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Simulation and Flight Evaluation of a Head-Up Landing Aid for General Aviation

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SUMMARY

A head-up general aviation landing aid called a landing site indicator (LASI) was tested by a total of five pilots in a fixed-base, visual simulator and subsequently in flight landing tests. In each testing mode (simulation or flight), each of 4 pilots performed 20 landing approaches with the LASI and 20 without it. The display, which had a simplified format and method of implementation, presented to the pilot in his line of sight through the windshield a graphic representation of the direction and magnitude of the airplane's velocity vector. The pilots' landing performance data such as altitude at runway threshold, rate of sink during approach, touchdown position, and airspeed at touchdown were analyzed for means and standard deviations. Use of the LASI improved pilot consistency (reduced the standard deviations) and also reduced elevator, aileron, and rudder control activity. The pilots commented that when they made landings of comparable precision with and without the LASI, the LASI reduced their work load. Although there was a general acceptance of the LASI concept by the pilots, the improvements suggested by them indicate that there is a need for further study and development with emphasis on the training and night landing applications of the display. An appendix is included with a discussion of the simulator effectiveness for visual flight tasks.

INTRODUCTION

Almost half of general aviation fatalities occur during the landing phase of flight. Most of the accidents involve overshooting or undershooting the runway or stall/spin during approach. In recognition of the more complicated and dangerous nature of this phase of flight, the Federal Aviation Agency (FAA) has set requirements for pilot competency and currency. In addition, the pilot has been provided with certain aids such as airspeed indicators, stall warning devices, and at some airports, visual approach slope indicator (VASI) lights. However, the general aviation accident rate is higher for landings than for all other phases of flight. Head-up displays have been developed to help military pilots in various phases of flight including the landing approach. These displays are complicated, very costly, and not suitable for general aviation. Therefore, because of the potential effectiveness of this type of piloting aid, a simplified head-up display more applicable to general aviation was developed at Langley Research Center. It is called the landing site indicator (LASI). The concept of the display is to present graphically the direction and magnitude of the airplane's velocity vector to the pilot in his line of sight through the windshield. The system is totally self-contained in the airplane so that the pilot requires only visual contact with the ground to establish the aim point. Thus, he can make approaches to any site he selects: municipal airports, secondary airports, or emergency fields. The LASI should help the pilot to set up the approach conditions without having to mentally visualize his projected flight path from changes in the observed landing scene. Therefore, it should give him more time to plan ahead and/or perform other tasks.

One simulation study exploring the LASI was reported in reference 1. Improvements in the pilot's ability to perform landings were indicated by the reduced scatter in several parameters of the flight trajectory. On the basis of these favorable results, flight tests of a breadboard version of the display were performed in a general aviation, single-engine airplane to measure the effectiveness of the LASI. The handling characteristics of the same airplane had been used previously to program the simulator used in the study of reference 1. (See ref. 2.)

This report presents results of the previous simulator tests and the current flight tests performed by a total of five FAA-certified pilots. The tests consisted of 40 landing approaches in each testing mode (simulation or flight) by each of 4 pilots; 20 approaches were performed using the LASI and 20 without the LASI. The data presented include altitude at runway threshold, rate of sink during approach, touchdown position, airspeed at touchdown, pilot control activity, and pilot comments.

A comparison of the simulator and flight test data and an evaluation of the simulator effectiveness are presented in the appendix.

SYMBOLS

h	altitude, meters
V	indicated airspeed, knots
x	distance along runway measured from threshold, meters
α	angle of attack, degrees
β	angle of sideslip, degrees
$\hat{\delta}$	average control-surface deflection from trim position, radians
μ	mean value
σ	standard deviation
ρ	density, kilograms/meter^3

Subscripts:

a	aileron
e	elevator
r	rudder
t	throttle

T threshold

TD touchdown

A dot over a symbol indicates a derivative with respect to time.

LASI DISPLAY CONCEPT AND PILOTING TECHNIQUE

The display presents to the pilot in his direct line of sight through the windshield a graphic representation of the direction and magnitude of the airplane's velocity vector with respect to the wind. The display format is depicted in figure 1. The magnitude of this velocity vector is displayed in a digital format and the direction of the vector is represented by a movable circle, hereafter called the α,β-index. This index can be thought of as the shaft of the arrow representing the velocity vector of the airplane. When viewed against the ground scene during a landing approach, the α,β-index shows the pilot his projected flight path which he can then adjust by manipulation of the control surfaces and throttle so that the index coincides with his desired aim point on the runway. The placement of the α,β-index in the visual field is determined in the vertical direction by the angle of attack and in the lateral direction by the angle of sideslip. Fixed reference lines are placed on the display to represent certain conditions such as zero or full flap deflection. Generally, the α,β-index is kept centered in the display to maintain zero side force, that is, coordinated flight conditions.

The pilot controls the airplane in the normal manner, as described in reference 3, so that no new piloting techniques must be learned; however, there is a learning process associated with interpreting the display in order that proper inputs can be used. The piloting technique is described as the following series of sequential steps:

Step 1. On the downwind leg, abeam of the intended touchdown point, reduce engine power to nominal approach setting and reduce airspeed slowly by applying back pressure on the elevator until the α,β-index is centered on the appropriate approach reference line. Cross-check the digital display of airspeed to verify that the display is functioning properly (if the α,β-index is on the reference line, the airplane should be flying at the nominal approach airspeed). Make downwind-to-base and base-to-final turns as usual, keeping the α,β-index aligned with the proper approach reference line.

Step 2. On the final leg, observe the position of the α,β-index relative to the intended aim point on the runway and adjust engine power and aircraft heading to place the index on this aim point. If it appears that the α,β-index is above the aim point, then engine power can be reduced; or if the α,β-index appears below the aim point, then engine power can be increased.

Step 3. Continue to maintain the α,β-index centered on the approach reference lines of the LASI by adjusting the elevator and rudder. Some airplanes require very little elevator inputs to compensate angle of attack for throttle changes.

Step 4. As flare altitude is reached, either flare the airplane without reference to the LASI or flare by placing the α,β-index on the far end of the runway and keeping it there. Using the LASI during the flare in this manner should result in a touchdown with low rate of sink.

These events associated with the landing approach have been described as a series of steps; however, some of the steps could be performed almost simultaneously. The LASI can be used on the base leg, and to a lesser extent, on the downwind leg to control the flight path. The intended aim point can be mentally rotated from the side to directly in front of the airplane's nose by selecting appropriate ground reference points to line up with the LASI, and engine power adjustment can be made accordingly as in step 2.

The piloting technique described compensates for steady winds with the resulting flight path being curved; however, a somewhat straighter path can be achieved by a technique of "leading" the intended aim point in the upwind direction. The leading of a cross-wind component can be accomplished by the conventional techniques of crabbing or sideslipping.

Gusty winds cause the α,β-index to oscillate and move erratically. The pilot then has to use the midpoint of the oscillation as the actual aim point. Since pilots generally increase their airspeed in turbulence to prevent an inadvertent stalled condition, the LASI should provide a more accurate adjustment of the approach speed because it shows the angle-of-attack variations directly. Therefore, the pilot can decrease his trim angle of attack (increase airspeed) to provide a given margin of angle-of-attack excursions in relation to the stall angle of attack.

EQUIPMENT, TESTS, AND SUBJECTS

Test Equipment

The reader should refer to the appendix of reference 1 for a full description of the simulator equipment. An abbreviated description of the simulator is given in this report. For the flight tests, the equipment described is the LASI display unit, the photographic grid tracking system, and the test airplane.

Simulation equipment.- The simulation required the use of three separate facilities: a digital computer, a cockpit, and a terrain-scene generating system which included a simulated head-up display. The digital computer processed the airplane equations of motion and the input and output signals associated with the other two simulation facilities 32 times per second. The handling qualities of the simulator were tailored to the test airplane (ref. 2). A fixed-base, multipurpose cockpit, designed primarily as a transport cockpit, was used. The left-hand side was laid out as a single-engine lightplane (fig. 2) with a visual scene of a runway and surrounding area. A color television system presented the terrain scene (fig. 3) at unity magnification and focused at infinity. The simulated LASI display was a television picture of a cathode-ray-tube image of the display symbols. The two television pictures were electronically mixed and fed to the cockpit monitor.

Flight equipment.- The head-up display unit was developed from a surplus Navy reflex gunsight (ref. 4) and was mounted at the top of the windshield (fig. 4). The gunsight's basic elements - dual collimating lenses, image-generating light sources, and combining mirror - were retained. New components were installed to generate the LASI symbols. The α, β-index, viewed by the pilot through the right lens, was a circle 2° in diameter with "wings" 1° long protruding from the side. This image was produced by placing a photographic negative of the index outline in front of one of the light sources. The image was reflected off a mirror (fig. 5) which pivoted about two orthogonal axes corresponding to angles of attack and sideslip. Two miniature low-cost servos positioned the mirror in each axis. The α, β-index could move through a circular visual area of approximately 10° covering an angle-of-attack range of 0° to 10° and a sideslip range of $\pm 5^{\circ}$.

The nonmoving symbols were generated through the left lens (fig. 6). The reference angle-of-attack lines were generated in a similar fashion to the α, β-index. The top reference lines corresponded to the angle of attack for full-flap-deflection approach and the bottom lines corresponded to a zero-flap-deflection approach. The airspeed digits were also focused to appear in the left lens. Each digit covered an area of 1° by 0.5°. The airspeed was displayed in 1 mile per hour increments. Since the pilot had to use both eyes to see the total display, head motion while viewing the display was limited to about 2.5 cm.

A block diagram of the signal conditioning of the display is shown in figure 7. The measured angles of attack and sideslip were buffered and scaled by operational amplifiers. The angle-of-attack scaling included a multiplication by 0.75 to account for upwash at the sensor located three-quarters of the mean aerodynamic chord ahead of the leading edge of the wing. The analog signals were electronically converted to pulse width drive signals for the mirror servos. The dynamic pressure signal (the pressure difference between the total and static pressures), derived from a differential pressure transducer, was buffered and scaled by operational amplifiers and then converted to a signal proportional to indicated airspeed by an electronic square root circuit. This signal was digitized by a nine-bit binary-coded-decimal (BCD) analog-to-digital converter, and the BCD output was fed to three 7-segment decoder/driver units which controlled the 7-segment incandescent digital readouts.

The LASI power switch and controls for display intensity and α, β-index zero adjustments were mounted on the airplane instrument panel. The display intensity was controlled by the pilot as needed. The zero-adjustment controls were used in the LASI alignment prior to flight operations.

The LASI display was aligned with the use of a calibration jig placed 8.7 m in front of the display unit. The jig had marks representing 1° increments in the visual field in both the vertical (angle of attack) and the lateral (angle of sideslip) directions. First the display unit was aligned with respect to the airplane. Then the α, β-index drive gains were adjusted so that a 1° change in free-stream angle of attack or sideslip corresponded to a 1° change of the index in the pilot's vision. The estimated accuracy of the LASI was considered to be better than 0.2° for the α, β-index and better than 1.5 miles per hour for the airspeed.

The airplane (fig. 8) was a four-place, low-wing lightplane with tricycle landing gear and a fixed-pitch propeller. The controls consisted of a conventional wheel and pedals connected to the elevator, ailerons, and rudder. Trim controls were available for the elevator and rudder. The research instrumentation that had been installed to measure flight handling qualities provided signals representing angles of attack and sideslip and dynamic pressure for the LASI display. Pilot control inputs, airspeed, rate of sink, and other parameters were recorded for subsequent analysis.

The grid tracking system described in detail in reference 5 was used to obtain flight-path and runway touchdown data. This system (fig. 9) consisted of a 16-mm motion-picture camera and a large photographic grid located between the runway and the camera. The grid was formed by a series of vertical and horizontal plastic strips fastened at their intersections to form squares 0.6 m on a side. The total grid system contained ten 6.1 by 6.7 m sections with an aluminum support pole between each section and at the ends of the grid. At the runway center line, the grid covered an area of 61 by 670 m. The tracking accuracy was estimated to be better than 0.3 m.

