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# PREVENTION OF AIRCRAFT LOSS OF CONTROL USING A SIMPLE HEAD-UP DISPLAY

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16. Abstract

To evaluate the concept of a simple head-up display (HUD) as an aid to noninstrument-rated pilots encountering reduced flight visibility conditions, two versions of such a display were flown by six pilots. The subject pilots were pretested to insure that they could not perform standard maneuvers when outside visual reference and panel attitude instruments were obscured leaving only the altimeter, airspeed indicator, gyroscopic direction indicator, gyroscopic rate-of-turn/slip-skid indicator and clock. Given either of the HUD instruments and a partial panel of basic instruments, plus a brief indoctrination in the use of the HUD, the pilots showed marked improvement in preservation of aircraft control. The opinions of expert observers suggest that, with a few hours of additional training, inexperienced pilots would be able to employ a simple HUD with a further improvement of aircraft safety when penetrating adverse weather.

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# INTRODUCTION

## Purpose

The purpose of this project was to evaluate the concept of a simple head-up display (HUD) employing a synthetic horizon, an aircraft reference, or other attitude indicators in the pilot's forward line of vision as an aid to the inexperienced pilot who loses VFR reference and becomes unable to fly straight and level or to change course successfully to withdraw from an area of reduced flight visibility.

## Background

FAA accident statistics show that inadvertent penetration of IFR weather conditions by a noninstrument-rated pilot constitutes a severe hazard. A flight originating in VFR weather may encounter industrial haze, cloud buildup, dark night, or other conditions in which lower level vision is so restricted that the pilot, lacking adequate experience, currency, or panel instrumentation, is unable to maintain adequate control of the aircraft.

When horizon and lower visual reference are lost in the three-dimensional world of flight, centrifugal force often replaces gravity in such a way that inner-ear sensations cannot be trusted. Flying seat-of-the-pants can quickly lead to illusions which in time produce disorientation, possible vertigo, or a graveyard spiral. Disorientation resulting from loss of ground plane visual reference in the presence of illusory gravitational sensations can mean that the pilot cannot tell which way is up. For a pilot in a cloud, this can be fatal. Particularly, the situation of a predawn takeoff with patches of fog and low clouds presents a hazard in that the visibility on the ground appears better than in the air. Lakefront Airport at New Orleans has been the site of several documented accidents of this general sort. On the runway, conditions may have appeared to be good VFR. Upon taking off out over the lake in the presence of haze or fog, the pilots suddenly enter atmosphere through which sky, horizon, and lake appear indistinguishable, leading to loss of control.

With all outside visual reference gone, the inexperienced pilot either is unable to fly on instruments or, as previous analyses have indicated, refuses to observe or accept the instrument information displayed when these readings conflict with his senses. If the disoriented pilot actually does make a recovery from a turn, bank, or spin, he has a very strong tendency to feel that he has entered a turn, bank, or spin in the opposite direction. These false sensations may lead to the graveyard spiral.

## Equipment

To determine different solutions on the effort, two types of simple head-up displays have been developed for use in general aviation aircraft. One type is known as the Attitude Baton (Figures 1, 2, 3, and 4). This system is self-contained and employs an electromechanically controlled "T" bar (baton) to represent the horizon. The baton is set in the pilot's line of forward vision so that it approximately overlays the external horizon. Pitch and roll information, from a self-contained gyro, drives the baton so that a deviation from either wings-level or nose-level attitudes is readily noted while the pilot is head-up and searching in a cloud for the actual horizon. A fixed bar is positioned in the rear to indicate the aircrafts reference. This equipment can be provided in the aircraft without encountering major installation problems.

The second type of HUD developed for test of the concept in general aviation aircraft is called the See-Thru Display (Figures 5, 6, 7, and 8). Placed in the pilot's line of forward vision, this device integrates the rate of roll and rate of turn so as to provide a presentation of what the plane is doing. Roll is shown by the movement of a miniature aircraft outline. When the aircraft symbol has left wing down, this indicates that the actual plane's left wing is down. Pitch is given by lighting one of two arrows: nose up is shown by an up-pointing arrow; nose down by a down-pointing arrow. Like the Attitude Baton, this See-Thru Display can be used in different aircraft without major installation problems.

The major question remaining to be answered was how well displays of these types accomplish the purpose of aiding the VFR pilot to remain in a safe or prescribed attitude and still maintain forward visibility through the windscreen when he encounters IFR visibility conditions.

## Test Procedures

The principal test series was conducted in flight, employing a small general-aviation-type aircraft (Figure 9) and subject pilots of limited experience and qualifications.

