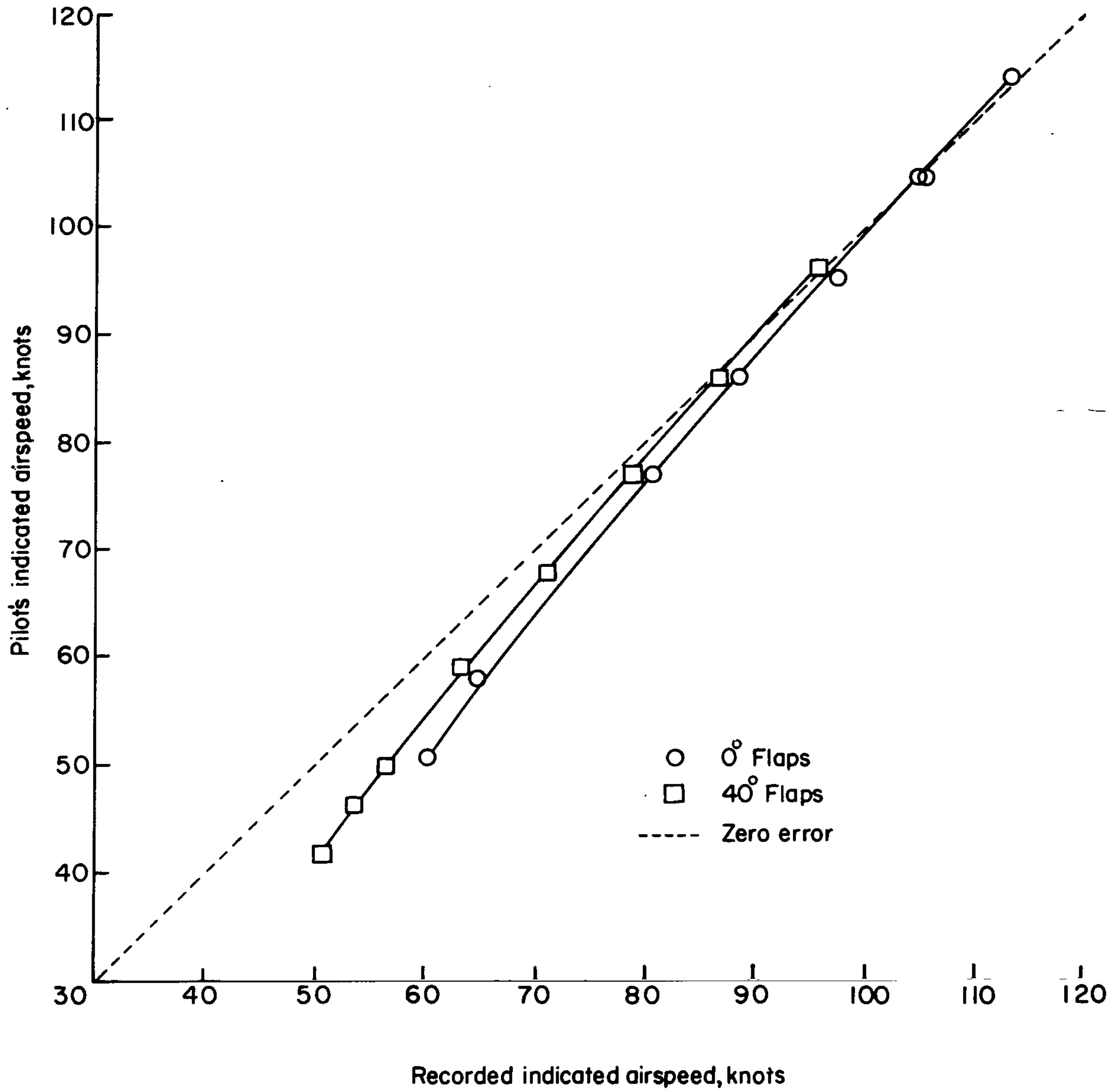
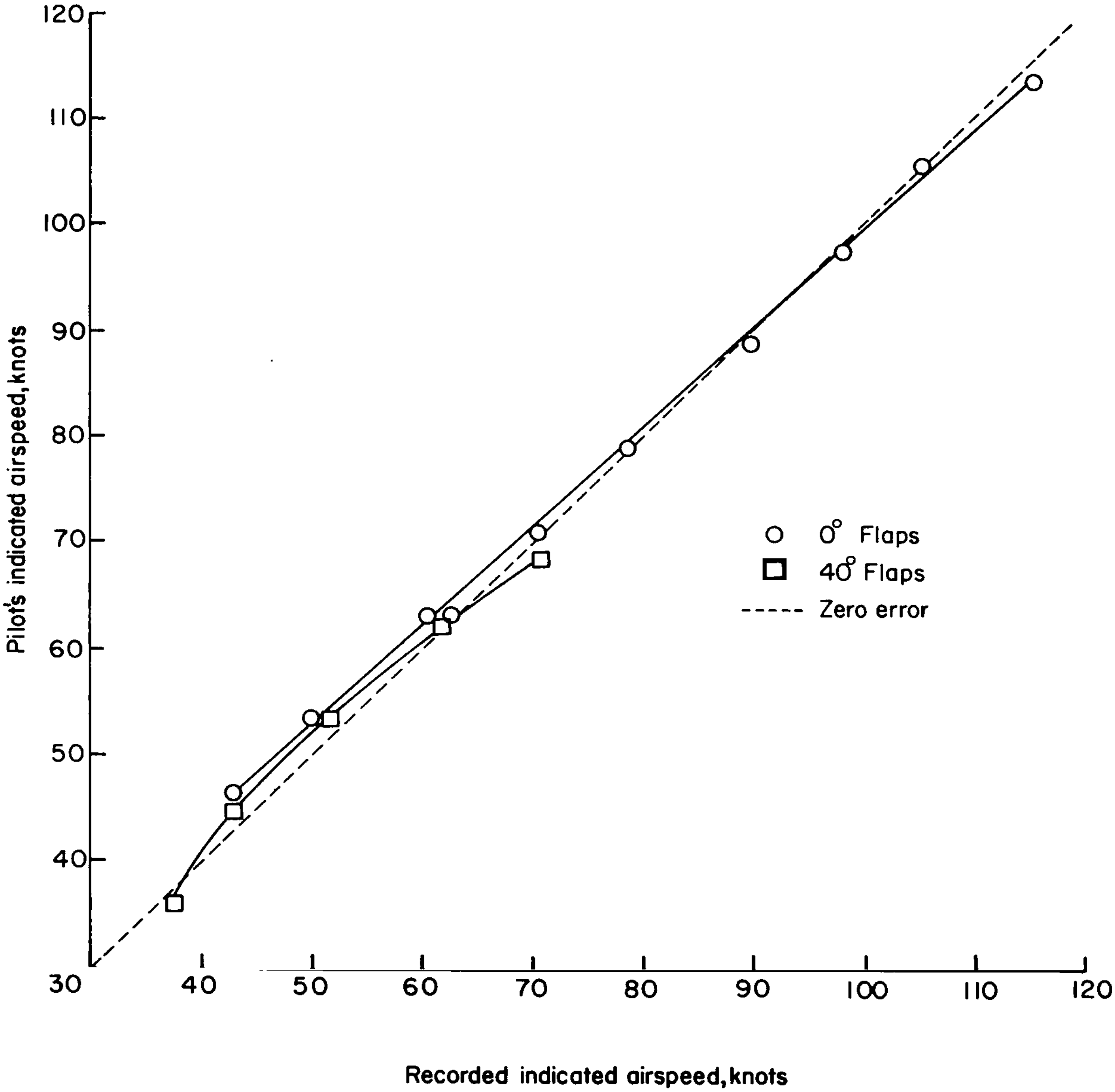
Figure 1.- Test airplanes.



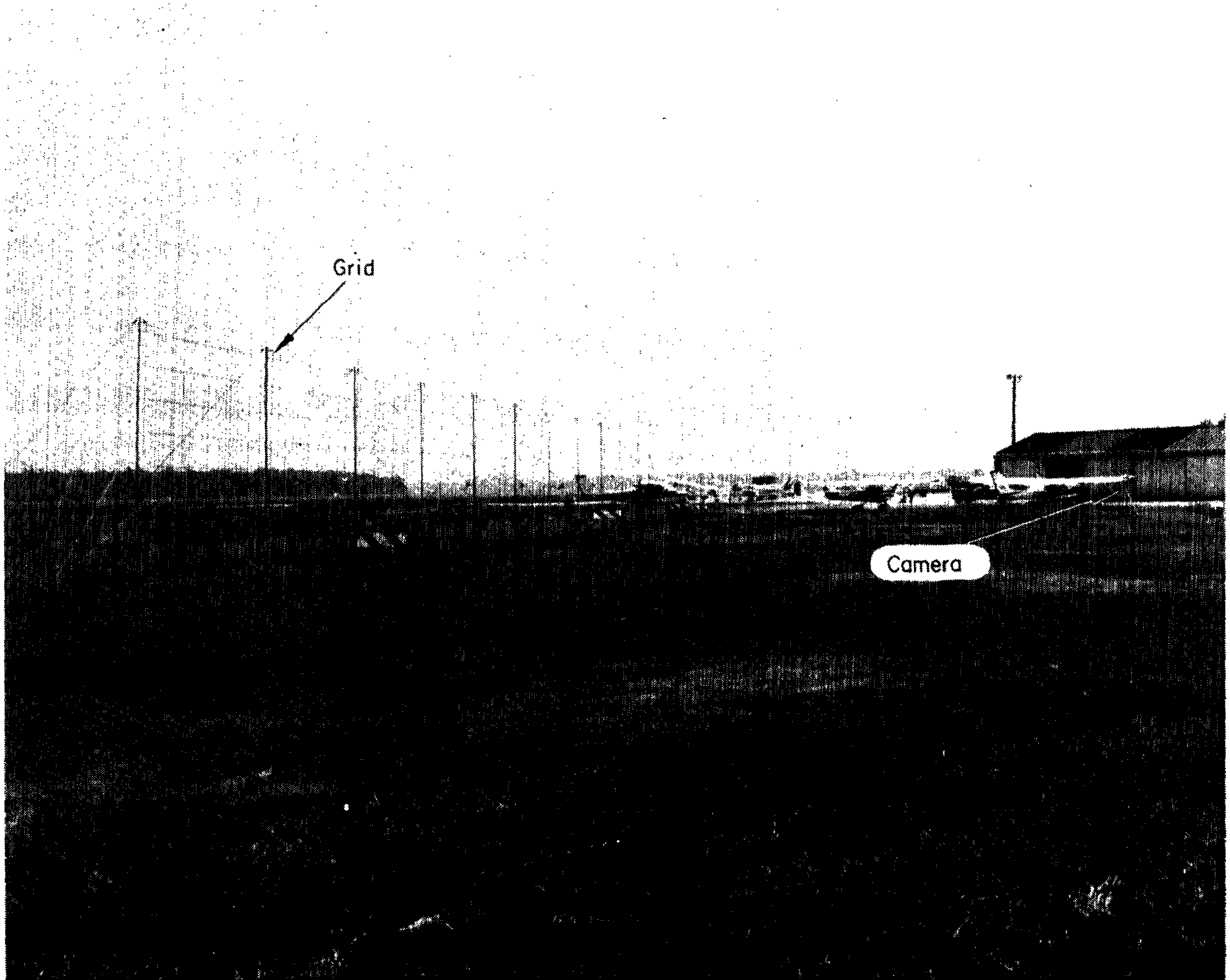
(a) Low-wing airplane.