Tests

The test procedure was essentially the same for both the simulation and the flight testing modes. A total of five pilots performed the tests with four pilots participating in each mode. Each pilot completed 4 sessions of 10 approaches to a landing, with each session consisting of 5 approaches with the LASI and 5 without it. After two sessions, the order of the test runs was reversed to minimize any training or fatigue effects. All of the pilots were given ample experience with the LASI prior to the actual testing sessions. In the flight mode, these practice landings were performed at several airports in the area.

The actual flight tests were performed at a busy military airfield (fig. 10) which served a wide variety of airplane types. The pilots were instructed to perform their approaches as normally as possible with the existing traffic mix. Consequently, the final leg varied in length from an estimated 600 m to as much as 2500 m. In contrast, the simulator runs were started 950 m from the runway threshold.

The simulator runway was 1050 m long, whereas the military runway was over 3000 m long. However, the tracking grid was set to cover only a portion in the center of the runway. So, in order to give the pilots a specific aim point and assist them in making approaches to the area covered by the grid, they were instructed to use a 3-m-wide white stripe across the runway as a threshold and to plan all touchdowns just past it. The pilots were instructed to perform the approaches in their customary manner; that is, using flaps at their discretion, using appropriate final leg lengths, and so forth. A safety pilot flew along in the right-hand seat for all flights with one of the authors in the rear seat as an observer.

In the simulation, a steady wind of 9.5 knots from 15° to the right of the runway was used with no simulated turbulence included. For the flight tests, the winds and associated turbulence level were generally light, averaging 5.5 knots for all runs (with an average maximum and minimum for each run of 7.9 and 3.4 knots). The wind direction averaged 15° to the left side of the runway with an average variation during each run of 15° about the mean.

Test Subjects

A total of five qualified pilots, designated A, B, C, D, and E, participated in these tests. Table I summarizes the pilots' professions, qualifications, and approximate flight hours. Pilot B could not participate in the flight evaluation and was replaced by pilot E, who had no simulator experience with the LASI.

DATA ANALYSIS

The flight test performance data consisted of the grid tracking data (altitude at runway threshold and touchdown distance from threshold) and the airplane recorded data (rate of sink during approach and touchdown airspeed). Pilot control inputs were also recorded. During the simulator tests, the performance data, which were extracted from the calculated aircraft motions, and pilot control activity had been recorded on magnetic tape.

These data were analyzed for means and standard deviations for each pilot, display condition (LASI on or off), and testing mode (simulation or flight). The approach rate of sink was analyzed in a slightly different manner. The rate-of-sink mean and standard deviation for each run were both averaged for each pilot and display condition. The control-position time histories were analyzed to arrive at a parameter called control activity, which was found useful in reference 1. To obtain this parameter for all of the pilot-activated controls, the control time histories were first analyzed for their trim position (assumed to be the average position during the approach phase of each run). Then the average displacement from this trim position $\hat{\delta}$ was calculated. Next, the average control velocity $\dot{\hat{\delta}}$ was calculated. The control activity for each landing approach was taken to be the product of these two time-history averages. During the final approach, the airspeed was almost constant, except for the last few seconds before touchdown. Consequently, the amount of control force exerted by the pilot would be proportional to the control deflection from trim. Therefore, the control activity should be proportional to the physical work being exerted by the pilot in controlling the airplane. Means and standard deviations were calculated for each pilot and display condition (LASI off or on) for the elevator, aileron, rudder, and throttle controls.

RESULTS

Pilot performance is generally consistent over a fairly wide range of workload conditions. Therefore, performance measures, by themselves, are not always a good method of evaluation but should be correlated with pilot comments. Consequently, the results of these tests are of two types: objective measures (performance, consistency, and pilot control activity) and subjective measures (pilot opinion).

Objective Measures

The objective measures were not necessarily normally distributed functions; however, the means are considered to be an indication of the pilot's performance and the standard deviations are considered to be an indication of the pilot's consistency in achieving that performance level.

Performance and consistency.- The means and standard deviations of the performance parameters are listed in tables II to V and plotted in figures 11 to 14. The LASI was not expected to affect the mean values of the performance parameters, so the discussion in this section is limited to the effect of the LASI on pilot consistency (standard deviation).

Consistency of altitude at runway threshold was improved in the simulation and to a lesser extent in flight. Without the LASI, the altitude-at-threshold consistency was much worse in the simulation than in flight; however, with the LASI, the simulation consistency was improved to almost the flight values. Consistency of approach rate of sink was improved with the LASI; thus the flight path was more stabilized when the LASI was used. Runway touchdown position in the simulation was more consistent with use of the LASI, but no change was evident in flight. For airspeed at touchdown, consistency was improved in the simulation and unchanged in flight.

Control activity.- Means and standard deviations of control activity are presented in tables VI to IX and in figures 15 to 18. In spite of the light turbulence of the flight tests, elevator control activity without the LASI (fig. 15 and table VI) was greater in the simulation than in flight. All of the pilots had lower average elevator control activity when using the LASI in the simulator and flight tests. For two of the pilots (C and D), who had the highest simulator elevator activity, using the LASI brought elevator activity down to flight values. In addition, all of the pilots improved consistency of elevator control activity when using the LASI in the simulator and flight tests.

Overall aileron control activity (fig. 16 and table VII) was greater in the flight tests than in the simulator tests. More than likely, this was due to the turbulence associated with the flight tests. Almost all of the pilots exhibited reduced aileron control activity when using the LASI in the simulator and flight tests. Although the average consistency of aileron control activity was better in the simulator when the LASI was used, the average aileron control activity was less consistent in the flight tests when the LASI was used.

Average rudder control activity (fig. 17 and table VIII) was also slightly higher in the flight tests than in the simulator tests, presumably because of the turbulence encountered in the flight tests. Average rudder control activity of the simulator tests was decreased with use of the LASI, whereas in the flight tests, it was unchanged. Use of the LASI improved rudder control consistency in the simulator tests and the flight tests.

Throttle control activity (fig. 18 and table IX) was measured in only the flight tests and showed very little effect of using the LASI on either the mean or consistency.

Pilot Comments

During the flight tests, the pilots made general comments about the LASI. In addition, at the conclusion of the test program, the pilots were asked several specific questions (table X) in order to evaluate their impressions concerning the LASI and their piloting techniques employed while using it.

Pilot training.- During the practice flights, pilot E, who had not used the LASI in the simulator previously, initially reported a feeling that the angle-of-attack motion of the α,β-index was confusing. However, after a little practice, this confusion disappeared. One pilot commented that the learning process associated with the LASI was very fast. Prior to the tests, pilots expressed concern that fixating on the display would interfere with their decision to flare. For two pilots, there was initially a slight tendency to fixate on the display; however, this tendency also disappeared quickly with experience.

Piloting techniques.- From the pilots' comments, it appeared that two of the pilots had developed a technique for using the LASI of adjusting engine power to control airspeed and elevator to control flight path. This is the technique that was being taught for instrument approaches.

All of the pilots used the LASI during portions of the final leg of the approach pattern. Four of the pilots used it on the base leg to set up the approach speed and extrapolate their flight-path angle by the transposition technique described previously. One of these four pilots reported that he also used the digital velocity feature during the climb to altitude and on the downwind leg so that he did not have to look inside the cockpit at all. All of the pilots stopped using the LASI just before flare altitude was reached.

Almost all of the pilots stated that the LASI helped them to determine the airplane's aim point more precisely and more quickly, and as a result they were able to control their approach with more precision, as shown quantitatively by the improved consistency. The pilots also commented that the LASI enabled them to make fewer control inputs. These comments correlated with the control activity measures mentioned previously. One pilot had the impression that his throttle inputs increased with the LASI. This statement, however, does not correlate with the throttle-control-activity parameter measured during the flight tests.

Wind effects.- The light turbulence of the flight tests did not present a big problem for the pilots. They were able to estimate the average α,β-index position. They did comment, however, that the LASI was easier to use in smooth air. Cross winds presented no problem either. One pilot suggested eliminating the lateral travel of the α,β-index. The lateral motions of the airplane relative to the runway are very easy to determine visually, and thus it is easy to keep the airplane aligned with the runway center line.

Pilot work load.- All of the pilots were in agreement that, when asked to perform approaches of comparable precision with and without the LASI, the LASI did reduce their work load. This statement agrees with the reduction of control activity noted previously. During a training flight, pilot A stated that the reduced work load was very noticeable when landing on a short runway over obstacles.

Suggested applications.- Two pilots thought that the LASI would be a help for night landings. After the flight tests, pilot A made a night evaluation flight. He found that control of the flight path was very easy and commented that the LASI was definitely a valuable aid for night landings.

All of the pilots suggested that the LASI might be a valuable training tool for a student pilot and/or the instructor. Subsequently, one flight was performed to evaluate this aspect with a student pilot making several approaches with and without the LASI. Although there was moderate turbulence present, both the student and the instructor throught the approaches were set up better when the LASI was used and that it was a help to the student.

Two other suggested applications were for bush pilots and crop dusting pilots.

Suggested improvements.- The mounting location of the LASI display unit was inappropriate because it was too close to the pilot's head and cut off some of his vision in the upward direction. In addition, the restricted head position required to see all of the symbols was unsatisfactory. A unit mounted in the instrument panel would be much more satisfactory.

Pilot A was concerned that the LASI did not give him a readout of the magnitude of his flight-path angle and thus would not warn him that he was making very shallow approaches. Pilot C suggested that turning the LASI display off just before time to flare might eliminate any possibility of fixation on the display. Pilot A suggested reducing the size of the α,β-index by one-half; however, pilot D suggested placing the airspeed digits inside the α,β-index, which might result in a larger sized index. If these improvements suggested by the pilots were included, then further tests should be conducted to determine whether they would be beneficial for general use or not.

Discussion of Results

A comparison of the simulator and flight test results and a discussion relating to the simulator's effectiveness are presented in the appendix of this report. The following discussion, however, concerns only the results as they apply directly to the evaluation of the LASI display.

As mentioned previously, pilot opinion of work load must be correlated with performance measures in order to obtain a proper evaluation. The pilots' opinions were that use of the LASI did reduce the work load. Generally, use of the LASI improved approach and touchdown consistency in the simulator but improved only the approach consistency in the flight tests. In addition, the measures of control activity for elevator, aileron, and rudder were decreased with the LASI in the simulator and in flight. Therefore, the LASI device was found to be generally helpful in reducing pilot work load and improving the consistency of pilot performance. However, whether or not this improvement in consistency and reduction in work load will result in improved safety of flight cannot be determined by these tests. This question of flight safety can only be answered effectively by widespread acceptance and use of such a device.

CONCLUDING REMARKS

The results of tests in which five pilots used a head-up display called a landing site indicator (LASI) in a general aviation landing simulator and airplane were favorable. In general, the pilots had a favorable opinion of the landing aid.

Reductions in the standard deviations of the measured parameters were used as indicators of improved pilot consistency. On the basis of these parameters, consistency in the simulator was improved with use of the LASI for approach and touchdown performance parameters; however, consistency in flight was improved for only the approach parameters with little or no change in the touchdown parameters.

As indicated by pilots' comments and by the reductions in the average elevator, aileron, and rudder control activity, the LASI reduced pilot work load.

Improvements suggested by the pilots indicated that there might be a need for further study and development.

The pilots suggested some possible applications of the LASI which included: instruction of student pilots (for both the student and the instructor), night landing approaches, and approaches to confined areas, such as those encountered by bush pilots or crop dusters.

On the basis of the findings of this study, it is recommended that appropriate tests be conducted to quantitatively evaluate an improved LASI as a training aid and as a night landing aid.

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APPENDIX

COMMENTS ON SIMULATOR EFFECTIVENESS FOR VISUAL FLIGHT TASKS

Performing the same tasks both in a flight simulator and in flight provides an opportunity to assess the limitations or effectiveness of the simulator for this type of visual flight task. The tests of this study were not planned or designed for such a comparison; however, there appears to be sufficient relevant data to make some inferences concerning the simulator.

