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1979

AN ADVANCED COCKPIT INSTRUMENTATION SYSTEM:

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SUMMARY

It will be difficult to modify current aircraft instrument panels to accommodate all new information required to operate within an increasingly complex air traffic control system. Cathode Ray Tube (CRT) and computer technologies have reached the stage where current flight and engine instruments can economically be replaced by computer-controlled CRT displays. This provides a tremendous opportunity for flexibility to the cockpit display designer, but the use of this flexibility should stay within the realities of the flight environment. This report describes one approach to the replacement of flight instruments, using three separate color CRT's. Each CRT displays information pertinent to one of the three orthogonal projections of the aircraft flight situation. Three airline pilots made a preliminary assessment of this display set. Comments, rankings, and ratings show that, in general, the pilots accepted the concept of pictorial flight displays.

INTRODUCTION

The aircraft instrumentation designer faces the prospect of designing for information requirements that will be continually changing in the future and changing increasingly in the direction of providing more information for the pilot to process. The information from new complex avionics systems, needed to operate within an increasingly complex air traffic control system, will have to be added to, combined with, or made to replace the already large array of cockpit instruments. Because the number of instruments cannot increase without limit and because current instrumentation appears to have nearly reached a saturation point, these new systems seem certain to force extensive cockpit instrumentation redesign. This paper is limited to a discussion of flight instrumentation systems; however, generalizations to engine instrumentation or other aircraft instrumentation systems are readily possible.

Opposing cockpit change are economic and operational realities of the commercial flight community. Due in large part to safety considerations, substantial changes in cockpit instrumentation cannot be imposed within short periods of time. Because airline pilots have served extensive apprenticeships using instrumentation that has changed very little in 20 years, it would be unwise to abruptly change all cockpit instrumentation, even if the economic factor were not involved. Moreover, many years of experience with current instrumentation have led to operational procedures that are optimized in terms of those instruments.

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Fortunately, there appears to be a natural solution to this seemingly contradictory need for change and the desire for stability. Cathode ray tube (CRT) and computer technology have reached the stage where replacement of flight and engine instruments with CRT and supporting computers can reduce weight while lowering first cost and maintenance costs (ref. 1). With this new equipment, the standard instruments can simply be reproduced on the CRT's by using proper computer software. Once this is done, it will be possible to make future instrument changes by changing the computer software. The way is also open for fundamental changes in overall format if it can be shown that such changes have the advantage of making pilot interpretation easier. Such a format change can be viewed as the goal of a series of evolutionary changes.

There are two situations in which rapid assimilation of the flight situation is especially necessary. The first is the higher-than-usual workload situation in which flight conditions are changing, communication demand is high, etc. The second is the very low workload situation that is interrupted by an unexpected event. In both cases, the need is for a display set from which the current situation can quickly and easily be assessed at a glance. This display set must also furnish appropriate information for all intermediate levels of decision and control functions.

There is a variety of approaches that could be used in the design of such an easily interpretable format. This paper describes one such approach and explains how it evolved. This entire display set is called the coordinated cockpit display (CCD) because of the coordination of information among the individual CRT's. Once the basic design was complete, it was necessary to see if line pilots could use it, in executing maneuvers, and to obtain their opinions of the design. The same maneuvers were also flown with standard-type instruments for comparison. There was no strong expectation of any difference between the two for this first phase of the project. The next phase will be to implement CCD within a simulator context where pilot performance can be measured under extremely high and low workload conditions. This will be a major effort and will be integrated into other programs within the Man-Vehicle Systems Research Division (MVSRD) at Ames Research Center.

ORIGINS OF CCD

The following requirements were established as essential characteristics of any potentially feasible cockpit instrumentation system:

1. The system was to be based on sound human factors principles

2. The system had to accept any new information that might be required for operation in the future National Airspace System without major hardware addition or redesign

3. The system had to accept any new information that might be required for operation in the future National Airspace System without introducing clutter or logical inconsistency

4. The system had to be acceptable to pilots trained on standard cockpit instrumentation, yet capable of evolution in accordance with criteria (2) and (3) above.

The need for the first criterion is obvious. Some of these human factors principles will be seen when the CCD is explained below. A more detailed rationale for some of the design decisions is given in reference 2. Criteria (2) and (3) were discussed in the Introduction. The logic used for the placement of information on the CCD takes care of much of criteria (4) by analogy with the basic "T" flight instrument arrangement. Also, a color selection scheme based on the instruments "information category" will be explained.

Basic "T"

The basic "T" (ref. 3) instrument configuration, which is standard for virtually all civil transports, does more than merely standardize placement of instruments. In the basic "T" configuration, those instruments that present position and motion information are selected and then positioned to help the pilot visualize his situation in three dimensions. In general, the position and motion information presented on an instrument is related to the instrument's position as though the aircraft's position and motion had been projected, from the interior, onto screens composing the front, right, and bottom of a box (see fig. 1), which is then folded flat.

In the basic "T" format, the attitude instrument is placed top center, as close as possible to the pilot's out-the-window line of sight. Directly below the attitude instrument is the direction or

