NASA Technical Memorandum 4010

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Summary

A ground-based aircraft simulation study was conducted to determine the effects on pilot preference and performance of integrating airspeed and altitude information into an advanced electronic primary flight display via moving-tape (linear moving scale) formats. Several key issues relating to the implementation of moving-tape formats were examined in this study: tape centering, tape orientation, and trend information. The factor of centering refers to whether the tape was centered about the actual airspeed or altitude or about some defined reference value. Tape orientation refers to whether the represented values were arranged in descending or ascending order. Two pilots participated in this study, with each performing 32 runs along seemingly random, previously unknown flight profiles. The results of this study are as follows. In general, both pilots always gave better ratings to the formats that used actual centering and had higher numbers at the top (high-to-low orientation). The actual-centered formats resulted in smaller altitude root-mean-square errors (better performance) than reference-centered formats. Additionally, greater attention to a secondary task was shown when actual centering was used. Formats with a high-to-low airspeed tape orientation resulted in fewer control (throttle) reversals than formats with a low-to-high orientation. At the same time, more attention was paid to the secondary task when the low-to-high orientation was used. Formats without trend information resulted in the pilots devoting more attention to the secondary task. Additionally, while one pilot was indifferent to trend information, the other pilot strongly favored it.

Introduction

Electronically generated, primary flight displays have shown great potential in reducing the pilot's visual work load, and their increasing use in aircraft is characterized by installation in the Boeing 757–767 and the Airbus 310–320 families. Because of this increasing use of electronically generated display formats, particularly formats generated with cathode-ray-tube (CRT) technology, several simulator studies were undertaken to determine the effect on pilot performance of electronically representing altitude and airspeed information on the primary flight display via moving-tape formats. This study, the second of two (the first is reported in ref. 1), utilized a seemingly random, unpredictable guidance task and employed two additional work load assessment methodologies.

Three primary questions relating to the representation of information on moving-tape formats were examined during this study: (1) tape centering, (2) tape orientation, and (3) trend information. The reasons for these choices were as follows. The first question relates to the criticality of what is considered the center of the tape. That is, does there exist a significant difference in interpretability if, for example, a reference altitude (such as a preselected altitude) is used as the centering index of the altitude tape instead of using the actual altitude as the center? Second, is the tape orientation or the direction that the tape moves critical? Conventional design criteria require that the larger numbers be at the top of the tape, that is, higher airspeed and altitude. Several new designs, however, have placed the smaller numbers at the top of the airspeed tape. Third, what are the potential benefits of providing trend information, such as acceleration on an airspeed tape? The possibility exists for reducing the pilot's mental work load by providing trend information that the pilot would otherwise have to derive from the original information. Conversely, the possibility exists for increasing work load by providing superfluous information or information that is overly compelling relative to its importance.

The previous simulator study (ref. 1) was conducted to provide some insight into the design implementation issues of these representations; the piloting task was to maneuver along a single, known flight profile. This previous study did not produce clear-cut results, possibly because the flight task was predictable. The current study is an extension of this previous work except that the flight profile was not made known to the pilot prior to its occurrence, thus requiring the pilot to use more of the information provided in the display.

Description of Equipment

Simulation Facility

This study employed a fixed-base simulator configured as the research cockpit of the NASA Transport Systems Research Vehicle (TSRV) airplane (ref. 2). This simulation included a six-degree-of-freedom set of nonlinear equations of motion as well as functionally representing the aspects of the advanced flight control configuration of the airplane with nonlinear models of the servo-actuators. The processing of the equations was performed in a Control Data Corporation (CDC) CYBER 175 digital computer at a 32-hertz iteration rate. A calm air model was used.

Electronic primary and navigation displays were provided in an over-and-under arrangement (see fig. 1). The navigation display was not used during this study. The format for the primary display was generated on an Adage AGT 340 graphics computer. The graphics computer was linked via a digital buffer to the CDC CYBER 175 computer. The display was a stroke drawing and contained no raster features. For this study, the primary display was presented on a cathode ray tube (CRT) of approximately 21-centimeter diagonal.

Airplane Control Mode

For this study, the velocity-vector control-wheel steering mode for the TSRV was used. The pilot flew the simulator using a two-axis sidestick (shown in fig. 2) rather than the panel-mounted controllers generally associated with this simulator. Manual throttles were also used throughout this study. Descriptions of the systems operations can be found in references 3 and 4.

Display Formats

The electronic primary flight display (PFD) in this simulator is custom tailored to the flight control system being employed. That is, the velocity-vector control-wheel steering (CWS) mode couples to a display format which centers the displayed information about the velocity vector (refs. 4–6). As can be seen in figure 3, the major information elements provided by this display are the velocity vector, attitude, horizon, roll scales, pitch scales, and path-deviation indicators. The electromechanical altitude, airspeed, and vertical speed instruments in the cockpit were covered during this study.

Eight PFD formats, designed around the format of figure 3 and including airspeed and altitude information, were used in this study. The variations in the eight formats were obtained from the 2 × 2 × 2 display factors under investigation and are shown in table I.

