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A Tactual Display Aid for Primary Flight Training

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The Ohio State University Research Foundation

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ABSTRACT

EXPERIMENT 1

Problem. Primary flight instruction has remained fundamentally unchanged for 75 years. Student trial and error practice traditionally has been carried out with the aid of an array of visual flight instruments and under the close supervision and verbal assistance of an instructor pilot.

Objective. A novel means of instruction was attempted here in which, in addition to verbal assistance, control feedback was continuously presented via a nonvisual means utilizing touch. In-flight and simulator evaluations of novice pilot performance were made with this feedback and subsequently without feedback to assess perceptual learning.

Approach. An initial in-flight study was conducted utilizing a kinesthetic-tactual (K-T) display as a readout and tracking device for a computer-generated signal of desired angle of attack during the approach and landing. Six novice pilots were initially trained with the K-T display and their performance was compared to that of another group of six novice pilots trained with a conventional display of airspeed. After the initial training, the display conditions were reversed. Both groups received the necessary verbal assistance.

Results. The following performance results were obtained: the tactual group while using the K-T display and subsequently using the conventional airspeed display (a) utilized the elevator more fully for angle of attack control, (b) had fewer verbal assists from the instructor pilot, (c) made a greater number of unassisted flares to landings, (d) had fewer takeovers by the instructor, and (e) more closely adhered to the runway centerline. Those using the K-T display, regardless of their grouping, (a) more accurately controlled angle of attack, (b) had fewer verbal assists for lineup, and (c) less often required instructor takeover on landing. Some problem or conflict did occur, however, for conventionally trained pilots when they were transferred to fly with the tactual display. The results was a substantial increase in the number of instructor pilot takeovers.

EXPERIMENT 2

Problem. From the first study it was unclear as to whether the findings were the result of the novel K-T display presentation, the information contained in the computer-generated signals of desired angle of attack, or both.

Objective. Therefore, a second study was conducted to control these conditions by presenting airspeed and glide path information via either kinesthetic-tactual or visual "heads-up" display techniques. Selective

feedback was provided by the simultaneous use of any combination of the two displays.

Approach. The second study was carried out in a laboratory setting where sixteen novice pilots flew simulated visual approaches to landing in a ground-based trainer. The experimental tasks during training and subsequent testing were control of both pitch and throttle. Training for each subject consisted of one of the four combinations of visual and tactual displays of airspeed and glide path error, respectively. Performance was measured during initial practice, and during test approaches (without the displays) following each hour of practice. Unlike the first study, none of these subjects received verbal assistance during training. Therefore, an additional group of four novice subjects received only verbal assistance during training and no such assistance during testing.

Results. Findings during the training periods with display feedback show performance with the heads-up display of pitch information was significantly better than performance with the K-T pitch display. Throttle error did not vary for the two groups during this training. These findings concur with those of others (Jagacinski, Miller, Gilson and Ault, 1978) indicating that the information fed back by K-T displays must be quickened with additional velocity information in order for K-T performance to compare equally with the unquickened visual display of the type used in this study.

In contrast to the results obtained during training, testing without the displays showed that novice pilots who had received tactually presented pitch error information performed both pitch and throttle control tasks significantly better than those who had received the same information from the visual heads-up display of pitch, during the test series of approaches to landing.

Testing for the verbal group showed that they significantly outperformed both display groups in pitch control, in apparent contrast to the poor showing of the conventionally trained group in the first in-flight study. However, in the first study necessary amounts of supplementary verbal assistance was given to both the K-T and airspeed groups, while in the second study verbal assistance was given only to the verbal group.

Conclusions. Under the conditions of Experiment 2, visual perceptual learning of the approach to landing task is more greatly facilitated by training with K-T than with visual heads-up displays of the same information. Secondly, ample verbal assistance by itself yields a training advantage over both K-T and heads-up displays when these displays are the only source of control information unassisted by verbal instructions. Therefore, based on these results and those of Experiment 1, the combination of verbal instruction and the K-T display of control information during approach and landing appears to be the best combination, of conditions tested, to significantly improve conventional training.

A TACTUAL DISPLAY AID FOR PRIMARY FLIGHT TRAINING

INTRODUCTION

In order to successfully control and maneuver an aircraft, the pilot must learn to utilize a great amount of information. The most effective and efficient means of presenting this information in training has been the subject of extensive research. Besides verbal instructions during training, the vast majority of information has traditionally been presented via an oftentimes overwhelming array of instruments and displays using the visual sensory modality. This is justifiable since most information in the natural environment, especially that required for locomotion, is visual. Consequently, the visual modality has become tremendously overloaded by panel instruments and visual environmental information.

Studies have shown, however, (Kahneman, 1973; Treisman and Fearnley, 1971) that when vision is overloaded there remains some capacity in other sensory modalities to receive information. Accordingly, numerous non-visual aircraft displays have been investigated, in particular those utilizing aural and cutaneous signals. For example, Hasbrook and Rasmussen (1971) investigated the use of an aural-versus-visual glideslope display in a study where experienced pilots flew ILS (Instrument Landing System) approaches under both display conditions. Despite some limited success, it appears unlikely that this technique would carry over well into the training environment. A student pilot's perception of aural information is already highly taxed by instructor's verbal comments, radio communications, aural warning signals, and other relevant aircraft sounds.

The use of cutaneous signals for communicating discrete information to a pilot is not new. Stick shakers for stall warning have been employed for many years. Further, a number of other techniques have been investigated for continuous communication including: a two-way vibrotactile communication system (Hirsch, Shafer, and Eitan, 1964), a stomach-chest mounted "cross" of stimulators for information transfer (Levison, Tanner, and Triggs, 1973), and an airjet stimulator moving across the forehead (Bliss, Link, and Mansfield, 1966). An excellent overview of such efforts is contained in both Bliss, 1970, and Geldard, 1973, special publications devoted to tactual displays. Unfortunately, many of these systems are difficult to implement in a cockpit which surrounds the pilot with extraneous vibrations and often require attachment to the pilot, posing a safety problem during rapid egression.

The displays used in the present studies are not known to be effected by vibration nor are they worn by the pilot, but rather consist of a relatively stationary part of the yoke and throttle controls. Both kinesthetic and tactual information are provided by touch and manipulation of the servo-controlled element embedded in the controls. Sensations of the stimulus and the necessary manual control response occur in the same hand and in the same modalities, i.e., touch and kinesthesis. Also, this presentation lends itself well to stimulus-response directional compatibility (Greenwald and Shulman, 1973), see Fig. 1.

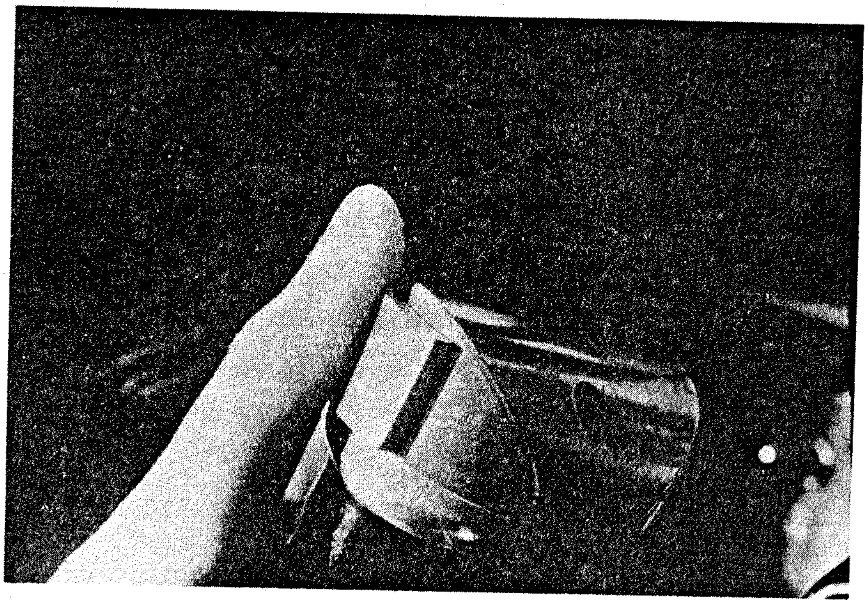


Fig. 1 - Kinesthetic-tactual display depicting a servo-controlled slide embedded in a control stick

This display has been used for many types of control tasks. Car-following (Fenton and Montano, 1968), aircraft approaches to landings, and turns around a point (Gilson and Fenton, 1974), helicopter instrument approaches and hover over a target (Gilson and Ventola, 1976), and a critical tracking task (Jagacinski, Miller, Gilson, and Ault, 1977) are examples of past research. In the present studies, this display will be tested as an aid to primary flight training.

During primary flight instruction, a student must develop a reasonable competence in both approaches and landings before any advanced training is undertaken. Such development, while time consuming, is at the very foundation of critical piloting skills. Unfortunately, considerable problems, both during and after training, arise primarily because aircraft control during approach and landing is relatively difficult, even under the best conditions, as is vividly illustrated by accident statistics. Current statistics show 43% of all civil aviation accidents (National Transportation Safety Board, 1976) occur during the approach and landing, even though this consumes less than 2% of all flight time (Hasbrook, 1975).

The difficulties inherent in an accurate approach and landing are often compounded by the heavy demands placed on the pilot--especially the division of visual attention required to control the flight path and airspeed. During the approach, information pertaining to the flight path is primarily obtained from visual cues outside the cockpit, while pitch information is, in part, obtained via a panel-mounted airspeed display.

In addition, just prior to touchdown, the pilot's visual attention is progressively drawn towards runway-specific cues allowing little, if any, use of instrument panel information. This results in a division of visual attention--a division which can be especially critical for student or inexperienced pilots who lack the skill to use relevant pitch, inertial, and aural cues.

Accordingly, a nonvisual or a visual heads-up display may be of benefit by allowing:

(a) an alleviation of this division of visual attention during the approach, particularly during initial training,

(b) the opportunity of also presenting pitch-command or other information during the roundout (or flare) just prior to touchdown, and

(c) enhanced visual perceptual learning of the subtle information needed for the approach and landing.

Although a simple visual heads-up display could provide some or all of the above, it cannot provide information when a subject is looking elsewhere, e.g., to the side during downwind or base leg segments of the approach or at the runway edges just prior to touchdown (Gilson and

Fenton, 1974). Therefore, the kinesthetic tactual display was the first choice for study.

The visual approach to landing, has two major components: pitch and glide path control. Airspeed, and therefore pitch, must be closely regulated to prevent overshooting the runway if too fast, or reaching aerodynamic stall and a lack of control, if too slow. The second component, glide path regulation, itself is twofold. Lateral alignment of the ground track with the runway centerline and glide path vertical angle along the centerline determine the point of touchdown.

Airspeed control is accomplished in small aircraft primarily by pitch adjustment. These adjustments can be made by direct observation of the distance between the aircraft nose and horizon, as viewed from the cockpit. Quantitative information concerning airspeed is provided by the airspeed indicator.

The lateral glide path component is controlled by roll and yaw of the aircraft. Detection of deviation relies on the observed offset of the runway centerline from the aircraft's ground track, and may be aided by reference to the directional gyro and, in some cases, localizer. However, this facet of the task is relatively easy to learn and perform unless a strong crosswind is present (Lane and Cumming, 1956).

As evidence indicates, control of the glide path angle is difficult even for experienced pilots. Eighteen percent of the approach and landing accidents, in 1976, were due to overshooting or undershooting the runway (National Transportation Safety Board).

The vertical glide path angle is a function of airspeed and rate of descent. Once the proper approach airspeed is established, the glide path is corrected by the throttle control. The information in the runway environment that reflects the accuracy of the glide path angle includes the position of the point of expansion in the optic array (for a description of this phenomenon see Gibson, 1955; Gibson, Olum and Rosenblatt, 1955). The angular distance between the horizon and the runway threshold, the apparent shape of the runway, the estimated glide angle, and when available, a deviation in the instrument glide slope also provide this vital information. All these cues, save the latter, are difficult to detect and interpret. The difficulty increases substantially with distance from the runway (Palmer, 1969), low visibility (Hasbrook, 1975), and at night (Mertens, 1978). With a combination of these conditions, errors of great magnitude can be unperceivable.

To properly land an aircraft, a student pilot must learn to attend to all the relevant information in the runway environment, and to ignore that which is irrelevant. This learning is not accomplished easily. Current training techniques, based on verbal corrections by the instructor pilot, are at best spotty, and often characterized by trial and error. The addition of more sensitive and interpretable feedback information can likely aid in the acquisition of landing skills.

In order to maximize the perceptual capability for assimilating and relating information from these diverse sources, one must attempt to minimize divided attention. It has been shown by Burke, (1978) that subjects using tactual, as opposed to even highly compatible visual displays, have less cross task interference when simultaneously performing another visual task. Hypothetically then, tactually trained pilot subjects may be more able to perceptually learn the subtle but relevant visual information available through the windscreen than those using visual displays which may compete with the perception of this information. When the displays are no longer available and only the subtle information is present, these pilots may be expected to perform the landing approach more accurately.

The above hypothesis addresses modality-divided information. However, many would argue that such a division of information does not reduce cognitive or attentional demands and thus no differences should be predicted.

A study by Burke (1978) also comparing tactual and visual displays, addressed the issue of attention capacity. The tactual display for a primary critical tracking task used velocity quickening to produce the same level of performance as the visual position error display, based on the results of Jagacinski, et al. (1977). Equal performance to a criterion level with the two displays was obtained before a secondary visual critical tracking task became operative. Preliminary results showed better performance on the secondary visual task when the primary task was tactual. This suggests that division of information via separate sensory modalities facilitates multitask performance and perhaps facilitates attention to secondary visual perception.

For the purpose of discussion, we may consider compensatory display tracking to be the primary task of the approach and landing study and the secondary task that of attending to relevant visual feedback cues from the runway environment. Should this analogy be valid, we would expect better subsequent performance by those previously using the tactual displays, due to their increased attention capacity for the secondary visual task prior to transfer.

EXPERIMENT 1

Introduction

The first study was conducted to evaluate the effects of presenting information pertaining to the desired and actual aerodynamic state of an aircraft via the kinesthetic-tactual display during the approach and landing. The control loop which was used is shown in Fig. 2. The reference input was a desired angle of attack (α_D) which was, of course, closely related to the desired aircraft pitch attitude and airspeed. The feedback signal was the measured angle of attack (α), and the display input was simply the difference $\alpha_D - \alpha$.

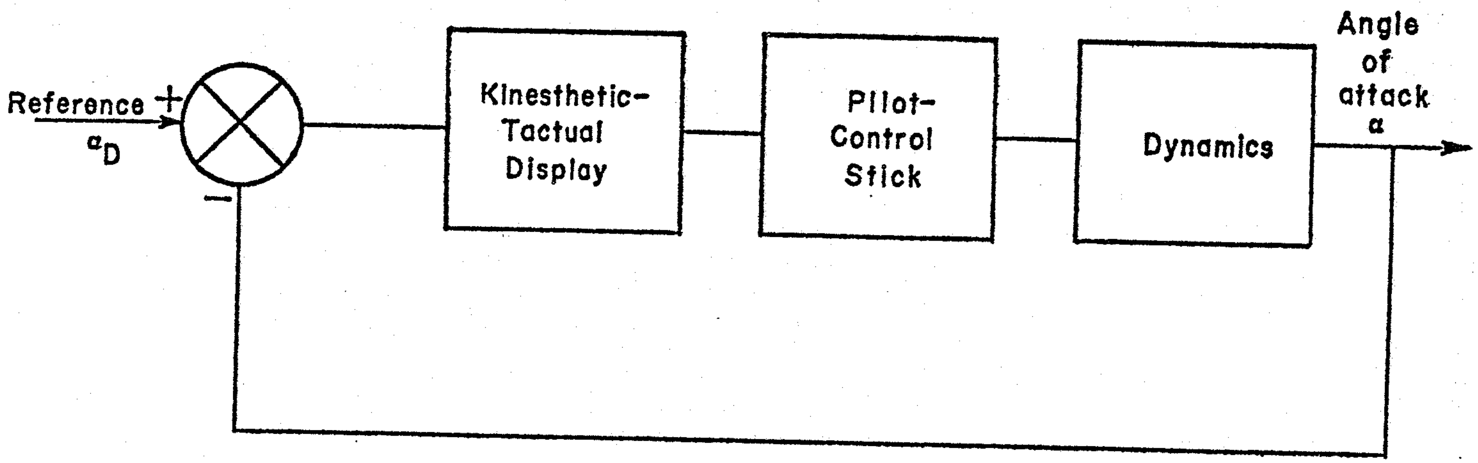


Fig. 2 - Control loop for angle of attack

The tactual display was programmed to present desired pitch commands from the beginning of takeoff roll through the approach and flare to landing. Figure 3 depicts the desired control information. Whenever the aircraft was higher than 50 feet above the ground the desired angle of attack was held at a constant (α = A) appropriate for both the climbout after takeoff and the approach to landing (see Appendix A). Below 50 feet, α_D was an increasing inverse linear function of height (h), so that α_D was near aerodynamic stall when h was equal to zero at liftoff and at touchdown [$\alpha_D = A - B(50 - h)$]. Thus, the desired signal was a function of the aircraft's state with respect to the runway. Since the display input was the difference $\alpha_D - \alpha$, the presentation was essentially a compensatory tactual "director" for the takeoff, climbout, approach and flare to landing.