Figure 2.- Airspeed calibration of test airplanes.



(b) High-wing airplane.

Figure 2. Concluded.



L-72-4073.1

Figure 3.- Ground-tracking system.

L-72-4069

Figure 4.- Portable weather station.

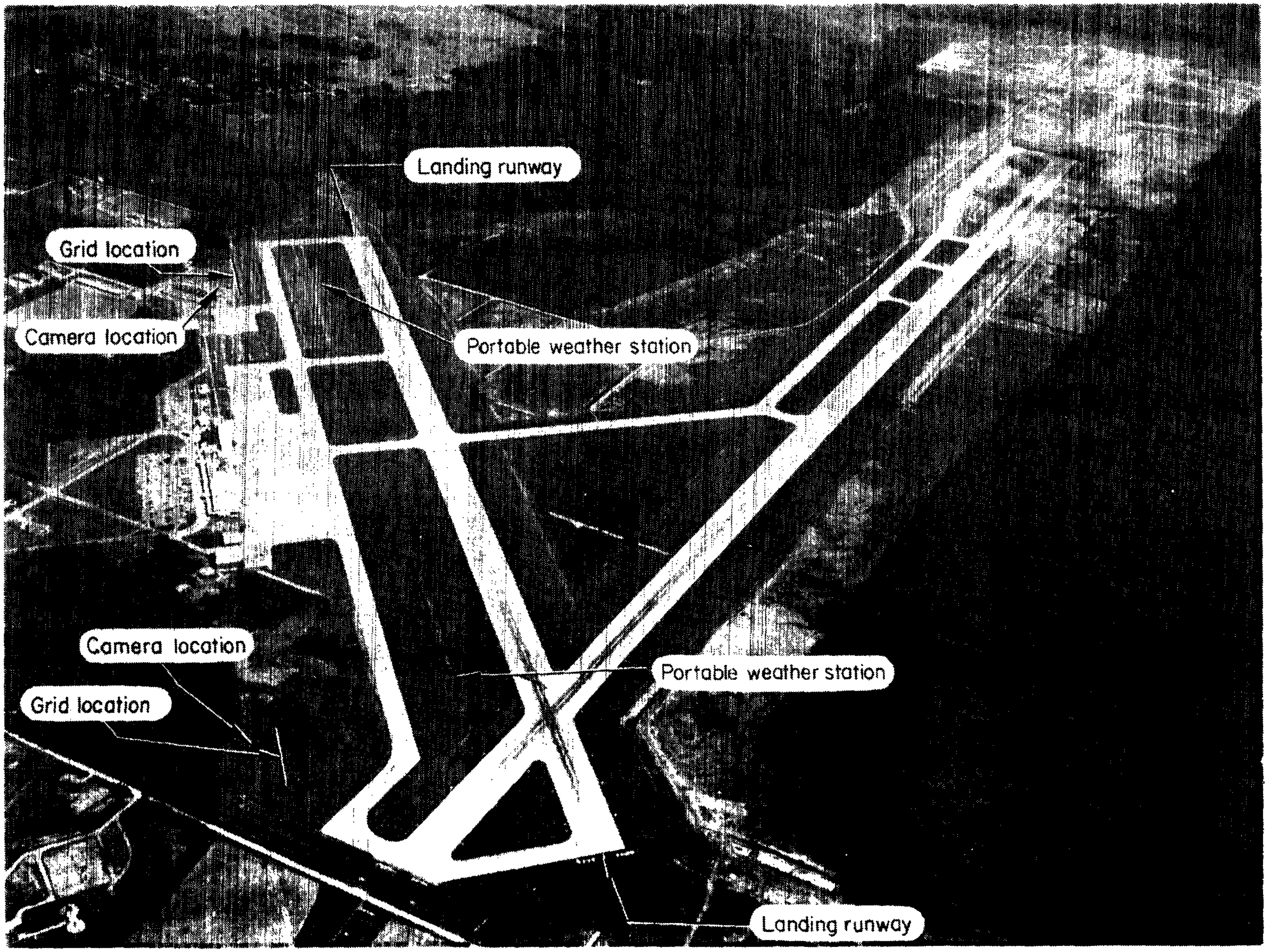


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Figure 5.- Airport with long runway.