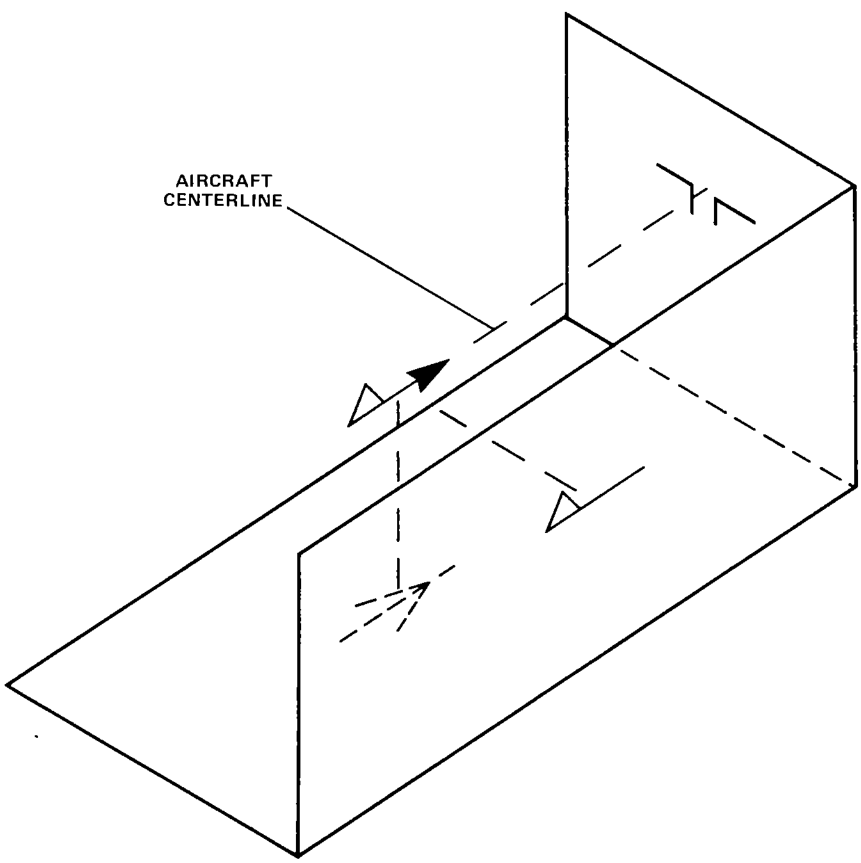


Figure 1.– Three orthogonal planes of aircraft situation.

course indicator; directly to the right of the attitude instrument is the altimeter; and directly to the left of the attitude instrument is the airspeed indicator. The attitude indicator displays information about the aircraft's motion, but not position, in a vertical plane through the wings. Hence, attitude is associated with the front of the box and so is placed top center. The altimeter displays information about the aircraft's position and the rate and direction of the pointer movement also yields an indirect indication of the aircraft's motion in a vertical plane. Hence, altitude is associated with the side of the box and so is placed top right. The course indicator displays information about the aircraft's motion in the horizontal plane. Hence, course direction is associated with the bottom of the box and so is placed bottom center. The airspeed indicator displays information about the aircraft's motion in the forward direction. This information, used in conjunction with other instruments, enables the pilot to extract information about the horizontal position of the aircraft.

By relating the side-by-side locations of the instruments to the three sides of the box, representing the three coordinate planes in space, the pilot can, presumably, more easily transfer instrument readings into the current situation in space (ref. 3).

The above suggests that the goal of the basic "T" instruments may be taken to provide the pilot a frame of reference in space and an image of the aircraft's motion relative to it. Mechanical instruments, however, are limited in the information relationships that can be explicitly shown, and for any information relationships that are not explicitly shown, the pilot must make the effort to construct that image. As stated by Hopkins (ref. 4): ". . . it is important for all crew members to have a good mental model of the aircraft situation at any time." The goal of CCD was to expand the idea of the basic "T" to a more graphic, therefore, more explicit representation of the aircraft situation.

Instrument Information Categories

Air Force Manual 51-37 divides flight instruments into three categories: control, performance, and navigation instruments (ref. 5). The control instruments reflect the aircraft's immediate response to control inputs; for example, a stick movement that results in an attitude change is first indicated on the attitude indicator. Hence, the attitude indicator is a control instrument. The performance instruments reflect the effects of changes in the control parameters; for example, after a sustained pitch change the flight-path angle, sink rate, and airspeed assume new values. Hence, the flight-path angle, sink rate, and airspeed indicators are performance instruments. The navigation instruments indicate aircraft position relative to ground references.

There are, of course, categories of information in addition to these. Flight directors and predictors are two important ones. Neither was included in this initial evaluation because the nature of the first set of maneuvers would have made the task trivial with either of these elements. They will both be integrated into future CCD.

COORDINATED COCKPIT DISPLAY

In general, the coordinated cockpit display (CCD) flight instrumentation system can be thought of as an evolved basic "T" which more nearly achieves the goal of the basic "T" instruments. The CCD coalesced as a resolution of the need for short-term flexibility while maintaining long-term adaptability. To satisfy the needs for flexibility and adaptability, CRT's displaying line-drawn, computer-generated indicators were used. To preserve the basic "T" relationship, the CCD uses three CRT's placed in a modified "T" configuration, as shown in figure 2. To ensure category separation, three different colors of line-drawn indicators were used, one for each category of information.

Modified "T"

The basic "T" instruments appearing in current flight instrumentation systems also appear in CCD and in a more-or-less familiar manner. The essential difference is that position and motion information, which is implicit in standard instrumentation, has been made explicit in CCD, primarily by the use of a pictorial presentation. This pictorial format enables a higher density of information without a concomitant increase in the number of instruments the pilot must scan. The values associated with appropriate flight parameters are used by a computer to calculate the current frames of reference and the aircraft's motion relative to them. These relationships are displayed in a pictorial format on three CRT's along with the standard information indicators, that is, attitude, altitude, etc.

Each of the three CRT's informs the pilot about the aircraft's position and motion in the particular coordinate plane most closely associated with the conventional instrument in the same respective position. Thus, "up" on the bottom CRT and "left" on the top right CRT are the directions of forward motion. These relations can be seen by comparing figures 1 and 3.

Because the information displayed on a particular CRT is related to the aircraft's position and motion in one of the frame of reference coordinate planes by the relative position of the CRT, each CRT instrument complex has been named for its respective plane: the CRT occupying the position of the standard attitude instrument is called the Vertical Situation Display (VSD); the CRT occupying the position of the altimeter is called the Side Vertical Situation Display (SVSD); and the CRT occupying the position of the course indicator is called the Horizontal Situation Display (HSD) (see fig. 3).

Several of the indicators used in the CCD system are based on the use of a sequence of DME and altitude pairs to establish a theoretical flight path, called the desired flight path. The desired flight path is displayed pictorially: (1) on the VSD as a waypoint symbol, one at a time showing next waypoint; (2) on the SVSD as a portion of the graph of the altitude versus accumulated ground distance along the desired path; and (3) on the HSD as the horizontal projection of the desired flight path. The position of the aircraft relative to the desired path is also used to drive altitude and airspeed error indicators on the VSD and an expanded lateral error indicator on the HSD. The CCD system assumes that such a three-dimensional waypoint sequence will be programmed into an on-board computer during preflight preparations.