Methodology

Subjects

Subjects were 12 male student volunteers from those registered for an introductory aviation flight course (The Ohio State University Aviation Course No. 201). They received this flight experience at no personal cost.

Apparatus

The kinesthetic-tactual display consisted of a metal slide mounted in a conventional aircraft control yoke. The position of the slide in the display indicated information of the magnitude and direction of the error scaled to the maximum deflection of the 1.25 cm. The movable metal section is shown in Fig. 4 as protruding from the forward part of the control grip and recessed into the aft part. This protrusion corresponds to an unwanted increase in angle of attack ($\alpha_D < \alpha$) and the pilot responds by moving the yoke forward so as to decrease α and return the display to its neutral or flush position ($\alpha_D = \alpha$). Next, in Fig. 5 is a view of the display protruding backward ($\alpha_D > \alpha$) which requires an aft corrective motion of the control yoke. In essence, the pilot "follows" the display commands to reduce errors to zero. The slide displacement was proportional to error up to the 1.25 cm limit. Slide movement was controlled by a closed-loop servomotor 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.

The experimental aircraft was a Beechcraft Musketeer (BE19-23A, Fig. 6) modified by the installation of a 180 hp Lycoming O-360 engine. The aircraft was equipped with sensors capable of measuring absolute altitude h, elevator position, angle of attack, and localizer/glide slope errors during the approach to landing. Just prior to touchdown, vertical velocity ($\dot{h}$) or sink rate was recorded by a modification to the Sperry RT-220 radar altimeter measuring h. The actual touchdown "g" loading was recorded with a cockpit "g" meter. Electrically the exact time of touchdown was recorded by an accelerometer attached to the landing gear and sensitive enough to

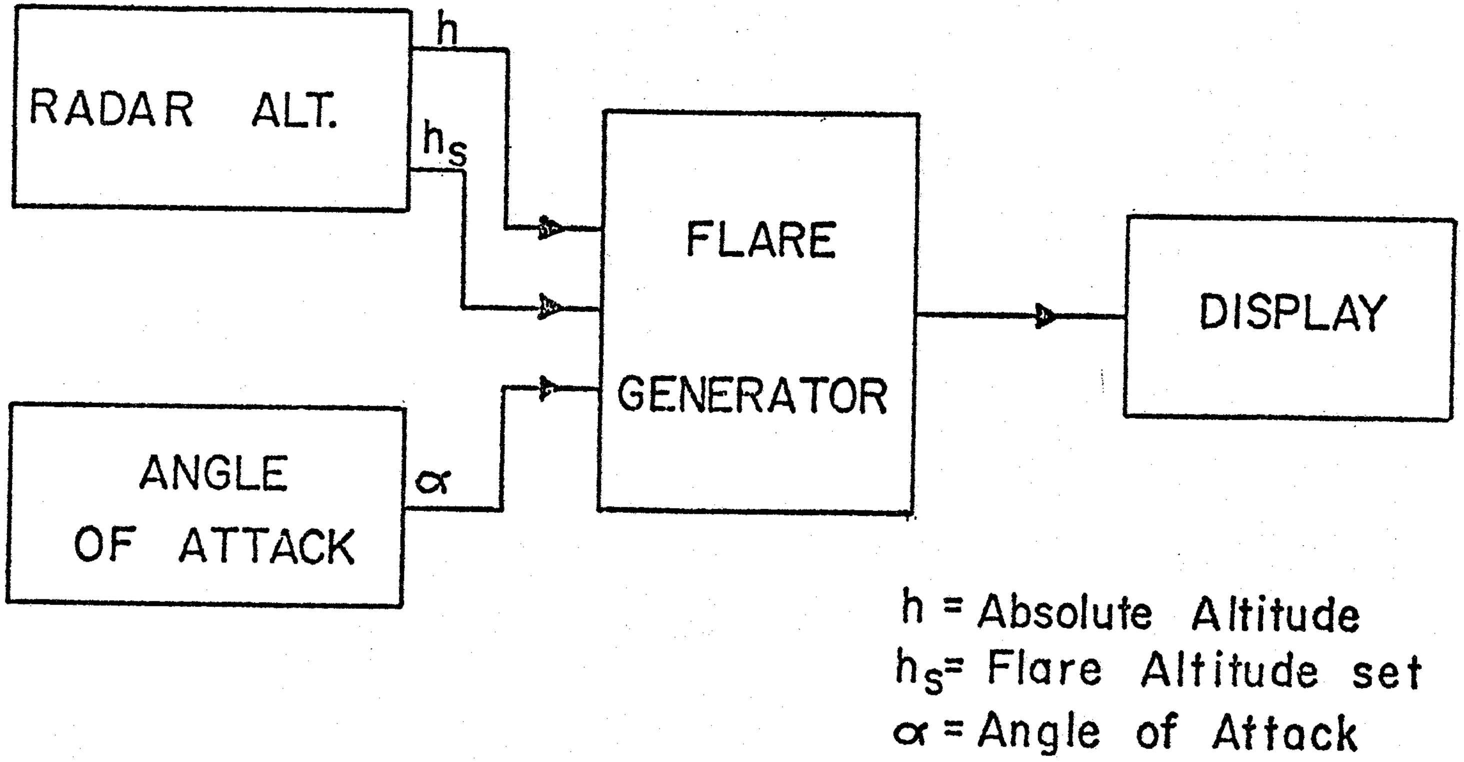


Fig. 3 - Desired control information

Fig. 4 - Kinesthetic-tactual display protruding forward

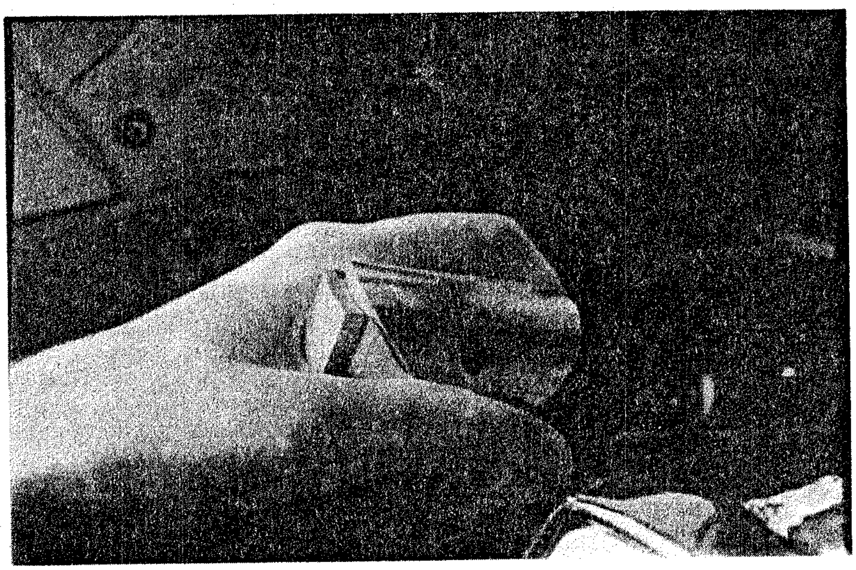


Fig. 5 - Kinesthetic-tactual display protruding backward

Fig. 6 - Experimental aircraft BE19-23A

record the initial spin-up of the wheel. The touchdown could thus be shown on a strip-chart record and measurements were made with this point as a reference. In addition, at touchdown maximal angle of attack and elevator position were recorded.

The generation of the flare command signals and the modification of the outputs for recording were accomplished with an onboard analog computer capable of multiplying, summing, and attenuating the various inputs. Continuous records of the above measures as well as all verbal comments made by the instructor were recorded on a 7-channel FM Lockheed Model 417 magnetic tape recorder.

Procedure

The experimental in-flight study considered novice pilot performance while flying approaches and landings. There were two study objectives:

(a) To separately evaluate performance with a tactual display of $\alpha_D - \alpha$ and a conventional visual airspeed display during the approach and landing.

(b) To compare the effects of discontinuing the tactual display on subsequent performance with a conventional airspeed display and the effects of initiating the tactual display after preliminary experience with airspeed.

Initially, each of the 12 novice pilots received flight instruction from an FAA certified flight instructor. Instructions given to both student and instructor pilots appear in Appendix B. The standard FAA-approved training syllabus was designed to teach students the fundamentals of aircraft control supplemented by the conventional array of flight instruments including airspeed, i.e., the minimum required for visual and instrument flight by FAR 91.33 (b,c, and d) excluding navigational displays such as localizer and glide scope. The primary maneuvers taught were standard combinations of straight and level flight, turns, climbs, decents, and airspeed control. Practice also included slow flight in the landing configuration used for the experiment but the actual practice of landings was not permitted.

At the completion of this preliminary phase, these novice pilots were evaluated on a standard series of test maneuvers designed to equally match subjects by performance, into two groups. This evaluation was conducted by the chief flight instructor of The Ohio State University Department of Aviation, who had no prior exposure to the subjects. This selection process was intended to supply some measure of uniformity of groups.

The first experimental phase then commenced, wherein the subjects flew four, one-hour test periods each consisting of six takeoffs and landings. One group, designated the airspeed group, received the visual display of airspeed with the tactual display deactivated. The other, the tactual group, received the tactually displayed information with the airspeed indicator covered. Both groups had available the other conventional flight instruments, i.e., the minimum required for visual and instrument flight.

The second experimental phase then followed, consisting of two one-hour test periods, wherein the display conditions were reversed; that is, the airspeed group now flew with the tactual display, while the tactual group received visual airspeed information. In all the experimental phases, performance was analyzed during the final approach and landing from approximately 1-1/2 miles out to touchdown.

Performance measures were broken down into three categories: the approach, flare (or round-out) and touchdown. These included:

1. Approach measures (from 60 to 30 seconds prior to touchdown) of:

   (a) angle of attack errors from the desired value,

   (b) elevator deflection from an average position,

   (c) localizer error,

   (d) glide slope error,

   (e) instructor pilot verbal assists of

      (1) lineup corrections

      (2) power corrections

      (3) pitch corrections.

Performance for a, b, c, and d, above was assessed on the basis of the percentage of time a preselected deviation threshold was exceeded. Visual Approach Slope Indicator (VASI) lights aided the subjects in glide path control.

2. Flare measures were categorized in the following way by degree of instructor pilot assistance:

   (a) the number of unassisted flares,

   (b) the number of assisted flares,

   (c) the number of instructor pilot takeovers.

Unassisted flares were those not expected to exceed three "g's" at touchdown. Assisted flares were those that could be redeemed with an assist from the instructor pilot. Instructor pilot takeovers were those flares where safety of flight was in danger and complete takeover was deemed necessary.

3. Touchdown measures (those touchdowns preceded by unassisted flares) of:

   (a) lateral and longitudinal touchdown position,

   (b) sink rate of "g" loading at touchdown,

   (c) pitch attitude from one second prior to touchdown as measured by α.

The point of touchdown was obtained via sightings by the two on-board experimenters. The instructor pilot observed the lateral touchdown deviation from centerline. Longitudinal deviation from the marked touchdown zone (Fig. 7) was noted by the second experimenter. Lateral deviation was scaled in proportion to the runway width and was rounded off to an equivalent of ±3 feet. Longitudinal touchdown position was noted by markers placed every 100 feet from the touchdown zone and sightings were made with ±50 foot roundoff errors.

Results

An analysis of variance was performed on all data for subject group including performance with both displays, display condition, and interactions. The results are shown in Table 1.

Approach

During the approach phase, two of the five measures had significant group effects; ($p \le .05$), elevator deflections ($p \le .005$), and verbal assists ($p \le .02$), and the display used significantly affected angle of attack control ($p \le .001$) and verbal assistance for line-up with the runway centerline. The direction and magnitude of these four measures show that subject utilization of the tactual display facilitated performance during the approach. First, control of α was enhanced with the aid of the tactual display by a factor of nearly two to one during the approach. Second, the tactual display group in controlling α, utilized the elevator to a larger degree than the airspeed display group (see Fig. 8). Third, the tactual display group required less verbal assistance by the instructor pilot than the airspeed display group, particularly in regard to the use of power. All subjects required less verbal assistance in line-up when they utilized the tactual display.

The other two approach measures were localizer and glideslope error. Neither of these were significantly different for the groups or displays. Both measures had a significant group by display interaction which indicated greater error by both groups using the initial display, a learning effect.

Flare

Instructor pilot assistance, or lack thereof, during the flare shows a definite superior performance by the tactual group compared to the

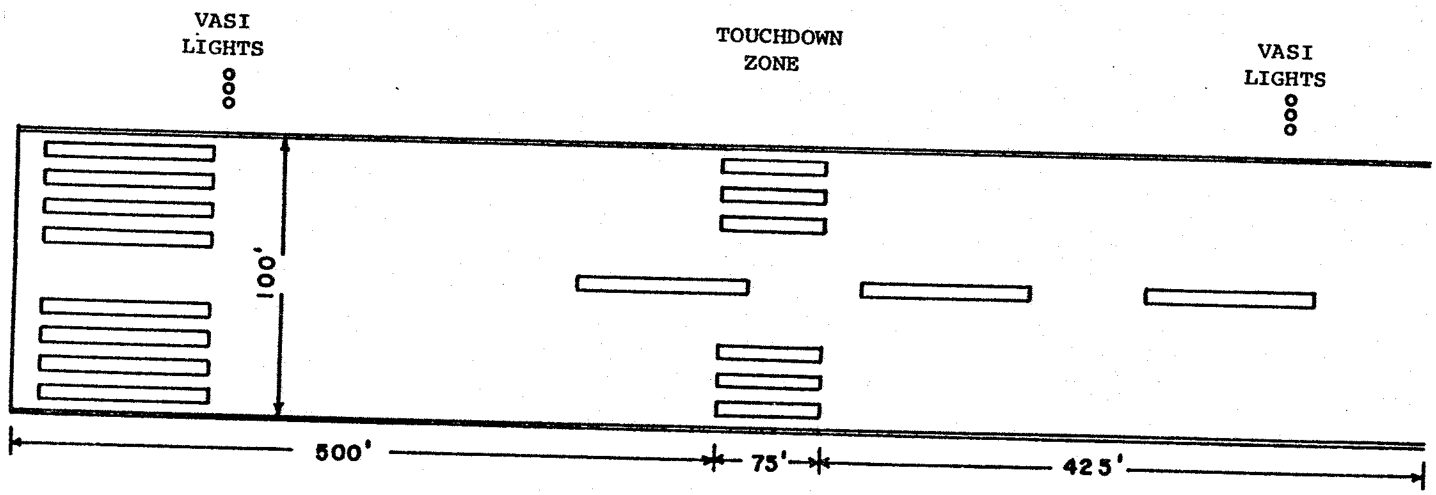


Fig. 7 - Runway depicting touchdown zone

Table 1

$\underline{F}$ Ratio Table for Experiment 1

		Dependent Measure	Between Subjects Effects: Group Effects				
			Hypothesis SS	df	Within Cell Error SS	df	F
APPROACH	a	Angle of Attack	.1661	1	.1924	428	.04
	b	Elevator deflection	.1144	1	.6054	428	8.08 **
	c	Localizer error	.1270	1	.4448	428	1.22
	d	Glide slope error	.2240	1	.4093	304	1.66
	e	Verbal assists (total)	.6230	1	.4541	428	5.87 **
		1 lineup	.1042	1	.6314	428	.71
		2 power	.4356	1	.1723	428	10.82 ***
		3 pitch	.7407	1	.1121	428	.03
FLARE	a	Unassisted flares	.7669	1	.1180	20	13.00 ***
	b	Assisted flares	.2456	1	.8681	20	5.66 *
	c	Takeovers	.6009	1	.2017	20	5.96 *
TOUCH-DOWN	a	Lateral position	.1281	1	.2698	200	9.50 **
	b	Longitudinal position	.5518	1	.7584	200	1.46
	c	Sink rate/"g" loading	.8749/.6052	1/1	.8332/.2570	74/119	.08/2.80
	d	Pitch attitude	.3739	1	.2523	200	2.96

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$

		Dependent Measure	Within Subject Effects: Display Effects				
			Hypothesis SS	df	Within Cell Error SS	df	F
APPROACH	a	Angle of Attack	.1574	1	.1924	428	35.01 ***
	b	Elevator deflection	.4092	1	.6054	428	.29
	c	Localizer error	.3189	1	.4448	428	.31
	d	Glide slope error	.1254	1	.4093	304	.93
	e	Verbal assists (total)	.1852	1	.4541	428	.00
		1 lineup	.9375	1	.6314	428	6.36 **
		2 power	.9375	1	.1723	428	2.33
		3 pitch	.1852	1	.1121	428	.01
FLARE	a	Unassisted flares	.2615	1	.1180	20	.04
	b	Assisted flares	.6534	21	.8681	20	1.50
	c	Takeovers	.4426	1	.2017	20	4.39 *
TOUCH-DOWN	a	Lateral position	.4104	1	.2698	200	3.04
	b	Longitudinal position	.1833	1	.7584	200	.48
	c	Sink rate/"g" loading	.7369/2121	1/1	.8267/2649	74/120	.66/.10
	d	Pitch attitude	.5827	1	.2523	200	.46