In a previous fixed-base simulator evaluation study (ref. 2) involving visual landing tests in the same fixed-base simulator and airplane, it was concluded that a reasonable degree of confidence could be placed in the simulator data. The present tests included trajectory measurements which could be used for more extensive comparisons than were performed in reference 2.

A comparison of pilot consistency (standard deviation) of two approach parameters, altitude at runway threshold and touchdown position, shows that with the LASI off, simulator consistency was worse than flight consistency (figs. 11 and 13). In addition, the average elevator control activity was greater in the simulator than in flight with the LASI off even with turbulence present in the flight tests (fig. 15). Use of the LASI did help to make the simulator consistency in the two approach parameters more in line with the flight LASI-on consistency and brought the simulator elevator control activity slightly below the flight LASI-on elevator activity. These data, along with the pilot comments of reference 2, indicate that the simulator is harder to fly than the airplane. For some situations, having the simulator harder to fly than the actual vehicle may be desirable, but not when attempting to evaluate handling qualities or testing display concepts.

The fact that use of the LASI improved agreement in pilot consistency and control activity between the simulator and flight tests would indicate that the cues in the simulator were not of sufficient fidelity to allow the pilot to perform to the same level of consistency as in flight. The LASI, however, either improved the cues or added cues to allow comparable consistency to be demonstrated.

The previous evaluation study indicated that the test pilots experienced some small difficulty in judging the attitude in the simulator. The approach reference lines of the LASI display would definitely be an aid in judging roll attitude and changes in pitch attitude and thus allow the pilot to make more precise and, perhaps, smaller changes in attitude.

To overcome this poor roll cue of the simulator, an expanded visual horizon or at least a peripheral indication of the horizon should be provided for the pilot. This peripheral presentation should also be helpful to pilots in executing the flare and touchdown.

In the opinion of the authors, it is doubtful that peripheral vision of the horizon alone would be sufficient to improve the pilots' judgment of pitch attitude or projected aim point. More than likely, the pilots' ability to judge these states is limited by the resolution of the visual presentation. The distance between the raster lines subtended a visual angle of 3 minutes of arc, whereas the human eye has a visual acuity of 1 minute of arc. Therefore, in the simulator, the eye can discriminate only one-third of the visual information that would be available in actual flight. It is recommended that tests be undertaken with a peripheral view of the horizon and a visual scene with better resolution to determine whether these additional or improved cues would be enough to improve the pilots' performance and consistency. This analysis has assumed that such visual scenes would also have negligible time delays, because a previous simulator study (ref. 6) has shown that time delays in the visual scene and/or motion base affect pilot performance.

Secondary tasks are used to measure the residual work capacity of a test subject. One requirement of a secondary task is to increase the work load of the subject without affecting his performance. If the simulator pilot's work load is already high enough to affect the performance and consistency, then in the opinion of the authors there is every reason to believe that the added work load of a secondary task would degrade them even further. This effect would need to be considered in analyzing the results. However, once the simulation is improved, then a secondary task could reasonably be incorporated.

Finally, these tests indicate that for a visual flight task, actual flight consistency could be expected to be slightly better than the simulator consistency and that the same amount of improvement in simulator consistency may not be realizable in flight tests.

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TABLE I.- PILOT EXPERIENCE SUMMARY

Pilot	Profession	Pilot qualifications	Total flight hours
A	Research pilot	Former military pilot, certified flight instructor, graduate of U.S. Naval Test Pilot School	4600
B	Aerospace engineer	Former military pilot (minimal lightplane experience)	650
C	Electrical technician	Active certified flight instructor	1300
D	Aerospace engineer	Private pilot, jump plane pilot	800
E	Aerospace engineer	Private pilot	100

TABLE II.- MEANS AND STANDARD DEVIATIONS OF

ALTITUDE AT RUNWAY THRESHOLD

Pilot	Simulation				Flight			
	LASI off		LASI on		LASI off		LASI on	
	μ, m	σ, m	μ, m	σ, m	μ, m	σ, m	μ, m	σ, m
A	5.71	3.26	4.50	1.17	2.55	0.54	2.88	0.91
B	6.93	1.34	5.93	1.91				
C	6.98	3.44	8.40	2.83	2.57	2.58	2.49	1.79
D	10.47	5.83	8.97	2.17	1.15	.37	1.39	.52
E					3.31	3.80	3.81	3.39

TABLE III.- MEANS AND STANDARD DEVIATIONS OF

APPROACH RATE OF SINK

Pilot	Flight			
	LASI off		LASI on	
	μ, m/sec	σ, m/sec	μ, m/sec	σ, m/sec
A	6.9	2.4	6.7	1.9
B				
C	6.5	2.5	6.0	2.0
D	5.9	3.3	6.1	3.3
E	6.9	2.7	7.1	2.1

TABLE IV.- MEANS AND STANDARD DEVIATIONS OF

RUNWAY TOUCHDOWN POSITION

Pilot	Simulation				Flight			
	LASI off		LASI on		LASI off		LASI on	
	μ, m	σ, m	μ, m	σ, m	μ, m	σ, m	μ, m	σ, m
A	179.0	81.0	119.4	52.9	146.7	45.4	163.8	38.4
B	151.6	52.8	119.7	40.1				
C	179.1	55.8	185.4	32.5	104.2	53.3	132.7	57.4
D	237.5	79.2	211.0	30.0	82.1	48.8	118.8	53.8
E					117.0	95.1	98.3	93.6

TABLE V.- MEANS AND STANDARD DEVIATIONS OF

AIRSPEED AT TOUCHDOWN

Pilot	Simulation				Flight			
	LASI off		LASI on		LASI off		LASI on	
	μ, knots	σ, knots	μ, knots	σ, knots	μ, knots	σ, knots	μ, knots	σ, knots
A	72.5	3.2	70.4	1.8	67.6	3.2	67.6	3.3
B	66.3	2.0	68.1	1.7				
C	72.3	2.7	68.1	2.1	56.7	2.7	55.7	2.8
D	71.8	3.5	70.9	3.7	64.5	2.5	64.8	2.5
E					63.6	3.4	65.6	4.0

TABLE VI.- MEANS AND STANDARD DEVIATIONS OF ELEVATOR CONTROL ACTIVITY

Pilot	Simulation				Flight			
	LASI off		LASI on		LASI off		LASI on	
	μ, rad^2/sec	σ, rad^2/sec	μ, rad^2/sec	σ, rad^2/sec	μ, rad^2/sec	σ, rad^2/sec	μ, rad^2/sec	σ, rad^2/sec
A	0.77×10^{-3}	0.34×10^{-3}	0.41×10^{-3}	0.25×10^{-3}	0.71×10^{-3}	0.32×10^{-3}	0.69×10^{-3}	0.27×10^{-3}
B	.44	.20	.37	.16				
C	3.99	2.36	1.51	.64	1.78	.53	1.45	.44
D	3.24	3.12	2.03	1.60	1.95	.48	1.81	.46
E					1.34	.53	.82	.32

TABLE VII.- MEANS AND STANDARD DEVIATIONS OF AILERON CONTROL ACTIVITY

Pilot	Simulation				Flight			
	LASI off		LASI on		LASI off		LASI on	
	μ, rad^2/sec	σ, rad^2/sec	μ, rad^2/sec	σ, rad^2/sec	μ, rad^2/sec	σ, rad^2/sec	μ, rad^2/sec	σ, rad^2/sec
A	1.30×10^{-3}	1.57×10^{-3}	0.81×10^{-3}	0.51×10^{-3}	2.40×10^{-3}	0.95×10^{-3}	2.57×10^{-3}	0.99×10^{-3}
B	.23	.12	.25	.17				
C	1.52	.80	.43	.24	2.24	1.32	1.46	.70
D	1.96	1.77	.70	.55	7.29	3.21	6.11	3.65
E					5.90	1.02	4.90	2.43

TABLE VIII.- MEANS AND STANDARD DEVIATIONS OF RUDDER CONTROL ACTIVITY

Pilot	Simulation				Flight			
	LASI off		LASI on		LASI off		LASI on	
	μ, rad²/sec	σ, rad²/sec	μ, rad²/sec	σ, rad²/sec	μ, rad²/sec	σ, rad²/sec	μ, rad²/sec	σ, rad²/sec
A	0.86×10^{-3}	1.66×10^{-3}	0.18×10^{-3}	0.26×10^{-3}	0.93×10^{-3}	0.41×10^{-3}	1.08×10^{-3}	0.34×10^{-3}
B	.92	.33	1.02	.53				
C	.46	.36	.25	.28	1.09	1.06	.68	.59
D	2.53	1.29	1.51	.82	2.34	1.29	2.77	1.97
E					.92	1.02	.73	.66

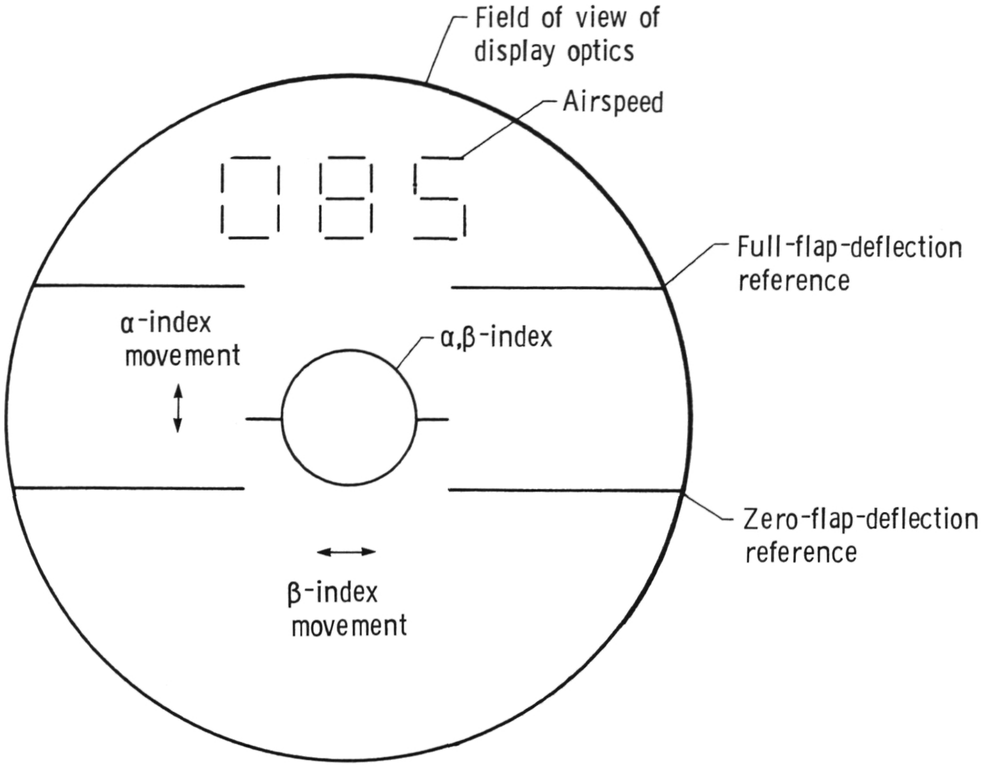
TABLE IX.- MEANS AND STANDARD DEVIATIONS