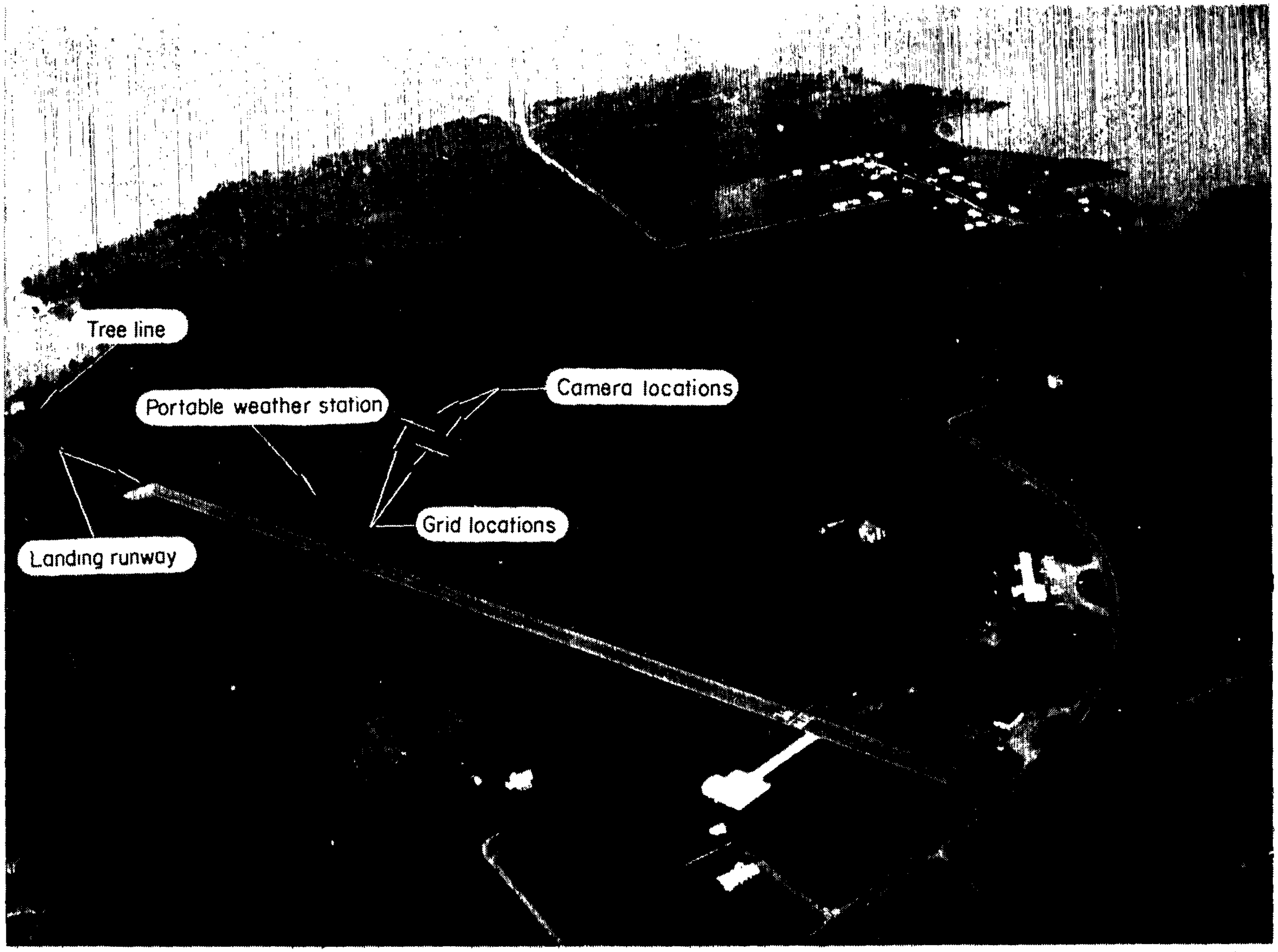

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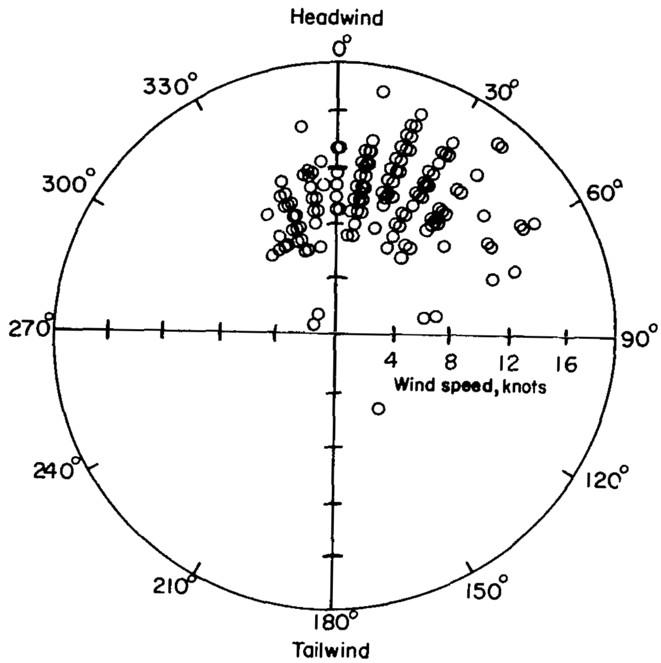
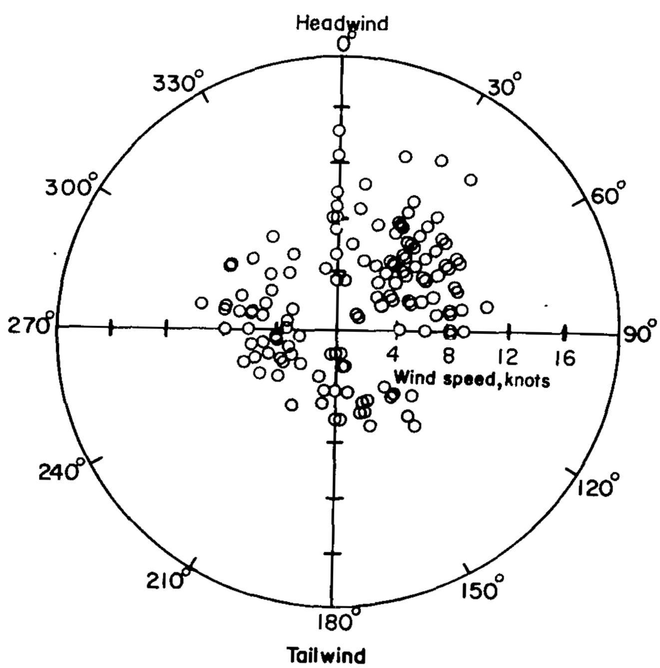
Figure 6.- Airport with short runway.

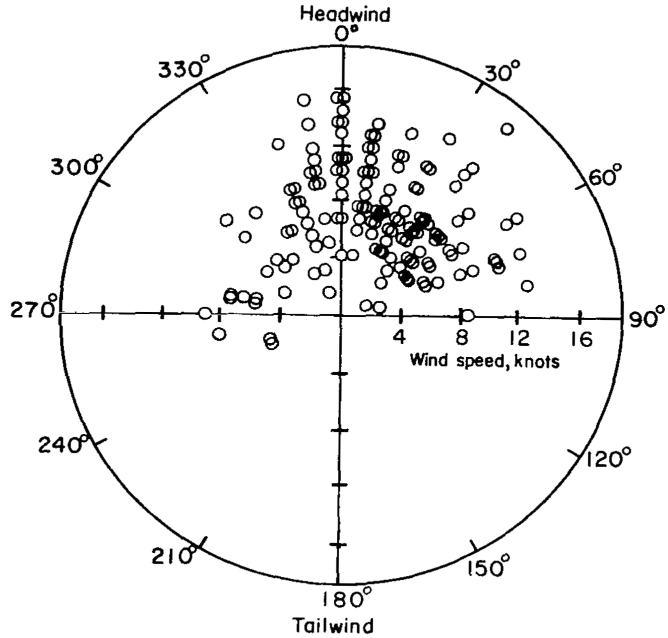


(a) Low-wing airplane on long runway.

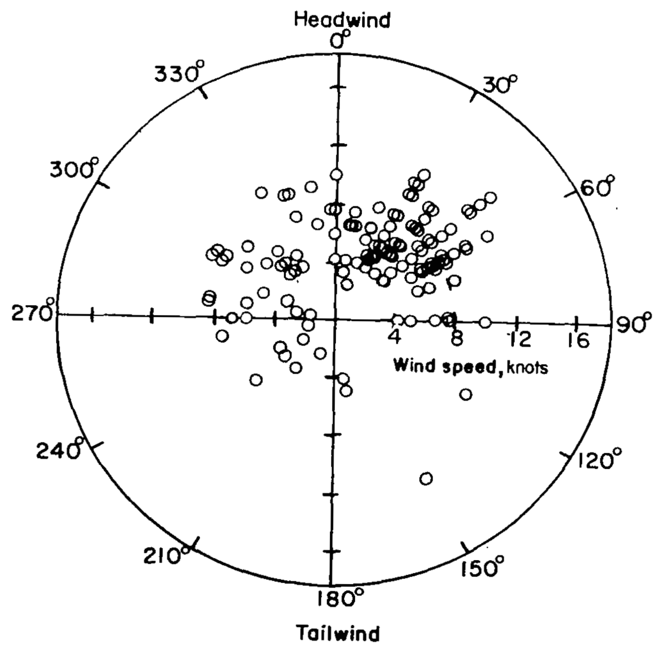


(b) Low-wing airplane on short runway.

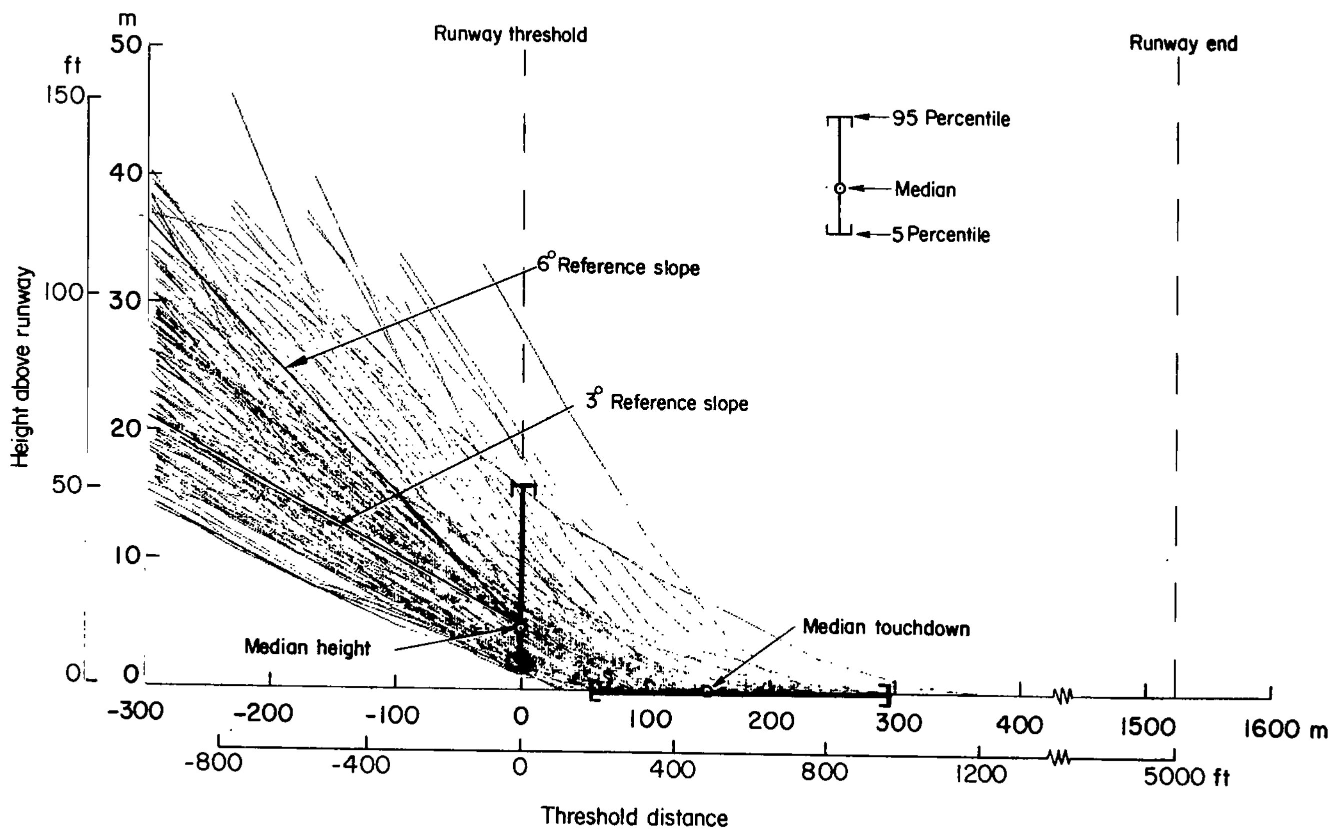
Figure 7.- Winds measured at touchdown relative to active runway.



(c) High-wing airplane on long runway.

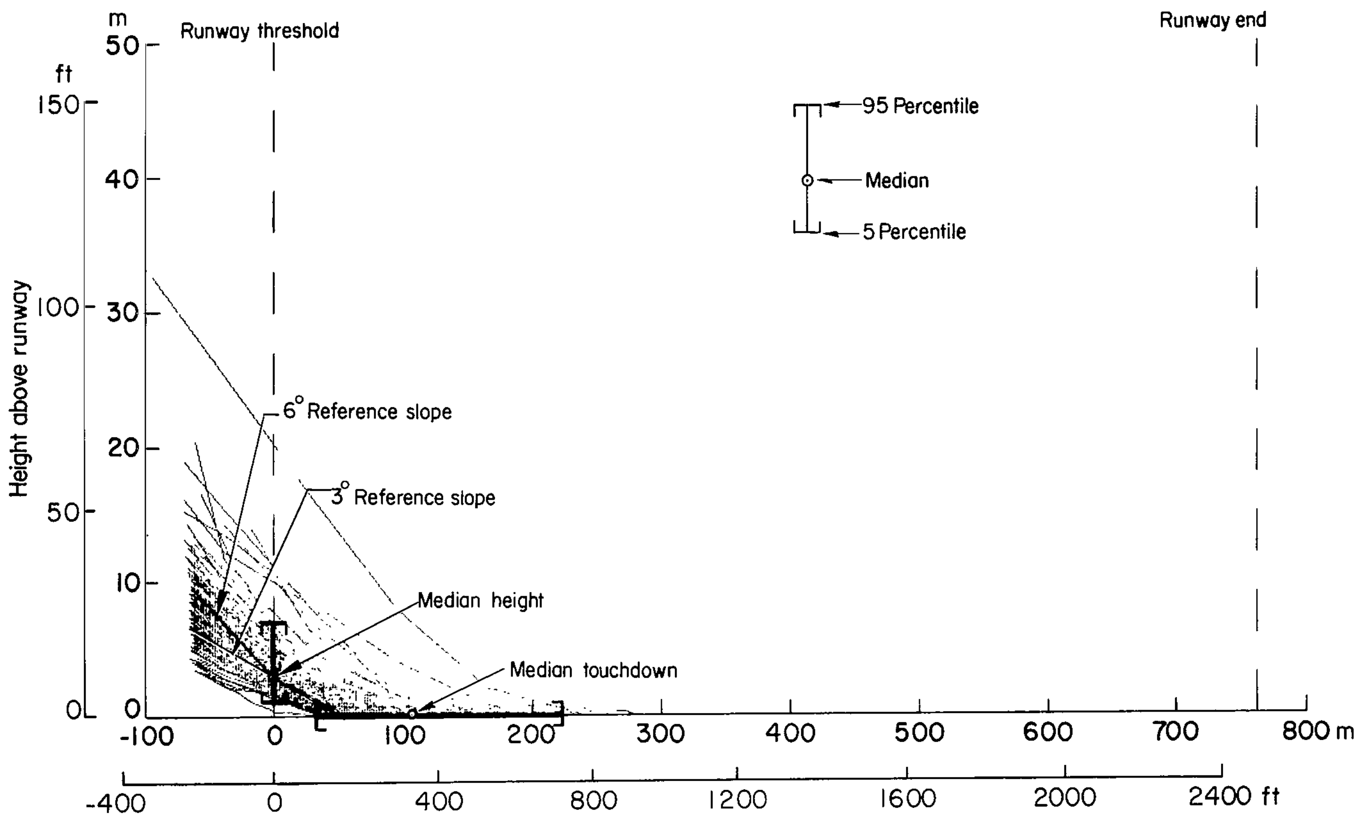


(d) High-wing airplane on short runway.
Figure 7.- Concluded.