		Dependent Measure	Group by Display Interaction				
			Hypothesis SS	df	Within Cell Error SS	df	F
APPROACH	a	Angle of Attack	.1848	1	.1924	428	.41
	b	Elevator deflection	.4530	1	.6054	428	.32
	c	Localizer error	.1824	1	.4448	428	17.55 ***
	d	Glide slope error	.1410	1	.4093	304	10.47 ***
	e	Verbal assists (total)	.8563		.4541	428	8.07 **
		1 lineup	.8963	1	.6314	428	6.07 **
		2 power	.5807	1	.1723	428	14.42 ***
		3 pitch	.2141	1	.1121	428	8.17 **
FLARE	a	Unassisted flares	.2903	1	.1180	20	4.92 *
	b	Assisted flares	.1648	1	.8681	20	3.80
	c	Takeovers	.6549	1	.2017	20	.65
TOUCH-DOWN	a	Lateral position	.6294	1	.2698	200	.05
	b	Longitudinal position	.2990	1	.7584	200	7.88 **
	c	Sink rate/"g" loading			NOT. AVAILABLE		
	d	Pitch attitude	.5871	1	.2523	200	4.65 *

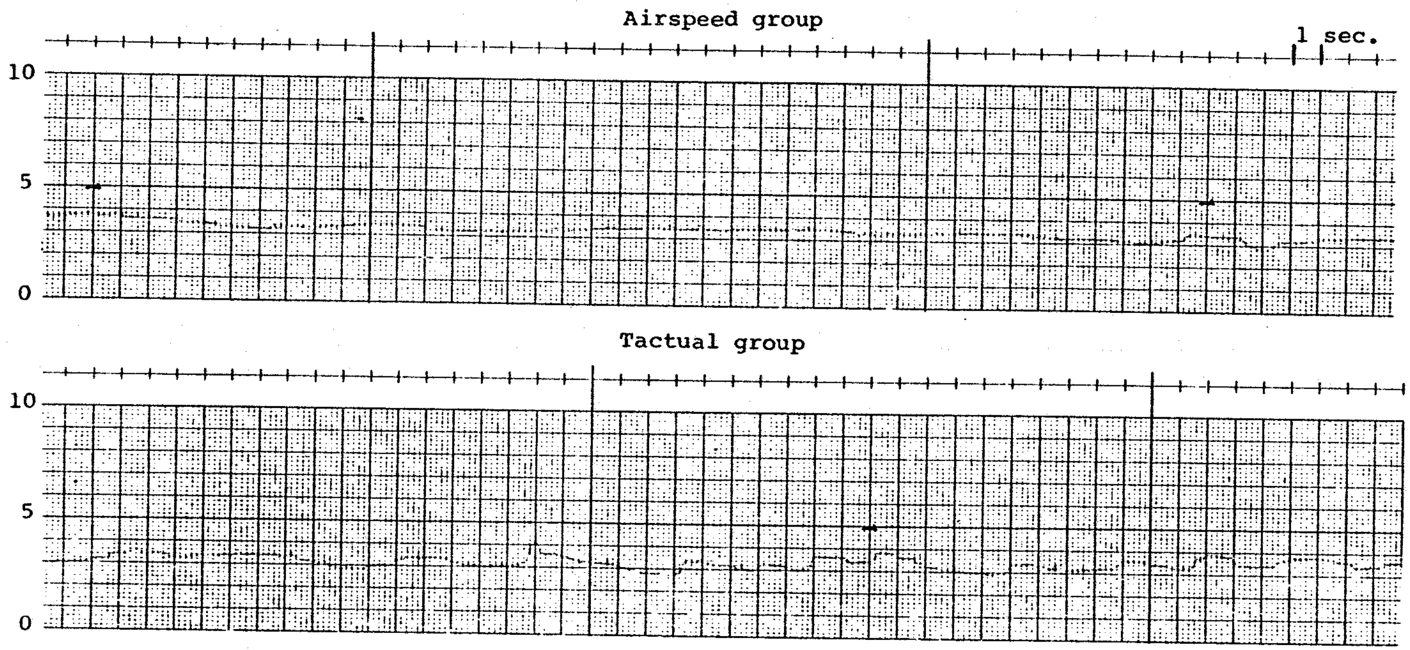


Fig. 8 - Example of elevator deflection recorded during the approach

airspeed group. Figure 9 illustrates this difference with the total number of unassisted flares performed by group per test period. The statistical analysis shows that the group initially utilizing the tactual display significantly ($p \leq .01$) outperformed the airspeed group across test periods. Figures 10 and 11 illustrate that the airspeed group required not only more assisted landings but more takeovers ($p \leq .05$).

Two other points must be noted. First, that when airspeed trained subjects were transferred to flight with the tactual display, there was a significantly greater number of takeovers ($p \leq .05$). Secondly, that there was a significant group by display interaction effect ($p \leq .05$) for unassisted flares. When the group initially utilizing the airspeed display was transferred to fly with the tactual display, they actually made fewer unassisted flares than did the tactual group during their first experimental phase (Fig. 9).

Touchdown

For measures of unassisted touchdowns, performance was largely remarkable. The only significant difference found was lateral touchdown position ($p \leq .01$), wherein the airspeed group had larger mean deviations from centerline. All other touchdown measures did not reach levels of significance ($p \leq .05$).

Note that for the approach, flare, and touchdown there were several interaction terms for group by display which were significant ($p \leq .05$ or .01). In general, the directions of these terms suggest a practice effect in that the subject groups showed improved performances for the second experimental phase.

Discussion

Approach

Considering the approach from 60 to 30 seconds prior to touchdown, the present findings support previous in-flight studies (Gilson and Fenton, 1974). Angle of attack errors were substantially smaller while using the tactual display than while using the conventional airspeed indicator.

It must be noted that previous results showed little or no difference between a tactual $\alpha_D - \alpha$ presentation and a visual $\alpha_D - \alpha$ presentation during the approach. This finding was attributed to the highly structured task wherein the instructor pilot positioned the aircraft initially and the fact that the visual display was placed on the instrument panel in nearly a direct line with the pilot's view of the runway itself. Without evidence to the contrary, it is presumed that for the approach segment, the previous results would be substantiated in the present study if a visual $\alpha_D - \alpha$ display was utilized. However, during the flare, a high degree of division of visual attention would be required between a visual $\alpha_D - \alpha$ presentation and the fast approaching runway. Under these

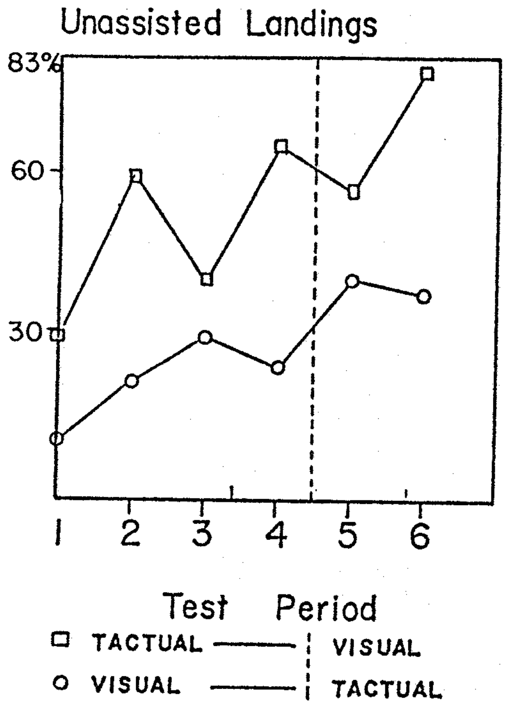


Fig. 9 - The number of unassisted landings for each group on each test period

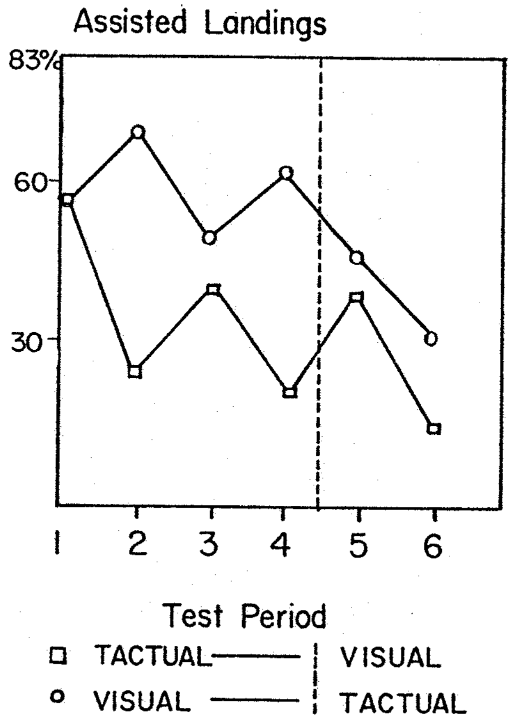


Fig. 10 - The number of assisted landings for each group on each test period

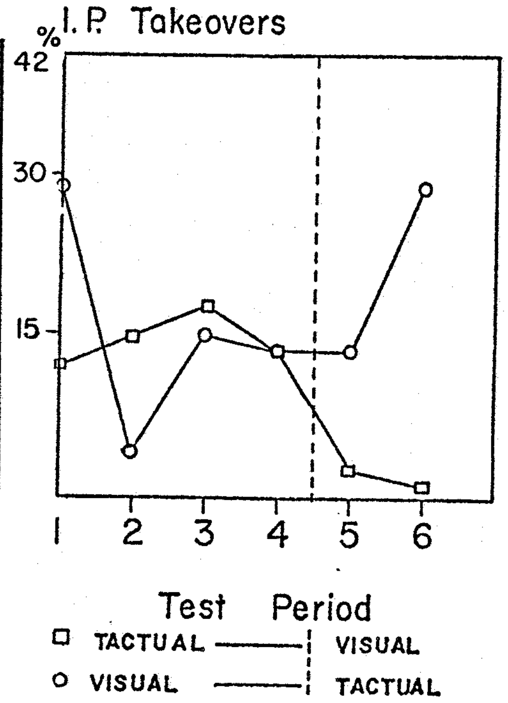


Fig. 11 - The number of instructor pilot takeovers for each group on each test period

conditions of high visual loading, the previous findings suggest that there would be substantial differences between the tactual and visual presentations (see Gilson and Fenton, 1974).

The two other significant approach measures, i.e., elevator deflection and verbal assists, not only support the α findings, but suggest some beneficial learning effects. First, considering elevator deflection, the tactual group had significantly greater elevator deflection than the airspeed group across test periods (Fig. 8). Presumably, the elevator deflections are in response to perceived errors in pitch control as noted by $\alpha_D - \alpha$ errors with the tactual display. Initial experience for the tactual group not only brought about greater elevator responses than the airspeed group, but these responses continued to be greater even during the transferred condition when the airspeed indicator replaced the tactual display. This would suggest that other cues had been learned and were being used by the tactual group under the transferred airspeed display condition, e.g., perceived pitch attitude.

Second, considering verbal assists, the greater number of verbal assists for the airspeed group suggest, (a) a reduced visual attention to external runway cues and/or (b) poor airspeed control created enough variability to make it difficult for subjects to perceive relevant "constancy" cues needed for the approach. That visual attention was divided is supported in part by the fact that all subjects needed more verbal assistance for line-up when they were using the airspeed display. This implies concentrated visual attention on the airspeed display. That poor airspeed control created confusion with regard to approach cues, is implied by the greater number of verbal assists for power required by the airspeed group. Poor attitude (airspeed) control engenders improper control of power since there is a high degree of interaction between pitch attitude and power during an approach. Thus, the airspeed group did not learn to judge power cues as well as the tactual group either in the initial experimental phase or subsequently under the transferred condition.

<u>Flare</u>

The tactual display group significantly outperformed the airspeed group in terms of unassisted flares. This suggests that: (a) the group initially trained with the tactual display was facilitated (50% unassisted flares) in their flares to landings by following the tactual display, and (b) that they had learned enough to later perform quite well (almost 70% unassisted flares) with the conventional airspeed display. This latter finding rejected an initial hypothesis that a "crutch-like" dependency on the display might manifest itself when the tactual group was transferred to the airspeed only condition.

The airspeed group performed approximately 22% unassisted flares during the first four test periods. What was remarkable, however, was that the airspeed group did not substantially improve when they were transferred to the tactual display--there were only 40% unassisted flares in the second experimental phase compared to 50% unassisted landings in the first experimental phase for the tactual group. This smaller than anticipated improvement is also evident in the number of instructor takeovers. It is apparent from Fig. 11 that when the airspeed group was transferred to the use of the tactual display (test periods 5 and 6) there was a dramatic increase in the number of takeovers. These data suggest that some apparent problem or conflict occurred when the airspeed group was transferred to the tactual display. One potential conflict may have occurred for the airspeed group because of their initial strategy. Their utilization of the available visual cues developed largely by trial and error. Such strategies most likely differed from the commands directed by the tactual display. Conversely, the group initially trained with the tactual display was forced to use and observe the desired flare-to-landing strategy. Thus, when the tactual group was transferred to the use of the visual airspeed display they relied on previous learning rather than trial and error. Further study of this and alternative hypotheses with regard to strategies used by subjects is obviously necessary before a firm conclusion can be drawn.

Touchdown

Considering the measures taken of unassisted touchdowns as indicants of the quality of touchdowns, few differences were found. The only significant difference was lateral position error with respect to the runway centerline which was significantly greater for the airspeed group. One possibility for this finding was that these subjects without tactual commands devoted their attention to learning to flare the aircraft at the expense of attention to runway centerline. Moreover, this initial concentration on proper flare may have carried over to the transferred condition, since they continued to make large lateral deviations at touchdown even with the tactual display. Accordingly, the tactual group may have performed better with regard to lateral touchdown position because with tactual commands "directing" their flares, they could devote more attention to lineup.

The lack of other group or display differences for unassisted touchdowns indicates that the subjects' unassisted landings were largely uniform. This implies little or no instructor pilot bias in the form of premature or unnecessary assists.

Initially, it had been hypothesized that the following benefits would accrue for a novice pilot utilizing a kinesthetic-tactual display of $\alpha_D - \alpha$ control information during the approach and flare:

1. the pilot would have better performance during the approach and flare through increased control, aided by a continuous knowledge of $\alpha_D - \alpha$, thus reducing the risk of errors that might result in stall-spin or touchdown accidents;

2. the pilot would be more proficient for the normal number of practice periods with respect to landings, aided by correct flare information and exposure to appropriate visual cues from outside the cockpit;

3. the pilot's improved control of aircraft attitude and flight path should carry over to later nontactually aided flight situations, e.g., during flight in aircraft equipped with only conventional airspeed displays where visual attention would be divided.

The present results suggest that the first two hypotheses were generally correct. Pilots flying initially with the tactual display were facilitated in their control of the appropriate pitch attitude for a given flight mode and in their recognition of inappropriate pitch attitudes that might result in aerodynamic stall or high touchdown loads. This is supported both by a closer control of α when the tactual display was employed and by the higher number of unassisted landings made by the tactual display group.

With regard to the third hypothesis, learning rather than a "crutch-like" dependency occurred during the initial practice by the tactual display group. Performance, as measured by unassisted landings, remained high and continued to improve after the tactual group was transferred to the conventional airspeed display. This may have been fostered through a continued observed relationship between aircraft pitch attitude and accurate regulation of α and/or through a higher degree of attention to subtle visual and nonvisual environment cues.

Some unanticipated problem of conflict did occur when the conventionally trained airspeed group was later transferred to the use of the tactual display. Not only did they require more instructor pilot assistance during flare, but this assistance was in the form of takeovers. The reason for this conflict is merely speculation at this time (see preceding discussion).

Additional benefits that may have occurred for the tactual group may only be implied from the present data. The kinesthetic-tactual display mounted on the yoke, leads to a natural stimulus-response action of either pushing or pulling that control. This may have resulted in eliminating the frequently encountered confusion in the subject's mind as to whether to compensate for $\alpha_D - \alpha \neq 0$ (or airspeed changes) with either the yoke or throttle, thus easing the instructional situation. This is perhaps supported by the fewer verbal assists for power given to the tactual versus the airspeed group. Secondly, there may also be a gain in collison avoidance because a pilot, without visual attention being drawn towards information within the cockpit, could be more continuously aware of events and information outside the cockpit. This is suggested by the tactual group's observance of the runway as evidenced by more accurate lateral touchdowns. A previous study by Gilson and Fenton (1974) also suggests this increased awareness. Novice pilots more accurately controlled angle of attack with a tactual display while maneuvering with respect to a ground reference to the side of the aircraft. Such speculated benefits should be the subject of further investigation to establish or deny their validity.

EXPERIMENT 2

Introduction

Experiment 1 demonstrated the advantage of presenting angle of attack information tactually over airspeed information visually to novice pilots during the approach and landing. The tactual information facilitated control performance not only while the display was present, but also in a transfer condition, where only visual airspeed indication was available. Based on the conditions of Experiment 1, it could not be determined, whether the improved performance with the tactual training was due solely to the sensory modality of presentation. The tactual information was different, i.e., angle of attack as opposed to airspeed. Also, due to the unavailability of a visual windscreen (heads-up) displays, the pilot using the airspeed indicator had the added distraction of looking inside the cockpit for that information, in addition to control by environmental information.

The second study was designed to delineate the performance differences due to the methods of information presentation, i.e., tactual versus visual displays, rather than differences due to the actual information displayed. To equate the information to the two modalities, both a tactual display and a version of a visual heads-up display were used to provide airspeed and glide path error information. Angle of attack was not used. In addition, the experimental work was conducted using laboratory simulation, rather than in flight, to eliminate such confounding factors as crosswinds and airport traffic.

