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**AN EVALUATION OF FOUR F-16 VERTICAL
VELOCITY INDICATOR CONFIGURATIONS**

Scott M. Cone
John A. Hassoun

Crew Station Evaluation Facility
Human Factors Branch
ASD/ENECH
Wright-Patterson AFB OH 45433-6503

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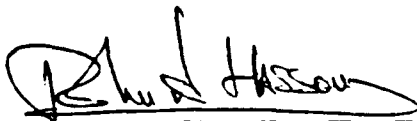
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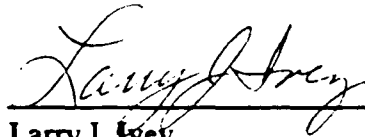
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John A. Hassoun
Program Manager
Crew Station Evaluation Facility



Larry J. Ivey
Technical Specialist
Human Factors Branch

FOR THE COMMANDER



John W. Vogt, Jr., Lt Col, USAF
Director
Support Systems Engineering

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Four different Vertical Velocity Indicator (VVI) configurations/mechanizations were evaluated in an F-16C simulator: (1) F-16C moving tape VVI, (2) electromechanical semicircular, moving pointer VVI, (3) liquid crystal, semicircular, moving pointer VVI and (4) same as 3 with a faster response time. Configurations 1, 2 and 3 had the same dampening characteristics as are currently used in the F-16C; configuration 4 was included to assess the impact of VVI dampening on pilot performance. Ten pilots flew a series of rate climbs/descents and an Instrument Landing System approach and landing for each configuration. Pilot performance data showed a larger average pitch rate for the moving tape VVI, suggesting greater workload, and an improved ability to maintain a specified vertical velocity when using configuration 4. Subjective data showed that the moving tape was the least preferred of the four, especially for use in dynamic conditions.					
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INTRODUCTION

The Moving Tape Vertical Velocity Indicator (VVI) currently in use in the F-16C/D aircraft is, according to Engineering Change Proposal (ECP) 1604 (General Dynamics, 1989), considered inadequate for rapid assessment of vertical velocity rate and trend information required during precision approaches. As a result, the F-16 System Program Office (SPO) is planning to incorporate a moving pointer display as a replacement for the moving tape VVI. Due to limited space availability, a standard F-16A/B circular VVI cannot be used. Instead, a semicircular design with a moving pointer is being considered. In support of this effort, the F-16 SPO has tasked the Crew Station Evaluation Facility (CSEF) to evaluate the acceptability of a liquid crystal, semicircular, moving pointer VVI as a potential alternative to the semicircular, moving pointer design.

Test Objectives

The primary objective of this evaluation was to determine the acceptability of a Liquid Crystal Display (LCD), semicircular moving pointer VVI for use in the F-16. A secondary goal was to compare the LCD display with the current moving tape display and a mechanical semicircular display built by the CSEF. A total of four configurations, moving tape, mechanical semicircular moving pointer, LCD semicircular moving pointer (slow response) and LCD semicircular moving pointer (fast response), were evaluated; details on these configurations are provided in the methods section below.

Specific test objectives were:

1. Subjectively evaluate the displays' dynamics and operational utility, including sufficiency of trend information, acceptability of display lag, legibility of display in static versus dynamic conditions and the degree to which it enhances the pilot's control of the aircraft.
2. Subjectively evaluate the overall layout of the displays, including display scaling, numbering and zero point.
3. Obtain pilot inputs regarding an appropriate failure indication for the LCD display.
4. Identify any pilot performance differences across the displays, including root mean square (RMS) vertical velocity deviation, pitch rate, RMS airspeed deviation, localizer deviation and glideslope deviation.
5. Subjectively evaluate the displays' legibility, including brightness, contrast, and design of markings and pointers.

METHOD

Subjects

Ten USAF F-16 pilots, stationed at Wright Patterson Air Force Base, participated as test subjects. Use of F-16 pilots assured familiarity with the performance characteristics and cockpit of the F-16 aircraft. All pilots had F-16A experience and flight hours ranged from 40 to 800 with an average of 296. Five pilots also had F-16C experience; flight hours ranged from 200 through 800 with an average of 520 hours.

Apparatus

Crew Station Evaluation Facility. The study was performed at the Crew Station Evaluation Facility, an Air Force simulation facility that belongs to the Human Factors Branch (ASD/ENECH) in the Crew Systems Division (ASD/ENEC). The division is part of the Support Systems Engineering Directorate (ASD/ENE) contained within the DCS for Integrated Engineering and Technical Management (ASD/EN). The facility supports System Program Offices in their acquisition engineering through pilot interface evaluations using man-in-the-loop simulation. Currently, the CSEF has the capability to perform full and part mission simulations for a variety of aircraft including the F-16, F-111 and C/KC-135.

F-16 Simulator. The CSEF F-16C simulator was constructed using a salvaged single-seat F-16 cockpit, truncated in front of the forward portion of the windscreen, and approximately 57 inches behind the canopy hinge. The undercarriage was removed, and the floor panel section sat on small cannister-type wheels. The simulator did not employ a motion base. The cockpit controls and displays were configured to the F-16C Multi-National Staged Improvement Program (MSIP) Block 40 design which included two 4 x 4 inch multifunction displays (MFDs), an Integrated Control Panel (ICP), a Data Entry Display (DED), Hands-on Throttle and Stick (HOTAS) controls, centralized flight instruments and block 40 avionics suite. The head-up display (HUD) was present in the cockpit but was not functional for the current study. The side control stick, throttle and flight controls were actual F-16 components. All of the other instruments, controls, and displays were simulated using locally available equipment. A drawing of the cockpit is provided in Figure 1.

For the current study, all head down primary flight instruments were available to the pilot. Raw Instrument Landing System (ILS) information was presented on the Attitude Director Indicator (ADI), but no HUD display was provided. This configuration was chosen to force pilot reliance on head-down instruments. The remaining displays were not relevant to this study.

An IMAGE IIIT Visual System was mounted directly in front of the F-16 simulator. The IMAGE IIIT system presented collimated computer generated scenes representing the outside world, as determined by a data base, to the pilot. Three monitors presented a contiguous 120° visual scene directly in front of and to the left and right of the pilot's seated position. The



Figure 1. E-16C Instrument Panel

IMAGE IIT system had the capability to provide a variety of special effects including weather, time of day, continuous terrain (linked data bases), texture, and airfield lighting. For the current study, a daytime, Visual Flight Rules scene was provided during practice trials; a dense fog was provided during the data runs to prevent reliance by the pilot on the outside visual scene for visual cues. For the ILS approaches and landings, a 200-foot cloud ceiling was presented.

Although no lighting measurements were taken, the cockpit was relatively dark and display lighting was required to read the VVI and other flight instruments. The lighting characteristics for each VVI are discussed in more detail below.

Vertical Velocity Indicators. The four VVI configurations evaluated in the study are described below.