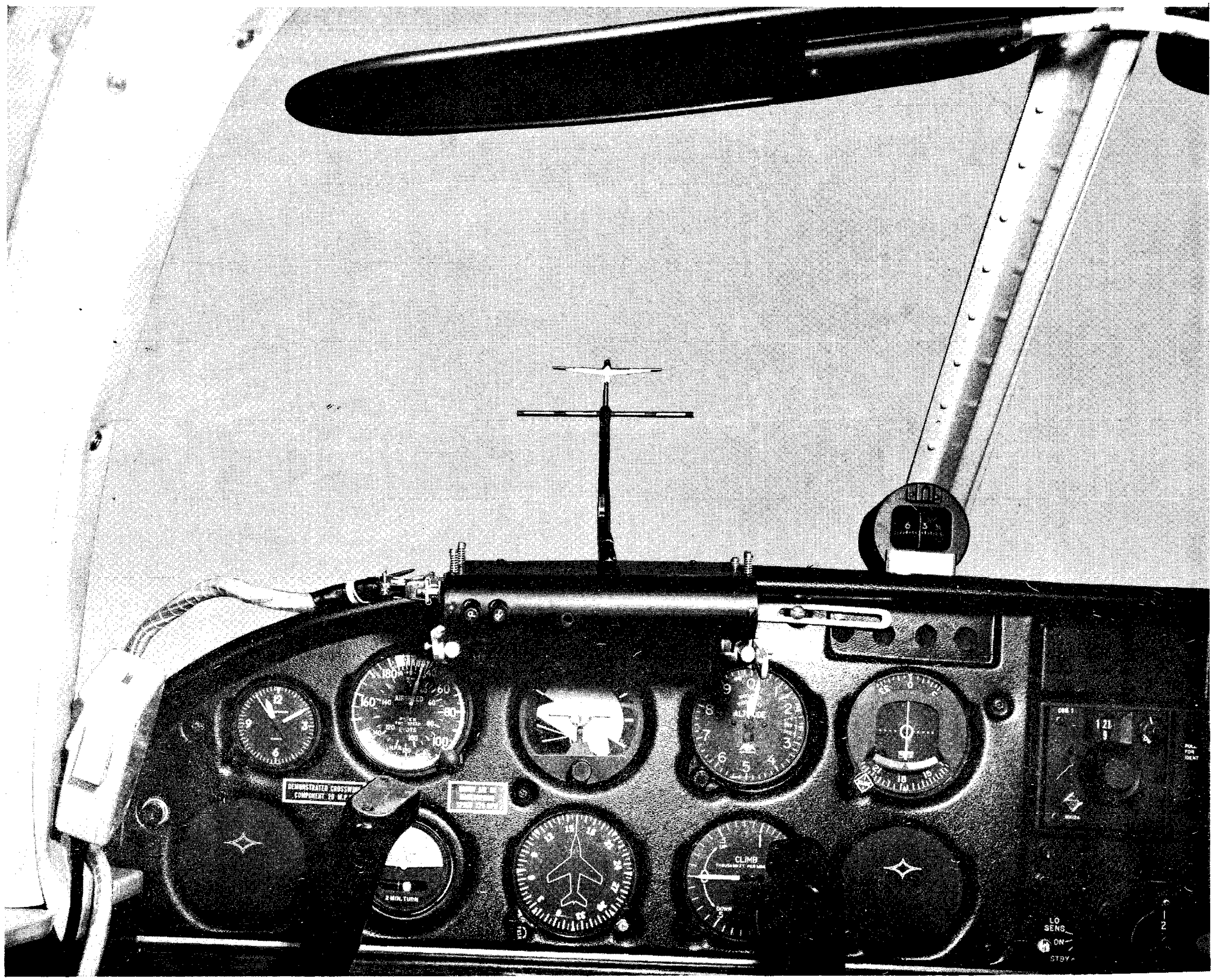

FIG. 1 ATTITUDE BATON HEAD-UP DISPLAY WITH AIRCRAFT REFERENCE

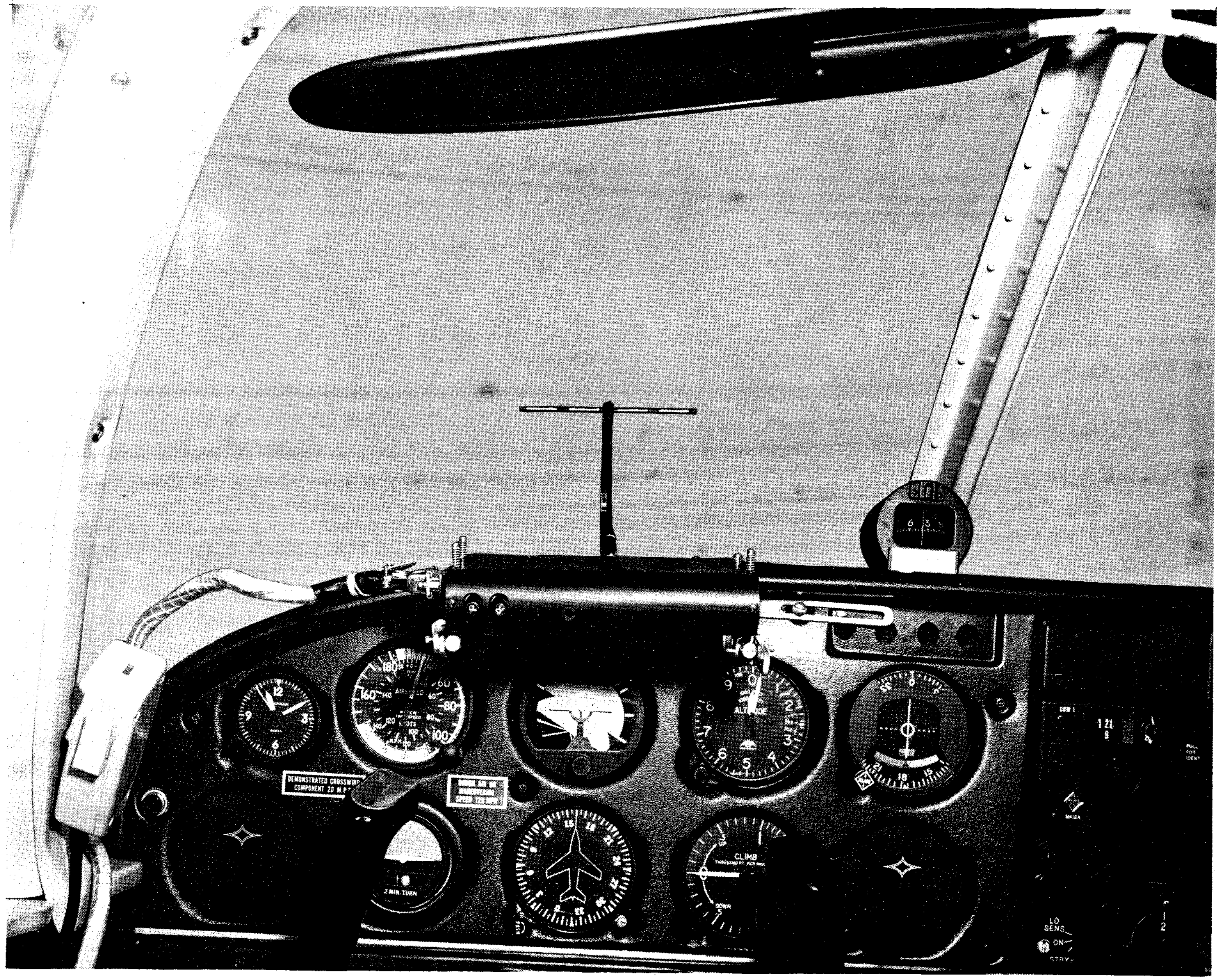


FIG. 2 ATTITUDE BATON HEAD-UP DISPLAY WITHOUT AIRCRAFT REFERENCE

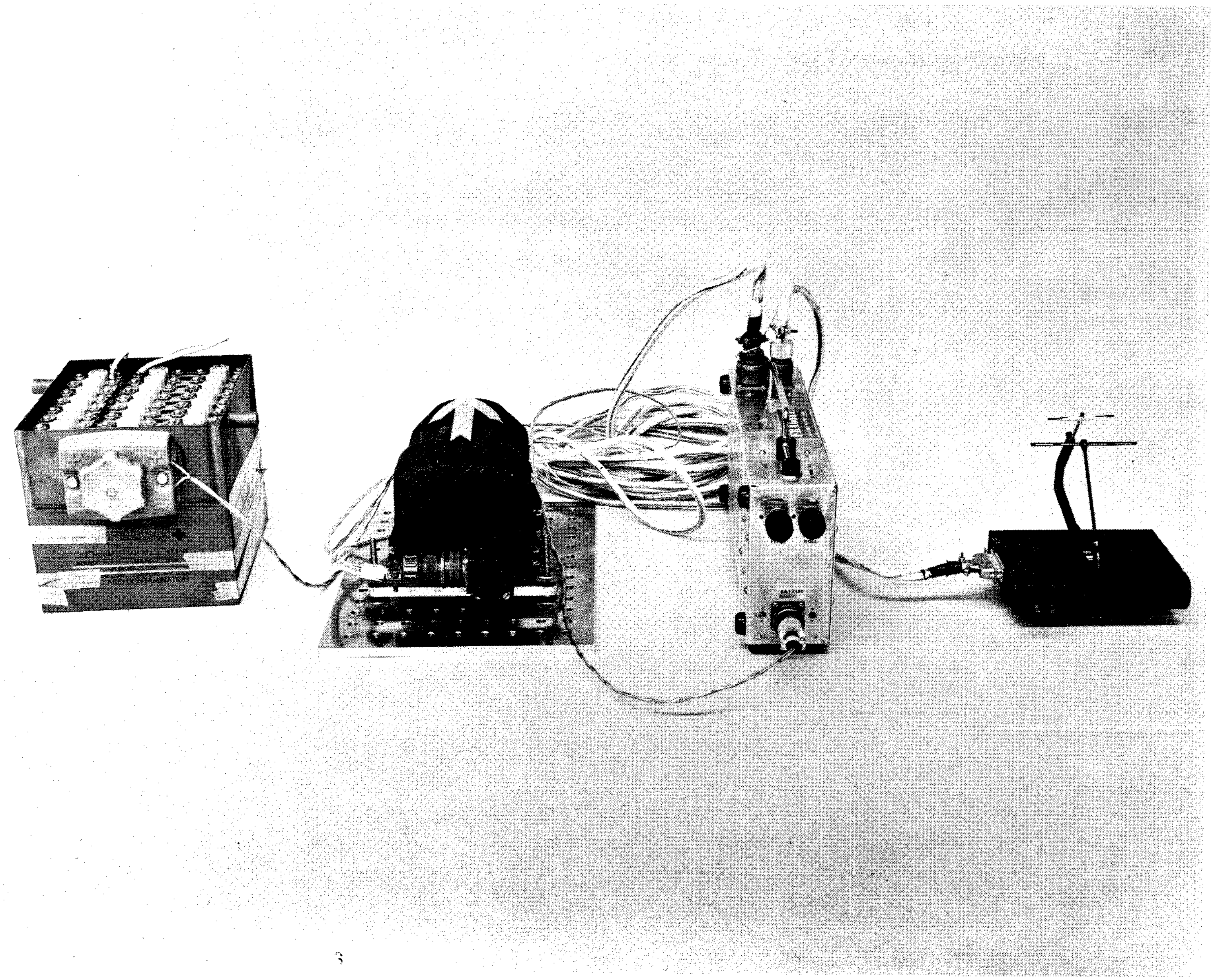

FIG. 3 ATTITUDE BATON DISPLAY SYSTEM

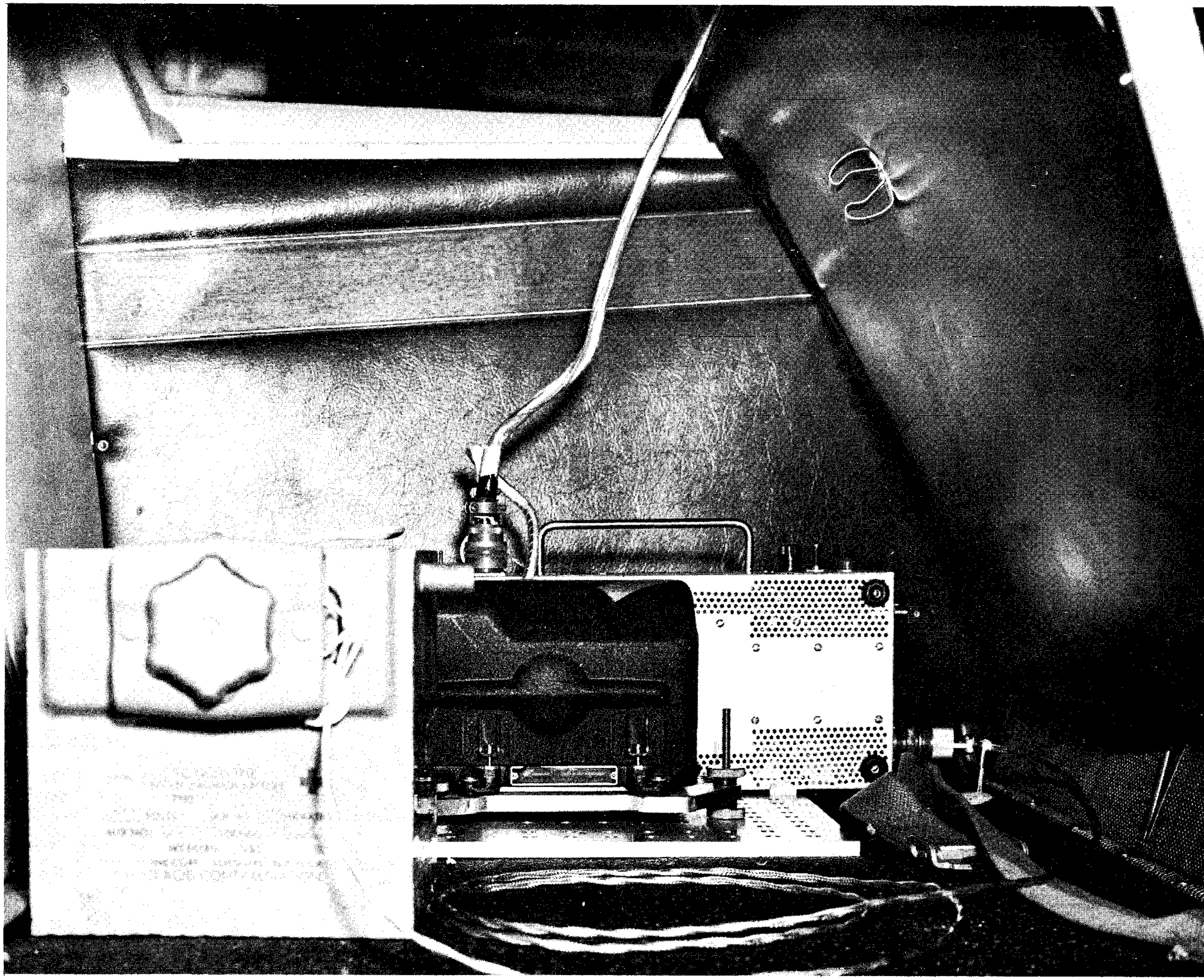

FIG. 4 ATTITUDE BATON EQUIPMENT IN BAGGAGE COMPARTMENT OF PROJECT AIRCRAFT

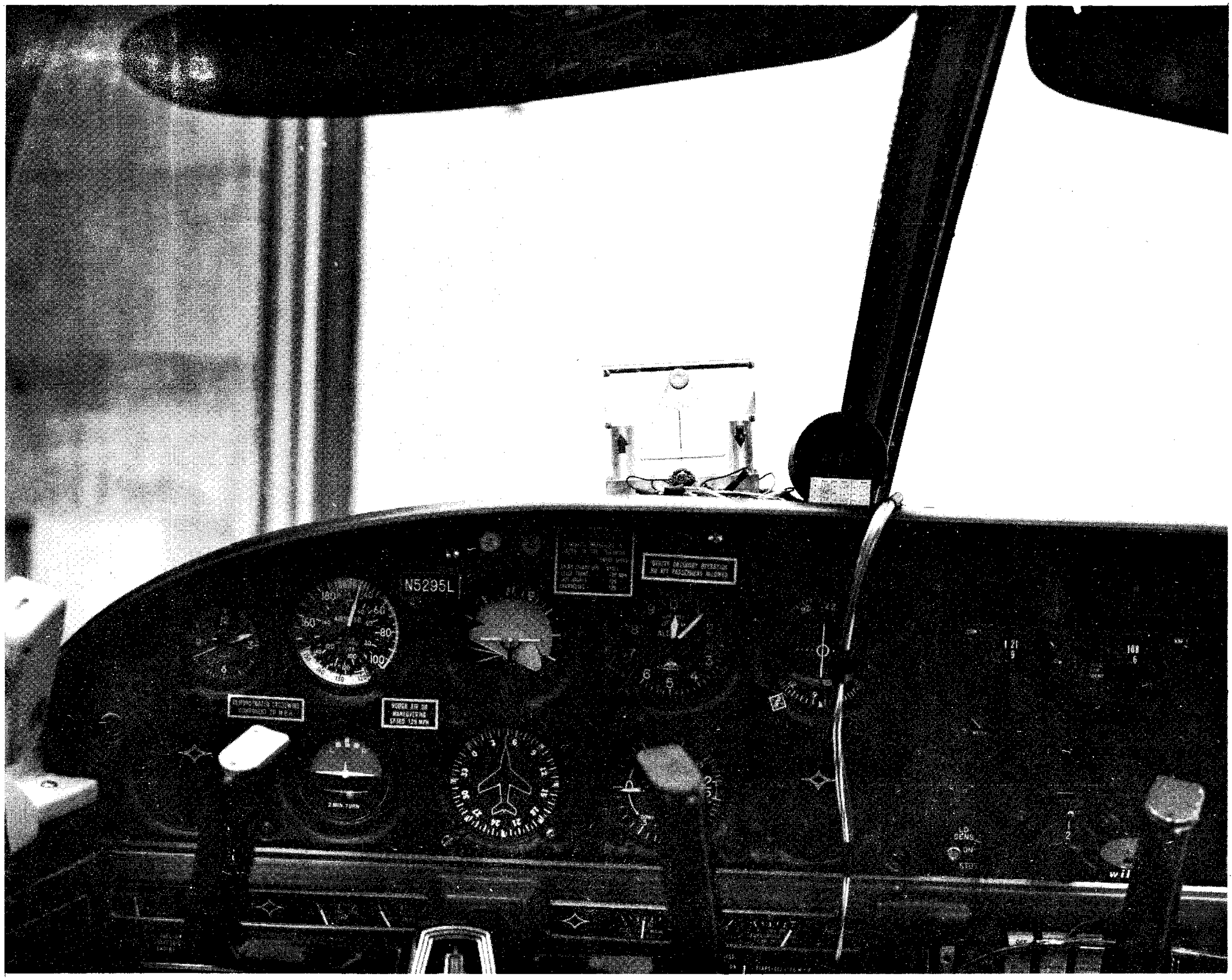


FIG. 5 SEE-THRU HEAD-UP DISPLAY IN PROJECT AIRCRAFT