It should be noted that performance with the tactual display was conservatively tested here; a known disadvantage was incurred. Jagacinski, et al. (1977) found that the tactually displayed error signal must be quickened with velocity information in order to result in the same level of performance as with a visual display on a critical tracking task. One apparent explanation for the need of quickening may be tactual insensitivity to small deviations that are visually discernable. The velocity quickening emphasizes these small errors and brings tactual sensitivity and, apparently, information extraction to the level of visual modality. Thus, with identical information provided by these different displays, subjects using the information visually perform better than those receiving this information tactually. Accordingly, any performance advantage for the tactual display upon transfer to the unaided (no display) landing approach is not caused by better performance with the tactual displays prior to transfer.

Methodology

Subjects

Five female and fifteen male volunteers of 16 to 55 years of age, took part in the present study. To each of the experimental groups, one female and three males were randomly assigned. None of the subjects had previously performed, or assisted in, the landing of an aircraft.

Apparatus

Experimentation was conducted using a motion-based Singer GAT-1 single engine airplane ground trainer (see Appendix C). Only two controls were used, those for pitch and throttle. The three degrees of freedom rotational motion base of the trainer was limited to that of pitch. The built-in auditory systems for engine sound and stall warning alert provided supplementary information regarding throttle setting, pitch attitude, and excessively slow airspeeds. To encourage the pilot to direct visual attention out of the cockpit, all panel instruments, except those for the engine, were inoperative.

A visual simulation system of a simplified runway environment was developed for this research project by members of The Ohio State University Electrical Engineering and Psychology Faculty. The 525 line, raster scan display (with 256-line resolution) was projected by an Advent Model 1000A System (Fig. 12). The pilot within the trainer's cockpit had a viewing distance of 2.4 m from the projection screen. The concave screen measured 1.2 m vertically and 1.8 m horizontally and subtended 28° by 41°, respectively, of the viewer's visual angle. The simulation provided a horizon across approximately the center of the screen where the blue sky met the green ground. No ground texture cues were provided. A gray textureless runway, with a blue numeral "1" at the approach end, varied in perspective with the distance and altitude of the aircraft (Fig. 13).

Two visual heads-up displays were generated as horizontal lines superimposed on the background view. One line in black extending the width of the screen, with a .6 m vertical range of movement, represented the projected point of touchdown. The line overlaid the point on the earth's surface where the aircraft would make contact, if the present vertical velocity (rate of descent) and groundspeed were maintained. Since a zero wind condition existed in this simulation, airspeed and groundspeed were equivalent. The desired point of touchdown was the approach end of the runway identification number. Projected touchdown error was graphically depicted when the line did not overlay the number. This error also provided a performance measure whether or not it was displayed to the subject. The pilot's task was to keep the projected point of touchdown over the number by varying the vertical velocity. This was accomplished primarily by the throttle control. Increasing throttle by forward movement of the control resulted in a decrease in the rate of descent.

A second line, colored red, comprised the visual display for airspeed error, and ranged ±.3 m in relation to the horizon reference. At an altitude greater than 50 feet (15 m), this red line, properly positioned on the horizon, corresponded to 75 mph, the desired approach airspeed for this aircraft. Below 50 feet the desired (reference) airspeed decreased linearly as a function of altitude, such that aerodynamic stall speed, with full flap and landing gear extension, was reached just at touchdown. When the red line was above the horizon, an aft movement of the control yoke was required for correction. This resulted in an increase in pitch attitude and therefore, an appropriate decrease in airspeed. If the

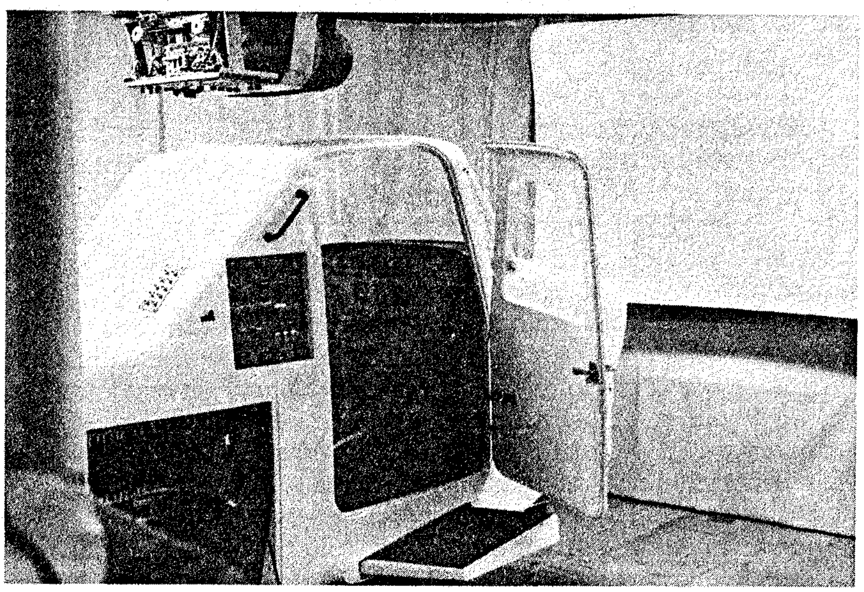
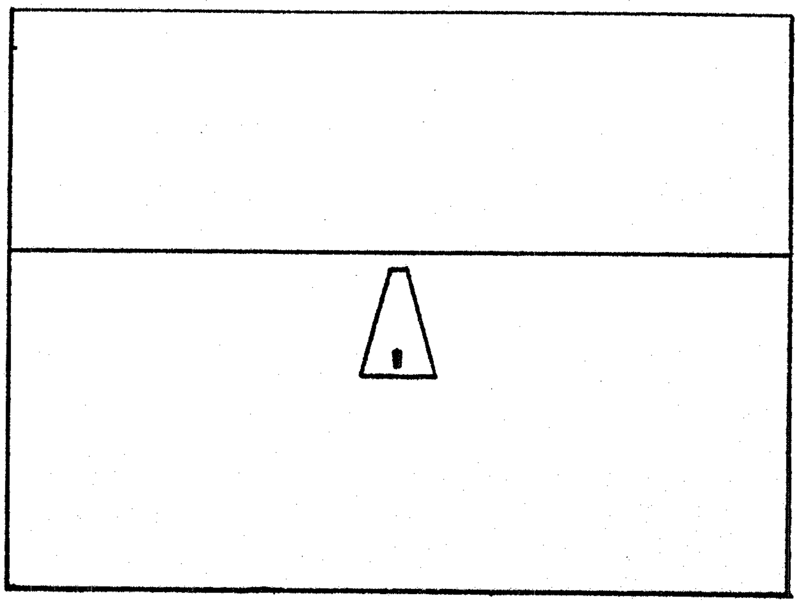
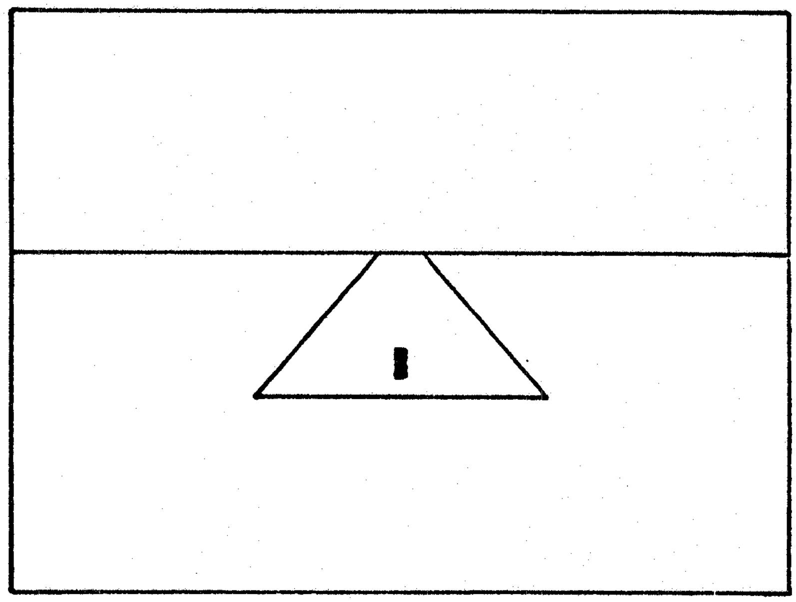


Fig. 12 - The advent Projection System with the
GAT-1 trainer



a



b

Fig. 13 - The visual simulation of the runway changes, view a to b, as distance and altitude decrease

difference between the actual and desired pitch attitude, i.e., the distance between the red line and the horizon, was kept within a close tolerance throughout the approach and touchdown, the approach would culminate in a gentle flare and full stall landing. Such accurate control would generate a low amplitude error signal which was also available for measurement whether or not it was displayed to the subject.

The same information was presented tactually. The tactual displays were, as before, mounted in the control handles. In this experiment there were tactual displays in both the yoke and throttle controls. An aft slide protrusion in the yoke control as shown in Fig. 1, corresponds now to a less than desired pitch attitude. The proper response would again be an aft movement of the control so as to increase the pitch attitude returning the slide to its flush position. The pilot's task was to track the slide to minimize the displayed error. The same error signals generated for the visual displays were used to drive the servo motors of the tactual displays. The pitch error was a function of the difference between the desired and actual airspeeds; the throttle error was a function of the difference between the projected and desired touchdown points. The sensitivities of the displays, with a range of ±1.25 cm, were set to correspond to the maximum sensitivity range for the visual displays. Also, with linear functions the rate of movement of the slides and the visual displays yielded indirect information as to the rate of increase or decrease in the error.

A warning system for the tactual displays was implemented, such that any time the force exerted on the slide's servomotor by the pilot caused a restriction in its movement, a light would be activated. This would alert both the pilot and the experimenter of the excessive hand pressure on the display. Typically, only a few such cautions were needed before the subjects developed a gentle touch on the displays. Movement of the control was easily accomplished without any interference in the display's movement.

The experimental data were recorded on a Brush RF1783-40 eight-channel strip-chart recorder.

Procedure

The experimental work took place in the Aviation Psychology Laboratory at The Ohio State University Airport. In general, participants reported for one hour a day, on four consecutive days.

On the first day, the experimenter gave all subjects an introduction to the visual simulation system without any display aids. Visual approaches were described to highlight perspective shape changes of the runway with varying distances, altitudes, and approach angles. Particular emphasis was placed on the center of expansion of the optic array as the projected point of touchdown (Gibson, 1955). Subjects were told to observe this point with the intent of keeping it on the runway number. Pitch as indicated by the relative distance between the engine cowling and the horizon, was presented as the reference visual cue for airspeed. The pitch and throttle controls necessary for the regulation of both airspeed and glide path were explained, followed by a demonstration of their movement. The use of fore/aft yoke movement, resulting in changes of pitch, was shown as the primary method to accomplish airspeed control. Participants were told to keep the desired approach airspeed until within 50 feet (15 m) of the ground. At this altitude, the airspeed should be gradually decreased until reaching stall and minimal vertical velocity at the time of touchdown. A brief explanation of aerodynamic stall was included.

The throttle was introduced as the control for glide path angle and, therefore, touchdown point. For example, forward throttle movement resulted in an increase in power and a decrease in rate of descent. The interaction of airspeed and throttle changes was discussed and the necessary pitch changes accompanying throttle changes described.

Two demonstration approach and landing trials were performed jointly by the subject and the experimenter. The subject, now the pilot, subsequently made four pretraining unassisted approaches and landings. Often the recordings showed these "landings" to be short of the runway threshold.

Each trial began with the aircraft positioned approximately 2 miles (3.2 km) from the runway and 500 feet (152 m) above ground level at an engine power of 2200 revolutions per minute. Each approach and landing took approximately two minutes to complete.

As previously mentioned, the roll and yaw capabilities of the ground trainer were disabled; the aircraft never deviated from alignment with the runway centerline.

There were five experimental groups (Table 2). Subject assignment to the groups occurred at the onset of experimentation. Group 1 used both the visual pitch and visual throttle displays. Group 2 had both tactual displays. Group 3 had the visual pitch and tactual throttle displays, and Group 4 had tactual pitch and visual throttle. The control group had no displays, only verbal instructions from the experimenter (see Appendix B).

On Day 2, the subjects were introduced to their respective display for pitch information, according to grouping. Eight training trials were run with the pilot controlling error with the respective display. It should be noted here that only the pitch displays were utilized. Previous work had shown that when subjects were given both the pitch and throttle displays initially, confusion from their interaction resulted in poor skill acquisition. Therefore, during these initial training trials, the experimenter controlled the throttle in order to minimize throttle error.

After these first eight trials, the throttle display was introduced as appropriate to the subject's grouping. Eight additional training

TABLE 2

The Respective Display Modality of the Experimental Groups

Group	Pitch Display	Throttle Display
1	visual	visual
2	tactual	tactual
3	visual	tactual
4	tactual	visual
5	none	none

approaches to landing were made with both pitch and throttle displays activated. Data were recorded on the last four trials of this series. For all trials, pitch control was emphasized as the primary task. This emphasis was justifiable because the interaction between the two control systems was such that without pitch being held constant, throttle control was quite difficult. Also, a correction in pitch would often result in a correction in the projected point of touchdown and, therefore, no throttle control movement would be needed. Finally, the pitch control/display system had only a small time lag associated with it as compared to a rather long time lag associated with the throttle system.

Pilots were told to attend to the runway cues when using any of the displays to maximize transfer to the no-display test period. However, no verbal assistance was introduced during a trial except for the control group who received constant individualized verbal instructions.

The final four trials of Day 2 comprised Test Period 1, during which data were also collected. These approaches to landing were accomplished without the use of any displays.

On day 3, another series of 16 training approaches and landings was conducted with the respective displays, followed by 4 test trials without the displays or verbal assistance. The following day, two series of 16 practice and 4 test trials took place.

Results

Recorded data consisted of pitch error, throttle error, vertical velocity and altitude. Pitch and throttle error were analyzed in detail. Vertical velocity and altitude were used as validation references for strip-chart data analysis. Of the approximately 120-second trial, the central 60 seconds were examined. Errors during the flare and touchdown were not utilized as data because of a significant amount of noise in the two error signals during this portion of the approach. For the 60-second approach phase analyzed, two measures of each error signal were taken: root mean squared error and the integral of the absolute value of the error, sampled each second. These two measures did not differ appreciably in sensitivity to variance and yielded the same levels of significance. The integral error will be used for discussion.

Training Periods

Data were analyzed for the final four approaches of each sixteen-trial training series. As was expected with identical information from the two displays, those using the visual display performed pitch control significantly better than those using the tactual display for pitch error, while the displays were present, $F\ (1.15) = 17.33$, $p \leq .001$ (Table 3). There was no effect of pitch or throttle display modality on throttle error control with the displays. Figure 14 represents the group scores of mean integral error for these last four trials of each training session.

TABLE 3

F Ratio Table Generated from the Analysis of Variance Using the CANOVA Program (Poor, 1973) of Performance with the Displays

	Hypothesis SS			Within Cell Error SS			F	
Between Subject Source	Pitch	Throttle	df	Pitch	Throttle	df	Pitch	Throttle
Between Subjects Effect: Group Effects								
Group Main Effect	229822	54915	4	84008	161701	15	10.26***	1.27
Pitch-Visual vs Tactual	97056	21438	1	84008	161701	15	17.33***	1.99
Throttle-Visual vs Tactual	12873	25057	1	84008	161701	15	2.30	2.32
Pitch/Throttle Interaction	16738	168	1	84008	161701	15	2.99	.02
Within Subject Effect: Test Period Effect								
Main Effect			3			13	.49	4.54*
Linear	1184	19816	1	33774	54458	15	.53	5.46*
Quadratic	3192	7847	1	32397	38024	15	1.48	3.10
Cubic	174	2643	1	39685	65164	15	.07	.61
Group by Test Period Effect								
Group by Test Period			12			34	.37	.39
by Test Period Linear	2728	1788	4	33774	54458	15	.30	.12
by Test Period Quadratic	2885	10129	4	32397	38024	15	.33	1.00
by Test Period Cubic	3154	11194	4	39685	65164	15	.30	.64
Pitch-Visual vs Tactual			3			13	.56	.21
by Test Period Linear	2516	266	1	33774	54458	15	1.12	.07
by Test Period Quadratic	308	1224	1	32397	38024	15	.14	.48
by Test Period Cubic	2021	2593	1	39685	65164	15	.76	.60

Between Subject Source	Hypothesis SS Pitch	Hypothesis SS Throttle	df	Within Cell Error SS Pitch	Within Cell Error SS Throttle	df	F Pitch	F Throttle
Throttle-Visual vs Tactual			3			13	.24	.84
by Test Period Linear	112	1109	1	33774	54458	15	.05	.31
by Test Period Quadratic	336	6907	1	32397	38024	15	.16	2.72
by Test Period Cubic	991	5771	1	39685	65164	15	.38	1.33
Pitch/Throttle Interaction			3			13	.26	.56
by Test Period Linear	47	335	1	33774	54458	15	.02	.09
by Test Period Quadratic	546	1931	1	32397	38024	15	.25	.76
by Test Period Cubic	135	2679	1	39685	65164	15	.05	.62
Trial Effect								
Main Effect			3			13	1.48	1.73
Linear	728	6157	1	26310	20848	15	.42	4.43*
Quadratic	4447	407	1	31218	13568	15	2.14	.45
Cubic	2429	21	1	14169	15703	15	2.57	.02
Group by Trial Effect								
Group by Trial			12			34	1.95	.49
by Trial Linear	1576	3796	4	26310	20848	15	.22	.68
by Trial Quadratic	3879	516	4	31218	13568	15	.47	.14
by Trial Cubic	20192	2505	4	14169	15703	15	5.34**	.60
Test Period by Trial								
Test Period by Trial			9			7	1.66	1.67
Group by Test Period by Trial								
Group by Test Period by Trial			36			27	.34	1.32