Indicator Information Categories

Each of the indicators on each of the three displays is drawn in a unique color which designates its information category. Although the three-color information-category concept as a

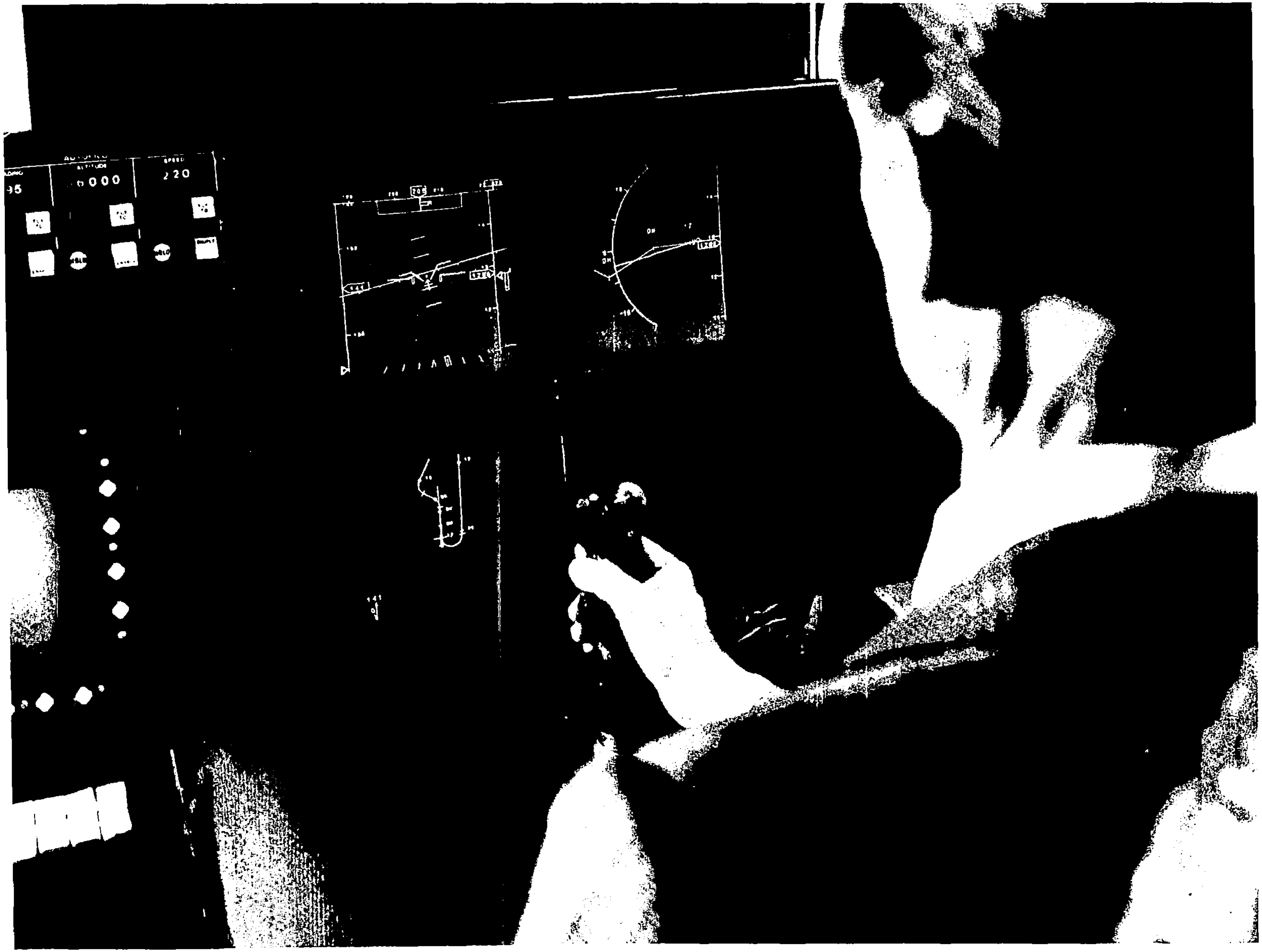
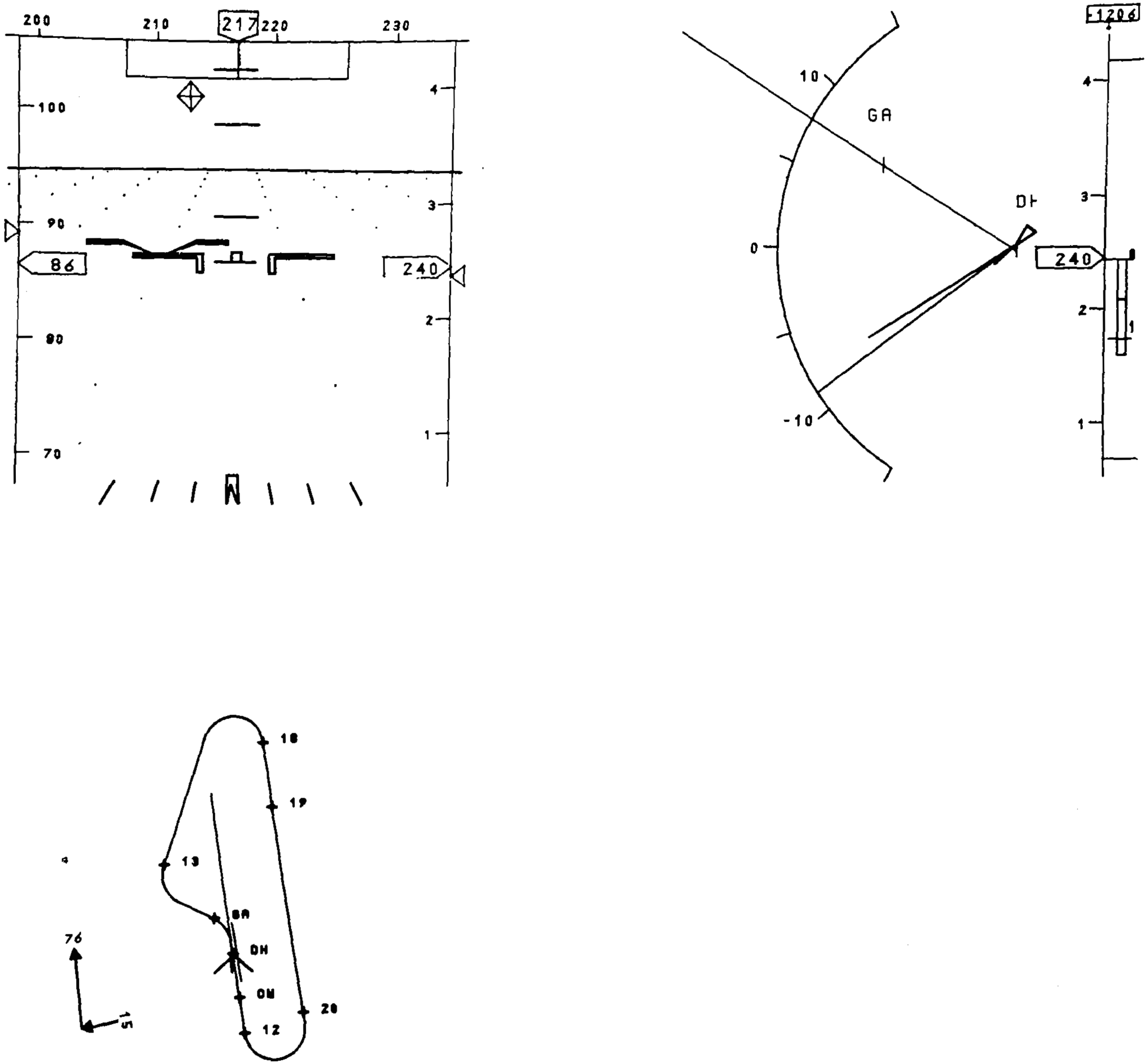


Figure 2.– CCD in simulator.