Airspeed information was presented by a moving-tape, fixed-pointer implementation (moving linear scale) positioned on the left side of the display screen. The center of this tape was always aligned with the velocity-vector symbol (figs. 4 and 5). The scales and associated values (240, 220, 160, 140, and 120 for the airspeed tape of figs. 4 and 5) moved as a unit. The total length of the tape, from top to bottom, was equivalent to 132 knots. Two pointers were provided on this tape, one indicating the actual airspeed (the value normally associated with an airspeed indicator) and the other indicating a reference airspeed (179 and 169, respectively, for the airspeed tape of figs. 4 and 5). The actual airspeed was represented by a caret and larger, unboxed numerals. The actual airspeed pointer always had priority over the reference pointer in that the reference pointer could be physically masked by the actual airspeed pointer when the two were in physical proximity. This priority scheme can be seen in figures 4 and 5, where the actual value is just beginning to mask the upper portion of the reference box. The value of the reference pointer was continuously, automatically set to the speed profile for the predefined path. As part of the experimental design, the fixed (that is, tape-centering) pointer could be either the actual or the reference airspeed. Four of the eight PFD formats utilized actual airspeed as the fixed pointer and the other four display formats used reference airspeed as the fixed pointer.

The second factor in the experimental design involved tape orientation. Four of the eight PFD formats had airspeed tapes with the higher values at the top of the tape (high-to-low) and the other four configurations had lower airspeed values at the top of the tape (low-to-high).

Table I. Display Formats for Airspeed and Altitude Presentation

Configuration	Fixed-pointer value (centering)	Orientation of airspeed tape (direction)	Trend information
Alternate displays:			
1	Actual	High-to-low	Yes
2	Actual	Low-to-high	Yes
3	Actual	High-to-low	No
4	Actual	Low-to-high	No
5	Reference	High-to-low	Yes
6	Reference	Low-to-high	Yes
7	Reference	High-to-low	No
8	Reference	Low-to-high	No

As a third factor in the experimental design, airspeed trend information (viz, acceleration) could be added to the airspeed tape. This information was displayed as an arrow with the base of the arrow at the actual airspeed position and the length of the arrow proportional to the magnitude of the acceleration. The length of the arrow indicated the instantaneous 20-sec prediction of the airspeed (predicting 170 for the airspeed tape of figs. 4 and 5). It should be noted that in the high-to-low, actual-value-centered tape configuration (fig. 5), the relationship of the tip of the acceleration arrow to the pitch angle scale indicated the flight-path angle that could be obtained while maintaining the current actual airspeed. Four of the eight PFD formats included acceleration information.

Similar to the airspeed information, altitude information was also presented by a moving-tape, fixed-pointer implementation (fig. 4). This tape was positioned on the right side of the display screen. The total length of the tape, from top to bottom, was equivalent to 1200 feet. Unlike the airspeed tape, where the center of the tape was always aligned with the velocity-vector symbol, the altitude tape and the altitude tape center was allowed to "float" as a function of the nominal vertical flight-path angle. For example, if the nominal flight-path angle was +2° for a climb condition, the center of the altitude tape would be positioned 2° above the center of the horizon line. For any condition where the airplane was paralleling the nominal flight path, the center of the altitude tape would be aligned with the commanded flight-path symbol.

Two pointers were provided on the altitude tape, one indicating the actual altitude (the value usually associated with an altimeter) and the other indicating a reference altitude. The value of the reference pointer was continuously, automatically set to the altitude profile for the predefined path. Again, as part of the experimental design, the fixed (or tape-centering) pointer could be either the actual or the reference altitude. Four of the eight PFD formats utilized actual altitude as the fixed pointer and the other four formats used reference altitude as the fixed pointer.

Path-deviation trend information could be added to the altitude tape. This information was displayed as an arrow with the base of the arrow at the actual altitude position and the length of the arrow proportional to the difference between the actual and the nominal flight-path angle. The length of the arrow was proportional (3:10) to the pitch angle scale such that a 3° path-deviation angle would be equivalent to 10° of pitch attitude. Figure 4 shows a path deviation of approximately 0.8° (the difference between the right tip of the velocity-vector symbol and the tip of the actual altitude caret), which produced a trend arrow equivalent to 2.7° of pitch attitude. Four of the eight PFD formats included path-deviation trend information. The altitude tape was always presented in a high-to-low configuration.

The eight PFD configurations are given in table I. It should be noted that the tape-centering conditions were always paired: the reference-centered tapes were always used together, and similarly the actual-centered tapes were used together. The same pairing scheme was used for the trend information: either both tapes had trend information or neither tape had trend information.

Task Description and Conditions

Primary Task

Each simulation run was conducted along one of eight paths. All the paths included vertical maneuvers (climbs and descents) and speed changes. The paths were designed to produce equivalent pilot work load and tracking deviations. These paths were considered relatively high-work-load paths, where the reference path changed in altitude, speed, or some combination of the two at approximately 15-sec intervals. The path changes were shown on the display by the appropriate movement of the altitude and airspeed reference pointers and "floating" of the nominal flight-path angle. Changes in path reference values were ramped over a 5-sec period to avoid discrete changes in the values. The paths were designed so that no aircraft configuration changes were required. The airplane was initialized at an airspeed of 150 knots, with flaps at 25°, in level flight, and on the path. A single run took approximately 3 minutes. The pilot's primary task was to fly the airplane along this path with a minimum of deviation in altitude and airspeed. No foreknowledge of the paths was provided to the pilots.