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$

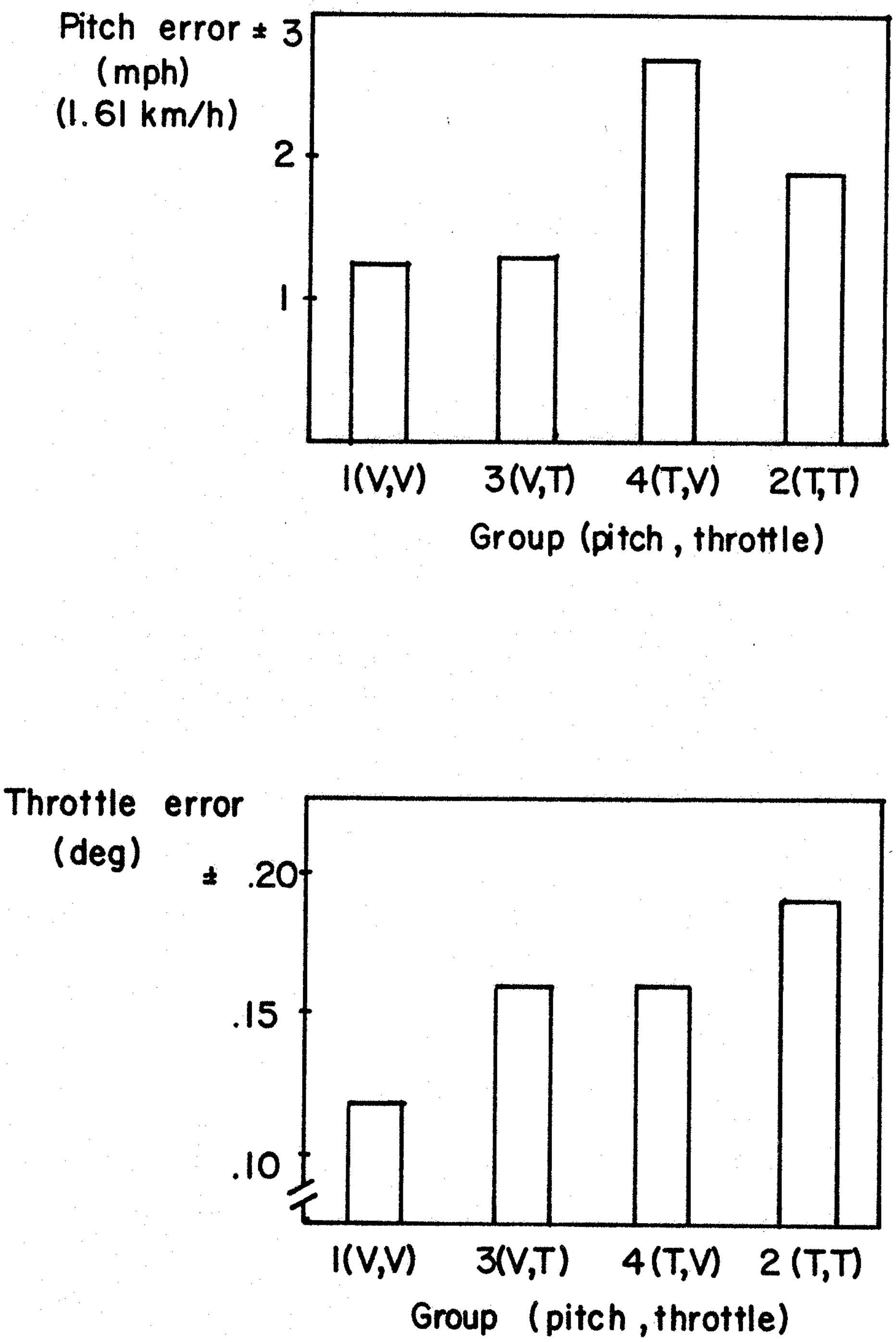


Fig. 14 - Group effects for visual (V) and tactual (T) displays; performance with the displays

Test Periods, Post Training

Data from the four test approaches subsequent to the training series were examined. It should be noted that no displays were present during these unaided test trials, the approaches were made with reference only to the runway environment.

The main effect was the significantly improved performance on pitch control with tactual pitch information prior to testing, (Groups 2 and 4) $F\ (1,15) = 4.97$, $p \leq .05$. In addition, this performance advantage was also reflected in throttle control, i.e., throttle control was significantly better for those pilots who had received training with tactual pitch error, regardless of the display modality of throttle error presentation, $F\ (1,15) = 5.16$, $p \leq .05$ (Table 4). The group effects during the test periods may be seen as mean integral error scores in Fig. 15. The pilots trained with both tactual displays had the least amount of pitch error (±4.33 mph), whereas, those trained with both visual displays exhibited the most error (±7.58 mph). The respective throttle errors were $\pm.193°$ and $\pm.235°$.

Contrary to expectation, the test period performance of the verbally assisted control group equalled, for pitch control, and significantly exceeded, for throttle control, that of the experimental display groups.

Pretraining

To insure that the random subject assignment to the groups eliminated any group biases, the initial four approaches were analyzed; these occurred before any display experience. There were no significant differences between the four experimental groups on integrated pitch error, $F\ (3,27) = 1.58$, $p \leq .26$ or integrated throttle error, $F\ (3,24) = .64$, $p \leq .61$. The combination of Groups 1 and 3, which subsequently had visual pitch training versus Groups 2 and 4, which had tactual pitch training also were not significantly different in pitch error, $F\ (1,33) = 1.17$, $p \leq .30$ or throttle error, $F\ (1,30) = 2.04$, $p \leq .18$ in these first four pretraining approaches.

Skill Acquisition

The improved performance without the displays due to training across test periods was significant, $F\ (3,13) = 12.05, 17.02$, $p \leq .001$. Figure 16 indicates the progressive but complex linear and cubic relationship of the training effects on pitch and throttle integral error with a negative slope of .38 and .03. Performance with the displays is depicted in Fig. 17 across practice periods. Throttle error was significant and linear with a negative slope and closely resembled the shape of the throttle error for performance without the displays.

Discussion

This second study shows that training with tactual presentations facilitates subsequent unaided performance more than training carried out

TABLE 4

F Ratio Table Generated from the Analysis of Variance Using the CANOVA Program (Poor, 1973) of Performance without the Displays

	Hypothesis SS			Within Cell Error SS			F	
Between Subject Source	Pitch	Throttle	df	Pitch	Throttle	df	Pitch	Throttle
Between Subjects Effect: Group Effects								
Group Main Effect	803608	71909	4	1591191	73765	15	1.89	3.66*
Pitch-Visual vs Tactual	527622	25371	1	1591191	73765	15	4.97*	5.16*
Throttle-Visual vs Tactual	58867	551	1	1591191	73765	15	.56	.11
Pitch/Throttle Interaction	11936	2927	1	1591191	73765	15	.11	.60
Within Subject Effect: Test Period Effect								
Main Effect			3			13	12.05***	17.02***
Linear	253584	139277	1	519871	50501	15	7.32*	41.37***
Quadratic	15610	846	1	357889	36857	15	.65	.34
Cubic	72441	17043	1	83353	62226	15	13.04**	4.11
Group by Test Period Effect								
Group by Test Period			12			34	2.80**	2.76**
by Test Period Linear	274900	61798	4	519871	50501	15	1.98	4.59*
by Test Period Quadratic	72305	26665	4	357889	36857	15	.76	2.71
by Test Period Cubic	146805	21489	4	83353	62226	15	6.60**	1.30
Pitch-Visual vs Tactual			3			13	6.14**	4.80*
by Test Period Linear	125432	5223	1	519871	50501	15	3.62	1.55
by Test Period Quadratic	6290	12420	1	357889	36857	15	.26	5.06*
by Test Period Cubic	39516	5298	1	83353	62226	15	7.11**	1.28

Between Subject Source	Hypothesis SS Pitch	Hypothesis SS Throttle	df	Within Cell Error SS Pitch	Within Cell Error SS Throttle	df	F Pitch	F Throttle
Throttle-Visual vs Tactual			3			13	1.24	1.49
by Test Period Linear	95513	8821	1	519871	50501	15	2.76	2.62
by Test Period Quadratic	6879	597	1	357889	36857	15	.29	.24
by Test Period Cubic	2685	10847	1	83353	62226	15	.48	2.62
Pitch/Throttle Interaction			3			13	5.72**	3.69*
by Test Period Linear	2467	37045	1	519871	50501	15	.07	11.00**
by Test Period Quadratic	57390	13603	1	347889	36857	15	2.40	5.54*
by Test Period Cubic	104292	3981	1	83353	62226	15	18.77***	.96
Trial Effect								
Main Effect			3			13	1.98	9.97***
Linear	42766	15038	1	231384	46565	15	2.77	4.84*
Quadratic	22095	4056	1	231418	12202	15	1.43	4.99*
Cubic	10045	18683	1	98978	14553	15	1.52	19.26***
Group by Trial Effect								
Group by Trial			12			34	.97	2.79**
by Trial Linear	44258	24220	4	231384	46565	15	.72	1.95
by Trial Quadratic	38364	15489	4	231418	12202	15	.62	4.76*
by Trial Cubic	60349	3606	4	98978	14553	15	2.29	.93
Test Period by Trial								
Test Period by Trial			9			7	5.83*	12.12**
Group by Test Period by Trial								
Group by Test Period by Trial			36			27	1.12	1.23

* $p \leq .05$
** $p \leq .01$
*** $p \leq .001$

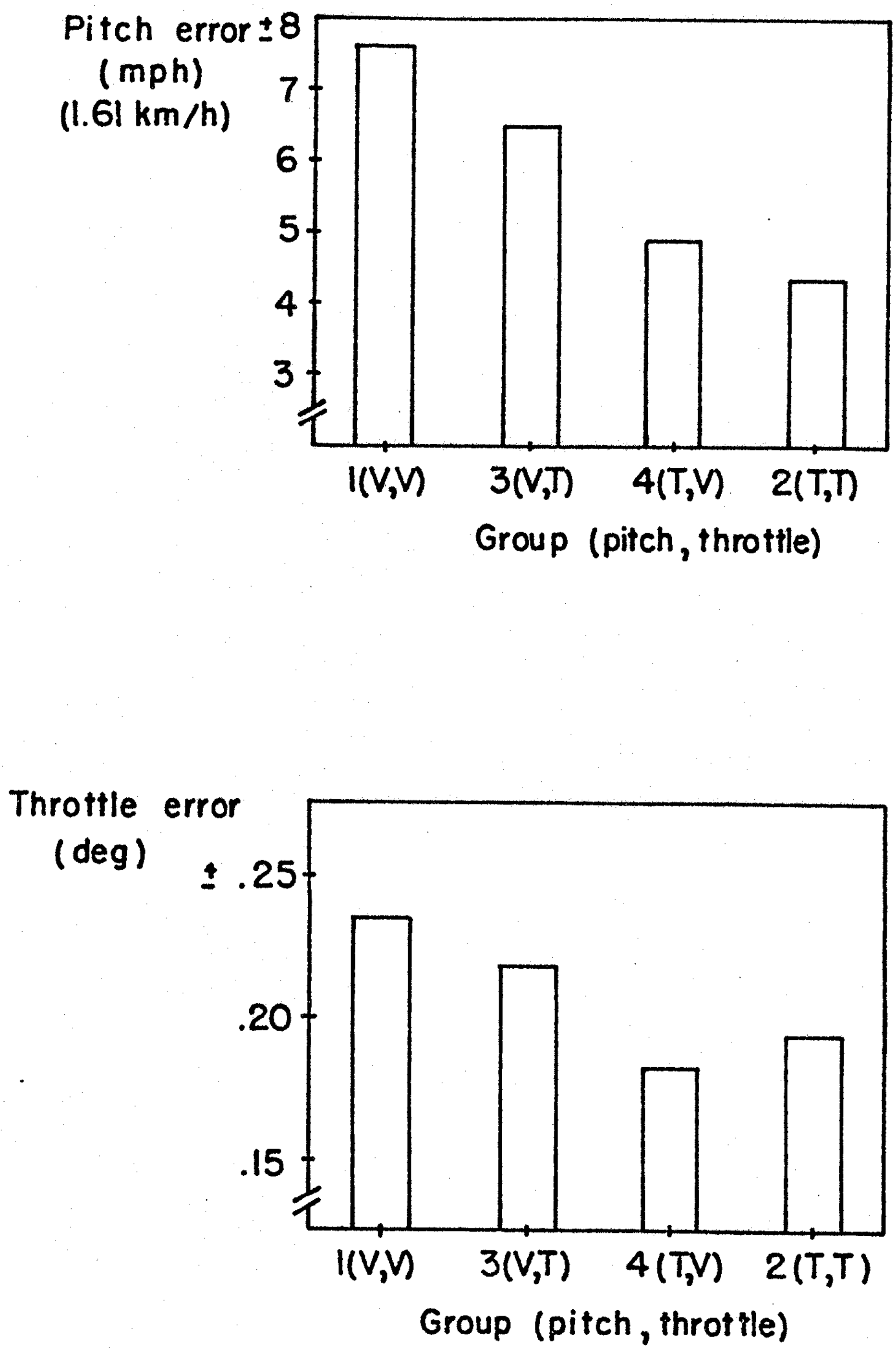
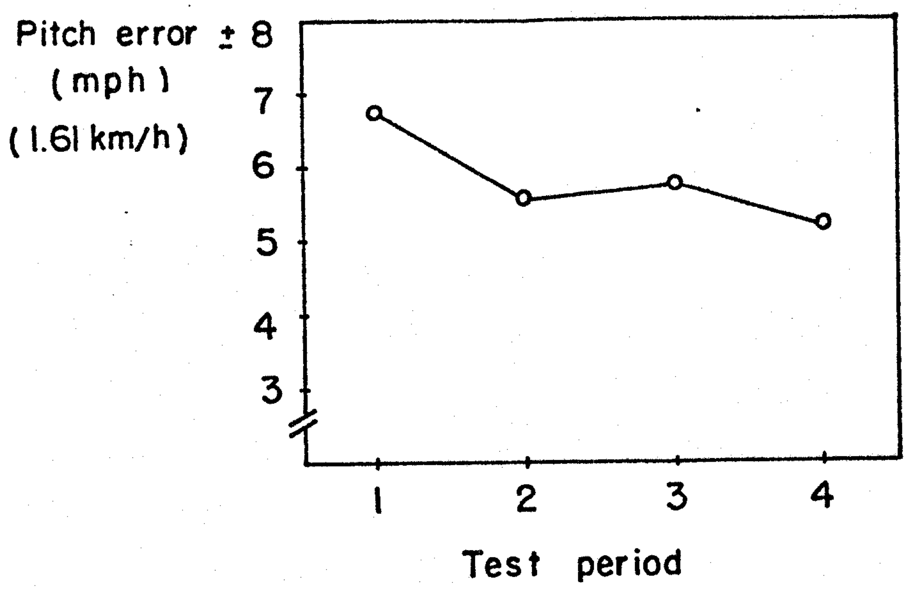


Fig. 15 - Group effects for visual (V) and tactual (T) displays; performance without the displays



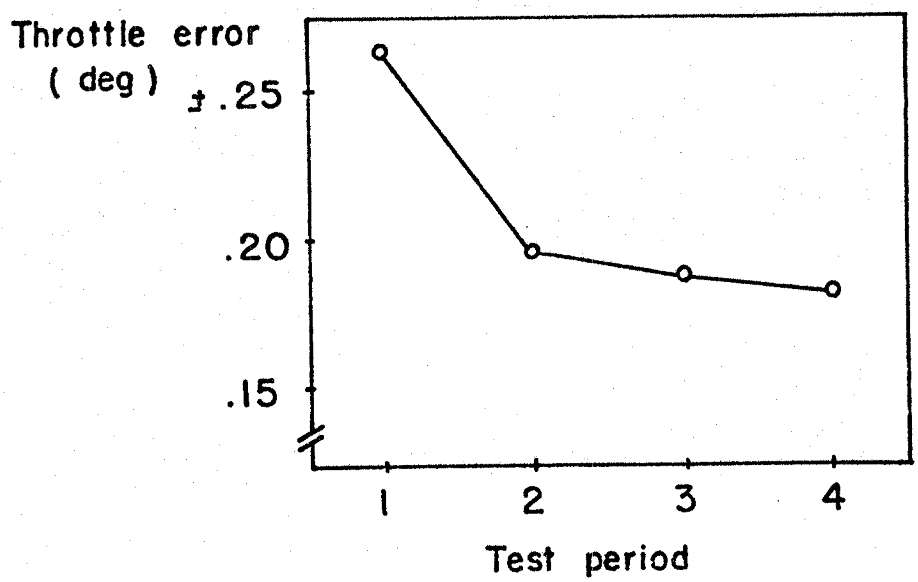


Fig. 16 - Test period effects of the integrated error for all subjects; performance without the displays