200
210
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220
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1206
18
19
13
GA
DH
OM
20
12
76
15

Figure 3.– CCD.

whole is important, the three particular colors chosen were selected for technical rather than theoretical reasons.

The control indicators are displayed in red and consist of:

(i) Aircraft symbol
(ii) Potential flight-path-angle indicator
(iii) 10° pitch marks
(iv) 10° roll angle marks and indicator
(v) Horizon line

This category of indicators, the CRT's on which they appear, and their representations are shown in figure 4.

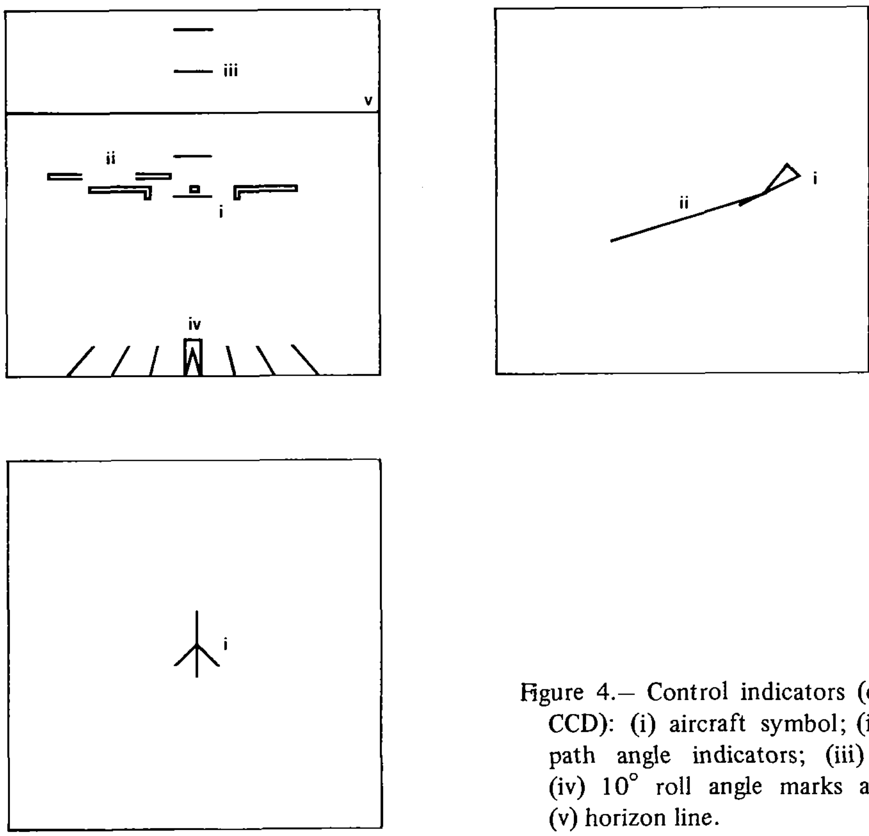


Figure 4.– Control indicators (displayed in red in CCD): (i) aircraft symbol; (ii) potential flight-path angle indicators; (iii) 10° pitch marks; (iv) 10° roll angle marks and indicator; and (v) horizon line.

The performance indicators are displayed in green and consist of:

(vi) Altitude tape and digital readout
(vii) Flight-path-angle indicator
(viii) Vertical-speed indicator
(ix) Airspeed tape and digital readout
(x) Heading tape and digital readout
(xi) Turn-rate indicator
(xii) Horizontal flight-path indicator
(xiii) Groundspeed and windspeed vectors

This category of indicators, the CRT's on which they appear, and their representations are shown in figure 5.

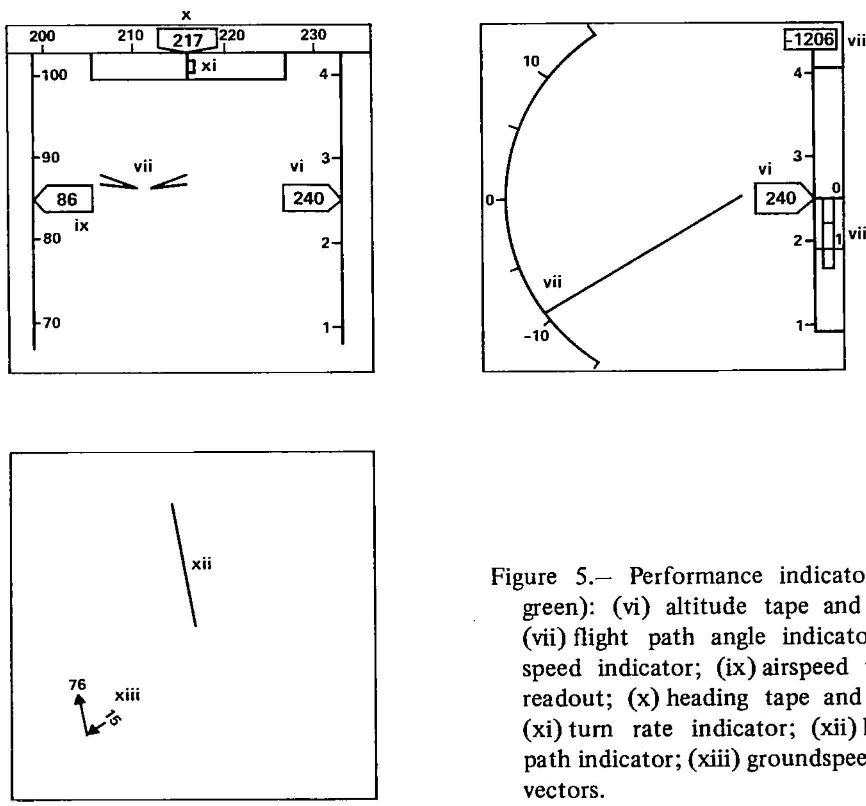
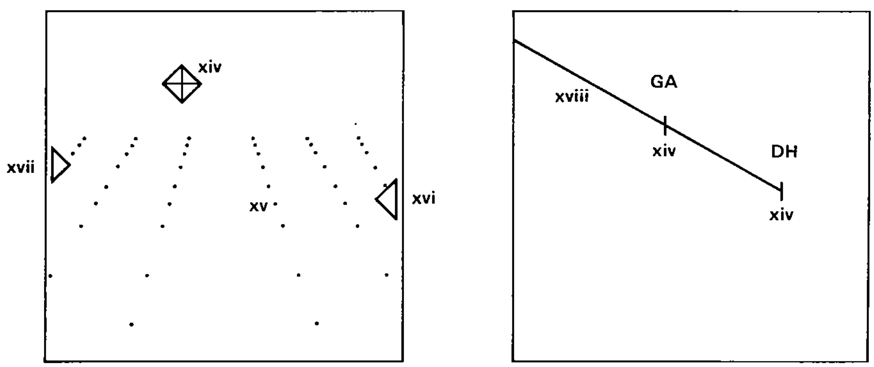


