A TACTUAL PILOT AID FOR THE APPROACH-AND-LANDING TASK -- INFLIGHT STUDIES

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ABSTRACT

A pilot aid -- a kinesthetic-tactual compensatory display -- for assisting novice pilots in various inflight situations has undergone preliminary inflight testing. The efficacy of this display, as compared with two types of visual displays, was evaluated in both a highly structured approach-and-landing task and a less structured test involving tight turns about a point. In both situations, the displayed quantity was the deviation $(\alpha_0 - \alpha)$ in angle at attack from a desired value α_0.

In the former, the performance with the tactual display was comparable with that obtained using a visual display of $(\alpha_0 - \alpha)$, while in the later, substantial improvements (reduced tracking error (55%), decreased maximum altitude variations (67%), and decreased speed variations (43%)), were obtained using the tactual display. It appears that such a display offers considerable potential for inflight use.

INTRODUCTION

The manual control of an aircraft during approach and landing is a relatively difficult task even under the best of conditions as is vividly illustrated by accident statistics. Approximately one-half of all aircraft accidents take place during this phase of operation despite its constituting only a brief portion of total flight time.[1]

The difficulties inherent in an accurate landing are primarily caused by the heavy demands placed on the pilot. He must simultaneously control both vehicle attitude, usually from visual cues outside the aircraft, and airspeed which he obtains via a cockpit display. This results in a division of visual attention -- a division which can be especially critical for novice pilots who lack the experience to use relevant pitch, inertial and aural cues.

It was hypothesized that if this division could be eliminated for a student pilot, then the following benefits would accrue:

1) His task would be simplified;
2) His performance would be improved; and
3) The number of accidents during the learning phase should be decreased.

The first two of these were evaluated via a preliminary inflight study in which information pertaining to airspeed was presented tactually to the pilot.*

DISPLAY DESCRIPTION

A control loop which is used by a pilot in making a final approach is shown in Fig. 1. The reference input is a desired angle-of-attack (α_D) which is, of course, intimately related to the desired approach airspeed. The feedback signal is the measured angle-of-attack (α), and the display input is simply the difference $\alpha_D - \alpha$.

The display consisted of a m... "finger" which was mounted in the head of the aircraft control stick shown in Fig. 2. A forward protrusion of the finger, such as is depicted in Fig. 3, corresponded to an unwanted increase in α, $((\alpha_D - \alpha) < 0)$, and a pilot would respond by moving the stick forward so as to decrease α and return the finger to its neutral or flush position. An aft protrusion of the finger would require an aft corrective motion of the control stick. That is, a pilot would "follow" the displayed tactual signal to reduce the displayed error to zero. This signal was proportional to error and thus one has a continuous tactual compensatory display. It was controlled by a closed-loop servo with a natural frequency of some 32 rad/sec and a damping ratio of 0.5; thus the display dynamics were negligible in comparison with those of the pilot and aircraft.

This display was initially evaluated in a series of car-following experiments performed under both simulated and full-scale conditions.[3-5] In both these tests, and the ones to be described here, the subjects frequently referred to the compelling nature of the display and how quickly one began performing the required control actions without conscious thought.

EXPERIMENTAL DESCRIPTION

Novice pilot behavior was considered under two conditons:

1) A final approach to landing; and
2) The execution of a continuous tight turn around a point.

A) Final-Approach-To-Landing Study

A flight instructor maneuvered the test aircraft, a Cessna 172, into position fo a final approach, selected an appropriate power setting, and then turned control over to a novice pilot (see Point A in Fig. 4). The latter was instructed to conduct his approach at an airspeed of 72 mph and

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*It is of interest to note the approach taken by Hasbrook and Rasmussen[2] to a related aspect of the approach-and-landing problem. They used aural glide slope cues in an inflight simulated ILS approach study.