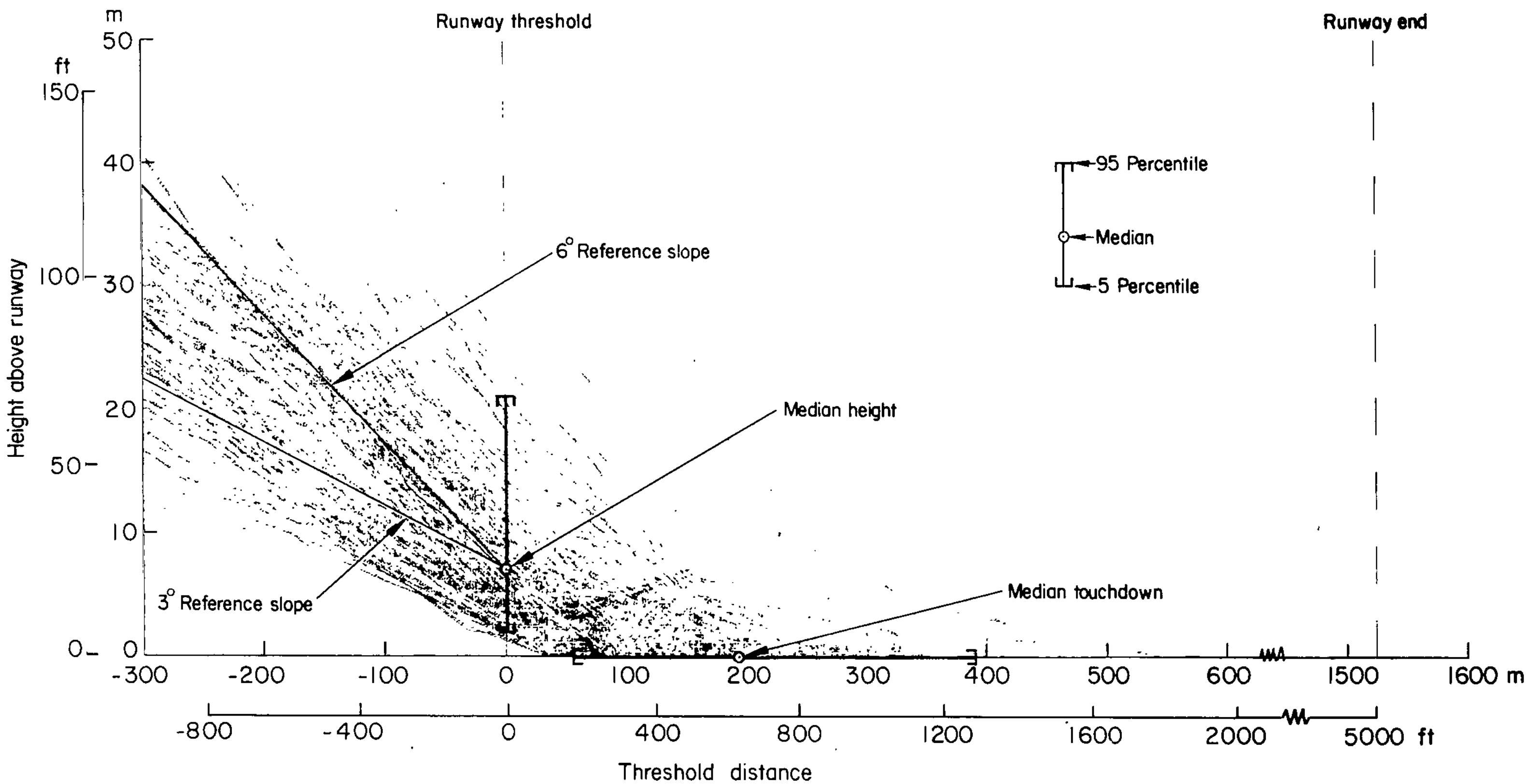
(a) Low-wing airplane on long runway.

Figure 8.- Final approach trajectories.



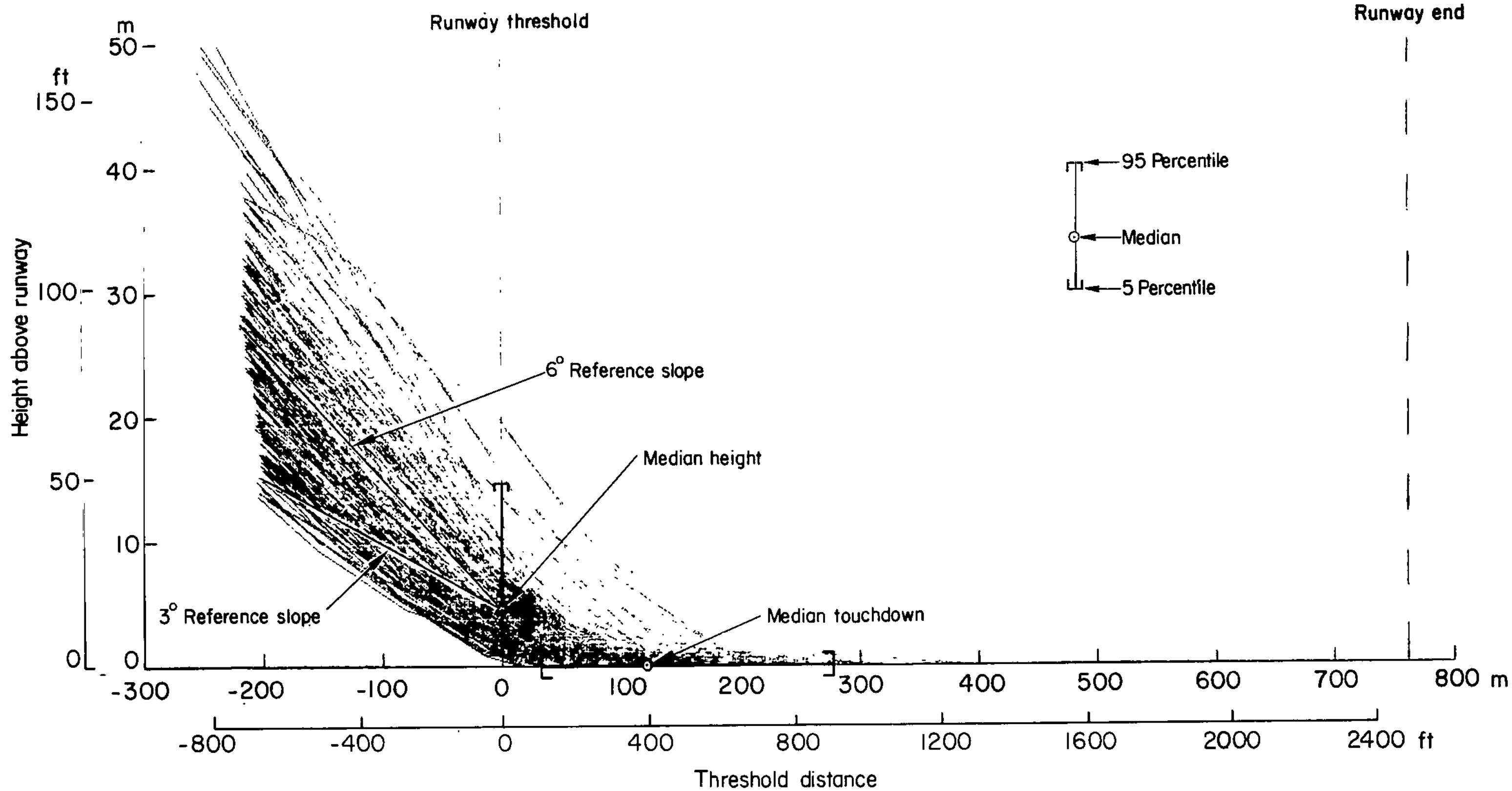
(b) Low-wing airplane on short runway.

Figure 8.- Continued.