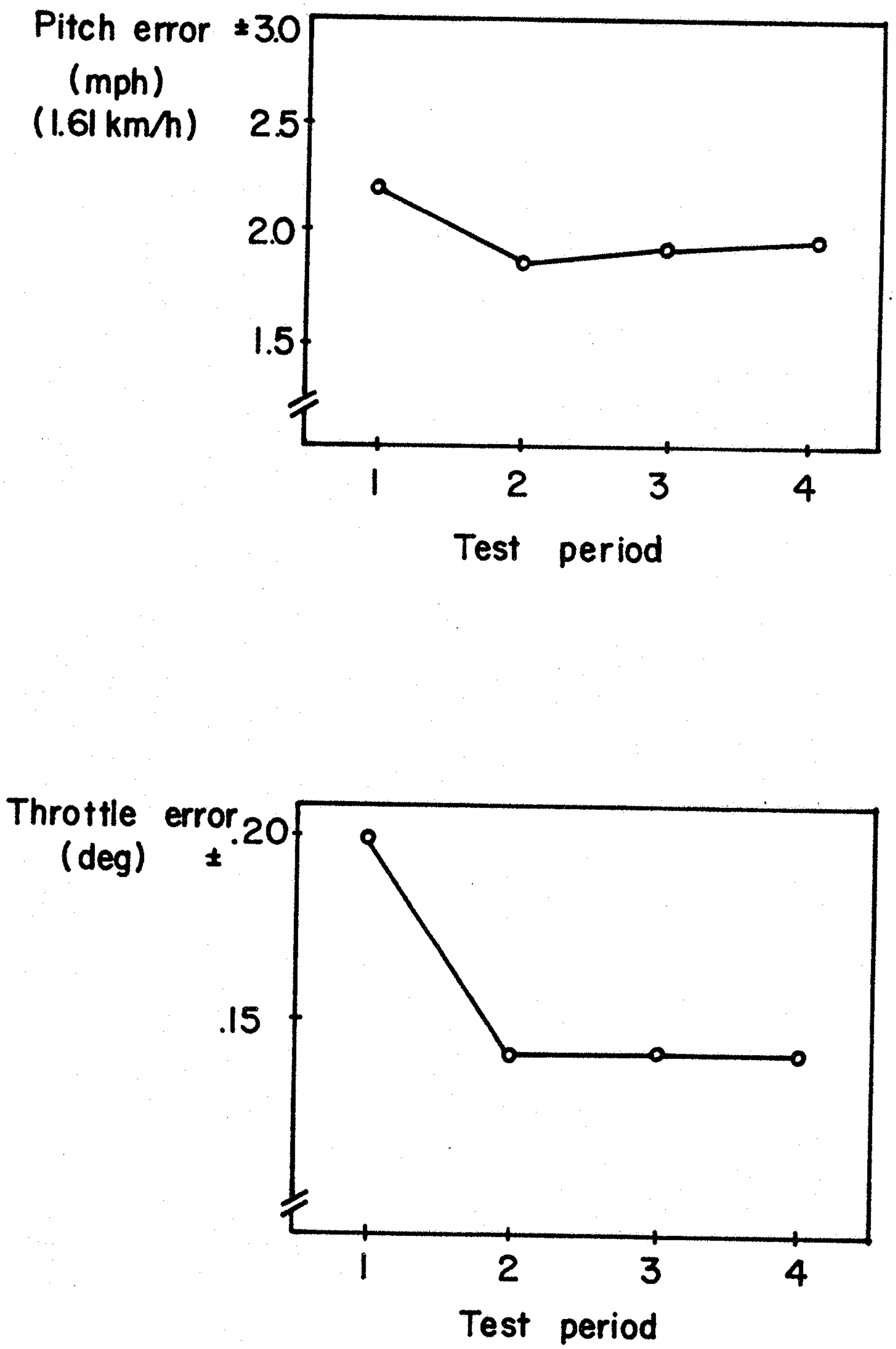


Fig. 17 - Test period effects of the integrated error for all subjects; performance with the displays

with even optimized visual heads-up displays of the same information. Facilitation occurred even though performance using the visual display exceeded that of the tactual. This suggests that the results of Experiment 1 may not have been as pronounced had a heads-up visual display of angle of attack been used since testing occurred during display usage. Thus, the display technique contributed to the training enhancement in both studies. This advantage may exist because of the high demands placed on the visual modality during training, by the visual compensatory control tasks. Because of the sublety, necessary visual information in the runway environment is difficult to perceptually extract and interpret. A pilot therefore must learn the relationship between the visual transformations and control of pitch and throttle. This learning would not necessarily occur if one is simply looking at the runway, without perceiving (being aware of) the visual relationships and transformations.

The tactual display has been shown in both experiments to facilitate the perceptual learning and integration of approach and flare information to a greater degree than the visual display. This facilitation may be all or in part attributed to the lack of interference in the visual field with a tactual display. Without perceptual interference in the visual modality, visual attention may be entirely consumed by the processing of the information available in the runway environment. Therefore, without the displays, the facilitated learning is evident. Further evidence supporting this argument is found with the verbal group who outperformed both display groups. Verbal assistance, like tactual information transmission has the advantage of little visual interference with the approach and landing task. However, in flight verbal assistance can cause attentional interference with radio communications, aural warning devices and other important aircraft sounds.

Due to the interaction of airspeed and glide path, a more stabilized and accurate air speed control could enhance glide path control. The significant effect of the pitch display training on throttle control, regardless of throttle display modality, reflects the importance of this interaction. Also because pitch control consumes much of the pilot's visual attention, the reduction of intramodality interference with the tactual pitch display may allow increased learning potential for throttle control. Therefore, the lack of significant performance improvement with the tactual throttle display training may not be surprising.

As a final point concerning throttle control, the visual simulation equipment provided no texture cues either on or around the runway. Therefore, the expansion of the runway edges can be assumed to have provided the only cue for projected touchdown point, in the unaided trials. This expansion was apparent only from a relatively close distance to the runway. In actual flight, objective texture cues normally are available, even at a great distance, in the form of the large texture of fields and trees below, or just in front of, the aircraft. Rapid descention is detectable by the texture expansion in this optic array. It is quite remarkable, given this lack of information, that glide path control via throttle control was so well accomplished by the novice pilots in this study. Parenthetically, this finding has specific impact for visual simulation considerations.

The reasons why individual verbal instructions in the second study were more effective than either the tactual or visual displays by themselves seem clear. There is more to the approach and landing task than just compensatory tracking of the yoke and throttle controls. Control interactions, anticipation of control input, and extraction of information from the landing environment are all required and can be provided by verbal instructions. Furthermore, this instruction does not compete with visual perceptual learning. Therefore, the combination of the two nonvisual techniques, verbal instructions and continuous tactual feedback of at least pitch information, as in the first study, augments training over conventional verbal techniques.

Summary

Through this and previous research, the tactual modality has gained substantial status as an input channel for control information. The use of the kinesthetic-tactual displays was shown to enhance visual perceptual learning of the approach and landing task.

In the first study, the utilization of the kinesthetic-tactual display for compensatory tracking of a computer-generated desired angle of attack produced the following results, in comparison to the visual display of airspeed:

1. a more accurate control of angle of attack;
2. an increased utilization of the elevator for angle of attack control;
3. fewer number of verbal assists given by the instructor pilot;
4. an increase in the number of unassisted landings both while initially utilizing the tactual display and subsequently when utilizing a conventional airspeed display, and
5. a closer adherence to runway centerline during landings.

Some problem or conflict did occur, however, for conventionally trained pilots when they were transferred to fly with the tactual display. The result was a substantial increase in the number of instructor pilot takeovers.

It could not be determined from this study, whether the advantages found were the result at the sensory mode of display presentation, or the fact that the tactual display group received angle of attack information and the airspeed group received airspeed information.

The second study demonstrated the advantage of tactual over visual presentation of the same control feedback for the approach to landing. The tactual feedback facilitated the learning of the interpretation necessary to use the available visual information in an approach. Since velocity quickening was not present in the tactual displays, performance with the heads-up visual pitch display was superior to that with the tactual pitch display. However, in the transfer condition, where displays were unavailable, the tactual advantage of less visual workload was evidenced in the better performance of those trained with the tactual pitch display.

In comparison to the display groups, the control group demonstrated the importance of adequate individualized verbal instruction. Given together, as in the first study, individualized verbal instruction supplemented by kinesthetic-tactual displays, of at least pitch error, may improve conventional verbal training of the visual approach and landing.

REFERENCES

Bliss, J. C. (Guest Editor). IEEE Transactions on Man-Machine Systems: Special Issue, Tactile Displays Conference, March 1970, MMS-11(1).

Bliss, J. C., Link, S. W., and Mansfield, P. K. Tactual Perception: Experiments and Models (Quarterly Report 1, Contract NAS2-3649). Menlo Park, California: Stanford Research Institute, September 1966.

Burke, M. W. Secondary Workload Capability with Primary Visual and Kinesthetic-Tactual Displays. Unpublished master's thesis, Ohio State University, 1978.

Fenton, R. E., and Montano, W. B. An Intervehicular Spacing Display for Improved Car-Following Performance. IEEE Transactions on Man-Machine Systems, June 1968, MMS-9(2), 29-35.

Geldard, F. A. (Editor). Conference on Cutaneous Systems and Devices. Psychonomic Monograph Supplement. Monterey, California, April 17-18, 1973.

Gibson, J. J. The Optical Expansion-Pattern in Aerial Locomotion. The American Journal of Psychology, September 1955, LXVIII, 480-484.

Gibson, J. J., Olum, P., and Rosenblatt, F. Parallax and Perspective During Aircraft Landings. The American Journal of Psychology, 1955, LXVIII, 372-385.

Gilson, R. D. A Tactual Display Aid for Primary Flight Training (Annual Report, Contract NAS 2-8954). Moffett Field, California: National Aeronautics and Space Administration, Ames Research Center, July 1976.

Gilson, R. D., and Fenton, R. E. Kinesthetic-Tactual Information Presentations - Inflight Studies. IEEE Transactions on Systems, Man and Cybernetics, November 1974, SMC-4(6), 531-535.

Gilson, R. D., and Ventola, R. W. Evaluation of a Tactual Display Device with Adapting Primary and Secondary Task Performance Methods (Final Report, Contract AMRDL CR-76-1). Moffett Field, California: United States Army, Air Mobility Research and Development Laboratory, Ames Research Center, February 1976.

Greenwald, A. G., and Shulman, H. G. On Doing Two Things at Once: II. Elimination of the Psychological Refractory Period Effect. Journal of Experimental Psychology, November 1973, 101(1), 70-76.

Hasbrook, A. H. The Approach and Landing; Cues and Clues to a Safe Touchdown. Business and Commercial Aviation, November 1975, pp. 39-43.

Hasbrook, A. H., and Rasmussen, P. G. Aural Glide Slope Cues: Their Effect on Pilot Performance During In-Flight Simulated ILS Instrument Approaches. (Report No. FAA-AM-11-24.) Oklahoma City, Oklahoma: Federal Aviation Administration, Office of Aviation Medicine, May 1971.

Hirsch, J., Shafer, J. H., and Eitan, A. Experiments in Tactile Communication. Paper presented at the 6th Annual Conference on Aviation and Astronautics, Haifa, Israel, 1964.

Jagacinski, R. J., Miller, D. P., Gilson, R. D., and Ault, R. T. Evaluation of Kinesthetic-Tactual Displays Using a Critical Tracking Task. Proceedings of the Thirteenth Annual Conference on Manual Control. M.I.T., Cambridge, Massachusetts, June 1977.

Kahneman, D. Attention and Effort. Englewood Cliffs, New Jersey: Prentice Hall, 1973.

Lane, J. C., and Cumming, R. W. The Role of Visual Cues in Final Approach to Landing (Human Engineering Note 1). Melbourne, Australia: Aeronautical Research Laboratories, May 1956.

Levison, W. H., Tanner, R. B., and Triggs, T. J. Evaluation of Tactual Displays for Flight Control. Proceedings of the 9th Annual Conference on Manual Control. M.I.T., Cambridge, Massachusetts, 1973.

Mertens, H. W. Perceived Orientation of a Runway Model in Nonpilots During Simulated Night Approaches to Landing. Aviation Space and Environmental Medicine, March 1978, 49(3), 457-460.

National Transportation Safety Board. Aircraft Accident Reports: Brief Format, U.S. Civil Aviation (Issue No. 1, 2, 3, 4, and 5 of 1976 Accidents, NTSB-BA-76-6, 76-7, 77-1, 77-2, and 77-3). Washington, D. C.: Author, 1976.

Palmer, E. A. Experimental Determination of Human Ability to Perceive Aim Point from Expanding Gradient Cues. Paper presented at the 1969 Annual Scientific Meeting of the Aerospace Medical Association, San Francisco, May 1969.

Poor, D. D. S. Analysis of Variance for Repeated Measures Designs: Two Approaches. Psychological Bulletin, 1973 80(3), 204-209.

Treisman, A., and Fearnley, J. S. Can simultaneous speech stimuli be classified in parallel? Perception and Psychophysics, 1971, 10, 1-7.

APPENDIX A

SC150--Angle of Attack System Technical Description

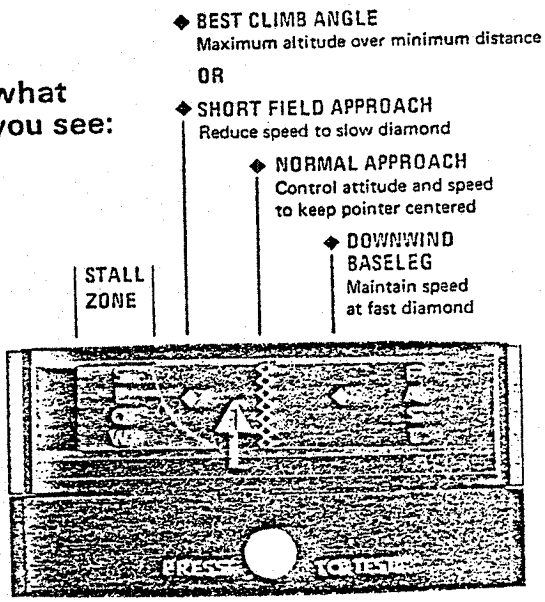
SAFE FLIGHT
INSTRUMENT CORPORATION
White Plains, New York

SC-150

SPECIALISTS IN AIRCRAFT SAFETY EQUIPMENT

SAFE FLIGHT'S TSO'D SC-150 angle-of-attack system combines pre-stall warning with speed control for maximum performance and safety

what you see:



you need the SC-150 for:

▪ Instantaneous Stall Trend Information ▪ Proper Speed/Attitude During Landing Approach ▪ Best Short Field Approach Speed/Attitude ▪ Best Climb Angle or Speed ▪ Best Engine Out Climb for Twin Engine Aircraft ▪ Easier Control During Turbulence

outstanding features:

▪ Combines Speed Control and TSO'd Pre-Stall Warning ▪ Shows Continuous Stall Trend Information ▪ In-Flight Self Test Capability ▪ Single Angle-Of-Attack Wing Sensor ▪ Anti-Icing Operation (Optional) ▪ Horizontal or Vertical Scale Indicator Available

operation:

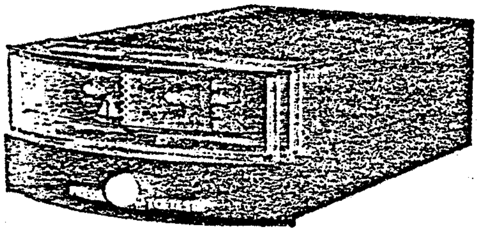
The SC-150 Angle-Of-Attack system is one of a second generation of Safe Flight's precision lift measurement systems which provide the pilot with necessary lift information to utilize the performance capabilities of his aircraft. It presents a continuous cockpit display that enables a pilot to evaluate instantly the lift performance of his aircraft, regardless of gross weight, wing loading, air density, attitude, ground effect, turbulence or flap/gear configuration.

By the increasing slope of red at the SLOW side of the Indicator scale, the SC-150 shows the trend towards stall. The reference diamonds at either side of the center-mark are provided as targets below and above the optimal 30% above stall generally approximated for the center-mark. These can be used for maximum performance short-field operations on the SLOW side and less critical or turbulent air approaches, on the FAST side.

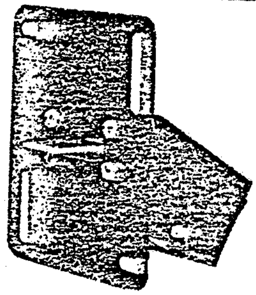
In addition to presenting instantaneous speed control information to the pilot, the SC-150 also provides a signal output which activates the aircraft Pre-Stall Warning Device when the aircraft approaches a stall condition.

technical information

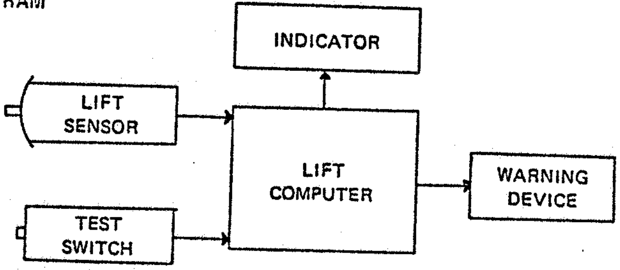
INDICATOR AND COMPUTER



LIFT SENSOR



TYPICAL BLOCK DIAGRAM



system description:

The Safe Flight SC-150 System is comprised of a wing mounted Lift Sensor, cockpit located Lift Computer and Speed Control Indicator.