1. F-16C/D Moving Tape Design (MT). See Figure 2. This display is the current F-16C/D configuration and is a moving tape, fixed pointer design. Two different scalings are used in the following ranges: 0-1500 feet per minute (ft/min) (minor graduation marks at every 100 ft/min), and 1500-6000 ft/min (minor graduation marks at every 500 ft/min). Numeric labels are provided at the tic marks associated with 500, 1000, 1500, 2000, 3000, 4000, 5000, and 6000 feet per minute. This label design reflects the usefulness of more accurate information at small vertical velocities, such as those typically associated with landing; this detail is less important at larger rates of climb and descent. Below the zero point (descent), white labels are displayed on a dark

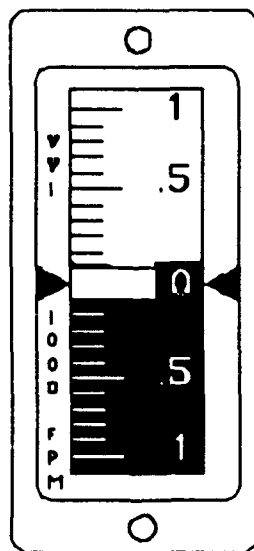


Figure 2. F-16 C/D Moving Tape VVI

background and above the zero point (climb), dark labels are provided on a white background. The scale is arranged so that increasing rates of climb result in downward tape movement and increasing rates of descent result in upward tape movement. The inherent damping characteristics of the display (2.2 second first order lag) were not altered for the study. According to discussions with F-16 SPO personnel, this lag was introduced to prevent jitter in the display which is encountered operationally due to "noise" in the signal (e.g. turbulence). Display lighting was not modified from that used in the aircraft; brightness was generally balanced with the remaining cockpit instruments and was adjustable through the instrument lighting panel.

2. Mechanical Semicircular Dial Design (MS). See Figure 3. This display was built locally by the CSEF to replicate the anticipated design of an electromechanical, semicircular, moving pointer design that is expected to be incorporated into the F-16 under ECP 1604 (General Dynamics, 1989). A semicircular scale is used to allow its placement in limited cockpit space. The labeling/scaling reflects the need for more accurate information at smaller vertical velocities and an effort to minimize excessive display clutter. This display was built for evaluation only and was not intended to be qualified for operational use. The display uses a nonlinear scale. Between 0 and 1000 ft/min, tic marks are provided every 100 ft/min. Tic marks are provided every 500 ft/min throughout the rest of the scale. Spacing between tic marks is slightly greater between 1000 and 2000 ft/min than for the rest of the scale. By modifying the input signal through software, a display lag equal to that in the current moving tape VVI was introduced into the display. This added lag controlled for any effects of lag differences on objective and subjective results. Prior to the study, lighting was retrofitted into the display and was noticeably unbalanced within the instrument, but sufficient for reading the display in the ambient lighting conditions; the display lighting was not adjustable through the instrument lighting panel in the cockpit.

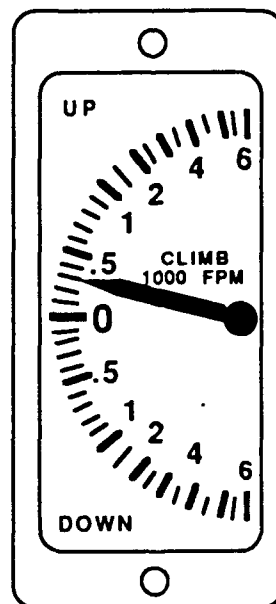


Figure 3. Mechanical Semicircular VVI (Labels Are White On Black).

3. **LCD Semicircular Dial Design, Slow Response (LCDSR).** See Figure 4. This prototype display was built by Litton Special Devices. Like (2) above, it is a semicircular, moving pointer design. Display labeling is painted (white labeling on dark background) and the pointer is a segmented liquid crystal display. The pointer moves in discrete 100 foot increments between 0 and 1000 ft/min and moves in 500 foot increments in the 1000-6000 ft/min range. Through modification of the software input, the display was mechanized to switch from one value to another at the midpoint between the graduation marks. Also through software modification of the display input, the same dampening characteristics as the moving tape configuration were incorporated to help control for effects of lag on pilot performance. Display lighting was adjustable through the master brightness control on the instrument lighting panel; however, the display was a prototype test unit and no effort was made to match intensities of the LCD display and other cockpit instrument lighting at a given adjustment setting.

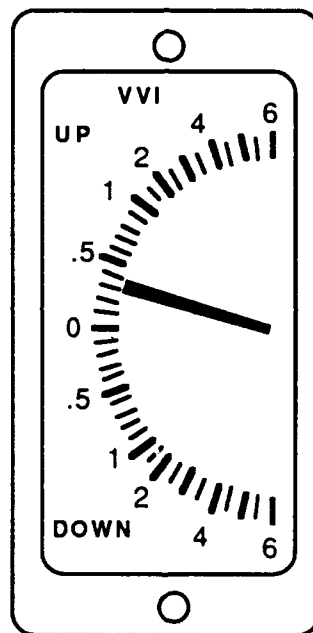


Figure 4. Liquid Crystal Semicircular Moving Pointer VVI (Labels Are White On Black).

4. **LCD Semicircular Dial Design, Fast Response (LCDFR).** This display is identical to (3) above with the exception that it is mechanized with less damping. Damping characteristics were those incorporated by the manufacturer (measured to be 0.8 second first order lag). This configuration was included to evaluate the effect of display lag on pilot performance with the LCD format. It was recognized prior to the study that the final determination of lag requires an actual aircraft signal and evaluation in turbulent conditions.

Experimenter's Console. The experimenter's console included a complete intercom system for four experimenter's/observers and allowed for communications between the simulator pilot and the experimenter. The console duplicated all electronic displays (HUD, MFDs) and provided

immediate feedback to the experimenter on pilot performance. From the console, the experimenter controlled simulator operation and selected appropriate experiment parameters (subject number, trial number, experimental condition, etc.).

Questionnaires. A set of five questionnaires was developed for the subjective portion of the evaluation. Four similar questionnaires specifically addressed each configuration. The fifth questionnaire allowed the pilot to directly compare the four configurations. All questionnaires are included as Appendix A. Where 5 point rating scales are used, the descriptors were selected to be an equal interval scale, based on data presented in Dyer, et. al. (1976).

Procedure

General Approach. In order to evaluate the VVI configurations, performance data were collected while having the pilots perform basic instrument flight maneuvers (rate climbs and descents) and an approach/landing. Each pilot flew four sets of simulator runs (one for evaluating each configuration). Immediately prior to each mission, the pilot was provided with training/familiarization on the configuration under evaluation.

Evaluation Maneuvers. The flight maneuvers selected for this evaluation were VVI-intensive and allowed a thorough evaluation of each configuration. The approach/landing was included as a realistic application of the VVI. Three climb/descent rates were used (750, 1500 and 3000 ft/min). These rates of climb and descent were selected to allow an evaluation of the various display scalings and provide tasks of varying difficulty. The following maneuvers were used in the evaluation:

1. Straight and level flight for 45 seconds while maintaining 10000 ft, 350 knots and heading of 268°.
2. Rate descent from 10000 to 6000 feet, maintaining 350 knots, 3000 ft/min, and heading of 268°.
3. Rate climb from 6000 to 10000 feet, maintaining 350 knots, 3000 ft/min, and heading of 268°.
4. Rate climb from 8000 to 10000 feet, maintaining 350 knots, 1500 ft/min, and heading of 268°.
5. Rate descent from 10000 to 8000 feet, maintaining 350 knots, 1500 ft/min rate of descent, and heading of 268°.
6. Rate climb from 9000 to 10000 feet, maintaining 150 knots, 750 ft/min, and heading of 268° (landing gear down).