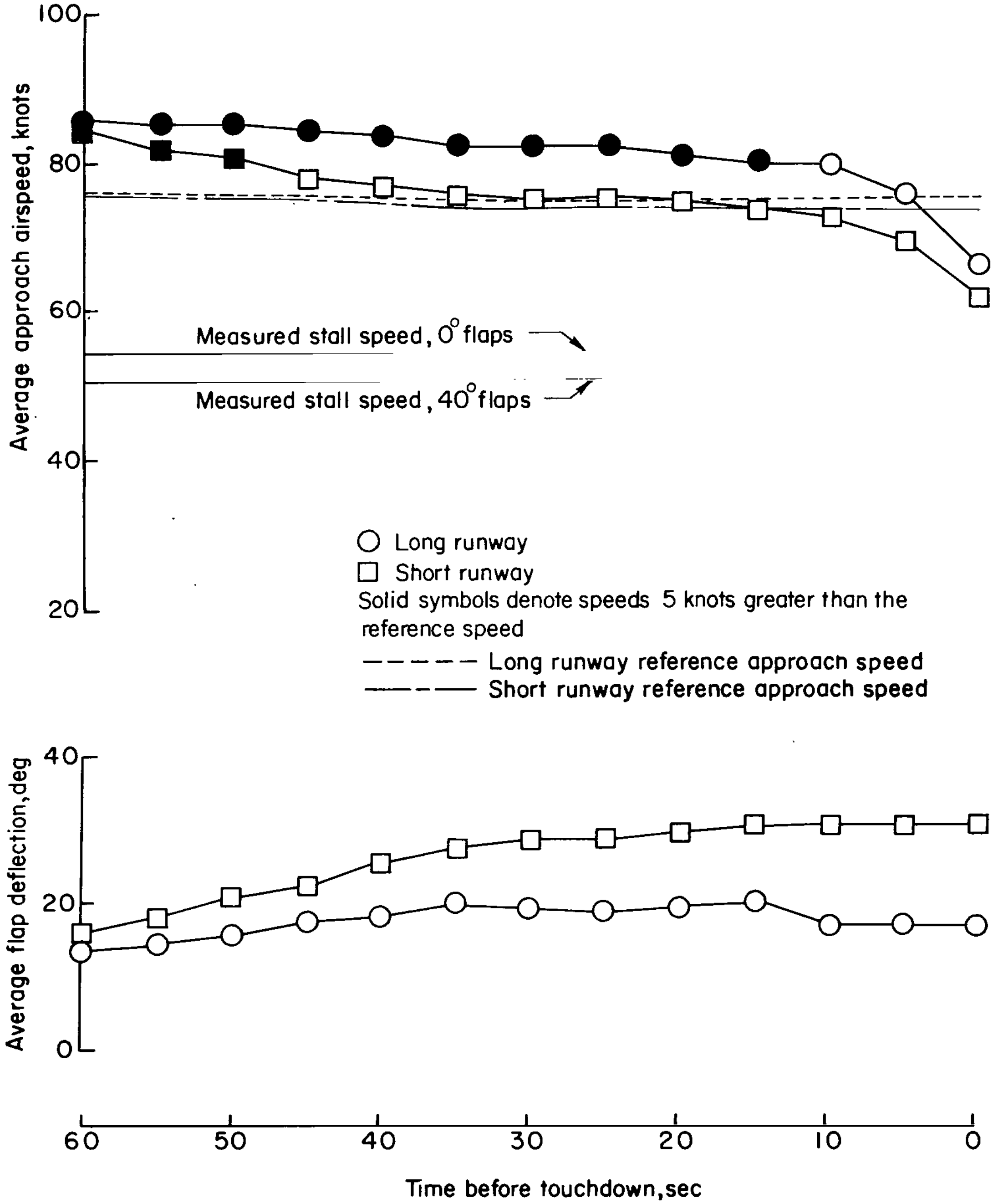
(c) High-wing airplane on long runway.

Figure 8.- Continued.



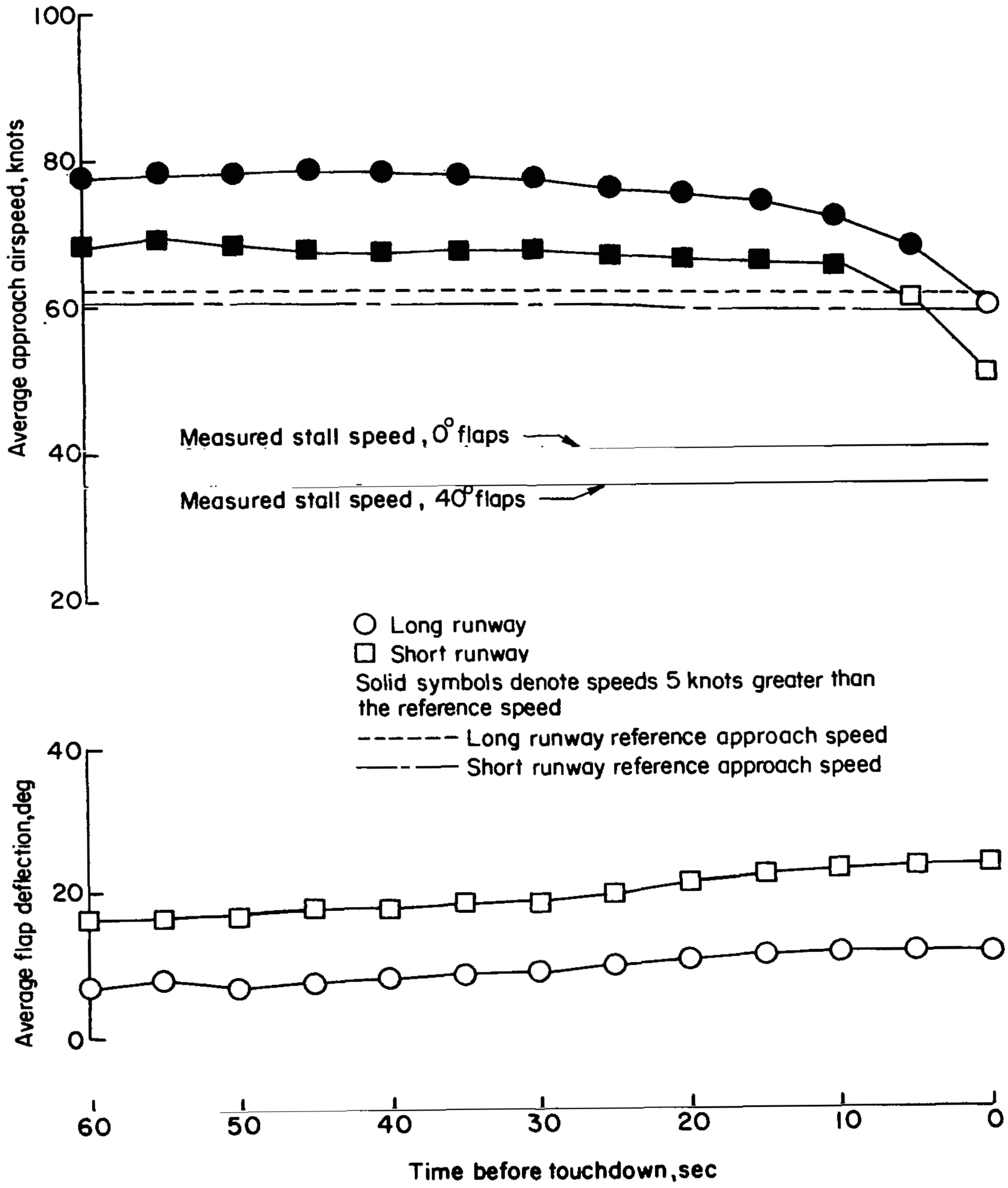
(d) High-wing airplane on short runway.

Figure 8.- Concluded.



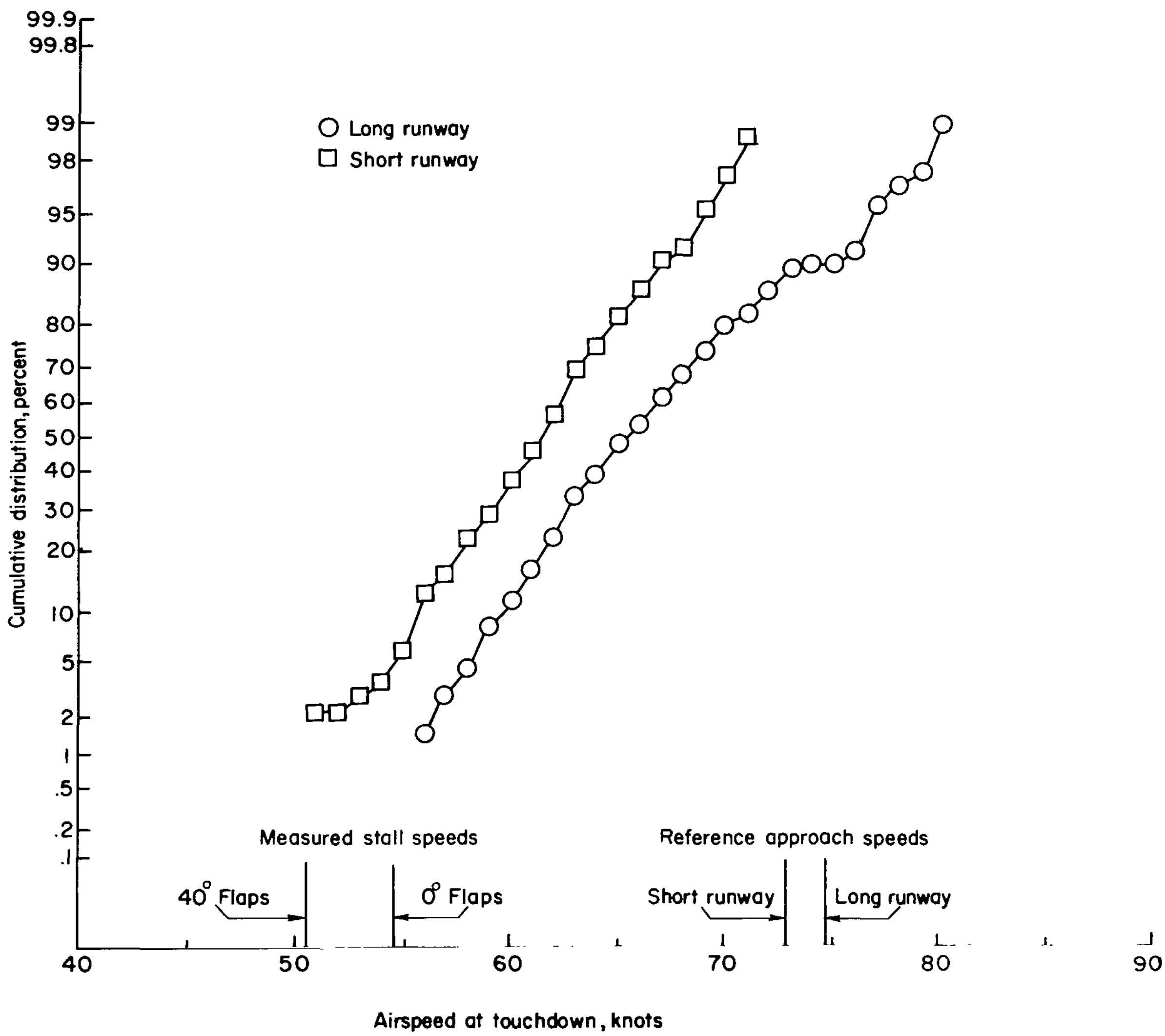
(a) Low-wing airplane on both runways.