Figure 5.– Performance indicators (displayed in green): (vi) altitude tape and digital readout; (vii) flight path angle indicators, (viii) vertical speed indicator; (ix) airspeed tape and digital readout; (x) heading tape and digital readout; (xi) turn rate indicator; (xii) horizontal flight path indicator; (xiii) groundspeed and windspeed vectors.

The navigation indicators are displayed in yellow and consist of:

(xiv) Waypoint symbol
(xv) Ground-plane dots
(xvi) Altitude-error indicator
(xvii) Airspeed-error indicator
(xviii) Desired vertical flight-path profile
(xix) Desired horizontal flight-path profile
(xx) Expanded-scale lateral-error indicator.

This category of indicators, the CRT's on which they appear, and their representations are shown in figure 6.



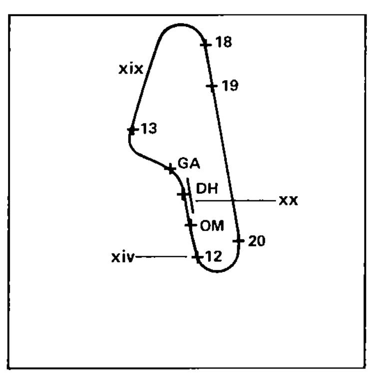


Figure 6.– Navigation indicators (displayed in yellow): (xiv) waypoint symbol; (xv) ground plane symbol; (xvi) altitude error indicator; (xvii) airspeed error indicator; (xviii) desired vertical flight-path profile; (xix) desired horizontal flight-path profile; (xx) lateral error indicator.

The ease of making changes and of incorporating new information into this framework was demonstrated by a separate study on pilot response to windshear. The necessary information was a natural addition to the SVSD and was somewhat more difficult to interpret on the VSD.

Indicator Interpretation

Although CCD instruments are computer-drawn instruments displayed on CRT's rather than the conventional electromechanical gauges, there are no physical or conceptual differences in reading and interpreting most of them. A brief explanation of those indicators that are new or unique follows.

Indicators (ii) (potential flight-path-angle indicator, fig. 4) and (vii) (flight-path-angle indicator, fig. 5) constitute an energy management complex: indicator (vii) indicates the current flight-path angle and (ii) indicates the constant speed climb/sink angle for the current power setting. These indicators are scaled to be read against the VSD and SVSD pitch scales. Indicators (viii) (vertical-speed indicator, fig. 5) and (ix) (airspeed tape and digital readout, fig. 5) are expanding tapes, lengthening or shortening as appropriate. Indicators (xiii) (groundspeed and windspeed vectors, fig. 5) are arrows whose direction and magnitude (as numerics) reflect their respective current parameter values. Indicator (xiv) (waypoint symbol, fig. 6) is a symbol that indicates any waypoint in space that the preprogrammed ideal flight path should intercept. Indicator (xviii) (desired vertical-flight-path profile, fig. 6) is a portion of an altitude versus accumulated distance profile of the preprogrammed desired flight path. Indicator (xix) (desired horizontal-flight-path profile, fig. 6) is a horizontal projection of the flight path, or some portion thereof, of the preprogrammed desired flight path. Indicators (xviii) and (xix) move in relation to indicator (i) (aircraft symbol, fig. 4); together, these indicators completely determine the aircraft's vertical position relative to ground. Indicators (xvi) (altitude-error indicator, fig. 6) and (xvii) (airspeed-error indicator, fig. 6) move along the altitude and airspeed tapes. They point at the current value of the preprogrammed desired flight path. Zero error is indicated by alignment of indicators (xvi) and (xvii) opposite the tape pointer/digital readout box for altitude and airspeed, respectively. Thus, current value, desired value, and error are related and can be seen at a glance. Indicator (xx) (lateral-error indicator, fig. 6) gives an arbitrarily expanded indication of the aircraft's lateral error relative to the preprogrammed desired flight path. Zero error is indicated by alignment of element (xx) with element (xix).

Despite some dramatic differences from conventional instrumentation, the CCD system could be readily implemented as a series of minor adaptations of current cockpit instrumentation. The only major change necessary would be the initial replacement of current basic "T" gauge instruments, perhaps only some of those of the copilot at first, with their CRT displayed, computer-drawn equivalents (see, for example, Preliminary Investigations: Displays, below). Although initially wasteful of the power of computer graphics, such a procedure would have a number of advantages, not the least of which would be the accumulation of experience with airborne computer implementations.

PRELIMINARY INVESTIGATION

The primary goals of the preliminary study reported here were to refine the CCD system, to explore some variations of CCD configurations, and to obtain some idea about the differences to be expected between the CCD variants and a more-or-less conventional instrument system. Because of the preliminary nature of this study, no attempt was made to do either a balanced experimental design or to extract rigorous quantitative data.