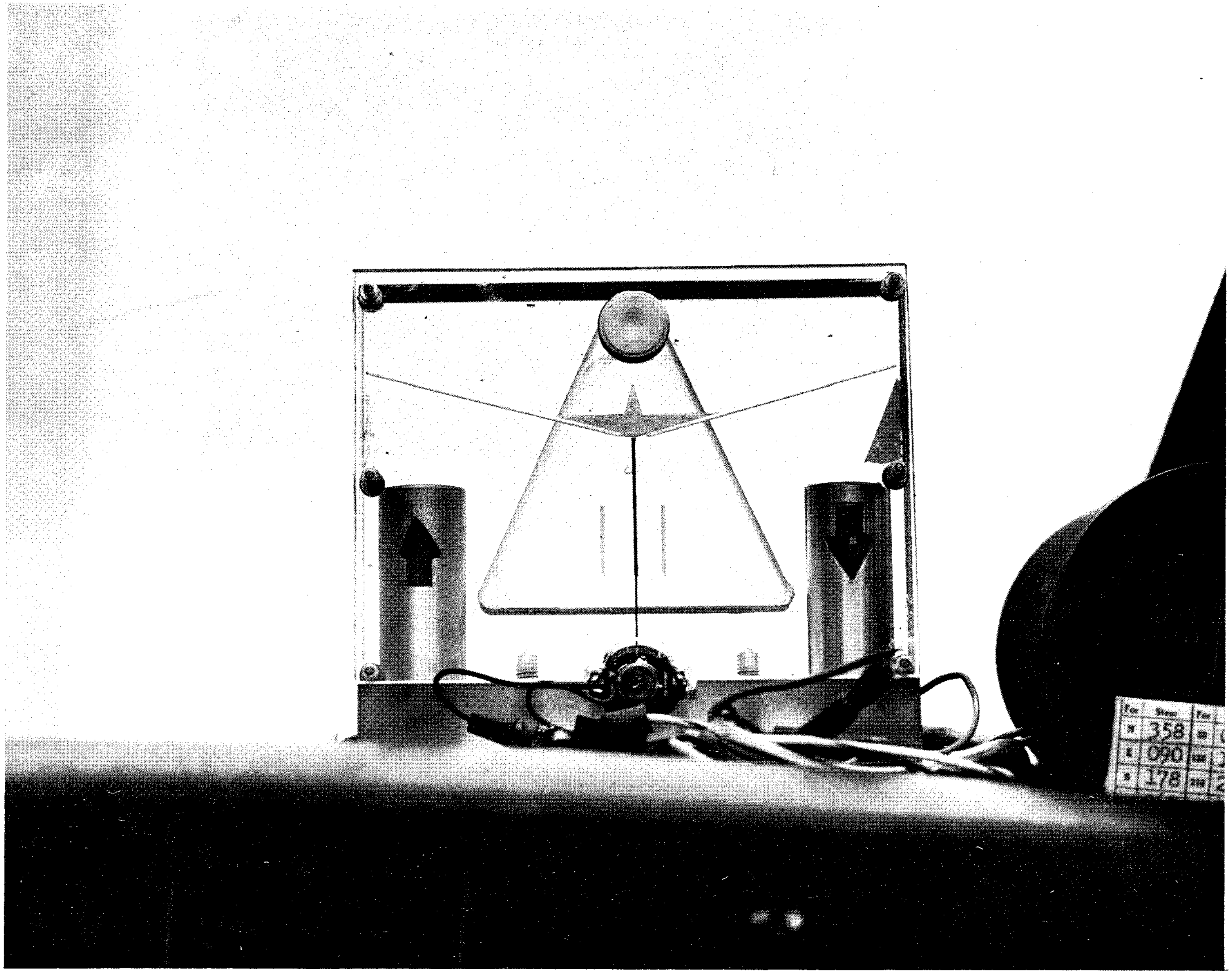


FIG. 6 CLOSE-UP VIEW OF SEE-THRU DISPLAY

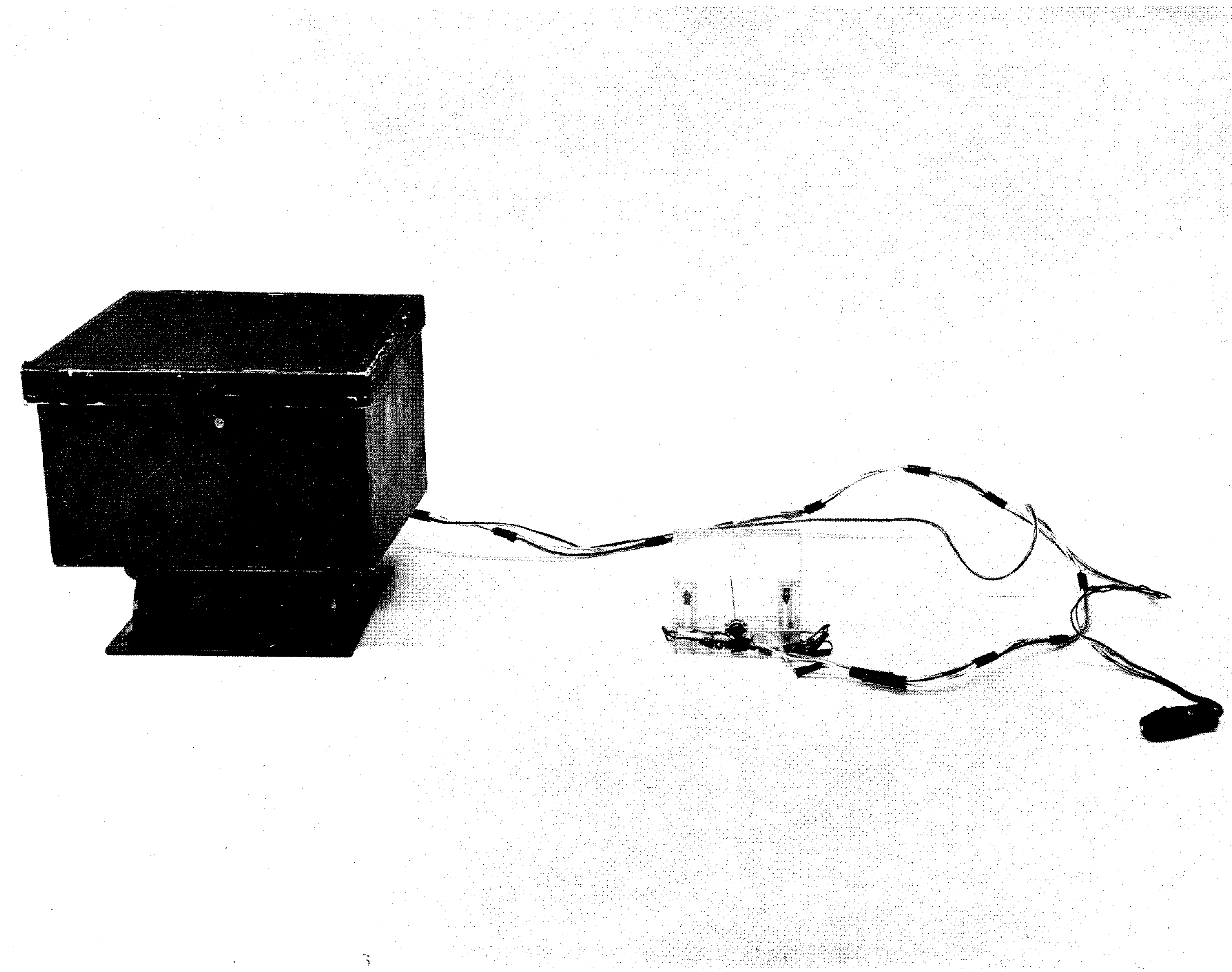

FIG. 7 SEE-THRU DISPLAY SYSTEM

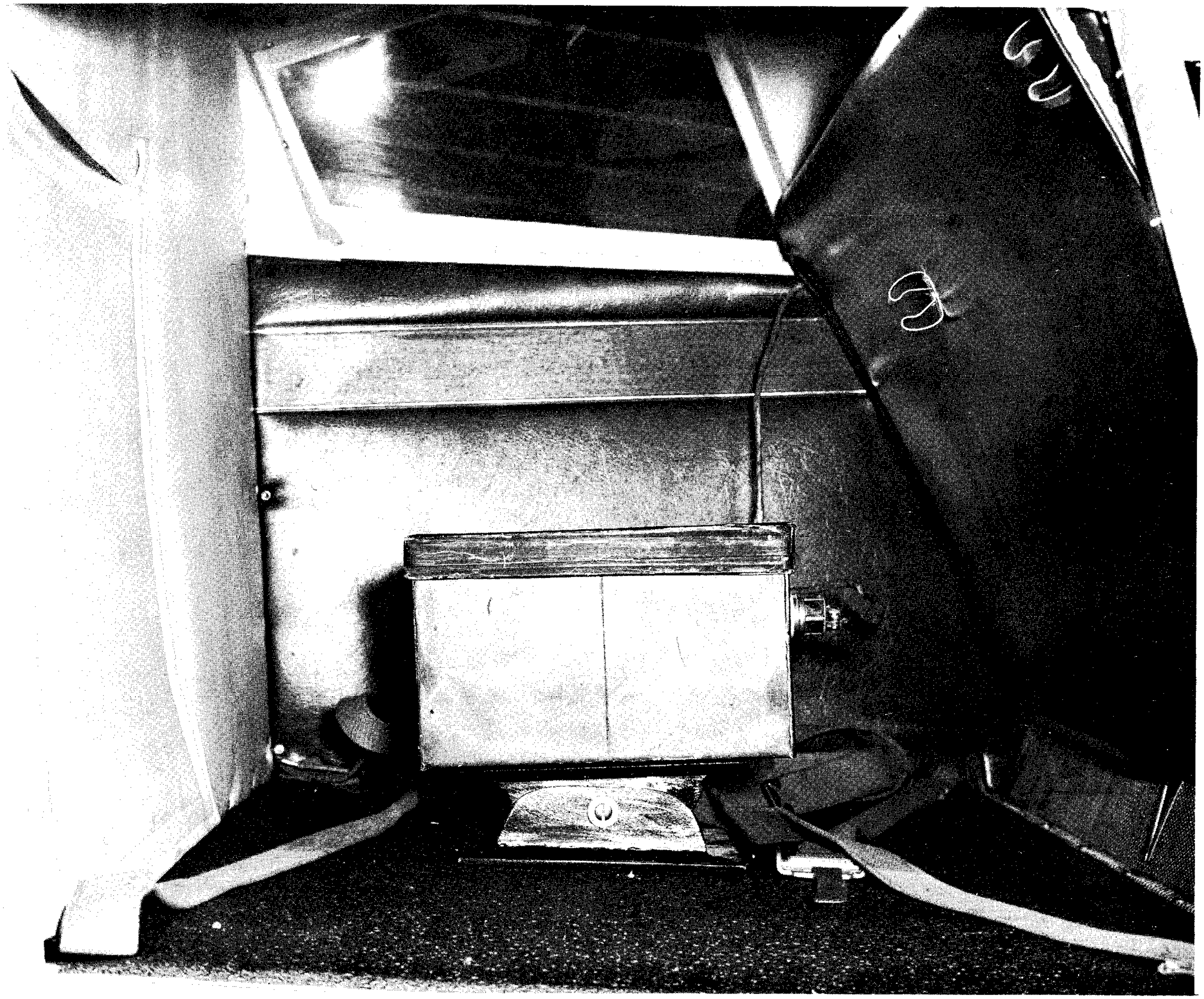

FIG. 8 SEE-THRU EQUIPMENT IN BAGGAGE COMPARTMENT OF PROJECT AIRCRAFT

FIG. 9 PA-28 CHEROKEE, 180 HP, PROJECT AIRCRAFT

Flights were made with a subject pilot in the left seat, a National Aviation Facilities Experimental Center (NAFEC) flight operations safety pilot in the right seat, and the experimenter-observer in the rear seat. Flights originated at NAFEC and employed a beacon transponder and separation service by NAFEC Approach Control.

There were two main phases--subject selection by flight screening and test of the two simple HUD's.

Phase I began with indoctrination and familiarization of the candidate subject pilots in the project aircraft. Following takeoff and departure to the operating area under control of the safety pilot, the safety pilot insured that the candidate could fly the aircraft satisfactorily VFR, that he understood and used correctly the legally required minimum instruments, (FAR 91.33(b) requires for VFR day flight: airspeed indicator, altimeter, magnetic direction indicator, plus engine, fuel, and landing gear position indicators, if the aircraft has retractable landing gear.), and that the special test procedures were understood. In VFR and simulated IFR flight during this project, the gyroscopic bank and pitch indicator and the vertical speed indicator were masked. Hence, only the legally required instruments plus the gyroscopic direction indicator and the gyroscopic rate-of-turn/slip-skid indicator were available. If the instruments were limited to the minimum as described above under FAR 91.33(b), it would be unusual for any pilot, even though instrument rated, to maneuver an airplane without the use of some outside reference such as the ground, cloud situation, or horizon. Following initial indoctrination and a short period of demonstration VFR flight (approximately 40 minutes), the visibility limiters were put in place.