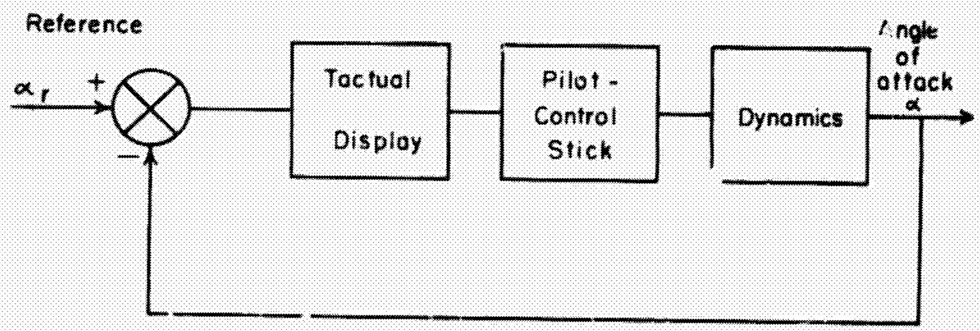

Fig. 1 Control loop for angle-of-attack

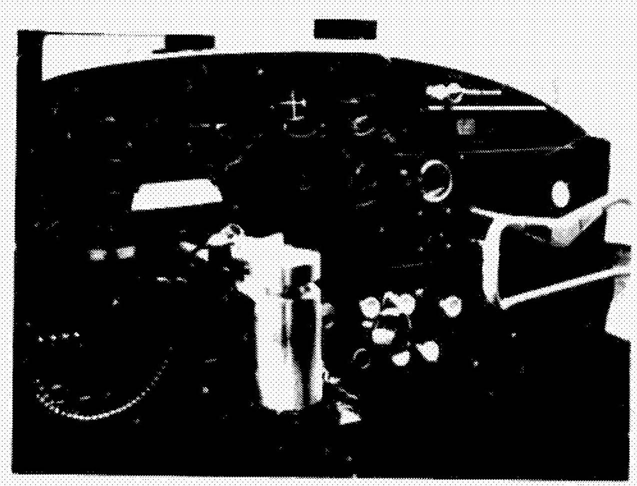

Fig. 2 Aircraft control stick with built-in tactual display

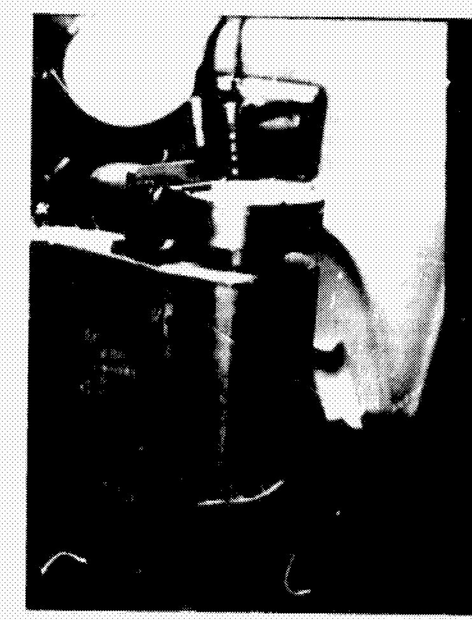

Fig. 3 Control stick with "finger" protruding forward.

to remain aligned with the runway center lane. He retained full control of the aircraft until his altitude decreased to some 50 ft; then the flight instructor took control and subsequently repositioned the aircraft for another approach.

These tests were conducted at the Ohio State University airport with only limited air traffic present. Thus, the testing situation was highly structured and each student could focus his full attention on the landing task.

Airspeed information, or some aspect of same, was provided in three ways with no more than one of these being used in any given approach:

i) A conventional visual display of airspeed;
ii) A visual display of α-- via a display which was mounted on top of the glareshield; and
iii) The tactual display.

Performance was assessed on the amount of time a subject exceeded a threshold of error in maintaining the desired angle-of-attack. The quantity α was recorded on a magnetic tape for the complete final approach; however the data were only evaluated for 50 sec beginning some 10 sec after a subject took control (See Fig. 5). This was done to minimize the effects, on the reduced data, of the changeover in control which occurred at both the beginning and the end of each run. It was also planned to use vehicle lateral position with respect to the desired flight path as a performance indicator; however, the prevalence of heavy traffic ruled out the use of the only locally available ILS facility for this purpose.

Six subjects, each of whom was making his first flight participated with each student making 3 approaches with each type of display. Counter-balancing was employed to evenly distribute any bias due to learning.

The results are shown in summary form in Table 1 where the percent time beyond threshold (the average of 3 runs on each of 6 subjects) is shown for each of the three display modes.*

TABLE I

	DISPLAY MODE		
	Airspeed	Angle of Attack (Visual)	Angle of Attack (Tactual)
% Time beyond threshold (Avg. of 18 runs)	23.9 %	13.9 %	16.7 %

* The raw data from this study are contained in Ref. 6.

Clearly, the least satisfactory performance was obtained when the airspeed indicator was used as the subjects were, on the average, beyond threshold 23.9% of the time. A dramatic improvement was obtained by using the visual angle-of-attack indicator as the subjects were beyond threshold only 12.9% of the time. Nearly as great an improvement was realized with the tactual display. Results showed a beyond threshold percentage of only 16.7%.

In evaluating the results from these highly structured tests, it appears worthwhile to consider the following factors. First, the approach task was somewhat unrealistic in that the testing proceeding in the absence of

a) Subject maneuvering into position for the final approach;
b) Other air traffic; and
c) Ground-to-air communication.

Further, in the visual display of α condition, the subjects vision was always directed along the display. Second, it also appears important to note that the subjects had never used the tactual display, until they were exposed to it in this flight situation.