Figure 9.- Final approach airspeed and flap deflection.



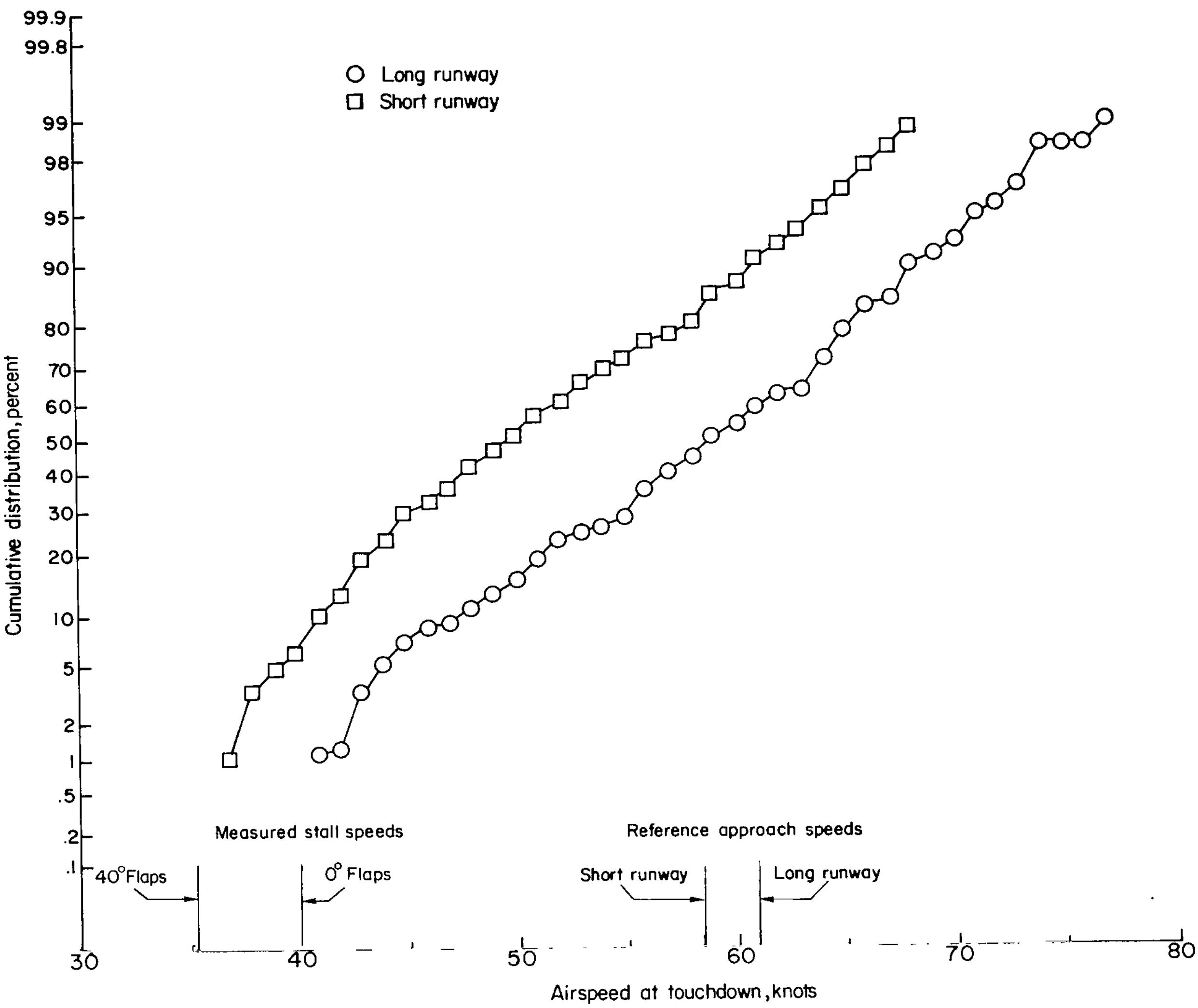
(b) High-wing airplane on both runways.

Figure 9.- Concluded.



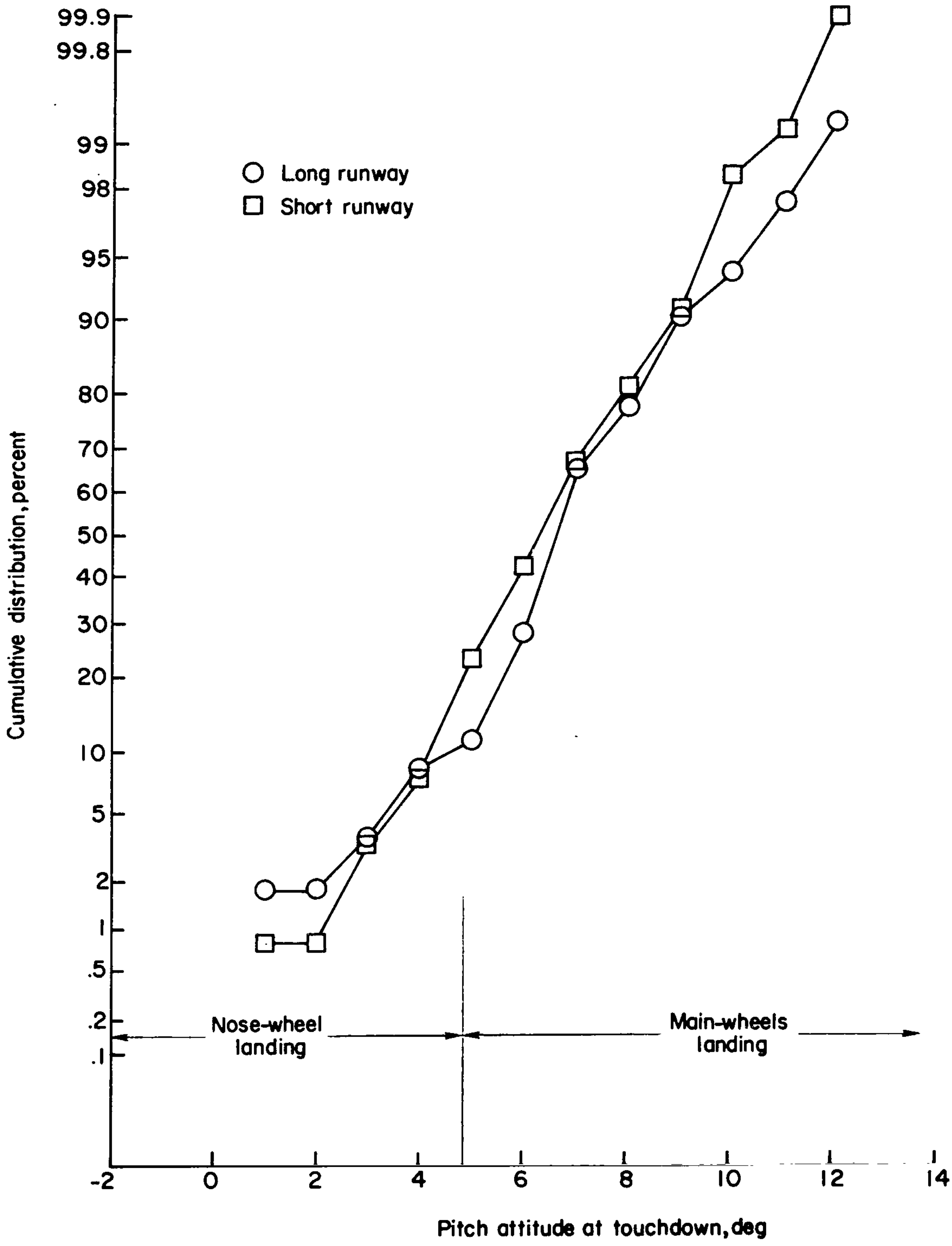
(a) Low-wing airplane on both runways.

Figure 10.- Cumulative distribution of airspeed at touchdown.



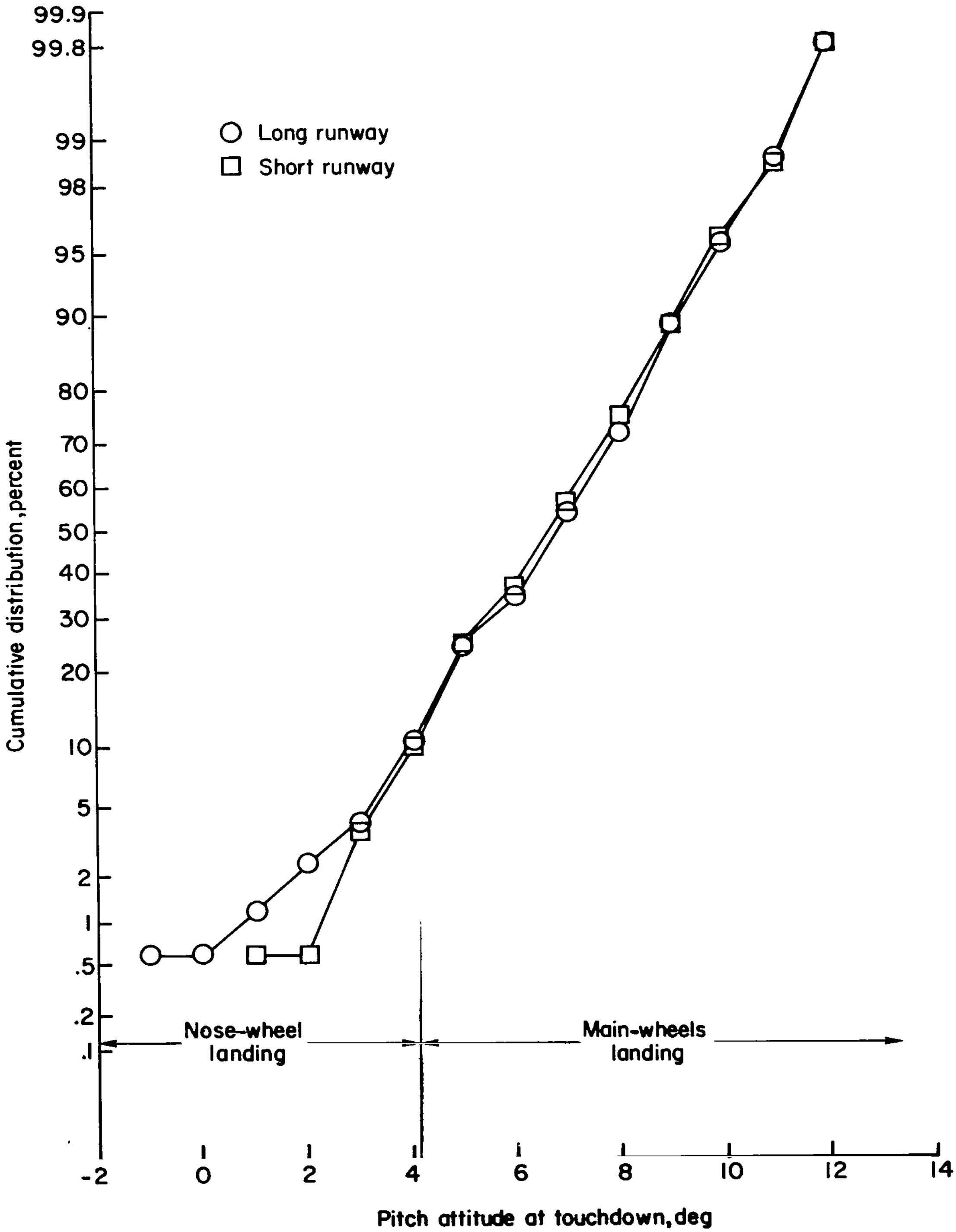
(b) High-wing airplane on both runways.