Secondary Task

To determine the mental work load of the pilot during the primary flight task, an electrical brain response measurement method was employed. The procedure (ref. 7) is as follows: a series of auditory tones (high- and low-pitched tones) are presented to the pilot, the pilot is instructed to mentally count only the low-pitched tones, and the auditory evoked potential (AEP) to each tone is recorded. The pilot's total count was recorded at the end of each simulation run. When the counting is the pilot's only task, the brain activity waveform peaks at approximately 300 milliseconds (P300) in response to the counted, low-pitched tones, and not to the uncounted, high-pitched tones. When the pilot is heavily engaged in a flight task, the waveform changes. An example of this is shown in figure 6, where the area of interest in this figure is between approximately 200 and 400 milliseconds. The attention that the pilot is devoting to the counting task is related to the difference between the AEP waveform to the counted tones and the uncounted tones. This technique has been shown to reliably discriminate between task and no-task conditions. As a secondary part to this study, AEP data obtained are being used to assess this measurement technique for the ability to discriminate gradations between the task and no-task extremes. In addition, it should be noted that since the pilots were required to count the low-pitched tones, this measurement technique was in itself an auditory, secondary work load task.

Data

Sampled data were gathered throughout the run and included path performance parameters, pilot-control inputs, and evoked response parameters. Through the use of questionnaires, subjective pilot opinion was gathered after each simulation run (appendix A). Included in the questionnaire data of appendix A was scoring on three variables known to be associated with the work load. This scoring method was the subjective work load assessment technique (SWAT) of references 8 and 9.

Conditions

Two evaluation pilots were used in this study. One of the pilots was a NASA test pilot and the other was a U.S. Air Force operational pilot. Both pilots were qualified in multiengine jet airplanes. The pilots were briefed prior to the simulation tests with respect to the display configurations, the control system, the secondary work load task, and the recorded performance measurements. In addition, each pilot was provided with approximately 4 hours of familiarization and practice in the simulator prior to the actual test runs. With the exception of a general description of the task, no familiarization or briefing was provided regarding the experiment flight profiles.

Each pilot flew a total of 32 data runs in the simulator. All runs were flown in velocity-vector control-wheel steering mode through a sidestick controller and with manual throttles. The test sequence is given in table II. The order of the test was counterbalanced within each block of eight runs to reduce carryover effects.

Simulation Results and Discussion

Quantitative Analysis

The results and discussion in this section are divided into three parts, one for each main design factor: centering, orientation, and trend information. Statistical results were deemed significant if the null hypothesis was rejected at the 0.05 level. Differences in a result within a display factor were deemed experimentally significant only if the difference in mean values, across all runs for that factor, was greater than 20 percent. For example, the difference in root-mean-square (rms) altitude error for actual value centering and reference value centering had to exceed 20 percent for one to be considered better than the other.

In considering the secondary task data, the observed differences in the AEP data could be interpreted in two ways. First, it could be assumed that the subjects are experiencing lower work load on one primary task (or display) versus another, resulting in more mental resources being available for the secondary task. The other interpretation is that the subjects may be attending less to the primary task which would again allow more mental resources to be available for the secondary task. An observed difference in AEP data could not, then, be used independently as a means for determining whether or not one within-design display factor was "better" than another.

Centering. Actual centering resulted in a two-thirds smaller altitude rms error (better performance) than reference centering (16.51 feet and 24.11 feet, respectively). Additionally the AEP P300 results were experimentally significant, showing greater attention to the secondary task when actual centering was used. It would then appear that from both a performance and a work load standpoint, actual centering is preferable.

Orientation. The high-to-low airspeed tape orientation resulted in 400 percent fewer throttle reversals than the low-to-high orientation (a reversal is when the pilot responds in a manner opposite to what the situation requires). (Of the total number of throttle inputs, 1.0 percent were reversals for the high-to-low orientation while 5.2 percent were reversals for the low-to-high orientation.) At the same time, the AEP P300 data were found to be experimentally significant with more attention being paid to the secondary task when the low-to-high orientation was used. There appear to be two explanations for the results: either the low-to-high orientation was easier to use but contributed to more errors or the low-to-high orientation was confusing, leading to more errors. The smaller number of control errors with the high-to-low orientation, however, makes that configuration preferable.

Trend information. Only the AEP P300 data were found to be experimentally significant for trend information. With trend information absent, the subjects devoted more attention to the secondary task. It should be noted, however, that unlike the centering and orientation factors, where the same information was presented in different forms, the inclusion of trend information increased the amount of information available on those display configurations on which it was presented.

Table II. Test Sequence

Run	Format	Flight profile	Pilot	Run	Format	Flight profile	Pilot
1	1	1	1	33	8	7	2
2	8	6	1	34	1	6	2
3	3	5	1	35	6	3	2
4	6	7	1	36	3	1	2
5	2	3	1	37	7	4	2
6	7	8	1	38	2	5	2
7	4	4	1	39	5	8	2
8	5	2	1	40	4	2	2
9	6	4	1	41	3	8	2
10	3	2	1	42	6	1	2
11	8	3	1	43	1	4	2
12	1	7	1	44	8	5	2
13	5	1	1	45	4	7	2
14	4	5	1	46	5	6	2
15	7	6	1	47	2	2	2
16	2	8	1	48	7	3	2
17	4	6	1	49	5	3	2
18	5	5	1	50	4	1	2
19	2	4	1	51	7	7	2
20	7	1	1	52	2	6	2
21	3	7	1	53	6	5	2
22	6	2	1	54	3	4	2
23	1	3	1	55	8	2	2
24	8	8	1	56	1	8	2
25	7	5	1	57	2	7	2
26	2	1	1	58	7	2	2
27	5	7	1	59	4	8	2
28	4	3	1	60	5	4	2
29	8	4	1	61	1	5	2
30	1	2	1	62	8	1	2
31	6	8	1	63	3	3	2
32	3	6	1	64	6	6	2