Visibility limiters consisted of sheets of amber plastic placed over the aircraft windows forward and to the subject pilot's sides, plus blue plastic goggles for the subject pilot. The result of these limiters was that the subject pilot could see nothing of the earth below or of the horizon ahead; he was in IFR conditions similar to flight in a cloud. At the same time, the safety pilot could see outside, since he was not wearing the blue goggles, and the observer in the rear seat had unimpaired vision to the sides.

Now that the candidate subject pilot was IFR, the safety pilot required him to execute elementary maneuvers and straight and level flight to ascertain the candidate's ability to fly and maintain attitude control without earth-horizon reference, and without attitude or vertical speed instruments. The elementary maneuvers consisted of turns to a heading, and gentle climbs and descents to an altitude, followed, if successfully executed, by a 360° or longer turn with a rollout onto a heading.

Based on the candidate subject pilot's performance, a decision was made to discharge him, or to retain him as a Phase II subject. The criterion of decision was the adequacy of flight control; i.e., if flight control was good or excellent, he was discharged; if poor, or such as to require intervention by the safety pilot, he was retained. This completed flight Phase I, and the safety pilot returned and landed the aircraft at NAFEC.

Phase II was conducted with the selected subject pilots who had shown a tendency to become disoriented or to lose attitude control when deprived of visual reference and the attitude gyro and vertical speed indicator. The Phase II flight began the same as Phase I, except that the HUD was in place. Upon reaching the operating area, the safety pilot indoctrinated the subject to use the HUD. He explained, demonstrated, and guided the subject to understand the display. The test then followed, as outlined in the Appendix, with a repetition of the maneuvers that caused poor flight performance by the subject when he did not have the HUD. If the subject demonstrated adequate control using the HUD, additional, more difficult tasks were required to enable the experimenter to arrive at a decision as to the value of the HUD. This process was not pushed to extremes of certain loss of control. Rather, the safety pilot gradually increased the stringency of the requested flight tasks, and terminated the process when it appeared that the control-guidance limits of the pilot-display had been reached.

Following the first HUD test, a change in the HUD was made. Changes were of two kinds, either degree or whole display. By degree is meant the removal of one feature of a HUD. By whole display, a replacement of one HUD type with another is implied.

A degree change was made on the Attitude Baton by removing the rear baton (aircraft symbol) (Figure 2). That gave two levels of baton HUD: two-baton HUD and HUD with only horizon reference in pitch and roll.

Replacement of the See-Thru Display was made after a flight break at a waystop by installation of the Attitude Baton HUD.

Six subjects were selected for the Phase II series of tests (Table 1). Each subject flew all displays. Obviously, this procedure leaves open the possibility that the subject learned and became more proficient in aircraft control due to the repeated test experience. Hence, it was necessary at the conclusion of Phase II flight tests to replicate briefly the Phase I screening maneuvers that had been found to reveal control difficulty. Again, this test was conducted without outside visual reference, gyro instruments, or HUD.

TABLE 1. - SUBJECT PILOT SELECTION

| Subject | Age | Flight Hours | Phase I Time (Hours) |
|---|---|---|---|
| 1 | 37 | 250 | 1.3 |
| 2 | 35 | 48 | 1.4 |
| 3 | 38 | 100 | 1.3 |
| 4 | 33 | 60 | 1.2 |
| 5 | 54 | 48 | 1.2 |
| 6 | 30 | 45 | 1.4 |

# DISCUSSION

## Results

The results of this project will be reported in three parts. First, the screening outcome of Phase I will be summarized. Next, the Phase II flight tests of the two HUD's will be reported and, finally, the replication of the Phase I screening maneuvers will be tallied.

It will be recalled that the purpose of Phase I was to identify a sample of private pilots who were not instrument rated and who demonstrated difficulty of flight control in IFR visibility conditions. Of course, it was necessary to conceal from the pilot candidates the fact that good flight performance in IFR conditions was disqualifying in regard to further participation in the project. They were told simply that this was a test of the pilot's ability to fly an aircraft with the minimum legal instrumentation. Twenty-five subject candidates were drawn from a variety of NAFEC organizations and occupational specialties. Age varied from 32 to 54 years, and previous flight hours ranged from 45 to 400.

Of the 25 candidates tested, 19 demonstrated "intelligent ability to maintain aircraft attitude in basic maneuvers," and "constructive use of the available instrumentation, which consisted of altimeter, airspeed indicator, directional gyro, turn indicator and clock." Put in the simplest terms, the remaining six candidates "lost the airplane," necessitating safety pilot intervention. Thus, the primary result of Phase I was the selection of six pilots, all with limited instrument experience and total flight times ranging from 45 to 250 hours. Table 1 summarizes the length of flight time each of the chosen six spent in Phase I, along with data describing the subject.

The Phase I results showed approximately one-fourth of the candidates to be pilots who needed more training, more visual reference, and/or more effective instruments if they were to be "safe" in IFR conditions. This demonstration ratio of one-fourth of limited experience, noninstrument pilots may or may not be typical of the capability of the larger private pilot population. The general aviation accident statistics on inadvertent IFR penetration suggest, however, that it may be reasonably representative.

Phase II consisted of four major parts: (1) indoctrination with the See-Thru Display, (2) test of the utility of the See-Thru Display, (3) indoctrination with the Attitude Baton, and (4) test of the utility of the Attitude Baton. Needless to say, there are no results to report covering the two indoctrination periods. Instruction and demonstration were continued until the safety pilot and rear seat experimenter-observer were satisfied that the subject pilots understood the display indications. During indoctrination, the subject pilots were not asked to demonstrate use of the HUD information, because that was to be the critical part of the immediately succeeding part of the test. Table 2 summarizes the results of the two tests of display utility and gives the flight times logged by the subject pilots in these tests.