Figure 10.- Concluded.



(a) Low-wing airplane on both runways.

Figure 11.- Cumulative distribution of pitch attitude at touchdown.



(b) High-wing airplane on both runways.

Figure 11.- Concluded.

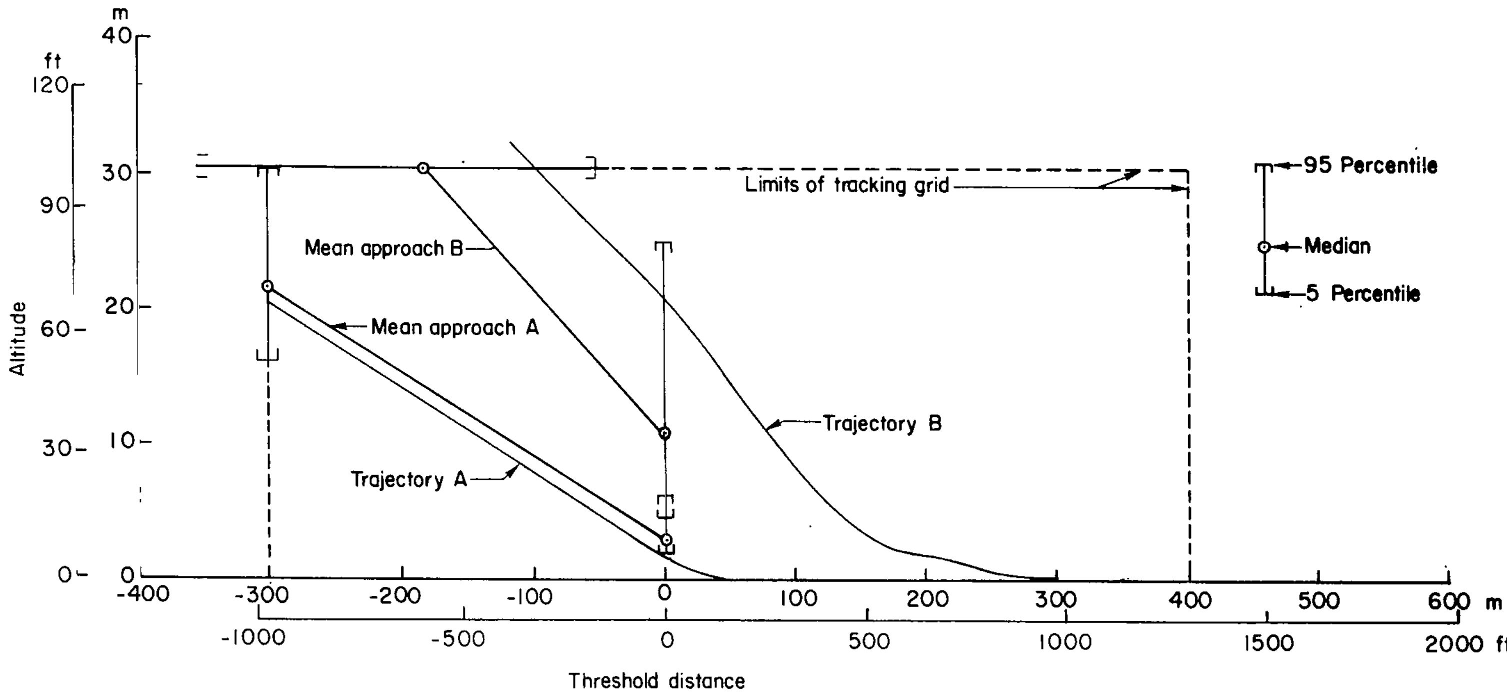


Figure 12.- Final approach trajectories of two selected landings including mean approaches of individual pilots.