OF THROTTLE CONTROL ACTIVITY

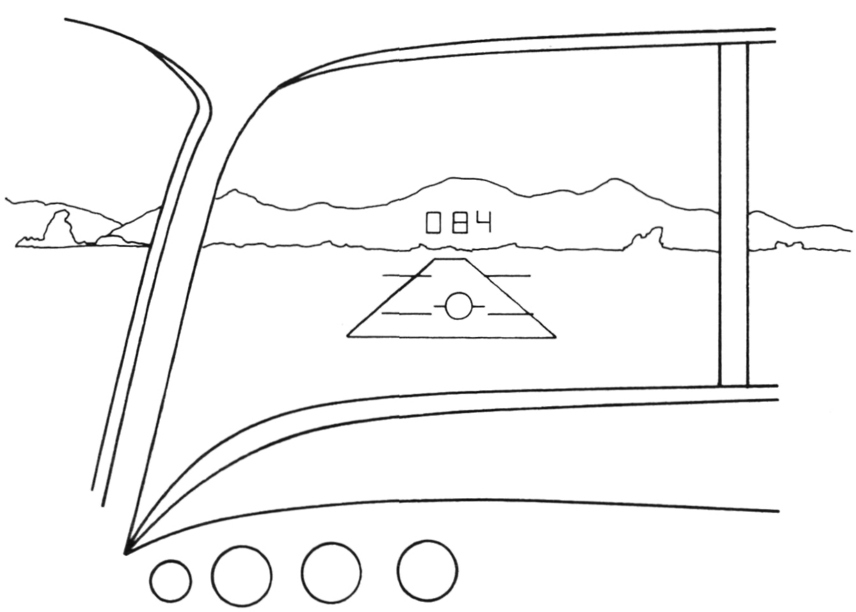
Pilot	Flight			
	LASI off		LASI on	
	μ, sec^{-1}	σ, sec^{-1}	σ, sec^{-1}	σ, sec^{-1}
A	7.17×10^{-4}	4.52×10^{-4}	7.52×10^{-4}	3.69×10^{-4}
B				
C	5.61	2.68	6.63	5.03
D	9.94	4.60	8.49	3.71
E	7.09	4.52	5.78	4.06

TABLE X.- PILOT QUESTIONNAIRE

1. When in the approach pattern did you use the LASI?
2. When in the approach pattern did you quit using the LASI?
3. Was there a tendency to fixate on the LASI?
4. Was it of any benefit at any other time than on the final approach?
5. How did you use the LASI?
6. Did it affect your landings?
7. Was it confusing as to what to do with the information?
8. To what degree did turbulence affect the use of the LASI?
9. To what degree did cross winds affect the use of the LASI?
10. Did it help you to anticipate where you were going?
11. Did it cause you to use the controls more or less?
12. Did it decrease or increase your total work load?
13. What feature of the display did you like or dislike?
14. What would help you to make better or more consistent landings?
15. How would you improve the LASI?

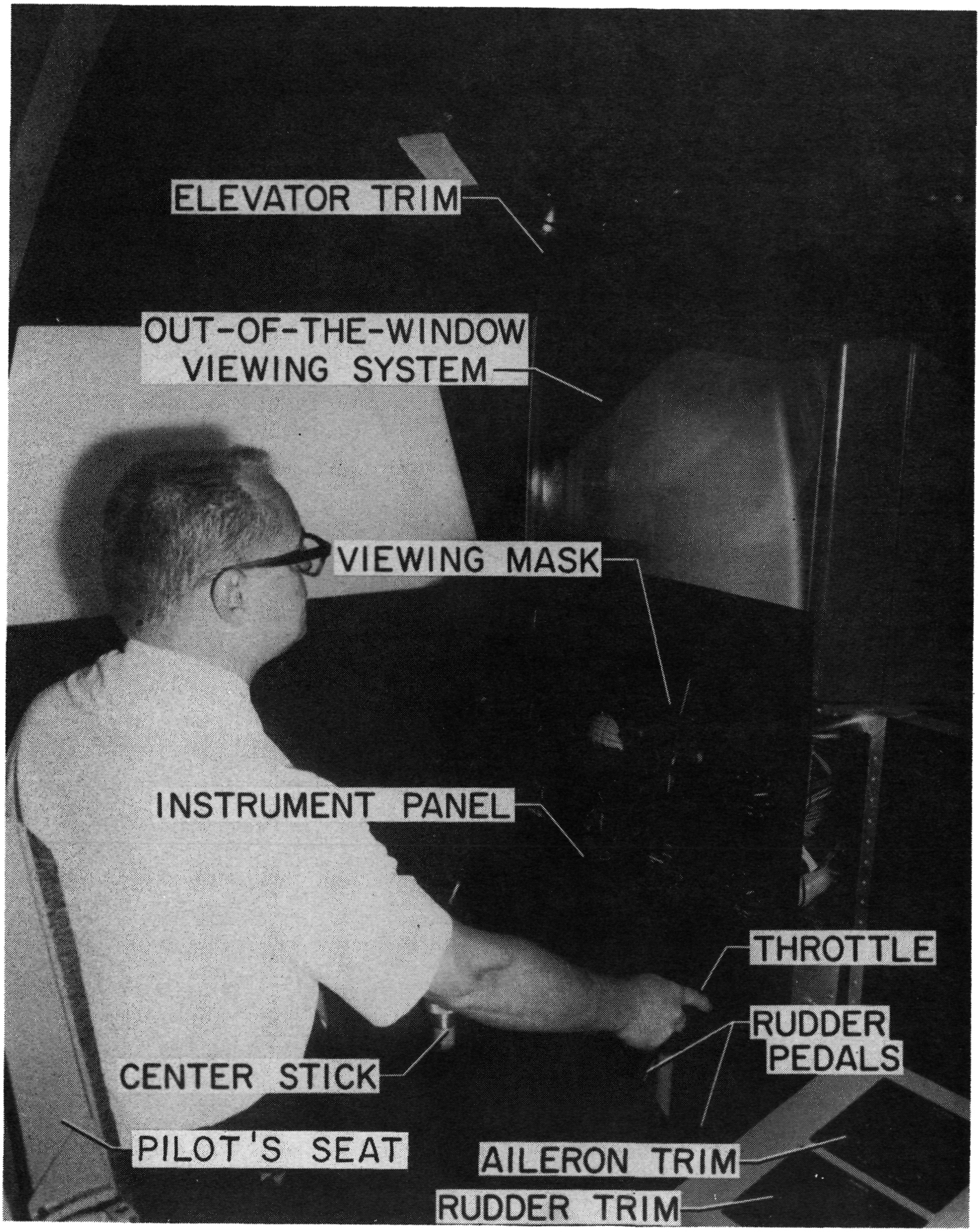


(a) Display format.



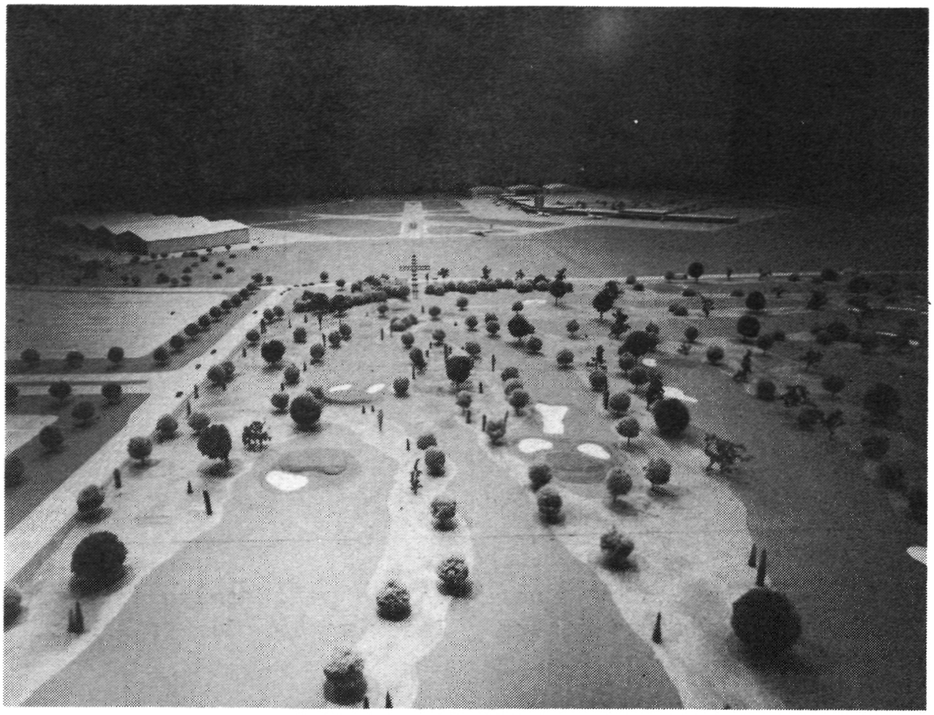
(b) Pilot's view of LASI and landing scene.

Figure 1.- Sketches of LASI display.



L-78-111

Figure 2.- Simulator cockpit.



L-71-4272

Figure 3.- Pilot's view during simulation of 1:300 scale model of airport as seen from landing approach position on final leg for active runway.

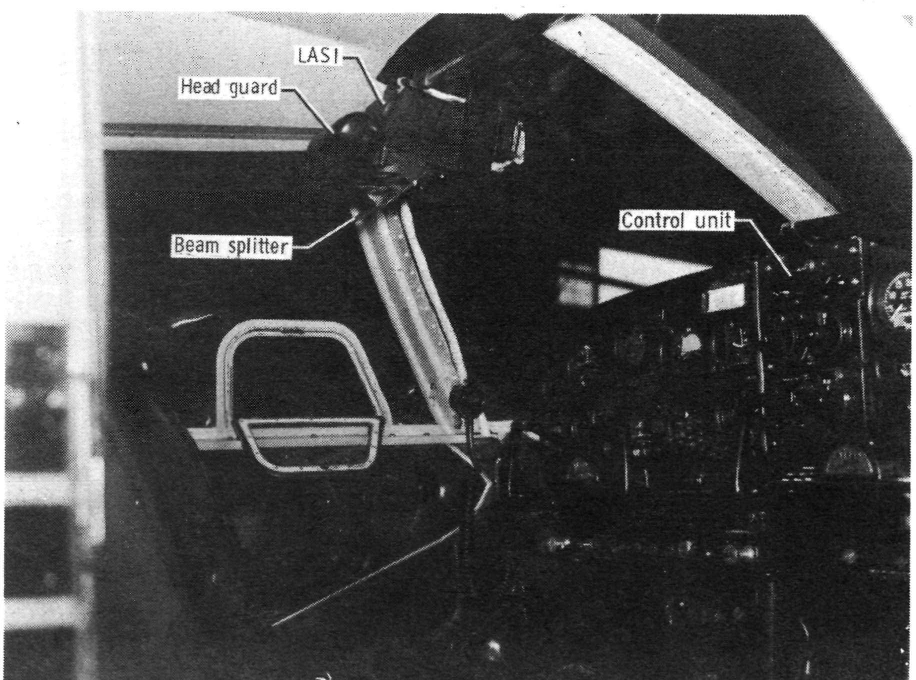


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Figure 4.- LASI display unit and the instrument panel of test airplane.

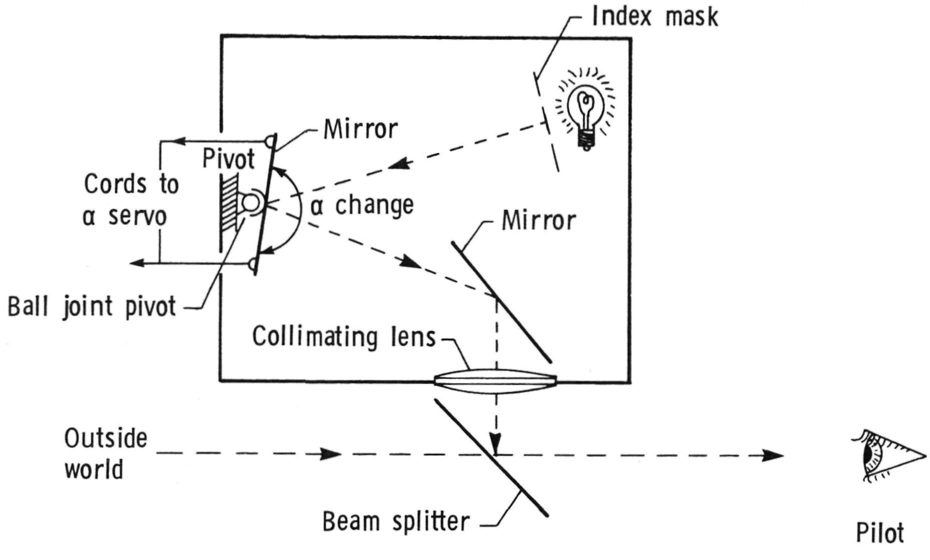

Figure 5.- Sketch index generation and positioning in response to changes in angle of attack. Index motion due to sideslip is identical but rotated 90°.