7. Rate descent from 10000 to 9000 feet, maintaining 150 knots, 750 ft/min, and heading of 268° (landing gear down).

8. ILS Approach and Landing at Ramstein AB. From reset, the pilot was on a heading of 222, altitude 3200 feet, 200 knots at 12 DME with landing gear down. Upon interception of the localizer, the pilot initiated a 45° turn to intercept final. The pilot was instructed to fly a final approach speed of 145 knots or 11° Angle of Attack.

Test Procedures. All pilots were given the same introduction and training briefing which included background on the study, descriptions of all configurations, and pilot tasks to be performed during the simulation. Prior to beginning data collection, each pilot was given 10 minutes to become familiar with relevant controls and displays. After familiarization, each pilot flew a practice ILS approach and landing at Ramstein AB.

For each VVI, the following procedure was followed. The test engineer described the configuration and dynamics of the VVI configuration to be tested and instructed the pilot to adjust display lighting to a comfortable level (except for the MS which did not have adjustable lighting). The pilot then performed three practice rate climbs/descents that were representative of the maneuvers to be performed for the data collection trials; maneuvers 2, 4 and 7, randomly ordered for each pilot, were used for this purpose. All practice trials were performed in VFR conditions with unlimited visibility.

After completing the practice trials, all eight maneuvers were performed for data collection. For each one, the test engineer described the maneuver, instructed the pilot to properly configure the simulator (i.e., gear up or down as appropriate, instrument mode in ILS or NAV, as appropriate) and reset the simulator. The simulator was automatically set to the proper altitude and airspeed for the maneuver being performed. Upon releasing the simulator, the test engineer announced, "You are flying" and the pilot immediately began the maneuver. Upon reaching his target altitude, the simulator automatically reset when the flight path of the simulator was within 3° of straight and level for 3 seconds and simulator altitude was within 50 feet of the target altitude for the task. For the ILS approaches, the test engineer manually reset the simulator after the aircraft was on the ground.

The order of VVI presentation was counterbalanced to compensate for training effects. The order of performance of the maneuvers for each VVI was randomized with the constraint that the ILS approach and landing was last. All rate climb/descent data collection runs were performed in Instrument Flight Rules (IFR) conditions with zero visibility. A 200 foot cloud ceiling was simulated for the ILS approaches and landings.

After flying with each configuration, the pilot completed the appropriate subjective questionnaire and took a short break while the next configuration was installed. After performance of all tasks for the last configuration, the pilot completed the comparison questionnaire and was debriefed.

Performance Data Collection

Rate Climbs and Descents. During rate climbs and descents, the following data were collected:

- a. Vertical velocity deviation (feet per minute). The Root Mean Square (RMS) deviation from the specified rate of climb or descent was collected.
- b. Airspeed deviation (knots). The RMS deviation from the specified airspeed was collected throughout each rate climb and descent. A VVI that is more difficult to interpret may result in greater attention being allocated to the VVI and, consequently, less attention being allocated to airspeed. Under these conditions, a greater airspeed deviation may occur.
- c. Pitch Rate (degrees per second). The rate of change, at a given time, of aircraft pitch in degrees per second. Pitch rate can provide an indication of workload (i.e. stick inputs to correct pitch) associated with the display.

All data were collected at a rate of 5 Hertz during the entire length of the maneuver. All these data were used for the analysis of the RMS airspeed and pitch rate measures. However, the RMS vertical velocity deviation data were only valid while the pilot was attempting to maintain a constant rate of climb or descent. An examination of the raw data showed that pilots were maintaining a constant rate of climb/descent during the middle third (based on altitude) of the maneuvers. Therefore, only data from the middle portion of the rate climbs/descents were extracted for use in the analysis of RMS vertical velocity deviation. For the level flight task, pilots used the first 15 seconds of flight to stabilize the aircraft and establish straight and level flight at 10000 feet. The first 15 seconds were therefore not analyzed.

ILS Approach and Landing. The following performance measures were collected during the ILS approach and landings, from glideslope interception until altitude reached 200 feet.

1. RMS glideslope deviation (degrees). The number of degrees of vertical deviation from the glide path (2.5°) was collected to determine any enhancement in vertical control offered by any one of the four VVI configurations.
2. RMS localizer deviation (degrees). The number of degrees of horizontal deviation from the runway centerline was collected and used as an overall measure of pilot performance. Variation in the variable was not considered to be influenced by vertical velocity.
3. Pitch rate. The rate of change, at a given time, of aircraft pitch in degrees per second. Pitch rate can provide an indication of workload (i.e. stick inputs to correct pitch) produced by the display.

4. Airspeed deviation (knots). RMS airspeed deviation from the preferred approach speed (145 knots) was collected. As stated previously, greater attention allocated to other displays (ILS data, altimeter, ADI, VVI) would result in less attention devoted to maintaining the specified airspeed.

Subjective Data Collection

Pilots completed questionnaires specific to the configuration under evaluation immediately after performing the data collections tasks. These questionnaires addressed such issues as legibility of various display features, display dynamics and operational utility and are provided as Appendix A. Pilot comments were also collected and are included as Appendix B.

RESULTS

Performance Data Analysis

The data from the rate climbs/descents (maneuvers 1 through 7) were analyzed separately from the ILS approach data (maneuver 8). For the rate climbs and descents, all data were reduced to a single average value for each pilot, VVI and maneuver. RMS airspeed deviation and pitch rate were analyzed as a function of the four VVI configurations and the six rate climbs/descents (maneuvers 2 through 7) in a 4 x 6 Analysis of Variance (ANOVA). Similarly, the RMS vertical velocity deviation data were analyzed as a function of the four VVI configurations and seven maneuvers (the six rate climbs/descents and the level flight maneuver) in a 4 x 7 repeated measures ANOVA. For the ILS runs, the data were also reduced to a single value for each pilot and VVI. Glideslope deviation, localizer deviation, airspeed deviation and pitch rate were examined as a function of the four VVI configurations in one-way repeated measures ANOVAs. An alpha level of less than 0.05 was used as the criteria for rejection of the null hypothesis in all of the analyses.

Results For Rate Climbs and Descents

RMS Airspeed Deviation. The results of the Airspeed Deviation ANOVA are presented in Table 1. No main effects for VVI, maneuver or their interaction were found. Average RMS airspeed deviations for different VVIs and different maneuvers are shown in Figures 5 and 6.

Table 1. ANOVA Table for RMS Airspeed Deviation.