Desired Flight Path

It was felt that a fairly difficult task would accentuate any problems with the system, so the flight-path task chosen for these studies was based on a proposed location for a STOL airport in the downtown New York City vicinity. At this proposed STOL airport, a missed approach requires a go-around path that must simultaneously: (1) avoid existing reserved flight corridors (JFK and Newark airports); (2) accommodate prevailing weather conditions; (3) and return the aircraft to an approach position. Because these constraints make any go-around path quite complicated, a potential go-around loop was selected as the flight-path task. A map of the path showing target altitudes and speeds is given as figure 7.

The path required a steep climb-out from the decision height (DH), arriving first at the go-around waypoint (GA), and then finally completing the loop at the original starting point, waypoint (18).

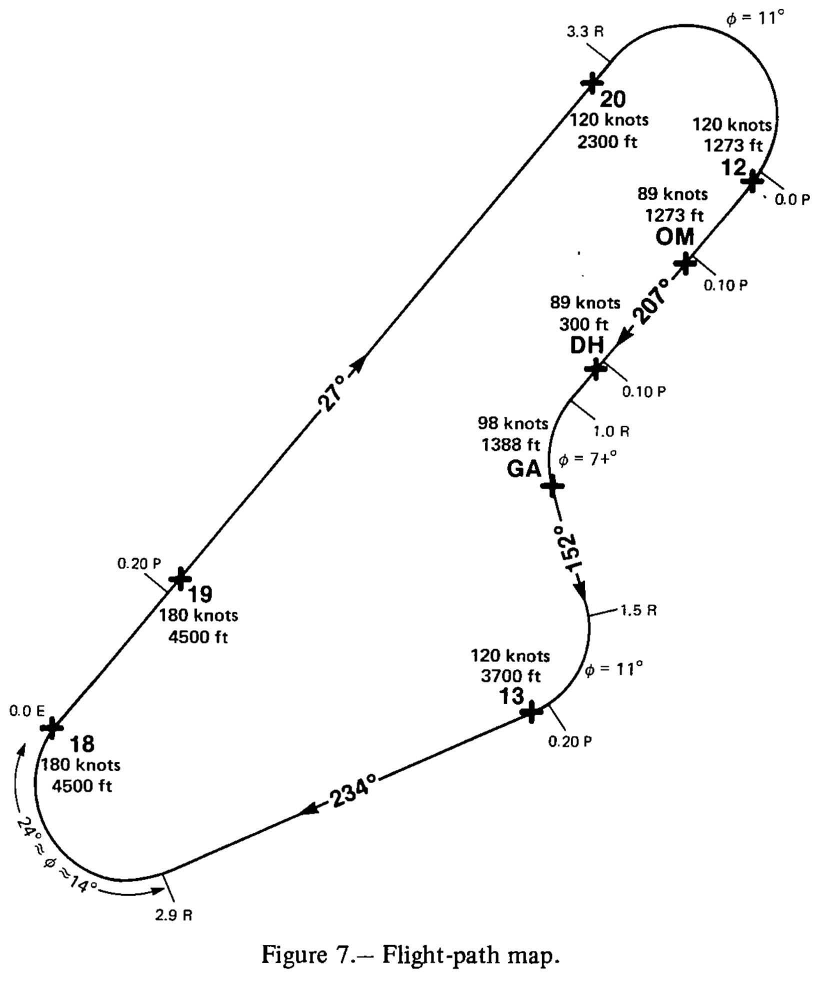


Figure 7.– Flight-path map.

Displays

Instrument configurations– In this study, two instrument formats, each with two levels of information content, were examined. The two configurations were: (1) a conventional mechanical pointer and scale instrument basic "T" configuration with the mechanical course indicator replaced by a computer-generated, CRT-displayed course indicator; and (2) the CCD.

The mechanical horizontal-situation indicator on the conventional configuration was simulated on a 16.51 × 13.97 cm (6.5 × 5.5 in.) CRT. The VSD, SVSD, and HSD of the CCD were simulated on 17.7 × 17.7 cm (7 × 7 in.) CRT's. The lines and dots that made up the displays were generated by an Evans and Sutherland LDS-2, modified to drive beam-penetration color CRT's. An SEL-840 computer interfaced with the LDS-2 to calculate the display parameters. The SEL-840 also generated the aircraft dynamics, navigation and guidance equations, and recorded the performance data.

Information content– The two different levels of information content of the conventional configuration were: (1) a system approximately equivalent to conventional instrumentation systems, that is, a basic "T" instrument configuration; and (2) a system that presented additional information so that the total system information was roughly equivalent to the CCD as described above. To make the conventional configuration comparable to the CCD, the following additional information, in pointer and scale format, was incorporated: (a) identifier for the next waypoint; (b) the distance to the next waypoint; (c) an indication of bearing to the next waypoint; (d) the flight-path angle; (e) the angle of the desired descent path; (f) the potential flight-path angle; and (g) the windspeed and direction. (These items of information are referred to later in table 1; they are identified in table 1 by the letter designations used here.) Figure 8 shows the conventional configuration that corresponded most closely to the CCD as described above. The level configured to be comparable with a conventional basic "T" was obtained by removing indicators (d), (e), (f), and (g).

The two different levels of information content of CCD were a reduced CCD with information comparable to the first conventional system and the CCD system as described above. The reduced CCD was obtained by removing elements (ii) (potential flight-path-angle indicator, fig. 4) and (vii) (flight-path-angle indicator, fig. 5) from the VSD and SVSD, element (xii) (horizontal flight-path indicator, fig. 5) from the HSD, and element (XIV) (waypoint symbol, fig. 6) from the VSD.

Task

The simulation dynamics were a simplified set of Buffalo (STOL) dynamics. Each flight began at waypoint (18) of the desired flight path from an altitude of 1371.6 m (4500 ft), in a trimmed attitude in level flight and at an airspeed of 92.6 m/sec (180 knots). When a change in airspeed or altitude was required between waypoints the change was linear. A 20-knot wind was inserted on approximately half of the runs. This was chosen to be a quartering headwind or tailwind from either left or right on the final approach leg. The subjects were requested to fly as close as possible to the desired flight path which has been described before and is illustrated in figure 7. Each run lasted about 13 min. The runs, rests, and longer breaks altogether required about 3 hr each day.