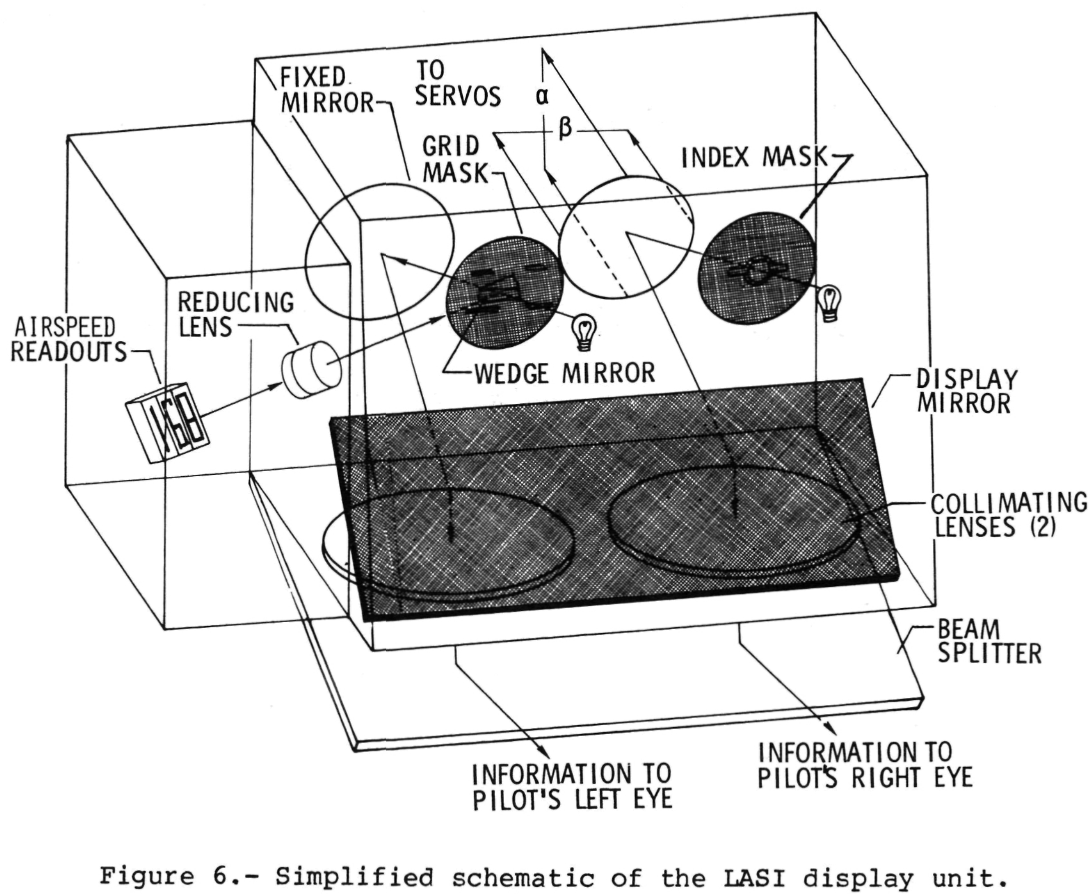

Figure 6.- Simplified schematic of the LASI display unit.

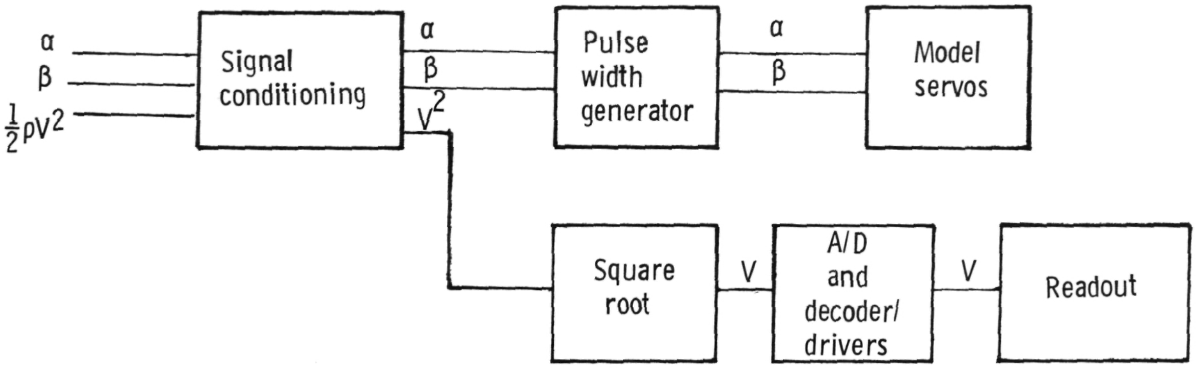

Figure 7.- Schematic of LASI electronics.

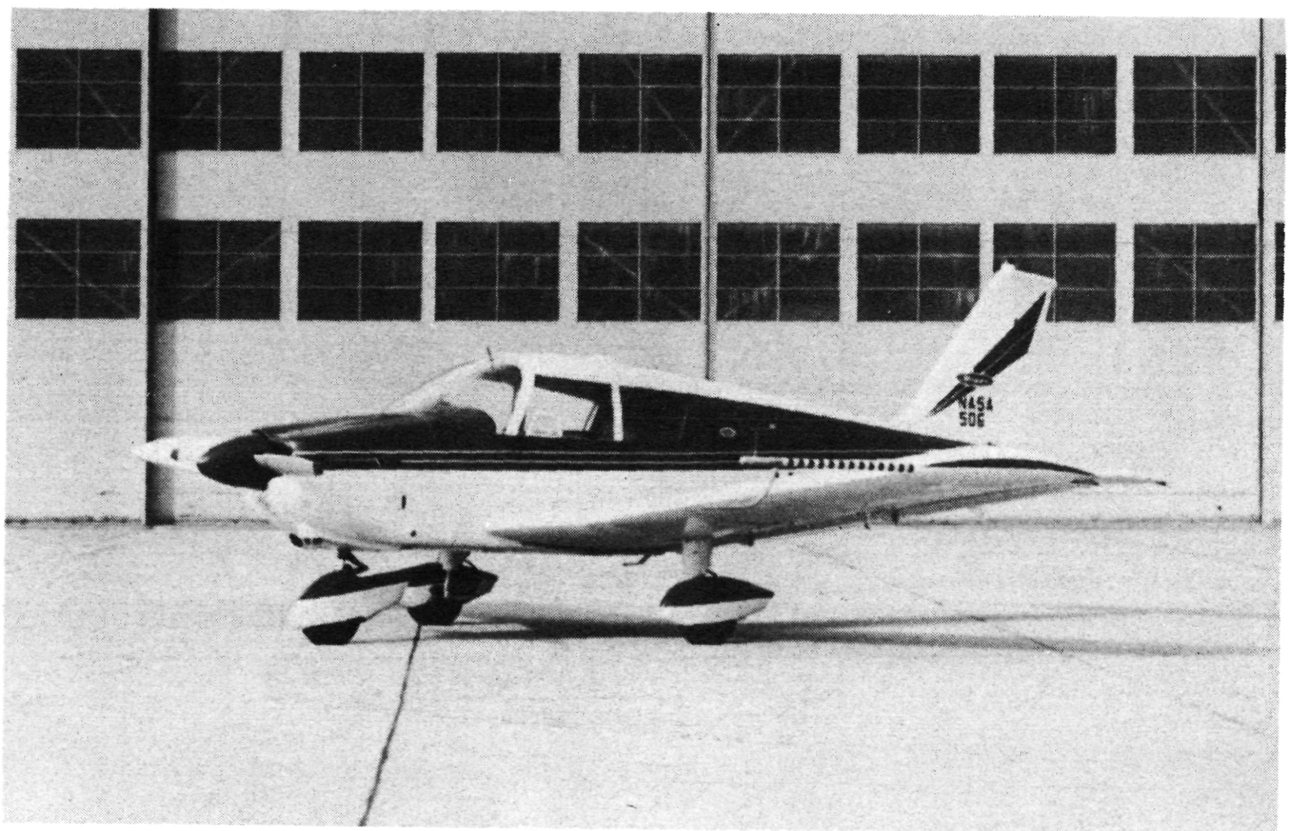

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Figure 8.- Test airplane. α, β, and velocity instrumentation are on left wing tip boom.

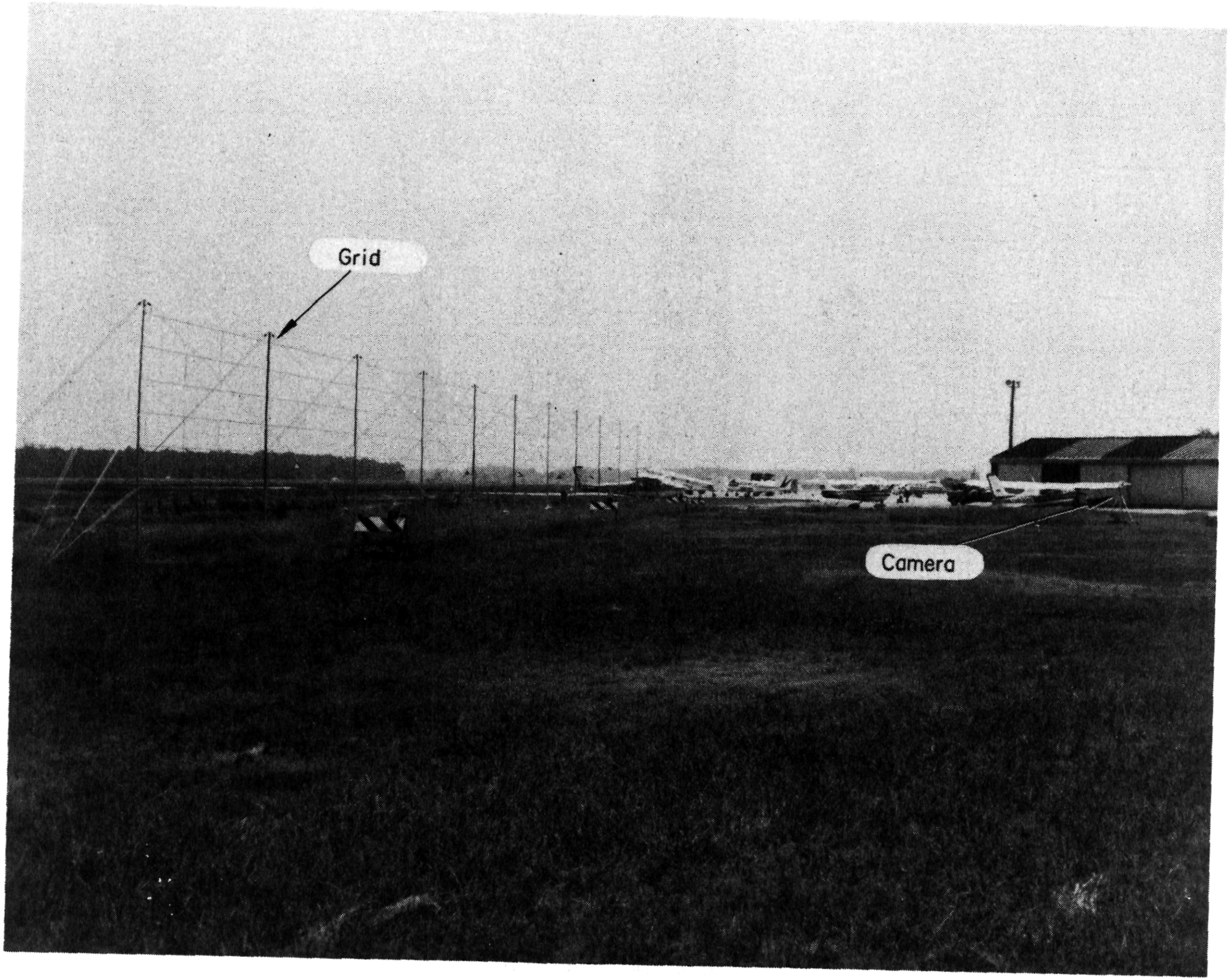

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Figure 9.- Grid tracking system.