Qualitative Analysis

This section focuses primarily on the responses to the post-run questionnaire of appendix A and particularly to the questions specifically relating to display centering, orientation, and trend information. In analyzing these responses, each response for each question was assigned a numerical score from 1 to 5, with 1 being the worst rating (inaccurate, confusing, disliked, distracted) and 5 being the best (accurate, clear, liked, helped). Additionally, for the responses relating to display centering, orientation, and trend information, three subgroupings were used: situational awareness, work load, and preference. The questions relating to each of these areas are shown in table III, where the number shown in the table is the question number assigned to the questions of appendix A. The numbering scheme and corresponding questions are shown in appendix B. The mean values of the responses to these questions are listed in table IV. Similar to the quantitative analysis, the differences in responses relating to centering and orientation were deemed experimentally meaningful only if the differences in mean values, across all runs for each pilot for that response, were greater than 20 percent. Using this criterion, the following results were obtained. A preference was shown for both actual centering and high-to-low orientation; the pilots always gave better ratings to the formats that used actual centering and a high-to-low orientation.

Table III. Questions Used in Detailed Subjective Analysis

[Question numbers correspond to those in appendix A]

	Centering	Orientation	Trend
Situational awareness	12	4	8, 24, 33
Work load	14, 15	6, 7	10, 11
Preference	13	5	9

Table IV. Results of Detailed Subjective Analysis

	Centering		Orientation		
	Actual	Reference	High-to-low	Low-to-high	Trend preference
Situational awareness:					
Pilot 1	3.18	2.75	2.88	2.13	3.48
Pilot 2	3.78	1.75	3.46	1.63	5.00
Average	3.50	2.25	[a]3.19	[a]1.88	4.32
Work load:					
Pilot 1	3.18	2.75	2.94	2.31	3.47
Pilot 2	3.72	1.38	3.38	1.48	5.00
Average	3.47	2.06	[a]3.17	[a]1.88	4.32
Preference:					
Pilot 1	3.18	2.25	2.79	2.00	3.44
Pilot 2	3.66	1.25	3.29	1.13	5.00
Average	[a]3.43	[a]1.75	[a]3.06	[a]1.56	4.31

[a]Defined as a meaningful result.

Since the pilots responded to questions regarding trend information only when trend information was presented, data could not be compared as was previously done. For trend information, a response was deemed meaningful only if the mean value, across all runs for each pilot for that response, was either greater than or less than one rating from the center value (numerically, greater than 4 or less than 2). Using this criterion, no meaningful results were found for trend information. It is noteworthy, however, that while one pilot was indifferent to trend information, the other pilot strongly favored it.

Conclusions

A ground-based aircraft simulation study was conducted to determine the effect on pilot performance of electronically integrating altitude and airspeed information on the primary flight display via moving-tape formats. Several key issues relating to the representation of information on moving-tape formats were examined during this study: tape centering, tape orientation, and trend information. Two pilots participated in this study, each performing 32 runs along seemingly random flight profiles. Based on the results of this study, the following conclusions are presented.

1. Both pilots always gave better ratings to the formats that used actual centering and a high-to-low orientation.

2. Actual centering resulted in smaller altitude root-mean-square error (better performance) than reference centering. Additionally the AEP results showed greater attention to the secondary task when actual centering was used. From both a performance and a work load standpoint, actual centering is preferable.

3. The high-to-low airspeed tape orientation resulted in fewer throttle reversals (when the pilot responded opposite to what the situation required) than the low-to-high orientation. Conversely, the AEP data were found to be experimentally significant with more attention being paid to the secondary task when the low-to-high orientation was used. The fewer number of control errors with the high-to-low orientation, however, makes that configuration preferable.

4. Without trend information, the pilots devoted more attention to the secondary task. This was an expected result since, unlike the centering and direction factors where the same information was presented in different forms, inclusion of trend information increased the amount of information available on the display configurations. Additionally, while one pilot was indifferent to trend information, the other pilot strongly favored it.

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Appendix A

Post-Run Questionnaire

Write the SWAT rating for the overall task work load: ______/______/______

For the following items, place a check mark [√] on the line that best reflects your opinion.

Example:

Preferred Hand

left	______ :	______ :	______ :	√ :	______	right

Tone Counting

1.	easy to do	______ :	______ :	______ :	______ :	______	difficult to do
2.	inaccurate	______ :	______ :	______ :	______ :	______	accurate
3.	hampered flying performance	______ :	______ :	______ :	______ :	______	no impact on flying performance

Airspeed Scale

4.	clear	______ :	______ :	______ :	______ :	______	confusing
5.	disliked it	______ :	______ :	______ :	______ :	______	liked it
6.	saved time	______ :	______ :	______ :	______ :	______	cost time
7.	helped	______ :	______ :	______ :	______ :	______	distracted

Trend Information

___ not presented. If not presented skip to actual centering.

8.	clear	______ :	______ :	______ :	______ :	______	confusing
9.	disliked it	______ :	______ :	______ :	______ :	______	liked it
10.	saved time	______ :	______ :	______ :	______ :	______	cost time
11.	helped	______ :	______ :	______ :	______ :	______	distracted

Actual Centering

___ not presented. If not presented skip to reference centering.

12.	clear	___ :	___ :	___ :	___ :	___	confusing
13.	disliked it	___ :	___ :	___ :	___ :	___	liked it
14.	saved time	___ :	___ :	___ :	___ :	___	cost time
15.	helped	___ :	___ :	___ :	___ :	___	distracted

Reference Centering

___ not presented. If not presented skip to vertical tracking.

12.	clear	___ :	___ :	___ :	___ :	___	confusing
13.	disliked it	___ :	___ :	___ :	___ :	___	liked it
14.	saved time	___ :	___ :	___ :	___ :	___	cost time
15.	helped	___ :	___ :	___ :	___ :	___	distracted