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	111.35	1.65	0.2007
Maneuver	5	111.78	0.47	0.7980
VVI x Maneuver	15	761.79	1.12	0.3460
Pilot	9	3666.01		
Pilot x VVI	27	606.52		
Pilot x Maneuver	43	2054.52		
Pilot x Maneuver x VVI	128	5809.12		

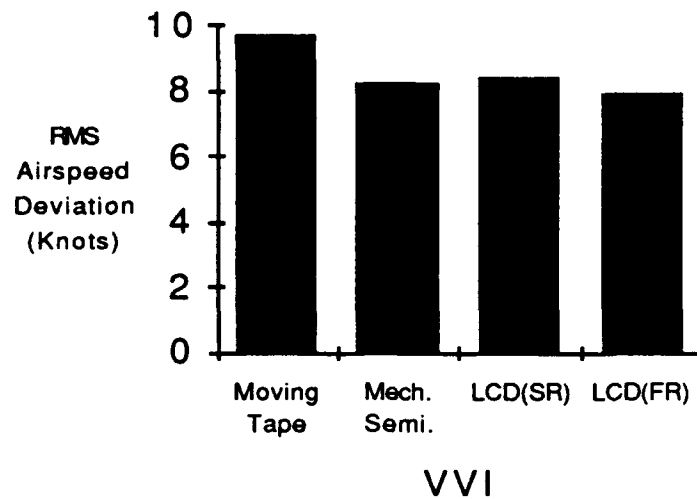


Figure 5. Average Airspeed Deviation for Different VVIs

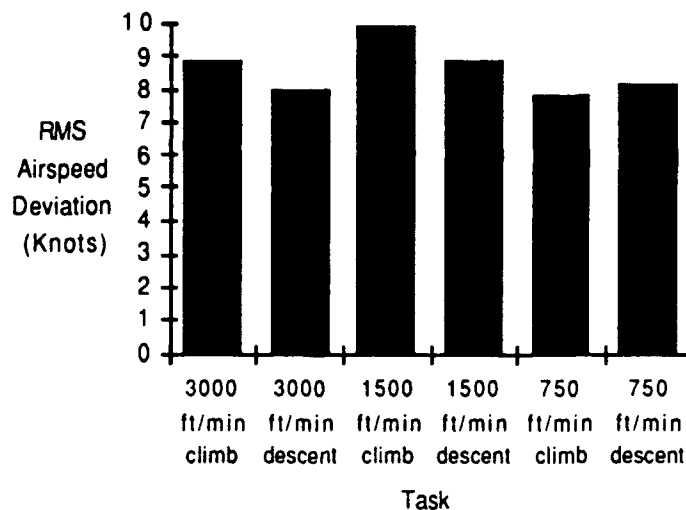


Figure 6. Average Airspeed Deviation for Different Maneuvers

Pitch Rate. Table 2 shows the results for the pitch rate as a function of VVI, Maneuver, and their interaction. Significant effects were found for VVI and Maneuver; average pitch rates for different VVIs are shown in Figure 7. The post-hoc Duncan test indicated that pitch rate for MT was significantly greater than that for MS, LCDSR and LCDFR; the latter three did not differ from each other. Average pitch rates for different maneuvers are shown in Figure 8. The post-hoc Duncan test showed the 750 ft/min runs yielded significantly greater pitch rates than all of the other maneuvers. No interaction was found between VVI and Maneuver.

Table 2. ANOVA Table for Pitch Rate

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	8.01	4.51	0.0108
Maneuver	5	24.21	11.11	0.0001
VVI x Maneuver	15	7.98	1.28	0.2225
Pilot	9	18.84		
Pilot x VVI	27	15.97		
Pilot x Maneuver	43	18.74		
Pilot x Maneuver x VVI	128	53.10		

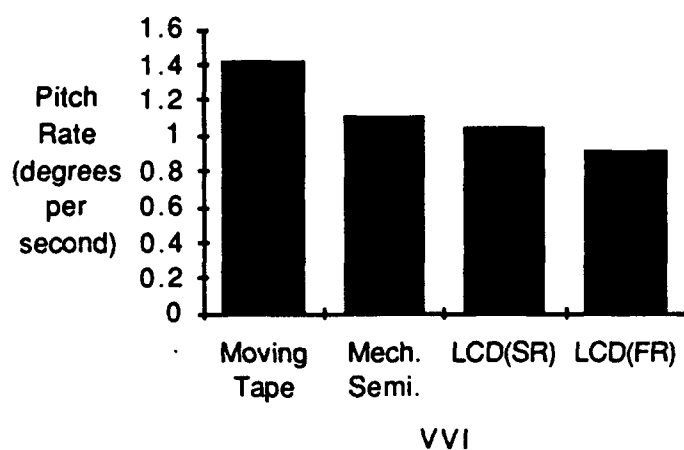


Figure 7. Pitch Rate for Different VVIs.

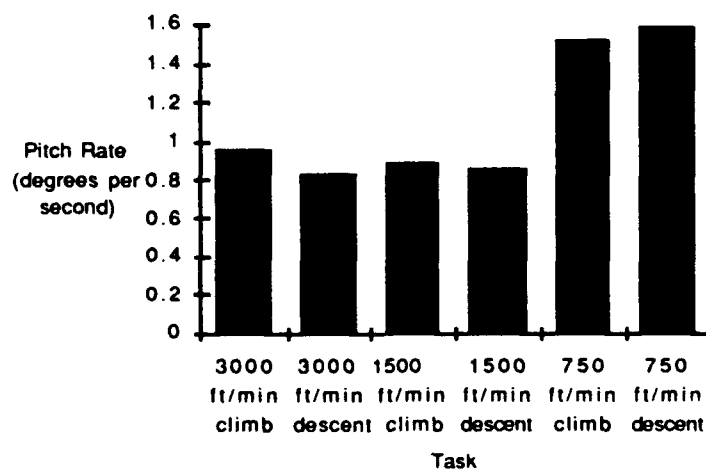


Figure 8. Pitch Rate for Different Maneuvers.

RMS Vertical Velocity Deviation. For RMS vertical velocity deviation, significant main effects were found for both VVI and Maneuver; the ANOVA results are shown in Table 3. Post hoc tests showed that RMS vertical velocity deviation was significantly smaller for the LCDFR than the MT and LCDSR; performance on maintaining the specified vertical velocity with MS did not significantly differ from any of the other displays. Average RMS vertical velocity deviation is shown in Figure 9.

Table 3. ANOVA Table for RMS Vertical Velocity Deviation

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	458625	3.39	0.0322
Maneuver	6	8323082	40.75	0.0001
VVI x Maneuver	18	783124	1.02	0.4362
Pilot	9	1890313		
Pilot x VVI	27	1216952		
Pilot x Maneuver	52	1770334		
Pilot x Maneuver x VVI	155	6585414		

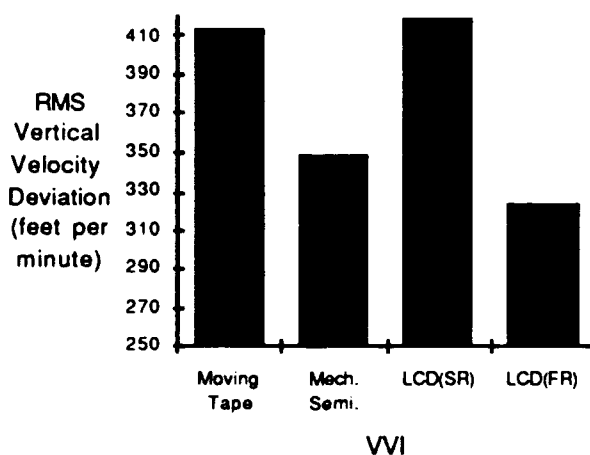


Figure 9. RMS Vertical Velocity Deviation Across VVIs

The 750 ft/min climb yielded the best performance in maintaining the desired vertical velocity (see Figure 10). The 1500 ft/min maneuvers did not differ from each other, but yielded worse performance than all other maneuvers. Performance on the remaining maneuvers did not differ from each other. The interaction between VVI and Maneuver was not statistically significant.