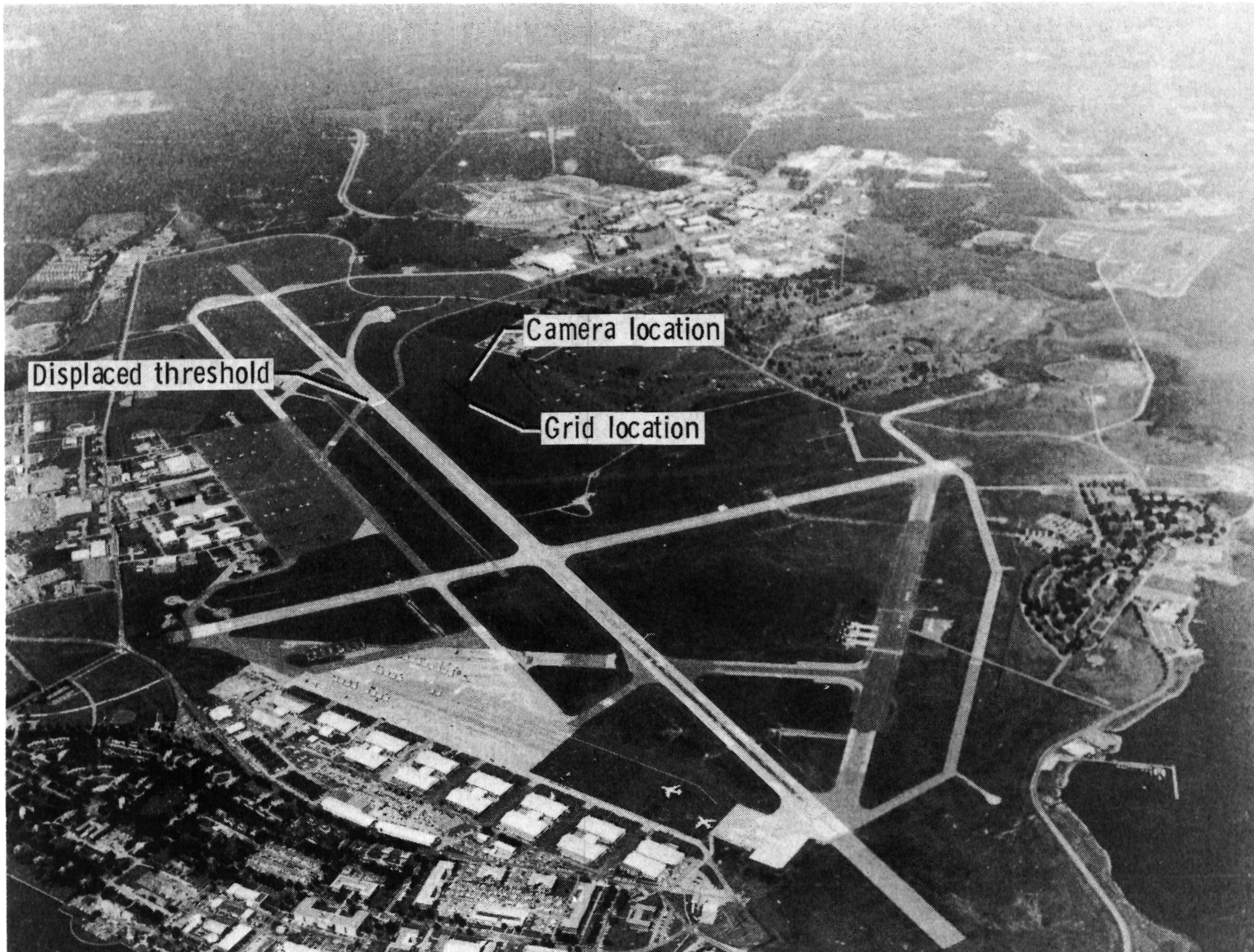

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Figure 10.- Military airfield used for flight tests. Approximate locations of displaced threshold and grid tracking system are shown.

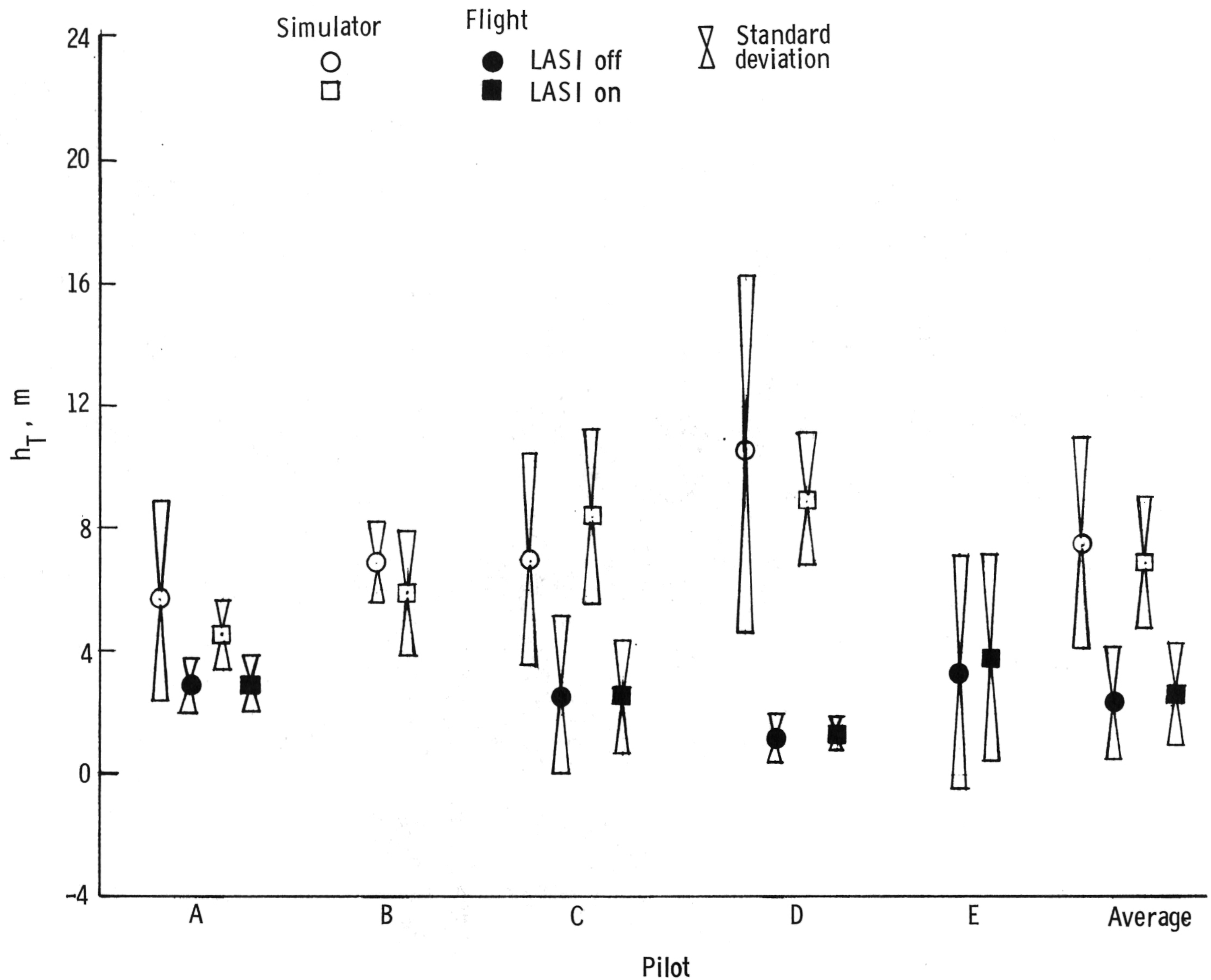

Figure 11.- Altitude at runway threshold in simulator and in flight with LASI off and on.

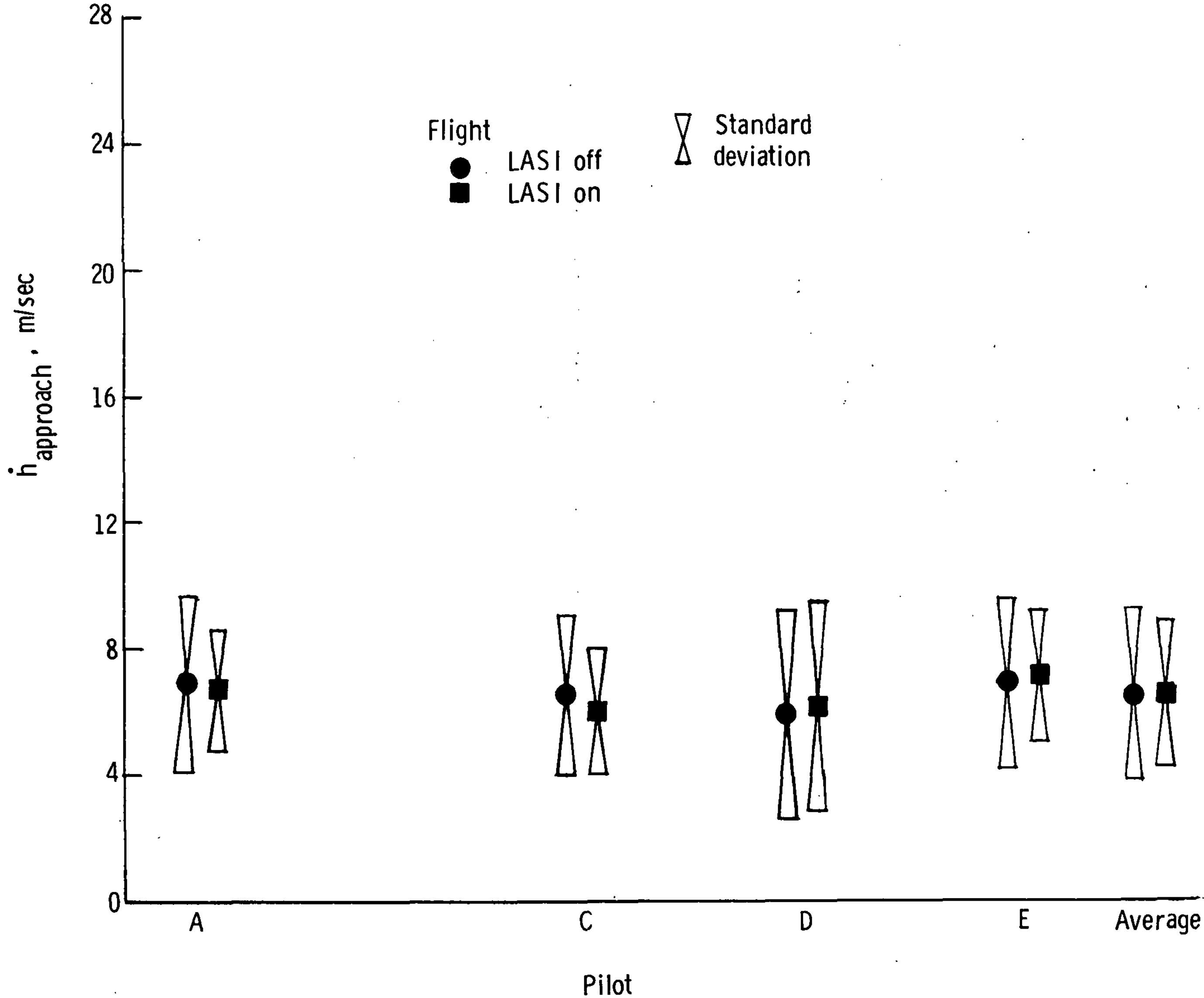

Figure 12.- Approach rate of sink in flight with LASI off and on.