Vertical Tracking

16.	easy to do	___ :	___ :	___ :	___ :	___	difficult to do
17.	few errors	___ :	___ :	___ :	___ :	___	many errors
18.	large deviations	___ :	___ :	___ :	___ :	___	small deviations
19.	few control reversals	___ :	___ :	___ :	___ :	___	many control reversals
20.	poor situational awareness	___ :	___ :	___ :	___ :	___	good situational awareness
21.	usually knew "actual" value	___ :	___ :	___ :	___ :	___	rarely knew "actual" value
22.	usually knew "reference" value	___ :	___ :	___ :	___ :	___	rarely knew "reference" value
23.	display helped situational awareness	___ :	___ :	___ :	___ :	___	display hindered situational awareness
24.	trend info helped situational awareness	___ :	___ :	___ :	___ :	___	trend info hindered situational awareness

Speed Control

25.	easy to do	______	:	______	:	______	:	______	:	______	difficult to do
26.	few errors	______	:	______	:	______	:	______	:	______	many errors
27.	large deviations	______	:	______	:	______	:	______	:	______	small deviations
28.	few control reversals	______	:	______	:	______	:	______	:	______	many control reversals
29.	poor situational awareness	______	:	______	:	______	:	______	:	______	good situational awareness
30.	usually knew "actual" value	______	:	______	:	______	:	______	:	______	rarely knew "actual" value
31.	usually knew "reference" value	______	:	______	:	______	:	______	:	______	rarely knew "reference" value
32.	display helped situational awareness	______	:	______	:	______	:	______	:	______	display hindered situational awareness
33.	trend info helped situational awareness	______	:	______	:	______	:	______	:	______	trend info hindered situational awareness

Appendix B

Questions Used for Subjective Analysis

Airspeed Scale

4.	clear	______	:	______	:	______	:	______	:	______	confusing
5.	disliked it	______	:	______	:	______	:	______	:	______	liked it
6.	saved time	______	:	______	:	______	:	______	:	______	cost time
7.	helped	______	:	______	:	______	:	______	:	______	distracted

Trend Information

8.	clear	______	:	______	:	______	:	______	:	______	confusing
9.	disliked it	______	:	______	:	______	:	______	:	______	liked it
10.	saved time	______	:	______	:	______	:	______	:	______	cost time
11.	helped	______	:	______	:	______	:	______	:	______	distracted

Centering (both actual and reference)

12.	clear	______	:	______	:	______	:	______	:	______	confusing
13.	disliked it	______	:	______	:	______	:	______	:	______	liked it
14.	saved time	______	:	______	:	______	:	______	:	______	cost time
15.	helped	______	:	______	:	______	:	______	:	______	distracted

Vertical Tracking

24.	trend info helped situational awareness	______	:	______	:	______	:	______	:	______	trend info hindered situational awareness

Speed Control

33.	trend info helped situational awareness	______	:	______	:	______	:	______	:	______	trend info hindered situational awareness

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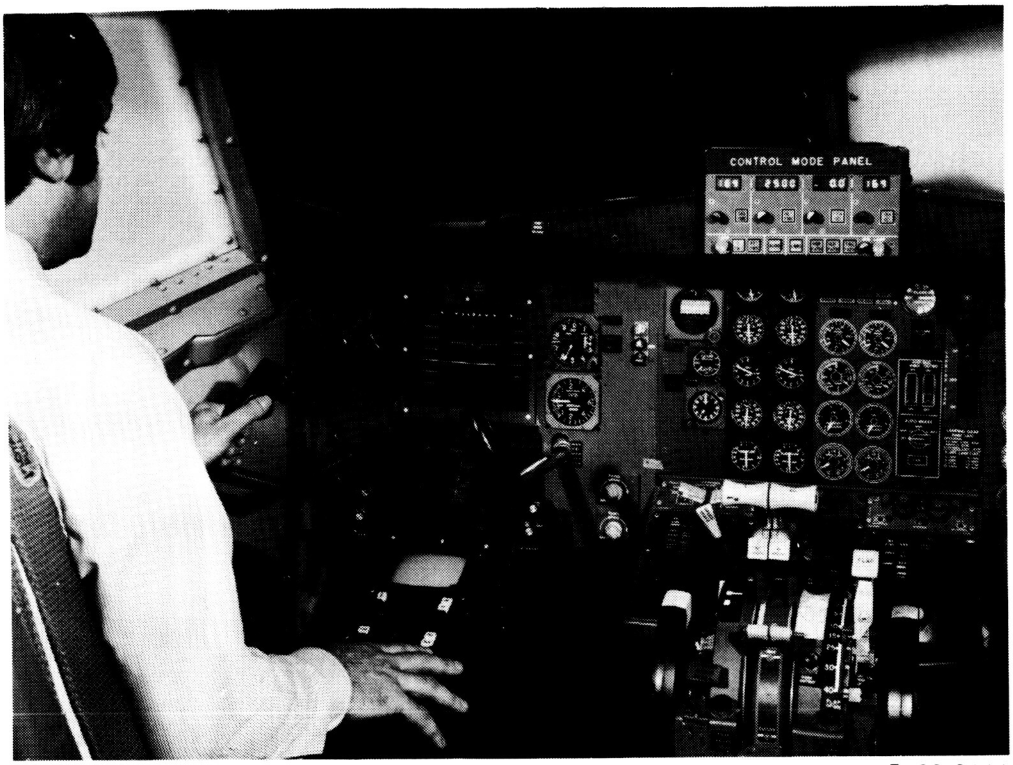

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Figure 1. Simulator cockpit.