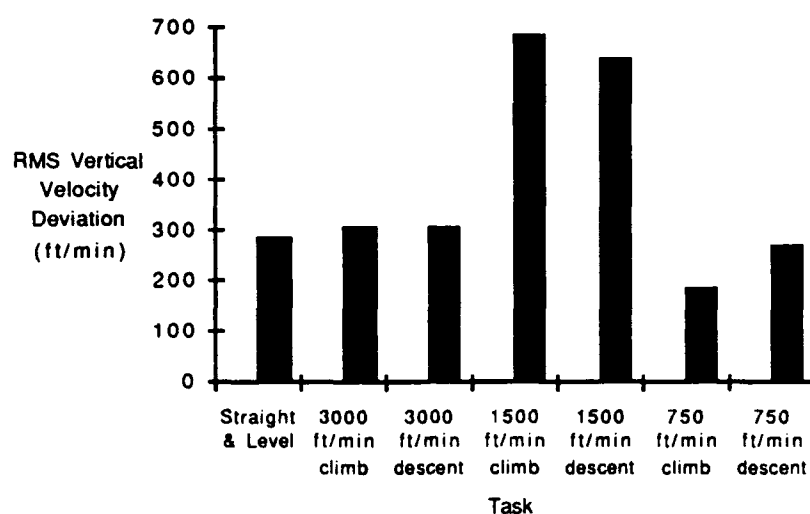


Figure 10. RMS Vertical Velocity Deviation Across Maneuvers

Results For ILS Approaches and Landings

Tables 4, 5, 6 and 7 show the results of ANOVAs for glideslope deviation, localizer deviation, pitch rate and RMS airspeed deviation. No statistically significant differences were found for any of the performance measures across the different VVIs. Average performance on glideslope deviation, localizer deviation, RMS airspeed deviation and pitch rate for each VVI is shown in Figures 11, 12, 13, and 14, respectively.

Table 4. ANOVA Table for Glideslope Deviation During the ILS Approach.

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	0.003	1.70	0.8350
Pilot	9	0.032		
VVI x Pilot	27	0.090		

Table 5. ANOVA Table for Localizer Deviation During the ILS Approach.

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	0.01	0.60	0.6183
Pilot	9	0.26		
VVI x Pilot	27	0.18		

Table 6. ANOVA Table for RMS Airspeed Deviation During the ILS Approach.

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	65.18	0.69	0.5640
Pilot	9	1779.54		
VVI x Pilot	27	845.88		

Table 7. ANOVA Table for Pitch Rate During the ILS Approach.

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>F</u>	<u>p</u>
VVI	3	0.14	0.28	0.8378
Pilot	9	15.33		
VVI x Pilot	27	4.60		

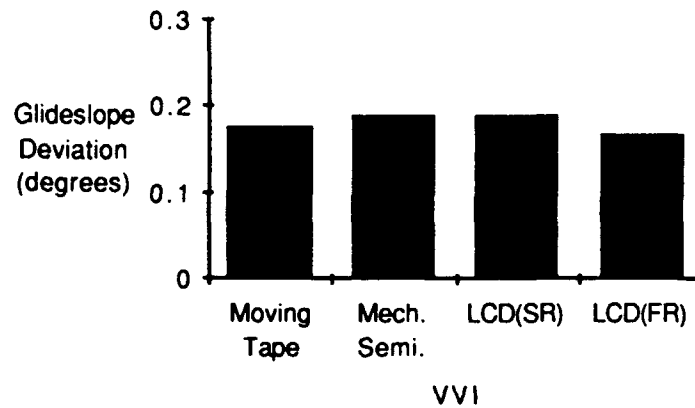


Figure 11. Average RMS Glideslope Deviation for Each VVI During the ILS Approach.

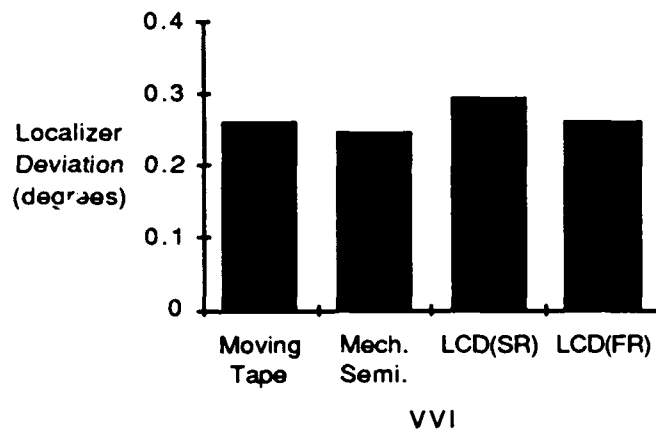


Figure 12. Average RMS Localizer Deviation for Each VVI During the ILS Approach.

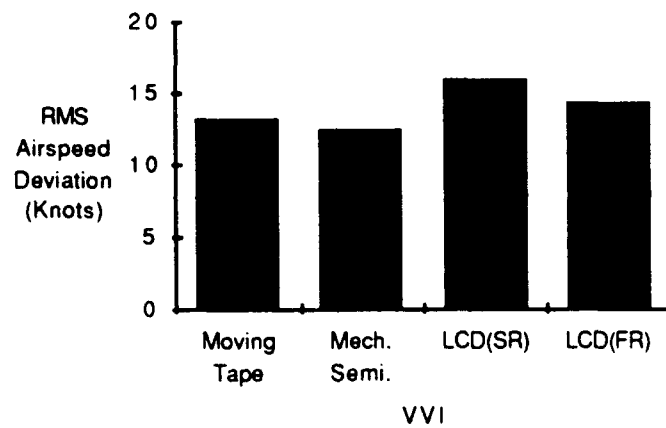


Figure 13. Average RMS Airspeed Deviation for Each VVI During the ILS Approach

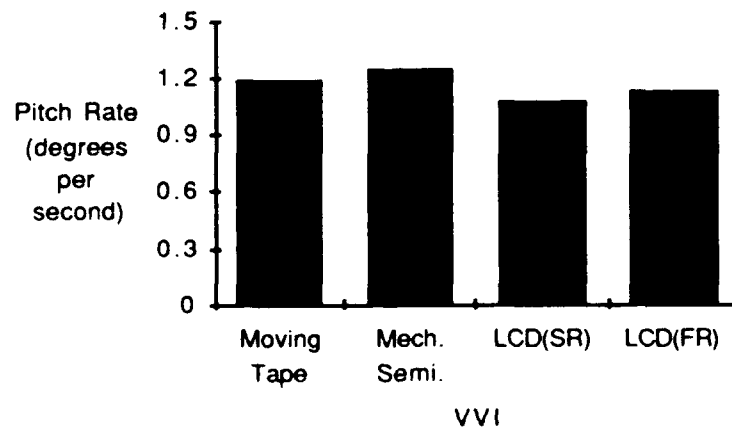


Figure 14. Average Pitch Rate for Each VVI During the ILS Approach

Subjective Data

The questionnaires addressed two general areas, (1) display design, layout and legibility, and (2) operational utility. No formal statistical analyses were performed on the data but frequency distributions were developed for all questions with nominal scale responses. Some questions were rated on a score of 1 through 5 (Completely Unacceptable = 1, Completely Acceptable = 5). Average ratings were calculated for each configuration.