TABLE 2. - TEST OF THE TWO HEAD-UP DISPLAYS

| Subject | Rating Using See-Thru Display | Rating Using Attitude Baton | Phase II Flight Hours |
|---|---|---|---|
| 1 | Fair Improvement | Fair Improvement | 1.5 |
| 2 | Major Improvemnt | Fair Improvement | 1.5 |
| 3 | Major Improvement | Major Improvement | 1.6 |
| 4 | Fair Improvement | Fair Improvement | 1.5 |
| 5 | Major Improvement | Major Improvement | 1.6 |
| 6 | Fair Improvement | Major Improvement | 1.6 |

The ratings given in Table 2 show that the well-qualified flight control team (safety pilot and experimenter-observer) found either major improvement or fair improvement in all 12 pilot-display instances. A rating category kept in mind during the tests, one that might be labeled "completely competent" or "would like to fly with this pilot," was not given to any of the subjects. But then, the six had already demonstrated marked difficulty in executing basic maneuvers with the minimum instrumentation that had sufficed to support adequate flight control for the majority test in Phase I. Hence, the Phase II panel of subjects represented a less capable pilot group and should not necessarily have been expected to come all the way up to a superior rating on the basis of about an hour of familiarization with a novel display.

The primary finding is that all six pilots showed improvement in each display test. This improvement is impressive in the opinion of the raters because of the brief familiarization time. If improvement can be shown on the basis of 1 hour of experience, it may be likely that 2 or 4 or some other small number of added hours of training would produce a fully competent test performance. This remains to be settled in future tests.

The differences between ratings achieved with the Attitude Baton and See-Thru Displays are not of commanding significance. They appeared to be of the order that would be expected through sampling variations or other chance factors. Hence, the primary result is the uniform and detectable improvement in flight performance found with either HUD.

Following test of flight control using the Attitude Baton, a change was made by removing the aircraft symbol. That left a single baton in view, one that approximately overlay the actual horizon. The result of this change was that the pilots were forced to use the sloping top on the instrument panel or the forward windscreen frame as a reference. The baton representing the horizon moved in the maneuvers, and this motion was judged, it seemed, primarily by reference to the padded top of the instrument panel. However it was done, the quality of the information obtained from the single baton appeared to be degraded. Flight control became less accurate in both pitch and roll, and the consensus judgment of the safety pilot and experimenter-observer was that aircraft attitude control became unsatisfactory or worse.

Provision of a single head-up reference to give a synthetic horizon has often been suggested as an aid in low-weather landing approaches. The results of this test do not reflect on the possible utility of a single horizon reference for this purpose. All that should be inferred at present is that the inexperienced pilots used in this test could not use the single baton to perform maneuvers to the same degree of success they had demonstrated with a two-baton display.

The final part of the results came from the replication of Phase I screening tests. This terminal repeat was necessary to insure that any improvement shown in Phase II was actually due to the added HUD, rather than to added time in the aircraft and repeated practice in the maneuvers.

When the final tests were conducted, it was found that all six subject pilots reverted to approximately their Phase I performances, which in all cases were inferior to their Phase II performances with either HUD. In the judgment of the safety pilot-experimenter team, all six were unable to maintain adequate control of the aircraft by reference to the basic instruments.

## SUMMARY OF RESULTS

Pretest of 25 pilot candidates produced a subject panel of six noninstrument-rated pilots, all of whom showed marked difficulty in control of the aircraft in simple maneuvers executed without outside visual reference or panel attitude instruments. Each of these pilots was given familiarization with the See-Thru Display, and was then tested in flight control using that simple HUD. Next, each pilot was familiarized with the Attitude Baton and tested with that HUD. The results were marked improvement in flight control with either simple HUD. When the aircraft reference was removed from the Attitude Baton Display, however, the success of maneuvers decreased substantially. After the subjects had shown improvement by use of the simple HUD's, the earlier screening procedures were repeated. The outcome of this test was similar to the initial screening. Aircraft control was definitely unsatisfactory. This indicates that the HUD effect was genuine and not simply a reflection of increased practice in flight control.

# CONCLUSIONS

Based on screening tests of 25 pilot candidates and subsequent flight tests with two versions of a simple HUD, to test the concept as an aid in reduced visibility, with six pilots who had shown difficulty in aircraft control under IFR conditions, it is concluded that:

1. There is a real need for an aid that a low-time pilot can use in changing course to get out of low visibility.

2. HUD's patterned on the concept of a simple aid to the inexperienced pilot provide marked improvement in safety of flight.

3. Only a brief period of familiarization is required to achieve improved flight control using a HUD.

4. The essential element of a HUD is that it provides an easy-to-read, real-world presentation in the pilot's normal forward viewing of the direction of flight.

5. The total of flight hours logged is not a good predictor of flight control performance for the noninstrument-rated pilot.

6. A basic HUD appears to be a feasible approach to the need for an aid to get out of low visibility.

# APPENDIX

## PROJECT FLIGHT TASK PROCEDURE

1. Indoctrinate and familiarize the subject pilot in the project aircraft as to information on the flight instruments (the attitude gyro, vertical speed, and the turn indicator will be blanked), aircraft power settings necessary for climbs, descents, slow speed, normal speed, and fast speed for the PA-28. The subject should fly the aircraft, after the project pilot has made the takeoff, until he is familiar with its handling.

2. Indoctrinate the subject pilot in the use of the designated HUD in VFR conditions, but with the attitude gyro, vertical speed, and turn indicators covered--uncover turn indicator if found necessary.

3. Inject the subject pilot into IFR conditions (amber glass - blue goggles) without outside references and with the attitude gyro, vertical speed, and turn indicators covered. Request the subject to fly the following flight maneuvers by reference to the HUD and the uncovered aircraft instruments:

a. Straight and level flight.

b. Shallow climbing turns to a predetermined altitude.

c. Shallow descending turns at a reduced power to predetermined altitude.

d. Normal turns of at least 180° left and right to within 20° of a preselected heading.

e. Recovery from the start of a power on spiral.

f. Recovery from the approach to a climbing stall.

g. The safety pilot will place the aircraft in an induced unusual attitude, and the subject pilot will be required to place the aircraft in a straight and level attitude using only his available uncovered instruments and his HUD.