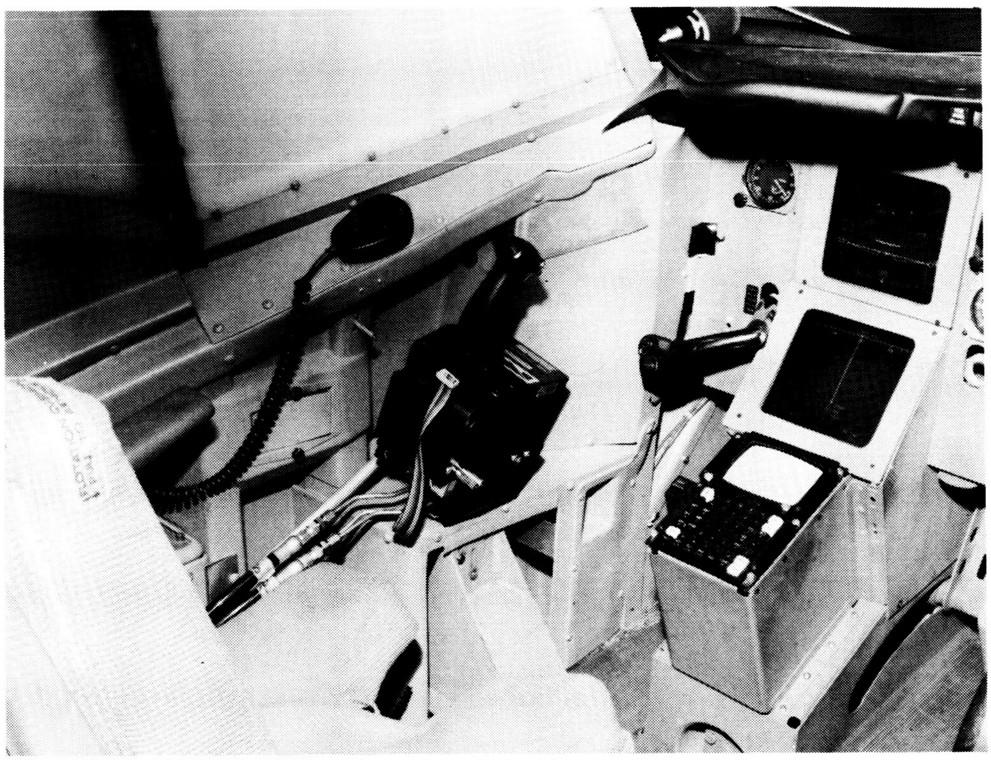

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Figure 2. Two-axis sidestick controller.

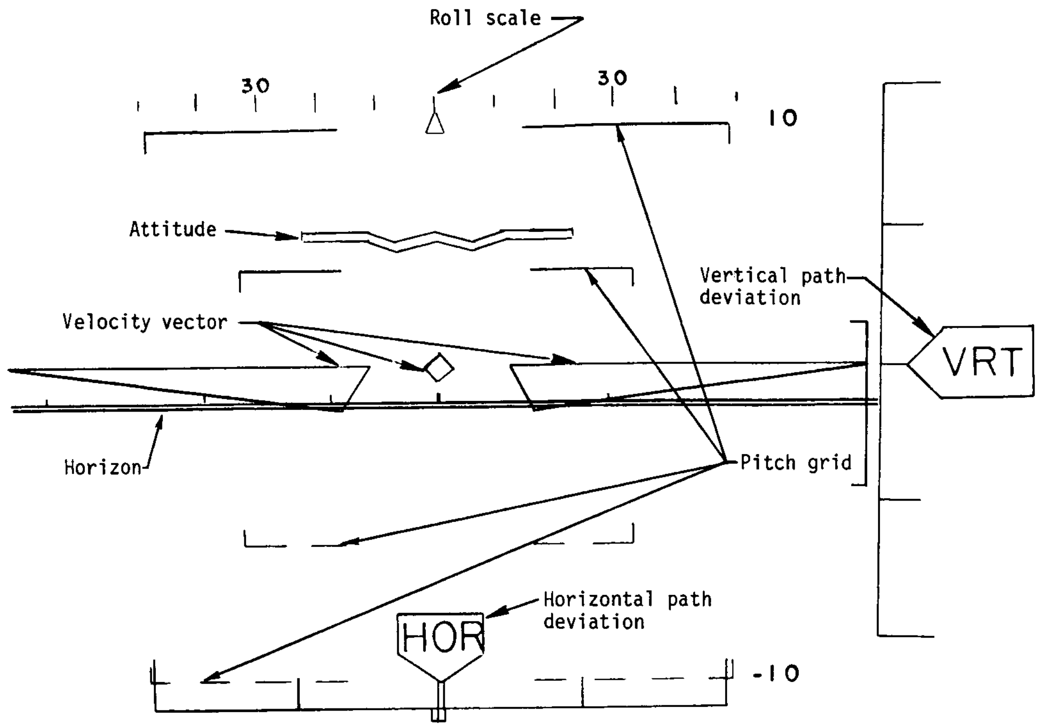


Figure 3. Basic display format for velocity-vector control-wheel steering mode.