Display Design and Layout. As shown in Figures 15, 16 and 17, the majority of pilots felt that label size, graduation mark size, and graduation mark spacing were about right for all displays. A small percentage of pilots felt that these features were too large for the MT display, and that these features were too small for the LCD and MS display.

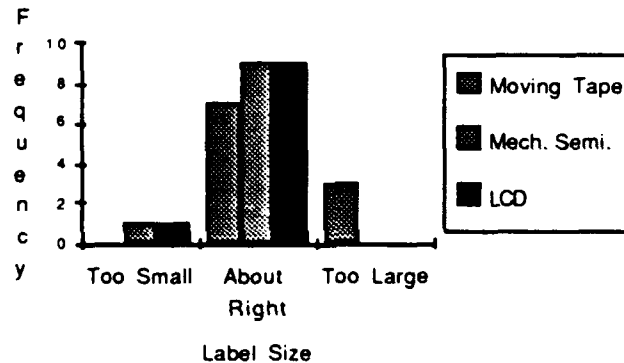


Figure 15. Pilots assessment of number label size for the VVI Configurations

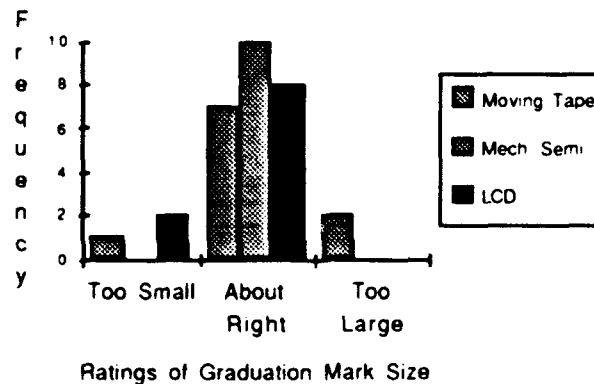


Figure 16. Pilots subjective assessment of graduation mark size

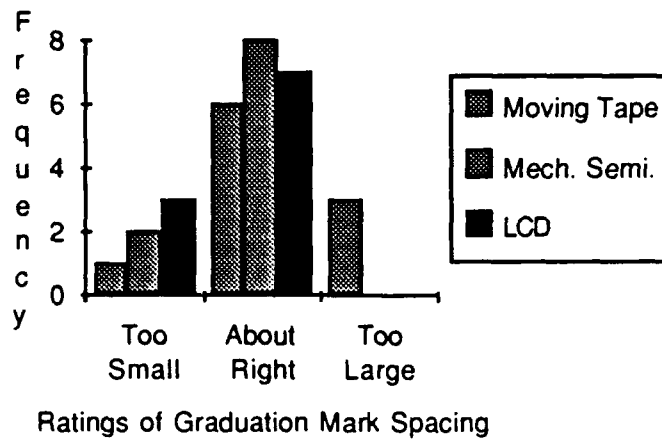


Figure 17. Pilots' Subjective Assessment of Graduation Mark Spacing

As shown in Figures 18 and 19, average ratings of label location and the acceptability of the zero point on each display were very high (between moderately and completely acceptable). Pointer legibility was given a high rating for both moving pointer displays (Figure 20). Pointer mechanization was rated, on average 4.4 (i.e., between moderately and completely acceptable) for the LCD display, suggesting that the discrete movement of the LCD pointer display was acceptable.

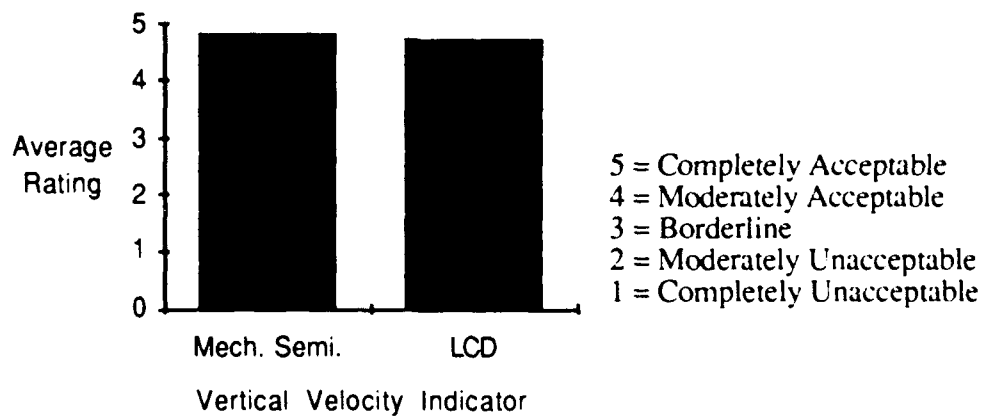


Figure 18. Acceptability of Location of Number Labeling on Scale

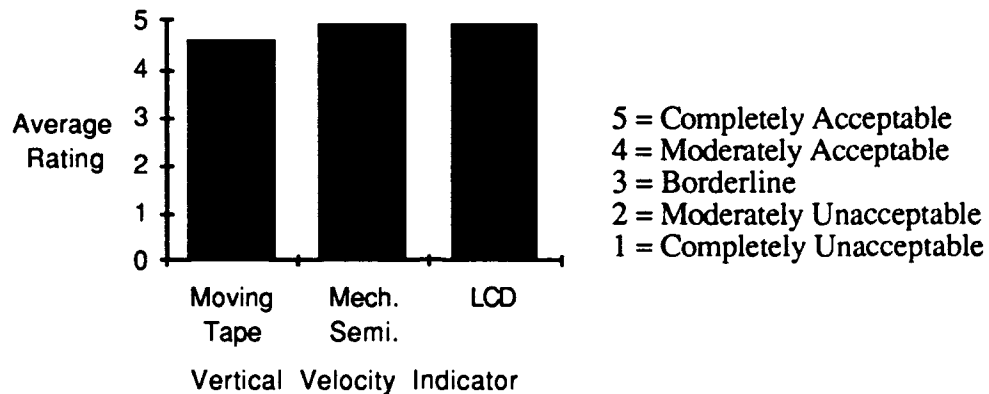


Figure 19. Acceptability of the Zero Indication

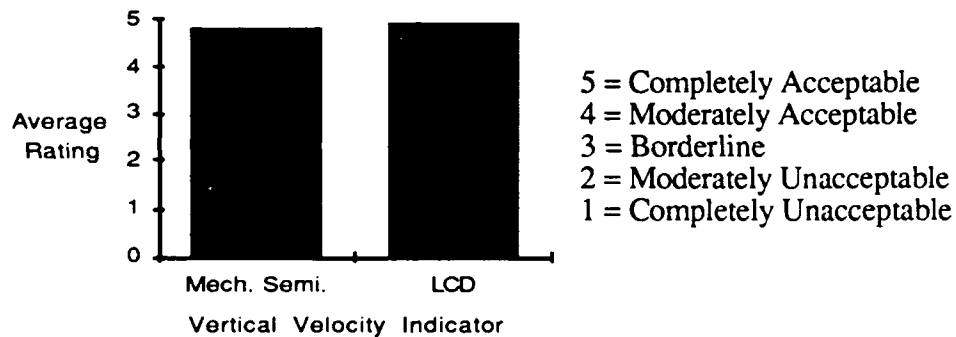


Figure 20. Acceptability of Pointer Legibility

Acceptability of display contrast for the three displays is shown in Figure 21. Only one pilot indicated that contrast was too low on the LCD display. All pilots felt the MS and MT displays had sufficient contrast. In the relatively dark ambient lighting conditions in the simulator, all pilots felt that the LCD brightness could be set to a comfortable level. Nine pilots felt that the MT could be set to a comfortable brightness.