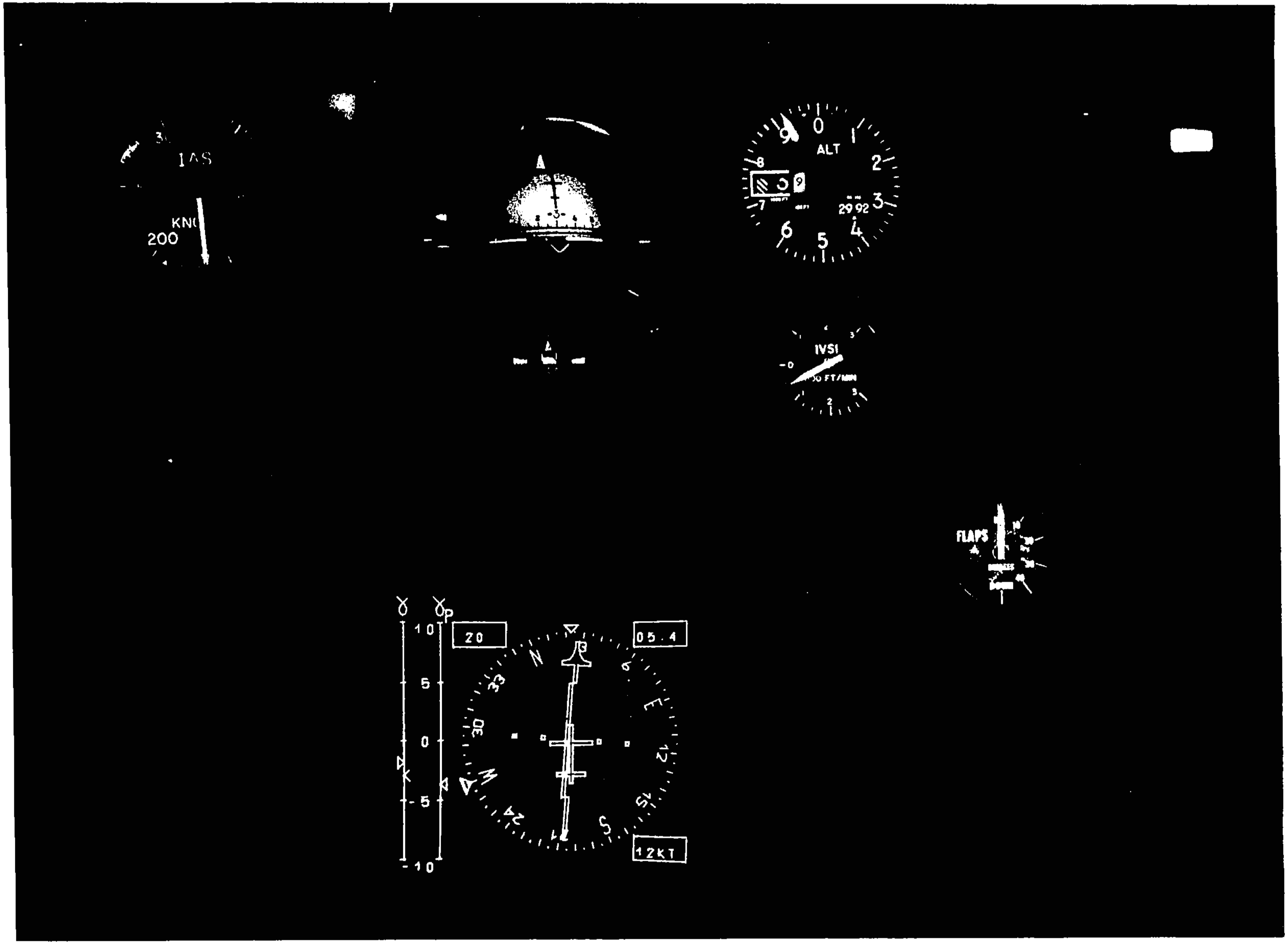


Figure 8.– Conventional instrument configuration.

The chart (fig. 7) was available to the pilots at all times. The desired airspeed, altitude, and course bearing were listed beside each waypoint on the map. (Color coding was used to enhance information discriminability.) Also included on the chart, shown outside the flight path, were nominal bank angles for the turns (zero wind values) and prompts for pitch and roll maneuvers. These DME readout-prompts were included to facilitate flying the conventional instrument system.

Subjects

The subjects for this study were three commercial airline pilots. A brief introduction to the purpose of the study, an explanation of the simulation, and a description of the task were given to each pilot before his first trial. The pilots were encouraged to experiment and get the "feel" of the aircraft, including handling qualities at various flap settings. Generally, the pilots preferred to fly the task after a few minutes rather than to explore the simulation. Each display was explained in detail when it was first presented to the pilot. Since this was an exploratory study, the pilots were free to develop their own strategy for using the information on each display to complete the assigned task. Each pilot saw the displays in a different order. The three pilots flew a total of 90 runs; 17 runs over 4 days for Pilot A, 37 runs over 7 days for Pilot B, and 36 runs over 6 days for Pilot C. Fifty-two of the runs were made using CCD (26 runs with full CCD, 26 runs with reduced CCD), and 38 of the runs were made using the conventional configuration (20 runs with maximum information and 18 runs with reduced information). Questions and comments were encouraged throughout the study, and a structured interview with a formal questionnaire was administered at the conclusion of each subject's trials.

Results

Performance data– When individual flights were analyzed it was often possible to detect some of the performance trade-offs being made by the pilot. However, consistent evidence for differences in performance due to differences in displays was meager, caused largely by changes attributable to learning. Each pilot had his own unique performance pattern. In general, however, Pilots A and C had lower airspeed and altitude errors and Pilot B had lower lateral error using the CCD format. Pilot B had about the same altitude error on both the conventional and the CCD formats. Otherwise, the pilots had lower error scores on the conventional format. Within a given display format, altitude error was less when flight-path angle was present. This trend for altitude error was present for each pilot whereas, for airspeed and lateral error, opposing pilot trends averaged out to mask any statistically significant effects.

Rating data– Three arbitrary rating scales were devised to ascertain the pilots estimation of the utility of the instrument systems. Each of the rating scales had a minimum value of 1 and a maximum value of 10. The items that the scales measured and some approximate scale positions were: (1) a degree of orientation (complete mental picture, 1, to completely disoriented, 9); (2) confidence in appropriate next control action (complete confidence, 1, to mostly uncertain, 9); and (3) degree of workload (completely undemanding, 1, to completely demanding, 9). On their last day, the pilots were asked to rate the four display alternatives considering the overall flight and also considering each waypoint to waypoint segment of the desired flight path. The overall average values are given in table 1 under "ratings." Also listed under "ratings" are the range of ratings given for the individual flight segments, the lower number for the easiest segment, and the higher number for the most difficult segment.