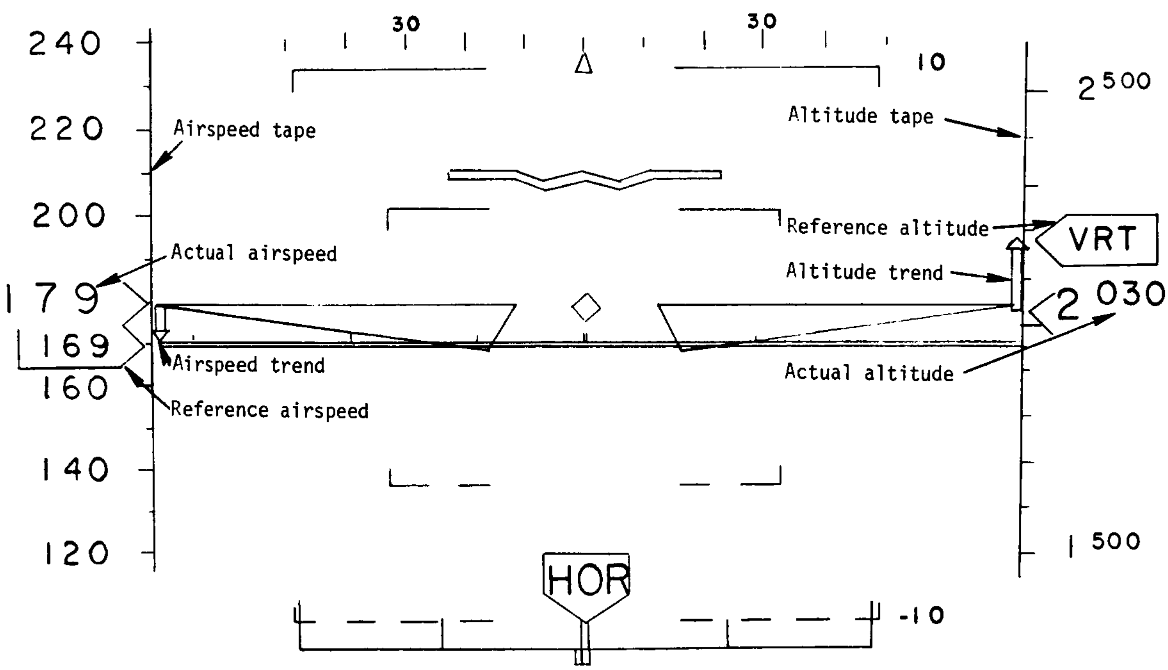


Figure 4. Primary flight display with moving-tape format.