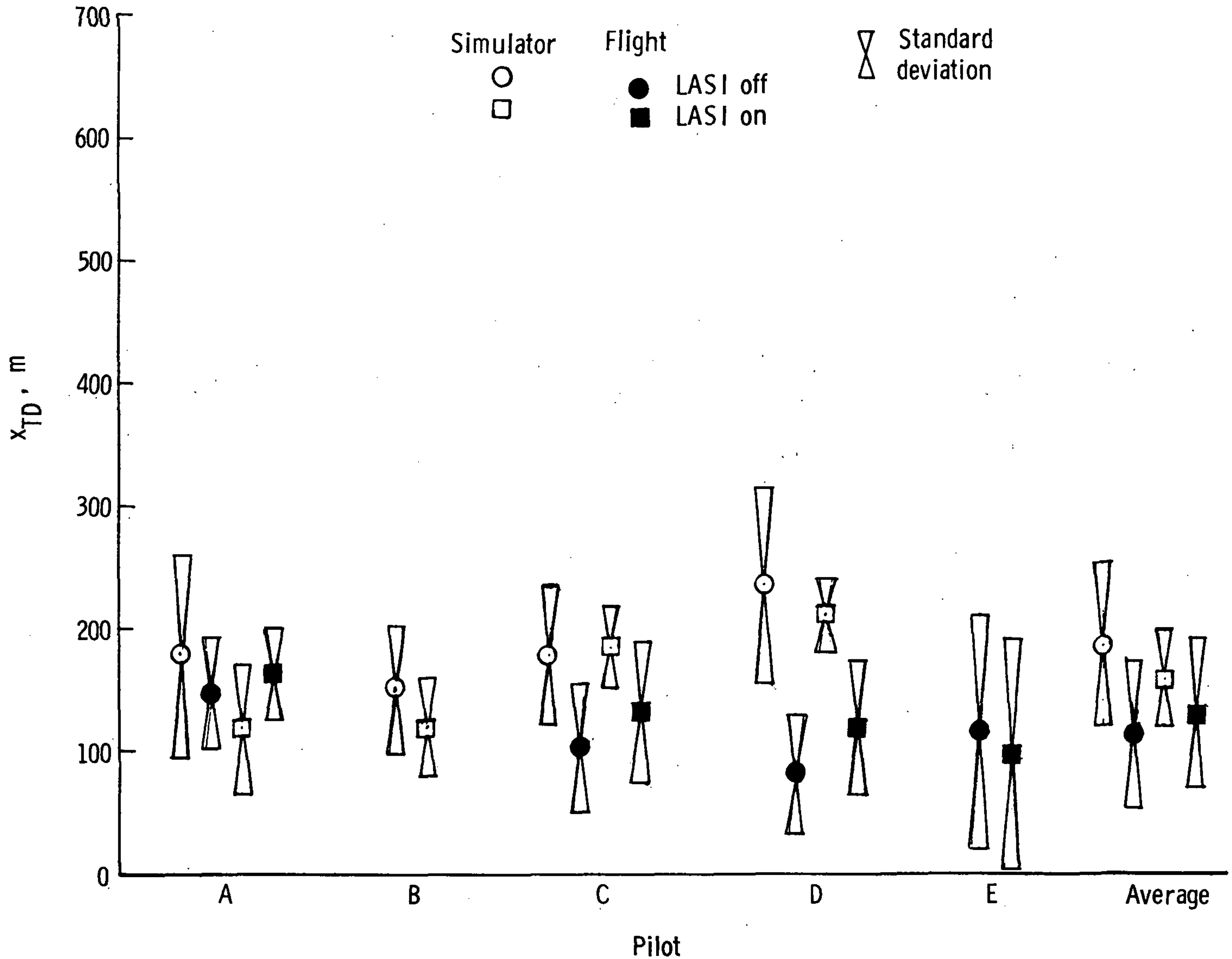

Figure 13.- Runway touchdown position in simulator and in flight with LASI off and on.

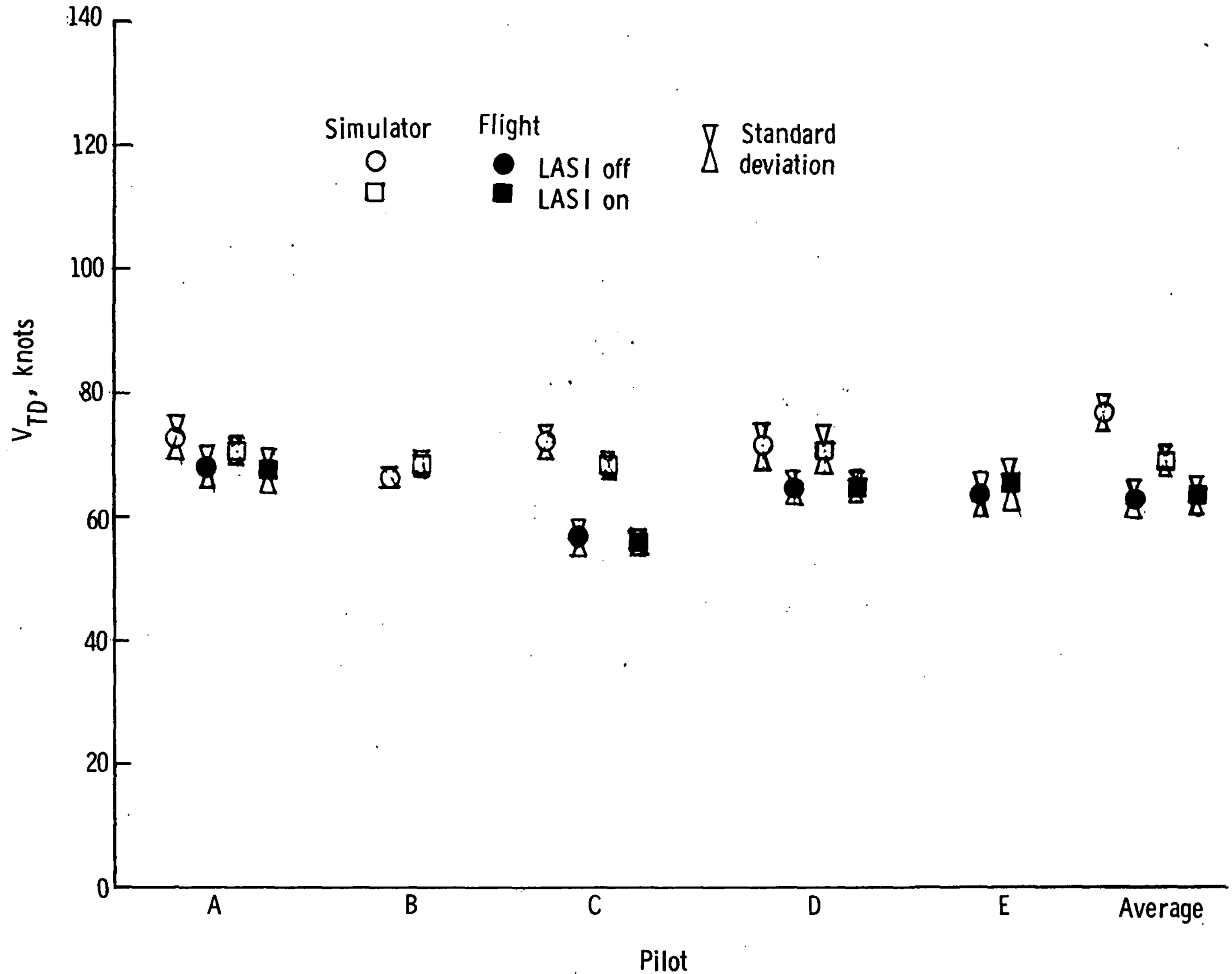

Figure 14.- Touchdown airspeed in simulator and in flight with LASI off and on.

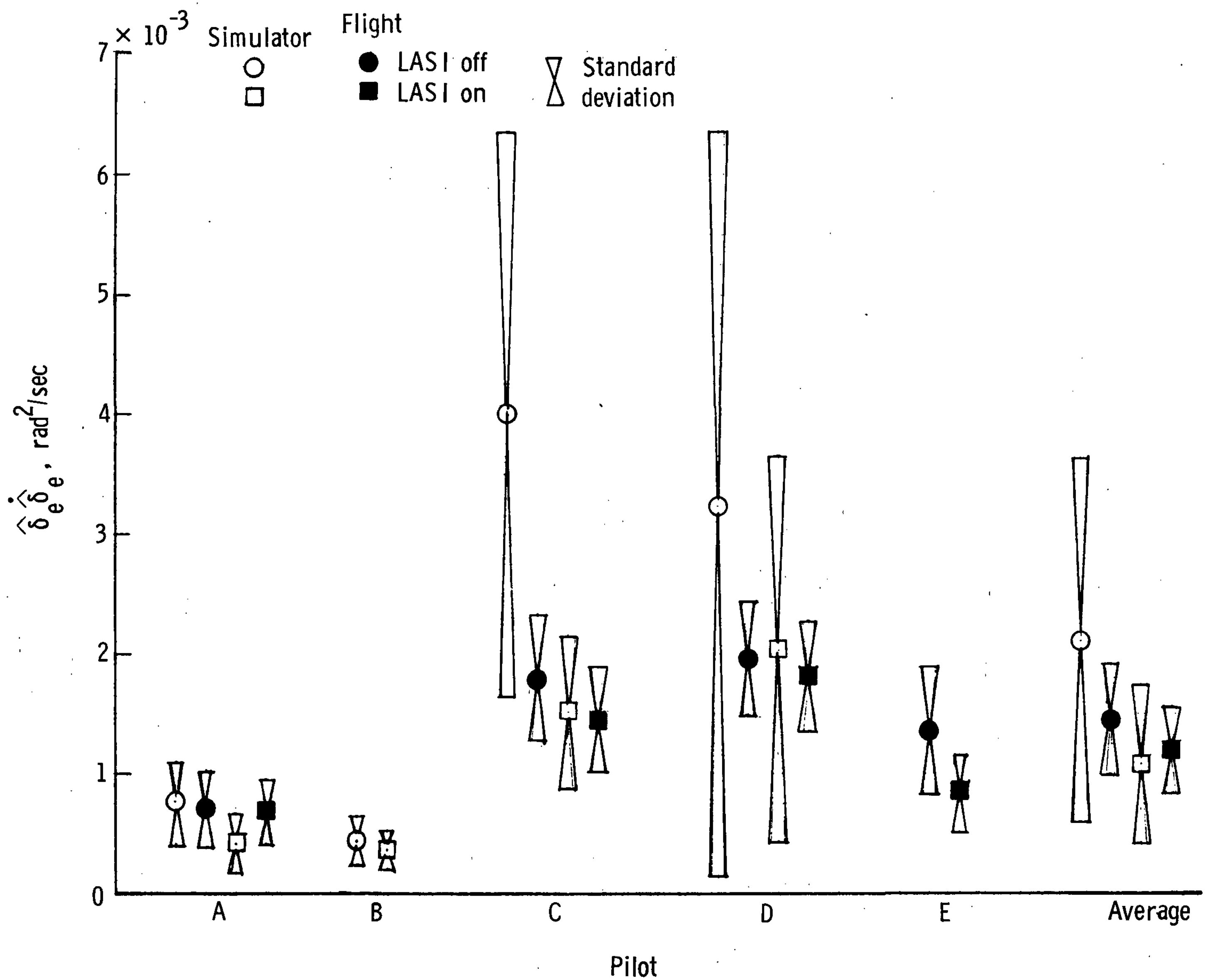

Figure 15.- Elevator control activity in simulator and in flight with LASI off and on.