TABLE 1.– PILOT AVERAGE RATINGS AND RANKINGS FOR FOUR INSTRUMENT DISPLAYS

Display		Ratings						Rankings for		
		Orientation		Confidence		Workload				
Configuration	Information content[a]	Overall	Segments (range)	Overall	Segments (range)	Overall	Segments (range)	DV[b]	CW[c]	TK[d]
CCD	(i)–(xx)	2	1–5	3	2–4	5	4–6.5	1[e]	1[e]	2.8
	(i)[f] (iii)–(vi) (viii)–(xx)	2.5	2–6	4	2.5–4.5	5.5	4–7	2	2[g]	4.3
Conventional	a–g	3	2–5	4	3–5	6	4.5–7	3	3	5.2
	a–c	3	2–5	5	3.5–6	6.5	4.5–7.5	4	4	8.2

[a] Indicators are defined in text.
[b] Deviation (DV).
[c] Crosswinds (CW).
[d] Overall task performance (TK).
[e] All pilots selected this order except where noted.
[f] Indicator (xiv) was deleted from the VSD only.
[g] One pilot rated the other three displays in the same relative order but with this configuration last.

The pilots were also asked to rank-order the instrument displays on the following questions:

1. Deviations (DV): Which display would you choose if you had to suddenly deviate from the planned flight path and then return to it?

2. Crosswinds (CW): With which display did you best cope with crosswinds?

3. Overall task performance (TK): With which display did you best perform this task? Now rate the four displays on a scale from 1 to 10, 1 being ideal, and 10 being absolutely unacceptable.

The rank order of the displays is given in table 1 under "rankings."

Pilot comments– The appendix contains a summary of the most interesting of the pilot's comments. Because some of the results were redundant, the separate pilot comments in the appendix are a combination of daily comments, responses to direct questions, and responses given during the structured interview.

All the pilots felt their performance would have improved given more practice with the task. In particular, they felt that more experience with the flight-path angle, potential flight-path angle, and wind-information indicators would be necessary before they would be able to make full use of them. All pilots claimed a positive learning transfer across all systems, that is, they felt experience with any one system led to improved performance on all the systems.

Generally, the pilots preferred systems with more information and liked the pictorial indicators. The pilots preferred to use the SVSD when interpreting flight-path angle and potential flight-path angle; one even suggested that this information be removed from the VSD. This may be contrasted with a NASA pilot who flew the display extensively during development and program debugging; he preferred to make use of the combination on the VSD.

The pilots were asked to specify those features among all the displays which they thought were best and worst. Pilot A thought that the best feature was the side-view projection of the desired flight path (element xviii) on the SVSD and that the worst feature was the flight-path/potential flight-path angle complex on the VSD. Pilot B thought that the flight-path angle (vii) on the SVSD was the best feature and that the flight-path angle on the VSD was the worst feature. Pilot C was more general and thought that the best feature was the SVSD and HSD CRT's and that the worst feature was (the lack of definition and the obtrusiveness of) the horizon line on the VSD.

CONCLUSIONS

The comments, rankings, and ratings show that, in general, the pilots accepted the concept of the pictorial systems.

The concept of drawing standard instruments on CRT's as a first step in the use of CRT displays appears to be a feasible one. The instrument HSI drawn on the CRT was accepted without question or comment.

It was observed that the pilots appeared to adopt different strategies for each of the four different configurations. This raised the warning that each step in the display evolution must be taken with care, considering the effect of new configurations on all flight regimes. The implications for training and procedures must be considered at each step.

Coupled with the favorable pilot comments about CCD, the finding of no performance differences of practical significance between the pictorial and conventional instrument systems indicates that it is worthwhile to go on to the next phase of research. The CCD pictorial approach is a promising one.

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Moffett Field, California 94035, February 8, 1979

APPENDIX

PILOT COMMENTS

Pilot A

1. Easily incorporated at SVSD into his scan. He did so on his first run.

2. Found the CCD airspeed-error indicator easier to read than the error indicator on the conventional configurations.

3. Found it easier to keep track of how to get back to the desired altitude or track when using the CCD.

4. Liked indicator (vii) (flight-path-angle indicator, fig. 5). He found it a good substitute for the VSI.

5. Had some trouble with indicator (ii) (potential flight-path-angle indicator, fig. 4). He thought it should be selectable by pilot.

6. Thought the method of combining indicators (ii) and (vii) on the VSD gave an unwanted illusion.

7. Did not like the "off-center" position of the indicator (ii) and (vii) combination on the VSD in crosswinds.

8. Commented every day that he missed a flight director.

9. Missed having a compass rose on the CCD. He has had a "rose" for many years.

10. Had a better overall inner spatial picture with the conventional configuration. He stated that, ". . . by necessity, (he had) to work harder at the job."

Pilot B

1. Stated (after flying CCD extensively), "(Conventional configurations) seem strange after getting used to pictorial displays."

2. Stated, "Keeping mental picture on pictorials is easy, it's done for you."

3. Would prefer a conventional VSI (speaking of CCD). He had some trouble bringing indicator (viii) (vertical speed indicator, fig. 5) into his scan pattern.

4. Would like flight-director information. He would rate CCD, with a flight director added, about two units higher than CCD as is.

Pilot C

1. Quickly adopted indicator (vii) (flight-path-angle indicator, fig. 5) for power settings and indicator (ii) (potential flight-path-angle indicator, fig. 4) for controlling flight path.

2. Found indicator (vii) most useful for increasing his confidence in his control actions.

3. Spent little time scanning the HSD and SVSD. He stated that, "a glance peripherally" was all that was needed to know where he was. He stated that, "(It was) very useful."

4. Thought that indicator (vii) (vertical speed information) needed to be more centrally located (speaking of CCD).

5. Thought that indicators (ii), (vii), and (xiv) (waypoint symbol, fig. 6) should be taken off the VSD.

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16. Abstract

It will be difficult to modify current aircraft instrument panels to accommodate all new information required to operate within an increasingly complex air traffic control system. Cathode Ray Tube (CRT) and computer technologies have reached the stage where current flight and engine instruments can economically be replaced by computer-controlled CRT displays. This provides a tremendous opportunity for flexibility to the cockpit display designer, but the use of this flexibility should stay within the realities of the flight environment. This report describes one approach to the replacement of flight instruments, using three separate color CRT's. Each CRT displays information pertinent to one of the three orthogonal projections of the aircraft flight situation. Three airline pilots made a preliminary assessment of this display set. Comments, rankings, and ratings show that, in general, the pilots accepted the concept of pictorial flight displays.

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