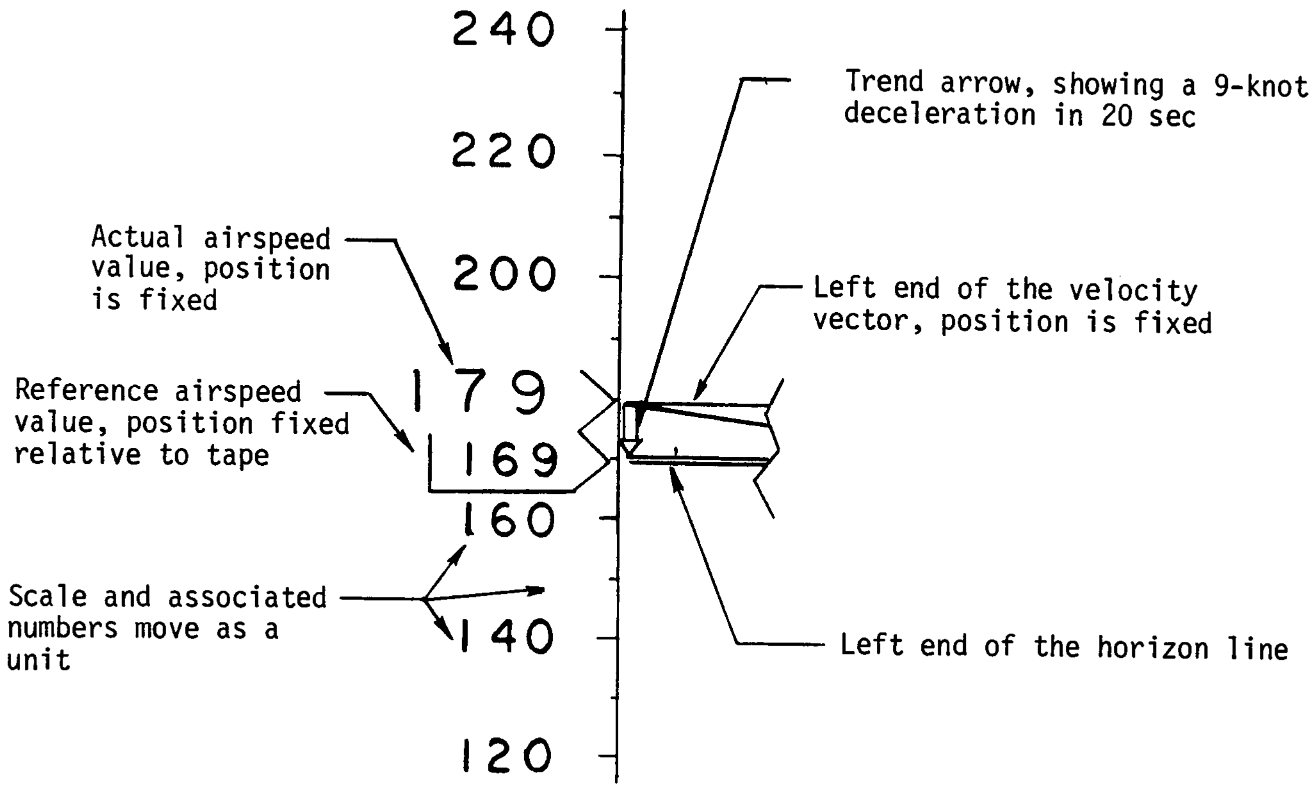
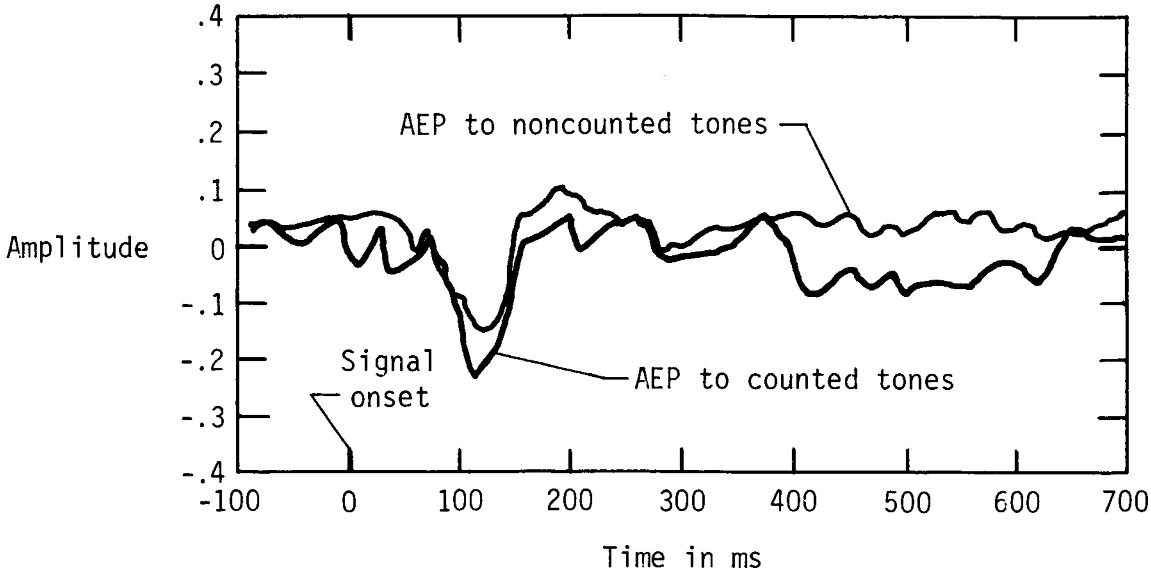
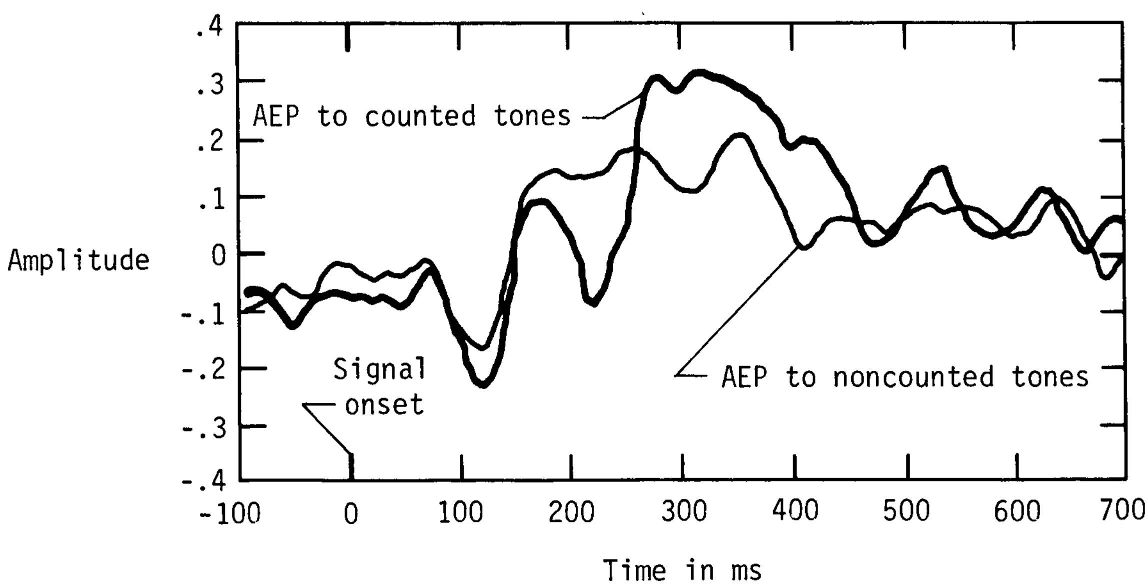


Figure 5. Airspeed tape in an actual-centered, high-to-low format with trend orientation.



(a) AEP when flight task is being performed.



(b) AEP when no flight task is being performed.

Figure 6. Example of mental demand effects on the auditory evoked potential (AEP).

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15. Supplementary Notes

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Mark Nataupsky: U.S. Air Force, detailed to Langley Research Center, Hampton, Virginia.

16. Abstract

A ground-based aircraft simulation study was conducted to determine the effects on pilot preference and performance of integrating airspeed and altitude information into an advanced electronic primary flight display via moving-tape (linear moving scale) formats. Several key issues relating to the implementation of moving-tape formats were examined in this study: tape centering, tape orientation, and trend information. The factor of centering refers to whether the tape was centered about the actual airspeed or altitude or about some defined reference value. Tape orientation refers to whether the represented values are arranged in descending or ascending order. Two pilots participated in this study, with each performing 32 runs along seemingly random, previously unknown flight profiles. The data taken, analyzed, and presented in this study consisted of path performance parameters, pilot-control inputs, and electrical brain response measurements.

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