The Lift Sensor is installed in the lower leading edge of the aircraft wing and can replace your existing wing stall warning sensor. The sensing vane of the unit protrudes into the airstream and during flight is positioned by local airflow velocity and direction. By correlating lift with airflow characteristic at the stagnation point on the wing, the Lift Sensor measures changes in angle-of-attack, or air-speed deviation from an airspeed represented by a reference angle-of-attack.

The output signal, combining angle-of-attack and local dynamic pressure, enters the Lift Computer which contains power regulation, signal processing and control circuitry. The computer activates the Pre-Stall Warning Device whenever the Lift Sensor signal approaches the stall angle-of-attack. An output signal (which represents wing lift condition) is also provided for visual display on the Speed Control Indicator.

A "Press To Test" switch is provided on the Lift Computer to allow test of the Indicator, Lift Computer and Pre-Stall Warning Device during ground or flight operations.

specifications

COMPONENT DIMENSIONS (In Inches):

Indicator and Computer 1¼ H x 2½ W x 4½ L
Lift Sensor 1¼ H x 1-3/8 W x 3 L
Sensor Mounting Plate 3¼ H x 2½ W

Pre-Stall Warning	TSO-C54
Power Source	14 or 28 V DC
Nominal System Power Drain*	.3 amps
Anti-Ice Heater Power Drain	85 watts

The measurement accuracy of the SC-150 system may be expressed in knots deviation from the speed associated with the calibrated desired angle-of-attack. This accuracy is usually within one knot.

**Does not include Warning Device or Anti-Ice Heater.*

For more information, please write, stating aircraft make and model, to:

SAFE FLIGHT INSTRUMENT CORPORATION
P.O.Box 550
White Plains, New York 10602
Tel: 914-946-9500

R-1274

Printed in U.S.A.

APPENDIX B

Instructions to Instructor and Student Pilots

Experiment 1

The instructor conducting the first 3 hours of training had approximately 300 hours flight time with commercial, instrument, multiengine and flight instructor single engine certificates. His experience as a flight instructor was very limited. The lesson plans from the standard training syllabus used for these first three hours of dual instruction are enclosed in this appendix.

The remaining 6 hours of training were conducted by an experienced flight instructor with approximately 400 hours dual given, 3000 hours total, flight instructor and airline transport--multi and single engine certificates. This portion of the instruction consisted of take-off, approach, and landing training. The airspeed indicator and tactual display were introduced at this time. Students were given a demonstration of their function and an explanation of their interpretation and the proper response. Verbal instructions were restricted to those regarding pitch, power, and line up with the runway along with "follow the display" or "maintain proper airspeed" as appropriate.

Following each lesson, the student was debriefed. Student's progress was discussed and problem areas brought to their attention.

Experiment 2

Experimentation was conducted by a commercial-instrument pilot under the direction of a certified ground instructor. Instructions to the display groups directed their attention to the display's position and the needed response. The control group, or verbal instruction group, was told to increase or decrease airspeed and power as necessary. All pilots were reminded to interpret the position of the nose with respect to the horizon and the apparent movement of the runway threshold and changes in the runway shape.

After each landing, comments were made concerning the approach angle, e.g., it was too steep and the appropriate response, i.e., reduce power sooner. Airspeed maintenance was discussed as to whether the pitch angle was too high or too low. The amount of increased pitch needed for flare at touchdown was evaluated.

Each lesson was concluded with a discussion of the pilot's progress and the direction of potential improvement.

THE OHIO STATE UNIVERSITY
DEPARTMENT OF AVIATION

PRIVATE PILOT CERTIFICATE COURSE (AIRPLANE)

FLIGHT TRAINING

LESSON NO. 1--1.0 HOUR DUAL

a. Objective. The student will be familiarized with the training airplane, its operating characteristics, cabin controls, instruments, and systems, preflight procedures, use of checklists, and safety precautions to be followed. The student will be instructed in basic flight maneuvers: straight and level flight, medium turns, climbs, climbing turns, glides, gliding turns, and level off procedures will be given.

b. Content.
   (1) Preflight discussion
   (2) Introduction
      a. purpose of preflight checks
      b. line (preflight inspection)
      c. airplane servicing
      d. importance of using a checklist
      e. engine start and runup
      f. basic radio procedures
      g. taxi
      h. pre-takeoff checklist
      i. takeoff-normal or crosswind
      j. traffic pattern departure
      k. local flying area familiarization
      l. straight and level flight (VR & IR)
      m. medium bank turns (VR & IR)
      n. collision avoidance
      o. climbs and climbing turns (VR & IR)
      p. glides and gliding turns (VR & IR)
      q. level off from climbs and glides (VR & IR)
      r. torque effect
      s. traffic pattern entry
      t. ground safety
   (3) Post-flight critique and preview of next lesson.

c. Completion Standard. At the completion of this lesson, the student should be able to, with assistance, conduct a preflight, use checklists, make engine runups, maintain altitude in straight and level and turns, within ±20, and display an understanding of ground safety.

THE OHIO STATE UNIVERSITY
DEPARTMENT OF AVIATION

PRIVATE PILOT CERTIFICATION COURSE (AIRPLANE)

FLIGHT TRAINING

LESSON NO. 2--1.0 HOUR DUAL

a. Objective. This flight period will be a review of maneuvers and procedures previously introduced. Flight at minimum controllable airspeed, steep power turns and power off stalls will be introduced.

b. Content.
  (1) Preflight discussion
  (2) Review
    a. use of checklist
    b. basic radio communications procedure
    c. engine starting
    d. normal or crosswind takeoff
    e. traffic pattern departure
    f. straight and level flight
    g. medium bank turns
    h. climbs and climbing turns
    i. glides and gliding turns
    j. level off procedures (f) through (j) to be done VR and IR
  (3) Introduction
    a. steep power turns
    b. slow flight and flight at minimum controllable airspeed VR and IR
    c. power off stalls (imminent and full)
    d. approach to landing
  (4) Post-flight critique and preview of next lesson

c. Completion Standards. The student should be able to establish proper climbs and descents, and control airspeed with ±10 knots with power and altitude adjustments, hold altitude within ±100 feet and headings within ±10 degrees.

LESSON NO. 3--DUAL 1.0 HOUR

a. Objective. This lesson will consist of a review of all previous maneuvers. S-turns across a road, turns about a point, power on stalls, and elementary emergency landings will be introduced.

b. Content.

(1) Preflight discussion

(2) Review

a. straight and level flight
b. medium bank turns
c. flight at minimum controllable airspeed and slow flight
d. takeoff and pattern departure
e. power off stalls
f. steep power turns
g. pattern entry

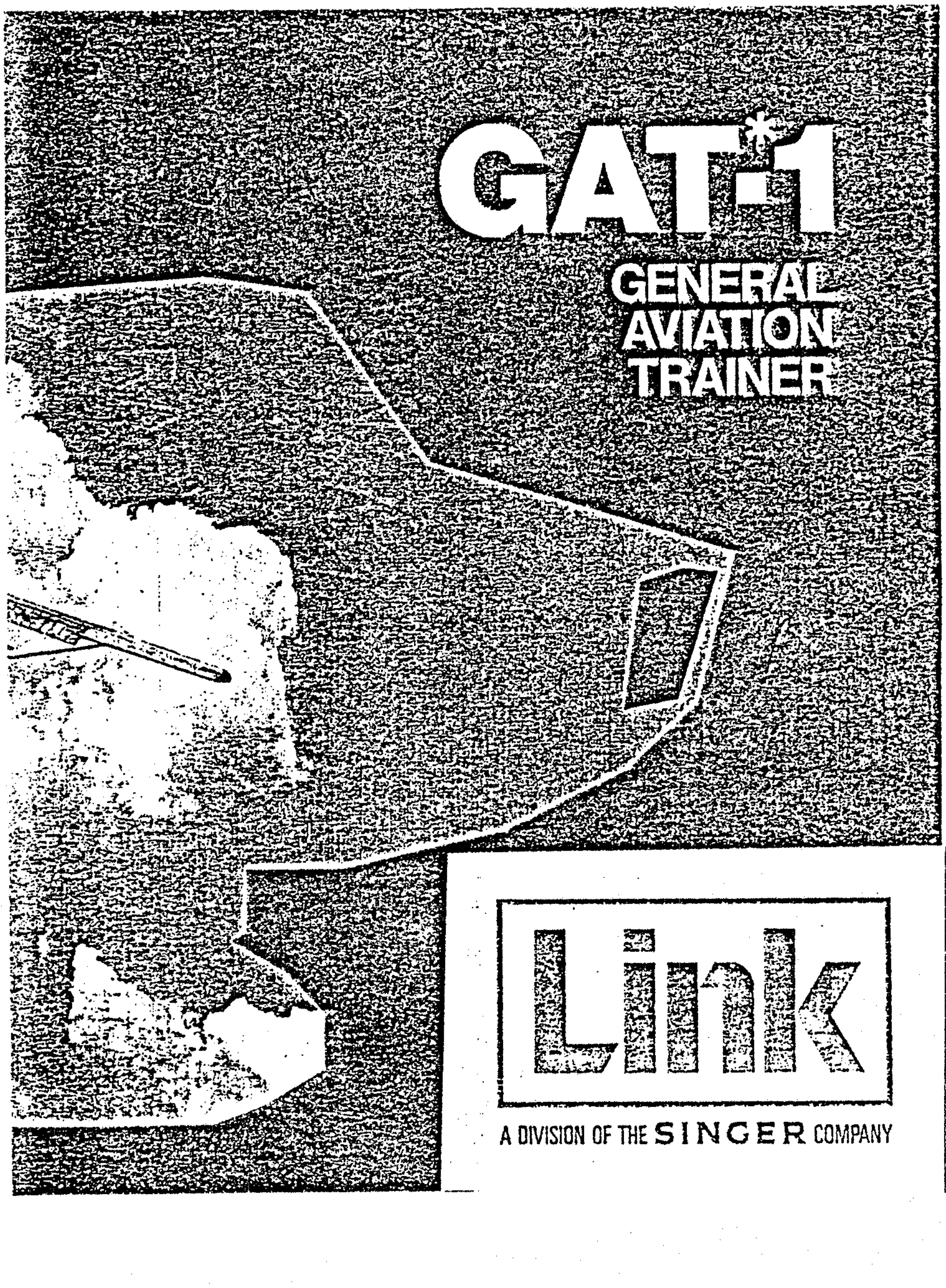
(3) Introduction

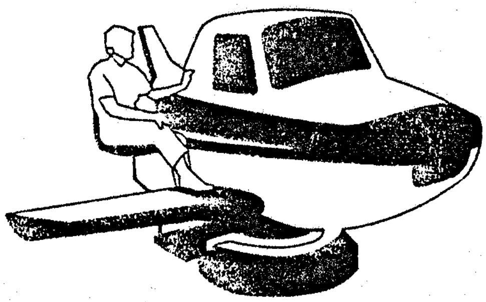
a. power on stalls (imminent and full) VR and IR
b. S-turns
c. turns about a point
d. elementary emergency landings

(4) Post-flight critique and preview of next lesson fully completes the lesson when he is competent to perform, with minimum assistance, the procedures and maneuvers given during previous lessons. He should achieve the ability to recognize stall indications and make safe and prompt recoveries. He should maintain assigned airspeed within ±10 knots, assigned altitude within ±100 feet and assigned heading within ±10 degrees, and display a basic knowledge of elementary emergency landings.

APPENDIX C

The Singer GAT-1 Single Engine Airplane Ground Trainer


GAT-1
GENERAL AVIATION TRAINER
Link
A DIVISION OF THE SINGER COMPANY



This brochure describes the GAT*-1 General Aviation Trainer developed and manufactured by the Link Division of The Singer Company.

This device, when used in a suitable training program, meets a major portion of flight and navigation training requirements associated with light, single-engine aircraft.

*LINK** trainers are finding increased acceptance by both small and large flight training establishments which are concerned with getting a maximum return on their training expenditures. Present users include schools and colleges, educational and aviation research institutes, commercial air carriers, the U.S. armed forces, the U.S. Federal Aviation Administration and a number of other military agencies and governments around the world.

What is Simulation?

Simulation is accomplished by creating realistic replicas of sophisticated mechanisms, such as aircraft cockpits. The primary objective of simulation training is to impart specific skills to a trainee. The simulator provides information related to a specific training task through a combination of cues, such as motion, visual and aural. This information, furnished in the simulator's realistic setting, helps to achieve the proper trainee reaction. He learns to respond in the right way, quickly, effortlessly—almost automatically.

*A trademark of the Singer Company

Advantages of Simulation

A man cannot learn to operate an aircraft merely by being told what to do. Neither can he become intimately familiar with the interaction between aerodynamic forces, flight control and engine performance by reading a book.

Unfortunately the learning process demands much more; it requires the motivation and stimulation associated with doing for one's self. This is especially true when close coordination between mind and body is necessary. Hands-on training has proven to be the most effective means to achieve proficiency in the operation of an aircraft.

The advantages of simulation devices for training are many. The most important are efficiency, economy and safety. Employing operational equipment for such training is costly, inefficient and impractical—and sometimes hazardous. On the other hand, the use of flight simulators or trainers is not only less expensive and less dangerous but actually in many instances far more effective than using the actual aircraft.

The advantages of this type of training become even more apparent when costs are considered. The U.S. Air Force Human Resources Laboratory reports that civilian experience has shown that 10 hours in the *LINK* general aviation trainer is as effective as 10 hours of initial light plane training. Similar findings were reported after studies by leading training specialists and universities. They found that nearly one-third of the 35 hours training required for private pilot certifications can be accomplished in this trainer.

Simulation training has been especially welcomed in these days of ecological concern and energy shortages.

Another big plus is safety. Pilots in trainers can test their prowess under various emergency conditions which would be too hazardous to attempt in the actual aircraft.

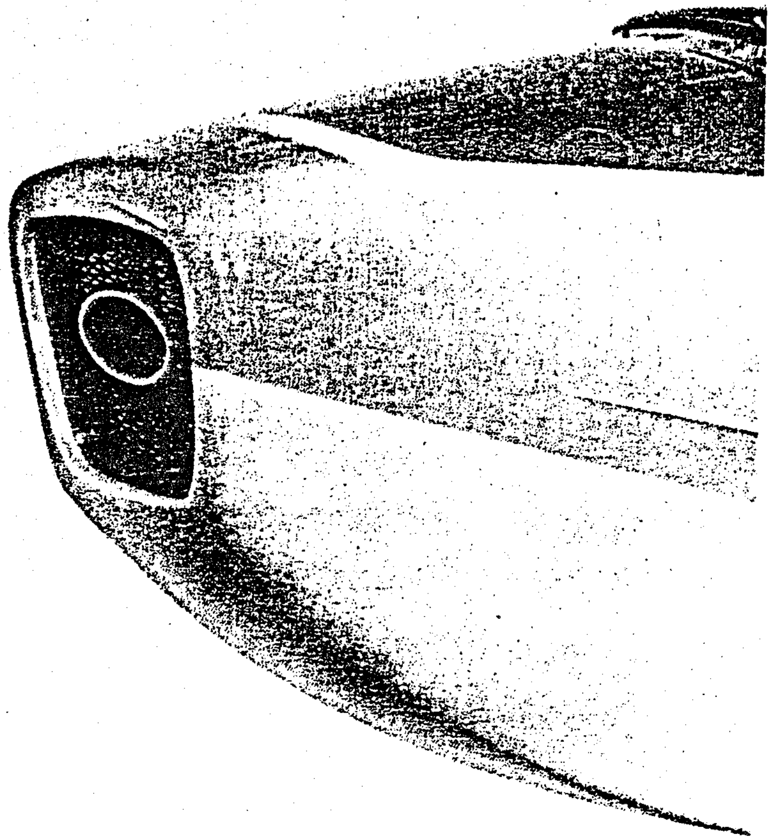
Efficiency, economy and safety, plus reliability, realism and adaptability, make these *LINK* trainers indispensable training tools.

The GAT-1 Trainer Concept

GAT-1 trainers from Link capitalize on the unrivaled expertise accruing from almost 50 years experience by the acknowledged world leader in flight simulation.

Each trainer provides a complete training system, oriented towards meeting the broad spectrum of flight/navigation and instrument training requirements associated with single-engine aircraft.

A common design concept embraces an advanced analog/digital solid state computer that utilizes state-of-the-art hardware to provide real time solutions to flight simulation problems. The scope of simulation includes primary flight control loading, motion to provide realistic kinesthetic cues, sound simulation and external environmental effects such as wind and rough air.



Major Design Features

Some of the major design features offered with GAT-1 trainers are worthy of special mention:

Motion — The motion system performance provides realistic cues in all normal and abnormal maneuvers. In addition to flight control effects, the motion system also provides appropriate cues of turbulence or rough air, landing impact, gear retraction, takeoff rotation and attitude changes due to flaps.

Computer — The computer provided for the GAT-1 trainer is an advanced analog version that utilizes all solid state electronic modular printed micro-circuitry. The computational techniques employ the time division method of multiplication. Printed circuit boards for a specific simulation function, such as engine sound or aircraft position, are plugged into a printed circuit mother board. The arrangement assures high reliability and easy maintenance.

Radio Aids — The radio aids simulation employs a hypothetical problem area 120 miles by 120 miles called Anytown, with two approaches or letdowns. Sixteen different tuneable radio facilities (four ADF, two ILS, six VOR and four marker beacons) are located in the area. Optional radio aids features include specific, fixed real-world navigation areas and programmable (selectable) navigation areas.