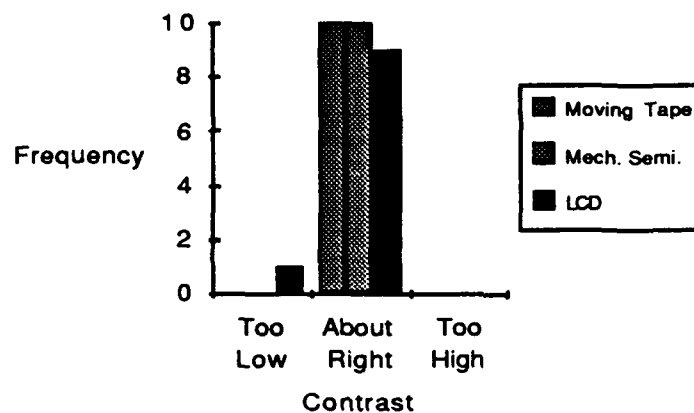


Figure 21. Pilots' Subjective Assessment of Contrast Between Marking/Pointer and Display Background

Operational Utility.

Figure 22 shows pilots' ratings of the overall scaling of the display. All displays were rated above "borderline," with the MS display having the highest average rating and the MT display having the lowest. Comments indicated that pilots would prefer more detail in the MT display between 0 and 1500 ft/min.

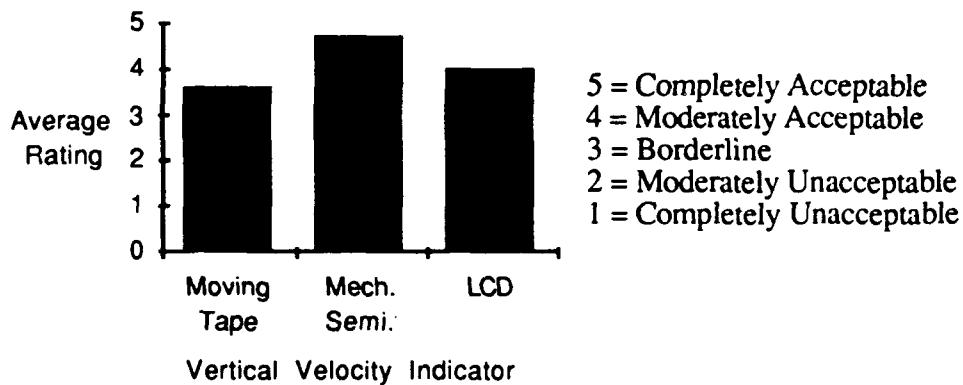


Figure 22. Acceptability of Display Scaling

As shown in Figures 23 and 24, the ability to quickly read the displayed value, and ease of interpretation under static conditions were rated, on average, above moderately acceptable for all displays.

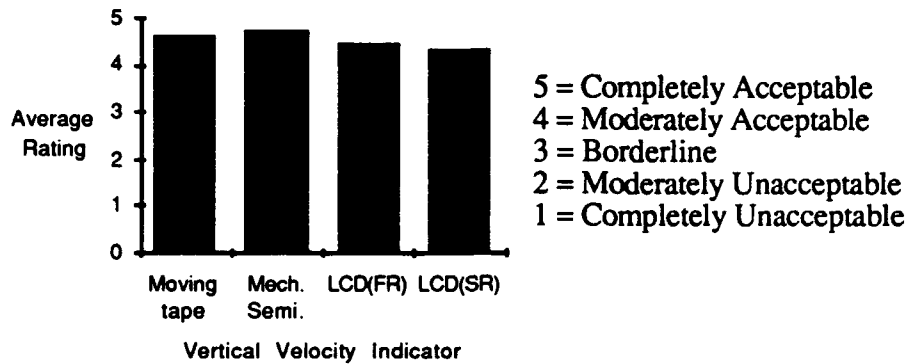


Figure 23. Average Ratings of the Ability to Quickly Read the Display

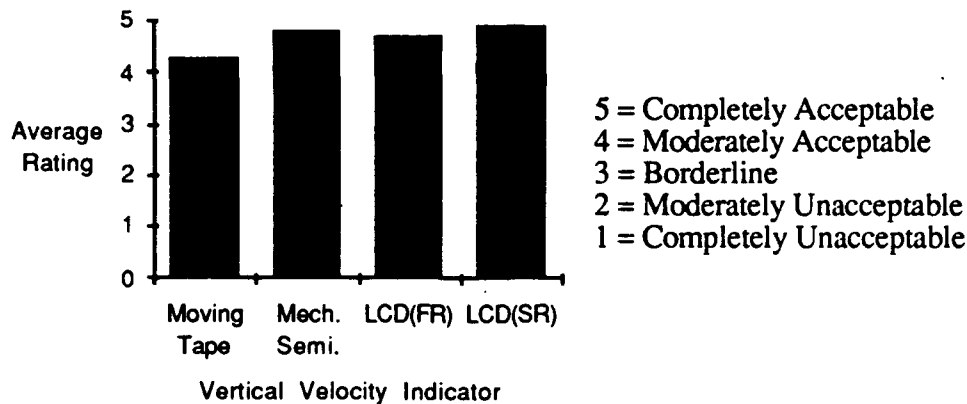


Figure 24. Ease of Interpreting the Displays Under Static Conditions

Figures 25, 26 and 27 all show a similar trend across the four configurations. The MS is consistently the most preferred for ease of interpretation under changing conditions, quality of trend information and ability to enhance aircraft control. The MT display is consistently the least preferred. Responses to the acceptability of display lag were mixed across the four configurations. The subjective results are shown in Figure 28.