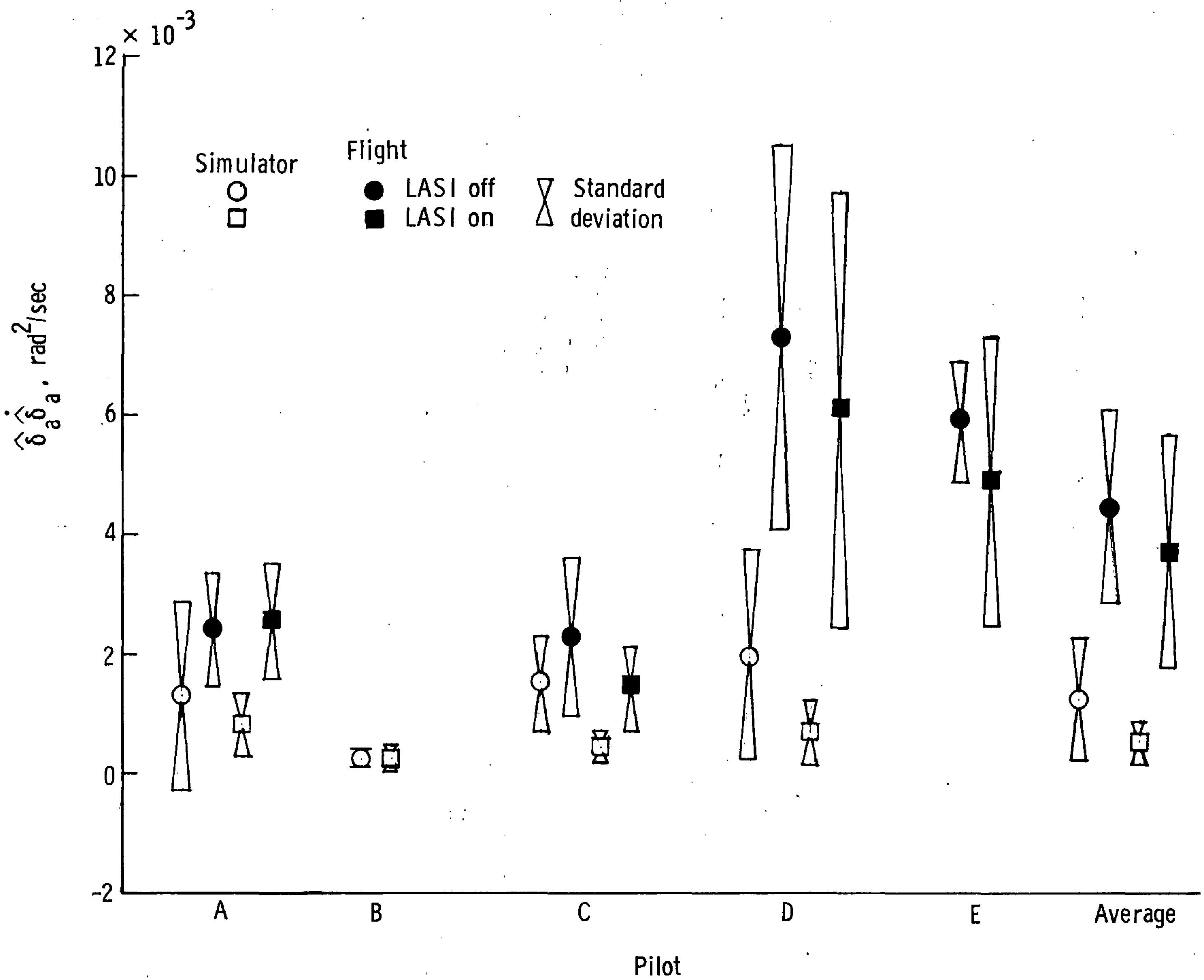

Figure 16.- Aileron control activity in simulator and in flight with LASI off and on.

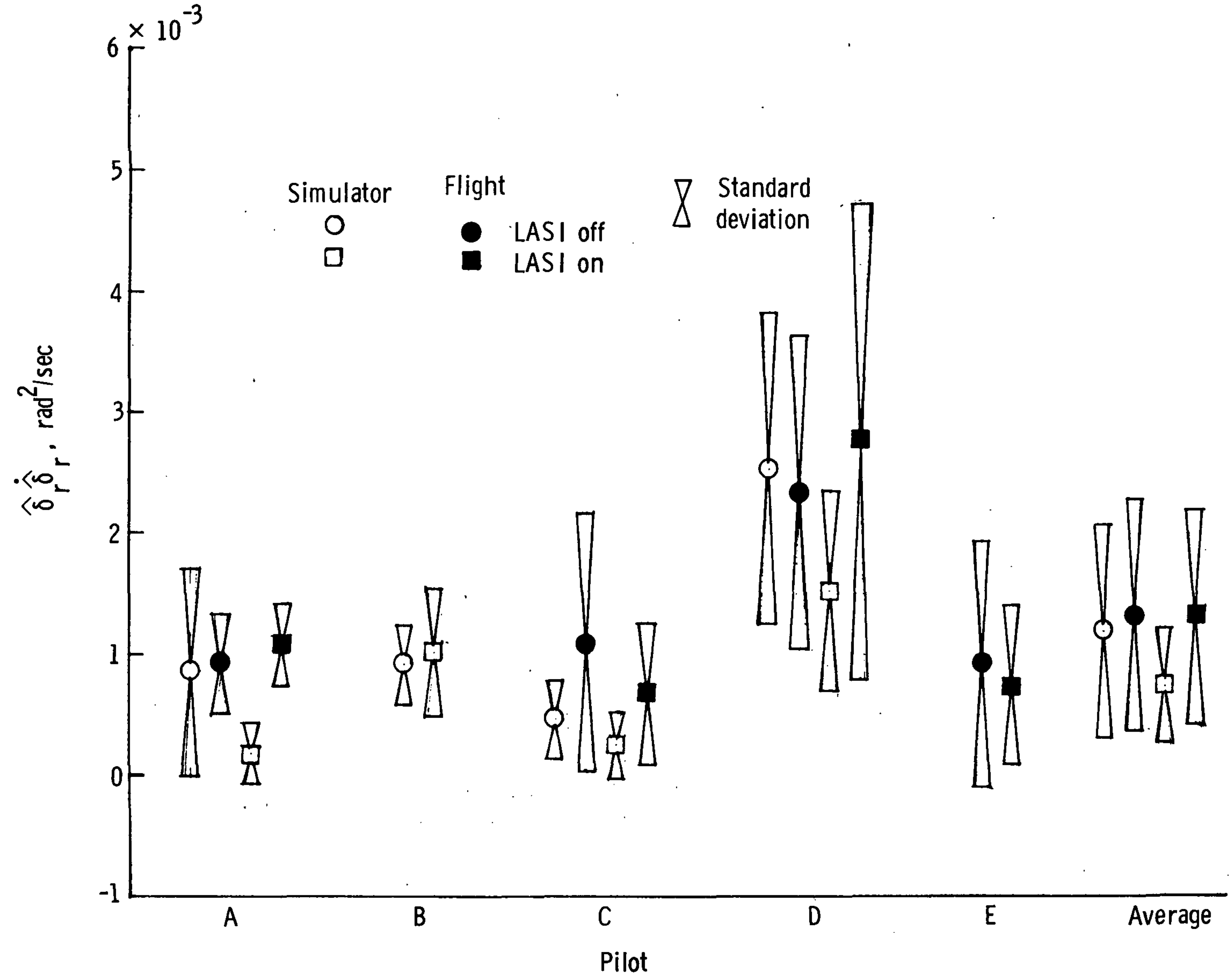

Figure 17.- Rudder control activity in simulator and in flight with LASI off and on.

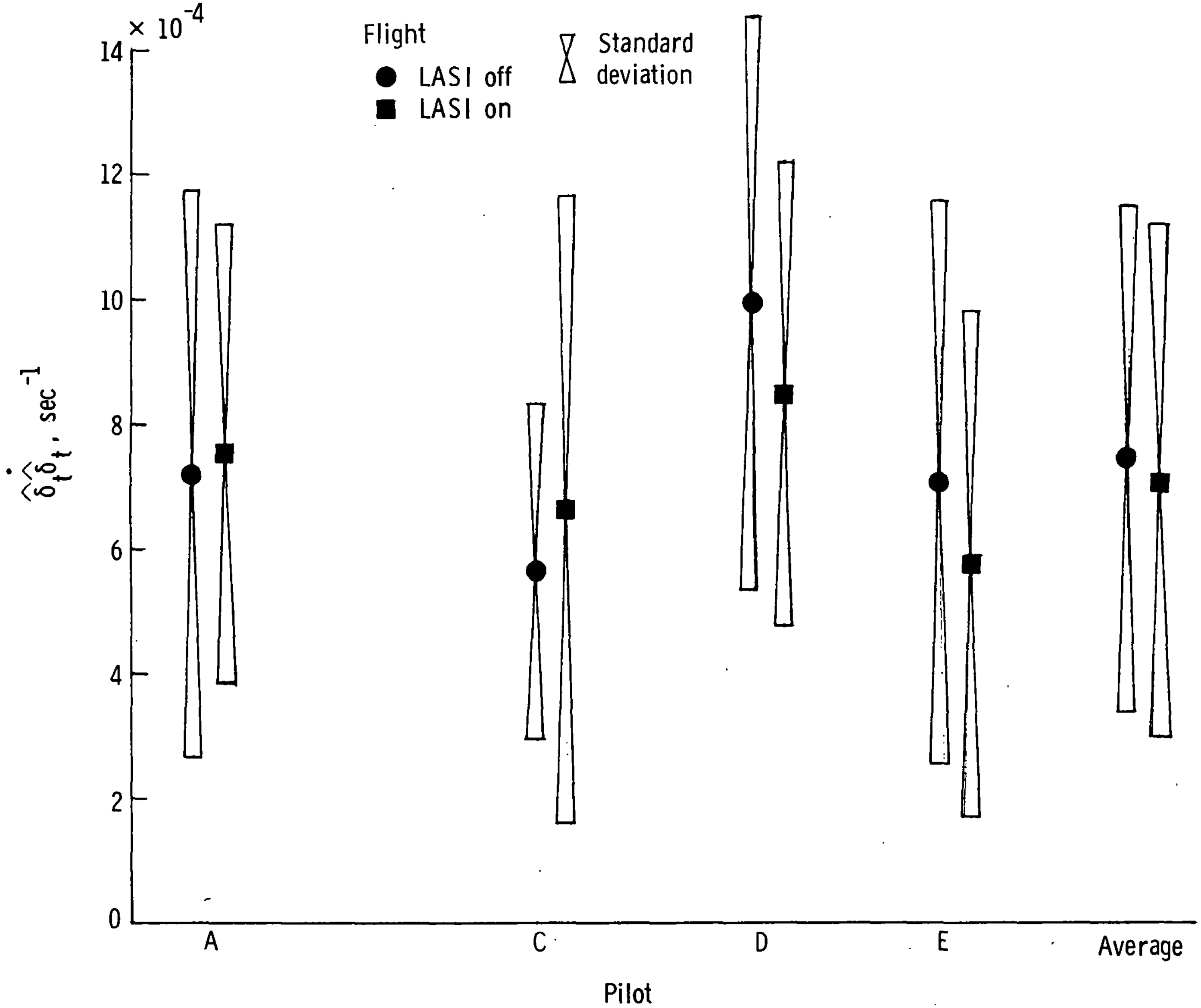

Figure 18.- Throttle control activity in flight with LASI off and on.

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15. Supplementary Notes

16. Abstract

A head-up general aviation landing aid called a landing site indicator (LASI) was tested in a fixed-base, visual simulator and in an airplane to determine the effectiveness of the LASI. The display, which had a simplified format and method of implementation, presented to the pilot in his line of sight through the windshield a graphic representation of the airplane's velocity vector. In each testing model (simulation or flight), each of 4 pilots made 20 landing approaches with the LASI and 20 approaches without it. The standard deviations of approach and touchdown parameters were considered an indication of pilot consistency. Use of the LASI improved consistency and also reduced elevator, aileron, and rudder control activity. Pilots' comments indicated that the LASI reduced work load. An appendix is included with a discussion of the simulator effectiveness for visual flight tasks.

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