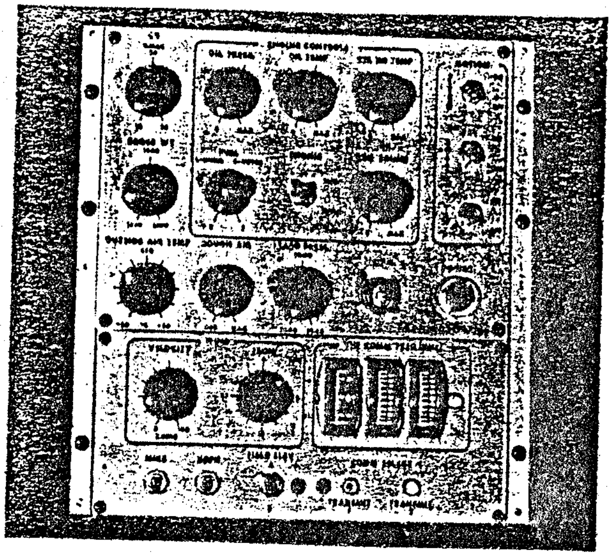
Durable Exterior — All GAT-1 trainers utilize a molded fiberglass shell, providing an exterior which is both durable and attractive.

Standard GAT-1 Trainer

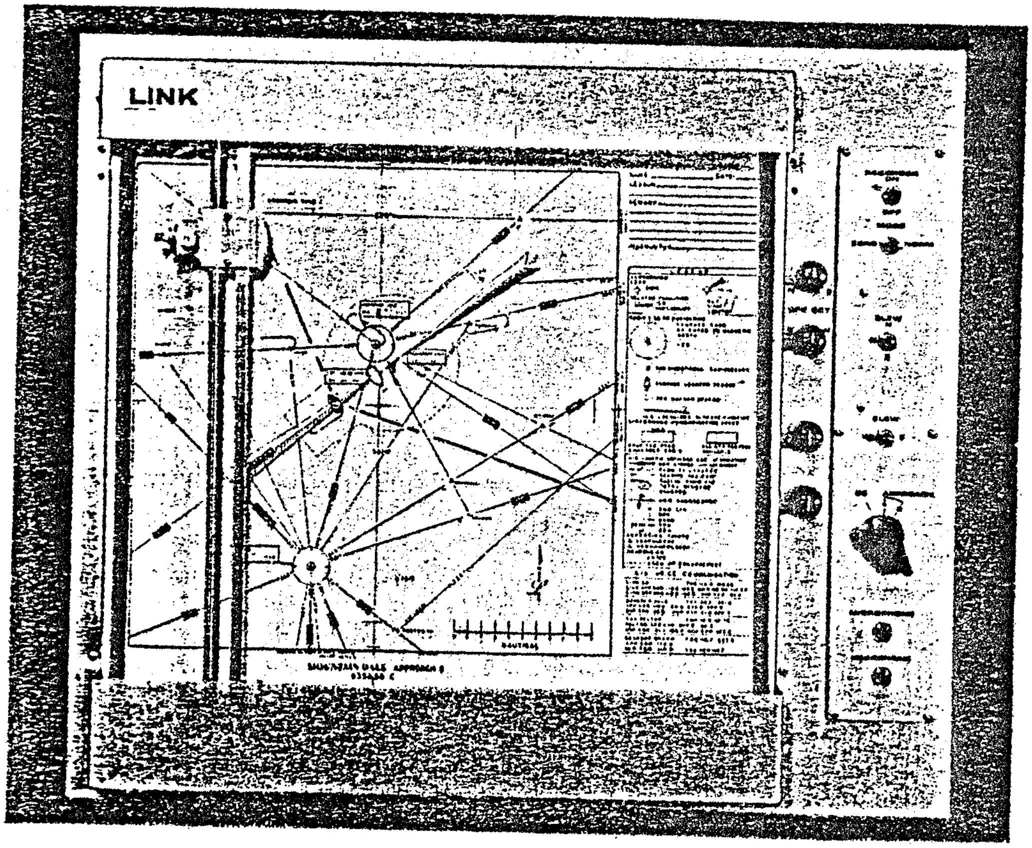
The Standard GAT-1 trainer comprises a functional cockpit with controls and full flight performance, complete IFR capability, a realistic sound system, instructor controls, operations and maintenance manual, system diagrams and a detailed circuit description.

The Standard GAT-1 trainer includes:

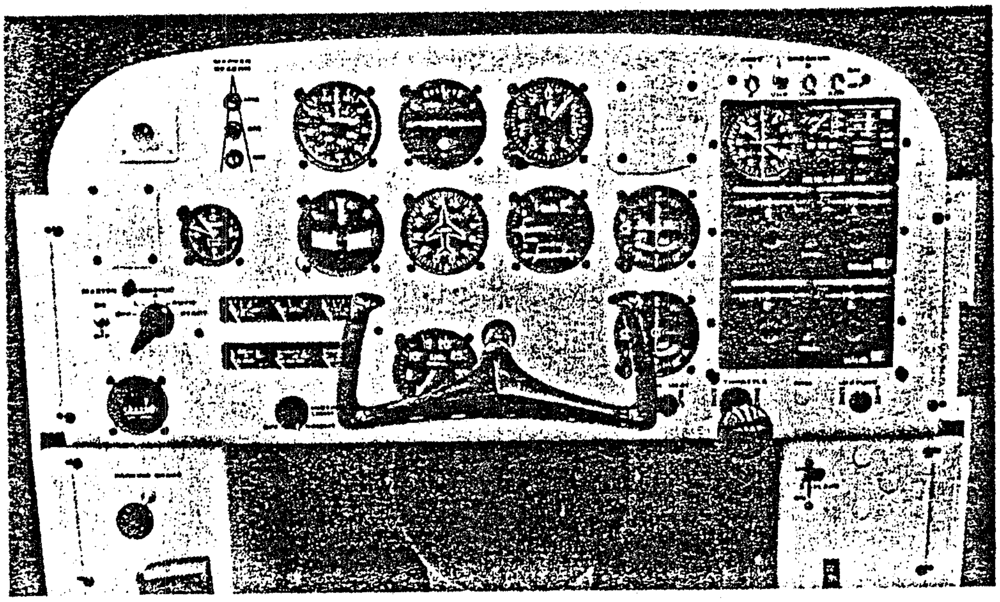
- ☐ **Instrument Flight Package:** Attitude gyro, directional gyro, clock, blackout curtains, rough air and instructor seat.
- ☐ **Avionics:** Dual 360 channel COMM, Dual VOR, ILS, ADF, marker beacons, cross country/approach recorder and intercom.
- ☐ **Malfunction Insertion Panel:** This provides instructor-controlled malfunctions in a number of systems, including: attitude gyro fail, directional gyro fail, altimeter fail, airspeed indicator fail, turn needle fail, rate of climb indicator fail, VOR/Localizer #2 fail, ADF receiver fail and glidescope receiver fail.



Instructor's Panel



Track Recorder



Options

A number of options are available to complement the trainer's capability, enabling customers to fulfill their particular training requirements with maximum effectiveness:

- ☐ **Wings and tail:**
  Non-movable control surfaces.
- ☐ **Special Area Charts and Radio Aids:**
  Fixed: Customer-selected chart areas to replace pre-programmed standard maps. Option includes area map 120 x 120 miles (scale 1 inch = 8 n mi), five mylar (translucent plastic) reproducible copies and two approach charts (scale 1 inch = 2 n mi.), five mylar reproducible copies and programming for 16 corresponding radio facilities. The latter include six VOR stations, two ILS stations, four ADF stations, two outer markers and two middle markers.

  Programmable: This option allows the instructor to program the VOR, ADF, OM, MM and ILS station in any location on real-world nav charts. The size of this programmable area is 120 nautical miles by 120 nautical miles. The instructor has controls to vary the NS and EW position and to program the frequency and code ident for six VOR stations, four ADF stations and two ILS stations. In addition to these controls, there are controls to set the two ILS runway bearings, set the OM and MM positions, set the glideslope angle and adjust the field elevation. These controls are located on a panel attached to the side of the GAT-1 cockpit.

☐ **Radio Magnetic Indicator:**
This indicator provides a dual needle indication of the relative magnetic direction of the ADF and VOR tuned by the NAV receivers.

☐ **Distance Measuring Equipment (DME):**
Includes DME indicator and computer modules required for range computation to tuned VORTAC stations.

☐ **Retractable Landing Gear:**
Includes gear lever and indicator lights and simulates aircraft performance and aerodynamic effects of typical light aircraft with retractable landing gear.

☐ **Constant Speed Propeller:**
This option, which includes a manifold pressure indicator, provides simulation associated with light aircraft equipped with variable pitch propeller.

☐ **X-Y Position Hold:**
This option provides a switch on the instructor's panel which allows the instructor to freeze the simulated geographical position of the trainer.

☐ **Non-yaw Motion Modification:**
Provides heading indications in cockpit and eliminates yaw axis of motion in order to conserve space in trainer room.

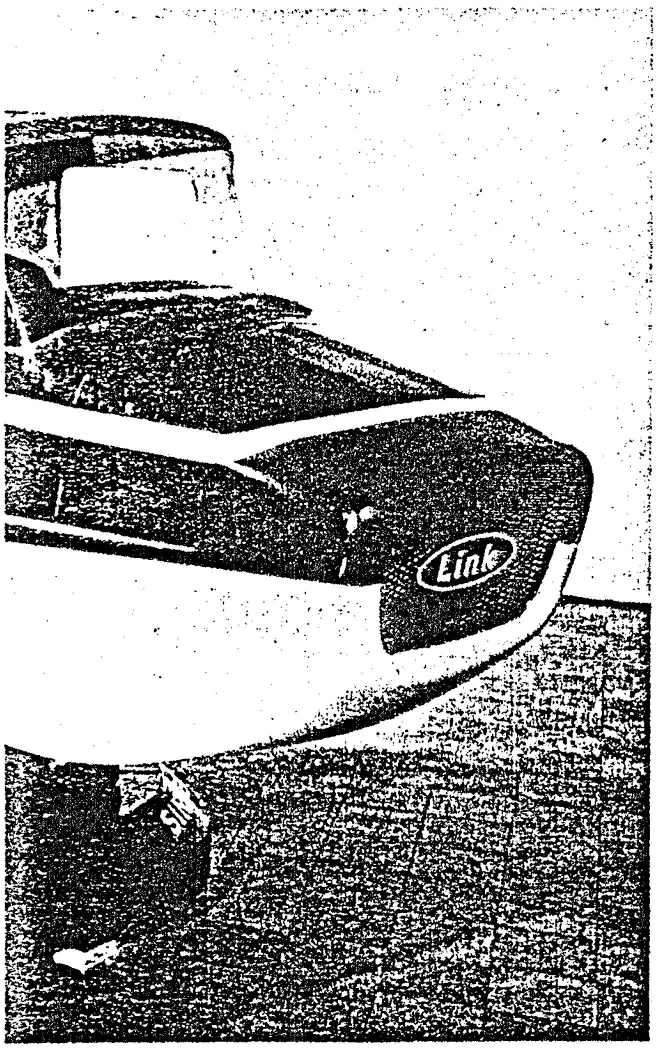
☐ **High-speed option:**
The basic GAT-1 trainer is designed to represent a typical single-engine general aviation aircraft with a cruising speed in the 110-mph range and an indicated air-speed indicator calibrated in miles-per-hour. The high speed option is offered for those customers who prefer to orient their training program toward a higher performance aircraft. If the high speed option is selected, the performance characteristics designed into the trainer's flight computer will be altered such that the trainer will represent a higher performance general aviation aircraft with a cruising speed in the 150-knot range; the indicated airspeed indicator provided will be calibrated in knots. (In order for the high speed option to be installed, retractable landing gear and constant speed propeller options also must be procured and installed.)

☐ **Support Operations:**
Spares provisioning: Kit of spares suitable for a single trainer installation includes fuses, transistors, amplifiers, p.c. boards, switches, drive cables and potentiometers.

Maintenance training (factory): One week of classroom training at a Link facility.

Maintenance training (on site): Similar sessions at customer's site for as many as six students at a time.

The Standard GAT-1 trainer and available options are described in detail in Link specification 72-4 (revised 1/14/77).



Simulated Characteristics

☐ Pitch, roll and yaw
☐ Engine torque and "P" factor
☐ Stall effects
☐ Realistic sound system (engine, propeller and airstream)
☐ Engine RPM
☐ Oil temperature/pressure
☐ Cylinder head temperature
☐ Fuel quantity
☐ Barometric pressure
☐ Center of gravity
☐ Gross weight
☐ Outside air temperature.

Flight Performance Envelope

☐ Altitude range—10,000 ft.
☐ Cruise airspeed—115 m.p.h.
☐ Glide and climb speed—75 m.p.h.
☐ Stall speed—52 m.p.h.

Facility Requirements

☐ Minimum room size—16 x 16 ft. (without wings and tail 12 x 12 ft.)
☐ Minimum door size—36 x 84 inches
☐ Minimum ceiling height—8 ft.
☐ Weight—1,000 lbs.
☐ Power—single phase 115/230 volt 50 or 60 Hz. at .6 kw.
☐ Operating environment—50° to 100° F, up to 80% humidity.

The GAT Family

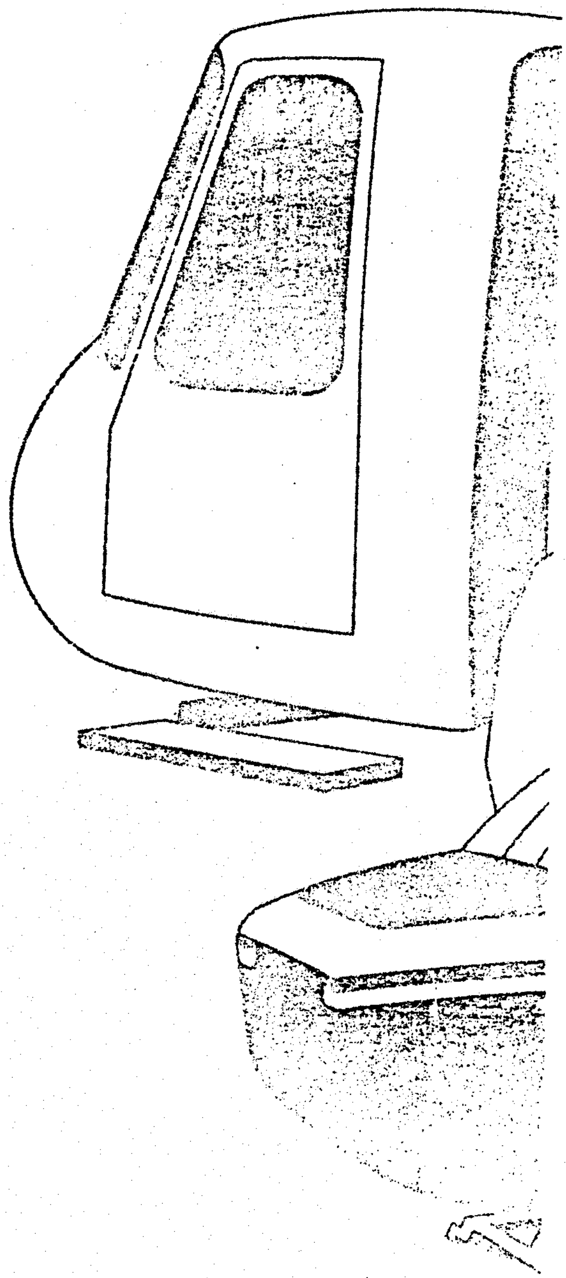
The GAT family is made up of the following trainers, each designed to meet specific training needs:

GAT-1 Trainer—An inexpensive cost-effective trainer reflecting the performance of a typical light single-engined aircraft such as the Cessna 150 or Piper Cherokee.

GAT-2 Trainer—A more sophisticated trainer with flight/engine performance and configuration representative of a light twin-reciprocating-engined aircraft such as the Beech Baron or Piper Aztec.

GAT-3 Trainer—A flight/instrument and navigation trainer with performance and configuration representative of a light twin-jet-powered aircraft such as the Saberliner.

Helicopter Operational Trainer (HOT)—This trainer, which has a high degree of design commonality with other GAT trainers, is intended to provide the basic flight/navigation and instrument training required for helicopters. The trainer performance and configuration are representative of a typical light single-rotor helicopter of the Bell Jet Ranger class.



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15. Supplementary Notes

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Abstract:

A novel means of instruction was attempted in which, in addition to verbal assistance, control feedback was continuously presented via a nonvisual means utilizing touch. An initial in-flight study was conducted utilizing a kinesthetic-tactual (K-T) display as a readout and tracking device for a computer-generated signal of desired angle of attack during the approach and landing. A second study was conducted to control the imposed conditions by presenting airspeed and glide path information via either kinesthetic-tactual or visual "heads-up" display techniques. The findings showed that performance with the heads-up display of pitch information was significantly better than performance with the K-T pitch display. In contrast to the results obtained during training, testing without the displays showed that novice pilots who had received tactually presented pitch error information performed both pitch and throttle control tasks significantly better than those who had received the same information from the visual heads-up display of pitch, during the test series of approaches to landing.

17. Key Words (Suggested by Author(s)) display, devices, flight instruments and flight training	18. Distribution Statement Unclassified - Unlimited STAR Category - 04

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