B. Turns-Around-a-Point Study

In order to evaluate the efficacy of the tactual display in a relatively unstructured and more realistic flight situation, novice pilot performance for turns about a point was considered. Each of six subjects was instructed to maintain a continuous tight turn about a point while maintaining both a constant speed (85 mph) and a constant altitude (800 ft.)* In essence, a subject was now frequently required to direct his attention out of the side window, and hence he could not devote as much attention to a visual display.

Each subject made 2 complete turns about the selected point and α, altitude (h), and airspeed (v) were recorded. Performance was assessed on the basis of the amount of time a subject exceeded an α threshold, the maximum altitude deviation, and the maximum airspeed deviation.

The average results are shown in Table II, and are so striking as to require no detailed discussion.** In essence, by using the tactual display as compared to either of the visual displays, the time beyond threshold was reduced by 55%, the range in airspeed was reduced from 50-130 mph to 75-95 mph, and the estimated altitude deviations from ± 600 ft. to ± 200 ft.

* Two of these subjects have previously participated in the final-approach-to landing study. The remaining four were making their first flight.
** The raw data from this study are contained in Ref. 6.

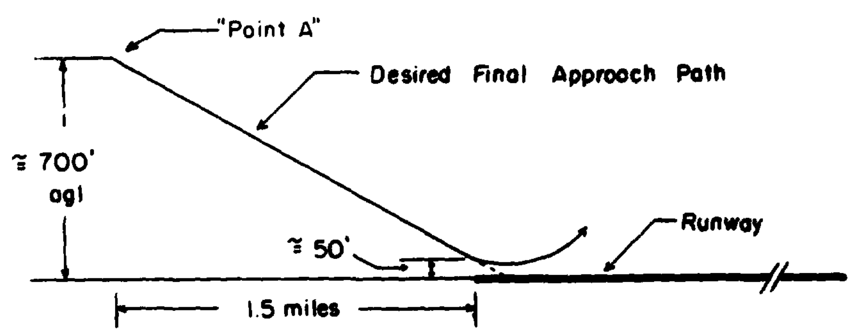

Fig. 4 Final Approach detail.

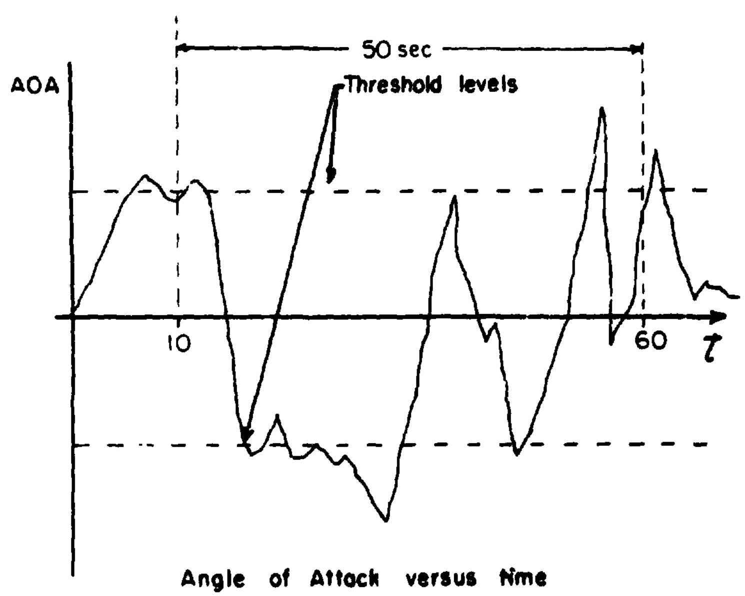

Fig. 5 Angle of attack versus time showing data evaluation interval.

TABLE II

	DISPLAY MODE		
	Airspeed	Angle of Attack (Visual)	Angle of Attack (Tactual)
% Time beyond threshold	21.5 %	25.3 %	11.4 %
Range of Airspeed (85mph desired)	50-130 mph	50-130 mph	75-95 mph
Estimated Variation in Altitude (h_d= 800 ft)	±600 ft	±600 ft.	±200 ft

CONCLUSIONS

In a highly structured approach-and-landing task, roughly comparable results were obtained by using either a visual display of angle-of-attack or a tactile one. This was despite the fact that the subjects were not trained in the use of the latter. In a more realistic, and less structured situation where the subjects' attention was required off to one side, the use of the tactual display was clearly superior.

These conclusions should not be generalized beyond this study; however, it does seem clear that a tactual display such as the one tested here, offers considerable promise for use in flight instruction, and perhaps ultimately in various operational situations.

ACKNOWLEDGMENTS

Dr. Marlin O. Thurston first suggested that the tactual display described here could be profitably used in the approach-and-landing task. Mr. Ronald Ventola was responsible for the design of the control stick-display combination and enthusiastically participated in the collection of the test data. It is a pleasure to acknowledge these contributions.

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