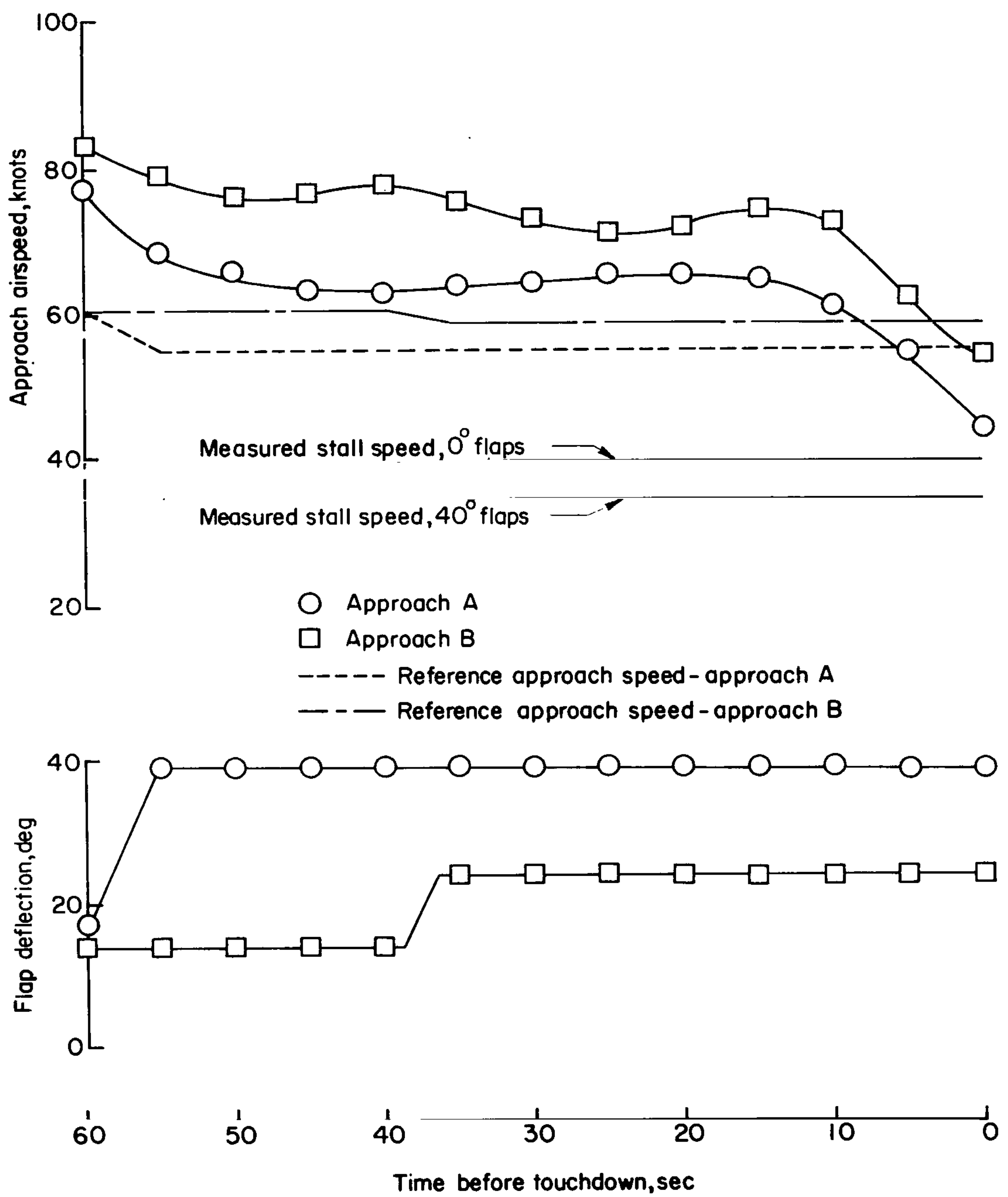
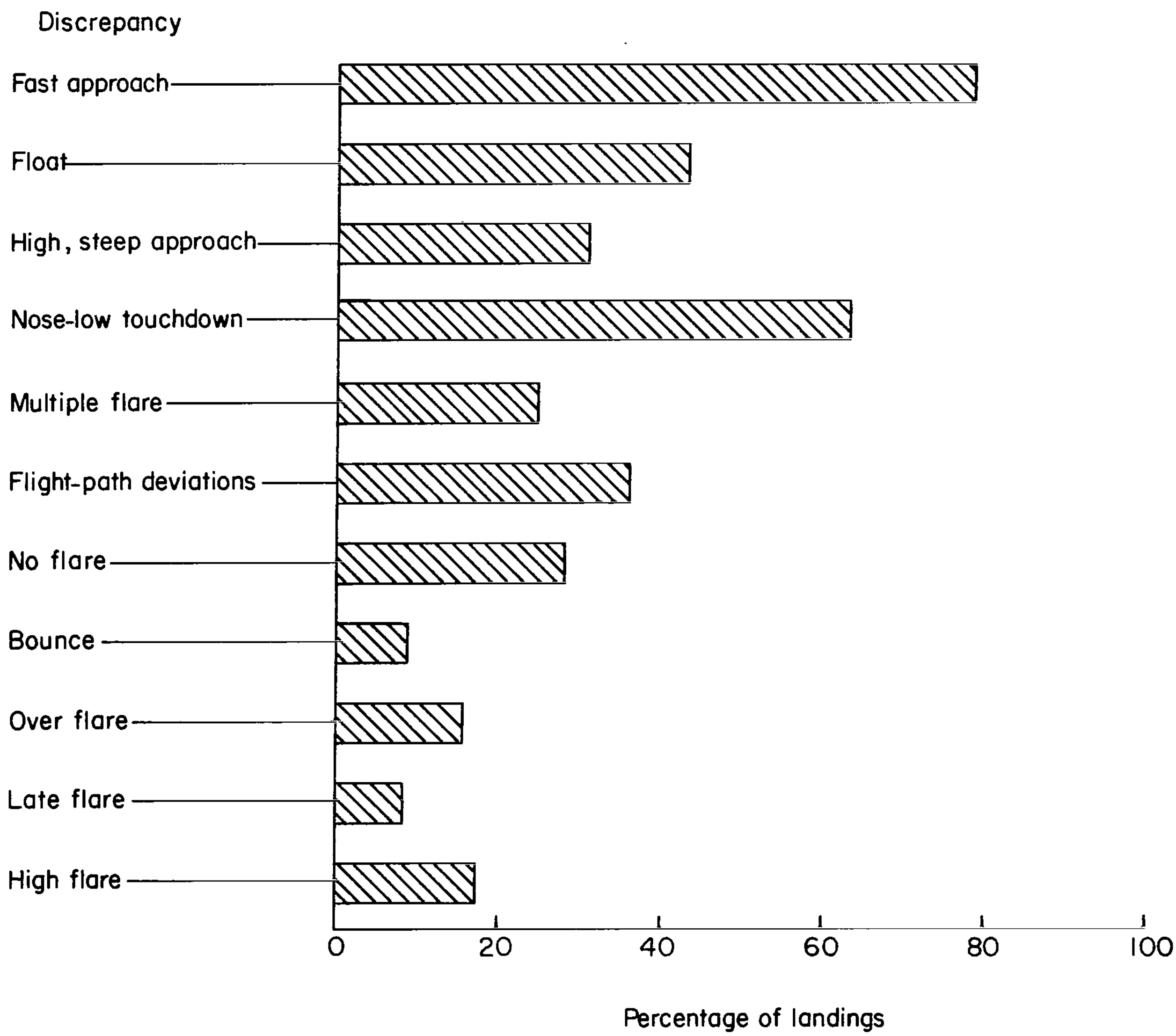
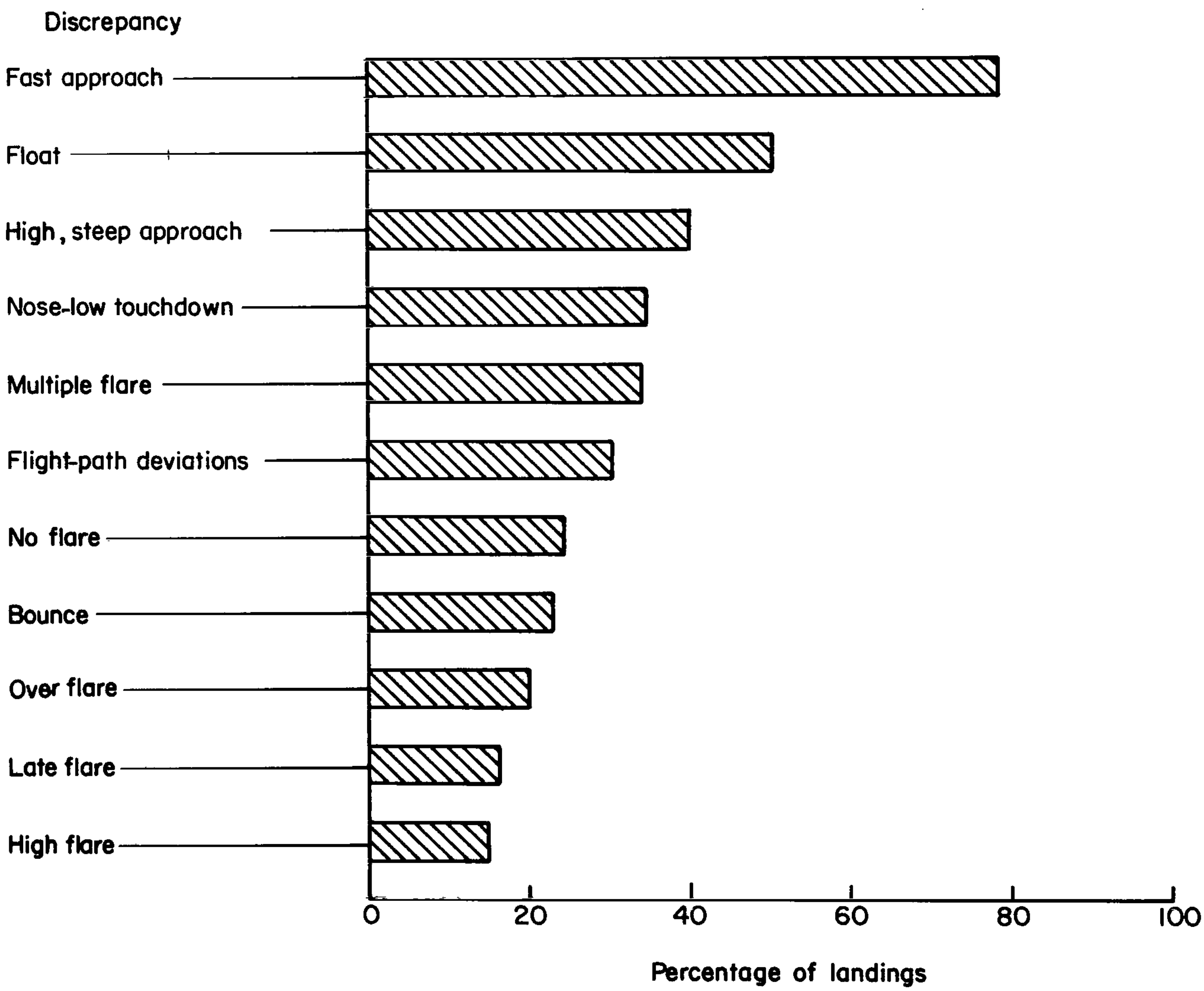


Figure 13.- Final approach airspeed and flap deflection of two selected individual landings.



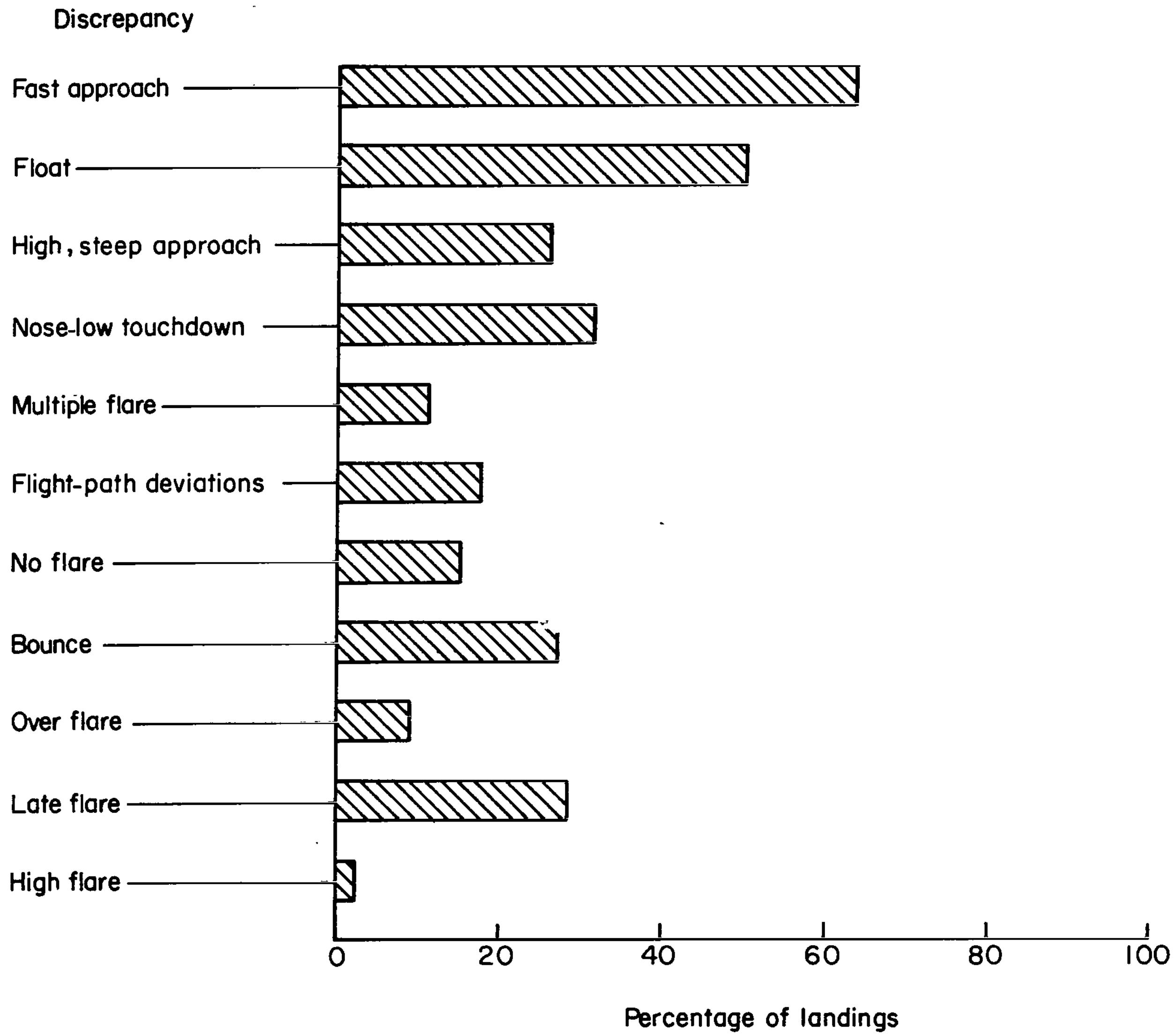
(a) Low-wing airplane on long runway.

Figure 14.- Summary of qualitative evaluations.



(b) High-wing airplane on long runway.

Figure 14.- Continued.



(c) High-wing airplane on short runway.

Figure 14.- Concluded.

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