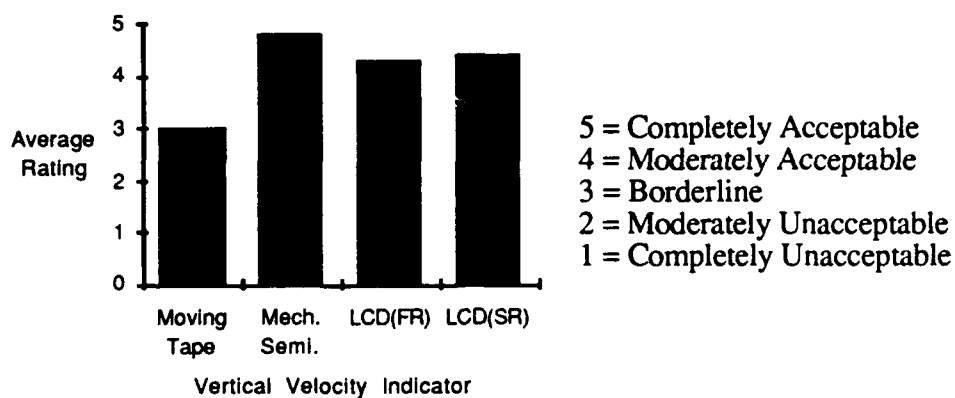


Figure 25. Ease of Interpretation Under Changing Conditions

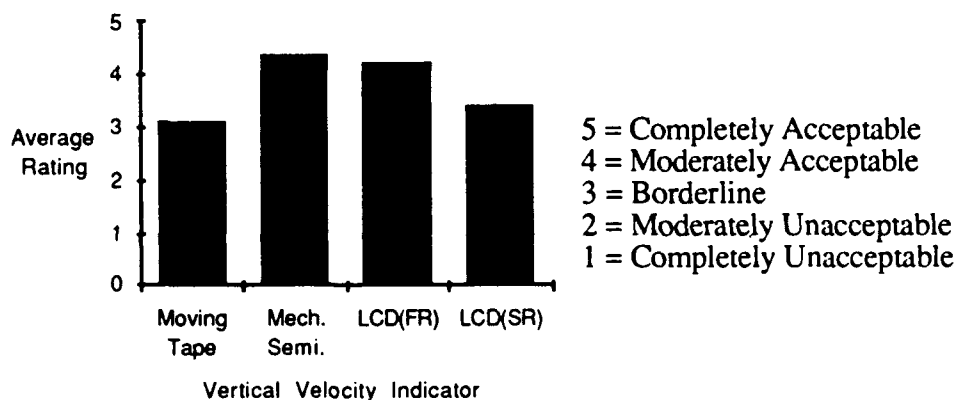


Figure 26. Acceptability of Trend Information Provided by the Display

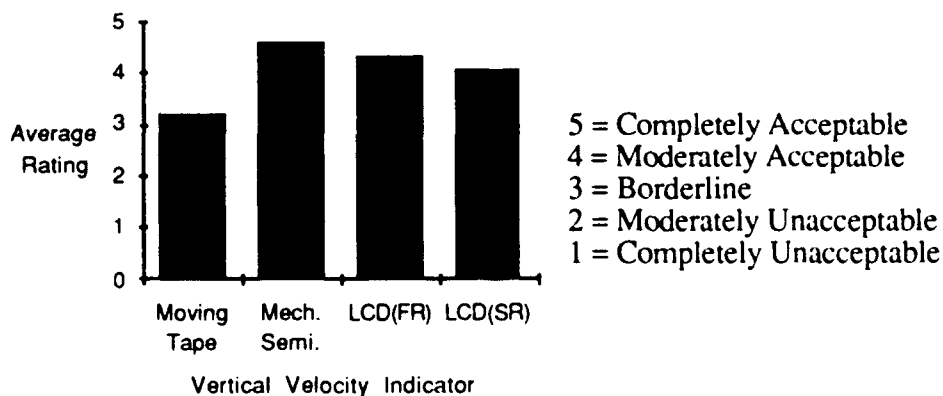


Figure 27. Subjective Assessment of Display's Ability to Enhance Aircraft Control

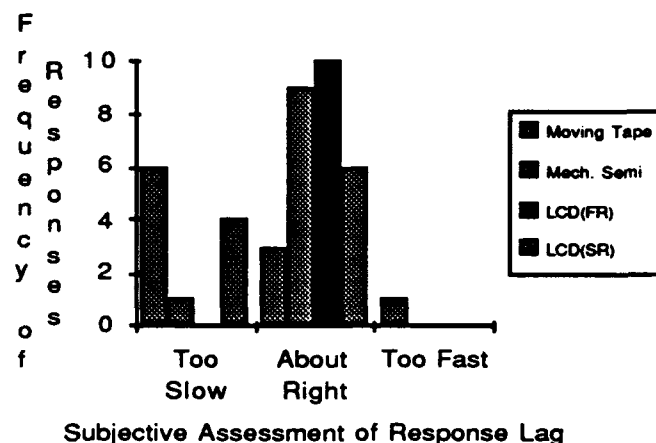


Figure 28. Subjective Assessment of Acceptability of Response Lag

Overall Ratings of the Displays. Figure 29 shows the overall ratings of the displays for use in the F-16; average ratings show the MT to be the least preferred with a slight preference for the MS display above the LCDFR, and a slight preference for LCDFR above LCDSR. Median rankings of the displays were consistent with Figure 24. Median rank of the displays (1 = most preferable, 4 = least preferable) on the basis of ease of interpretation and overall preference were 1, 2.5, 2.5 and 4 for MS, LCDFR, LCDSR and MT, respectively.

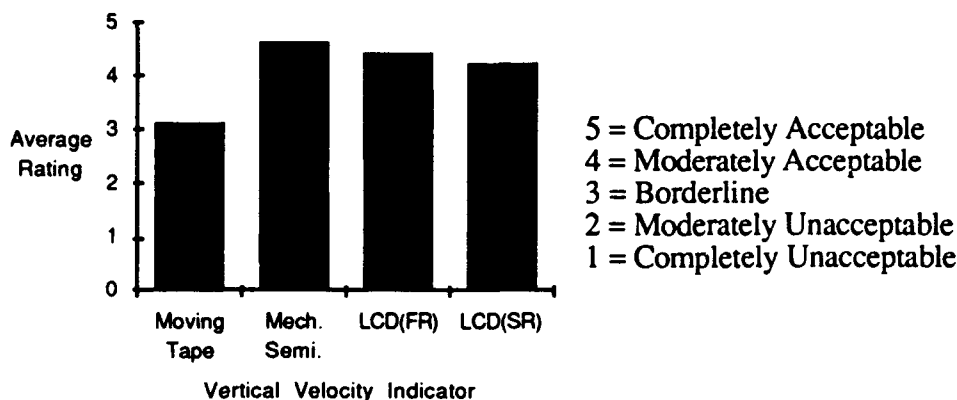


Figure 29. Overall Acceptability for Use in the F-16

Other results from the questionnaires include the following. Eight pilots felt that the MT displayed sufficient precision; nine pilots felt that the MS and LCD displays provided sufficient precision. About half of the pilots felt that the tic mark at -750 ft/min on the MT display was useful during approaches and landings (two did not notice the mark) and felt that a tic mark at -750 would be useful on the MT and LCD displays. Comments indicated that a 750 ft/min rate of descent is not appropriate for many landing configurations. When asked what would be a good failure indication for the LCD display, six pilots suggested the removal of the pointer from the display. Other responses included: an "X" displayed on the face, off flag, actuation of several pointers for a "fan" indication and an INS failure indication.

Pilot Comments. Highlights from the pilot comments are provided below.

- a. Three pilots commented that trend information is difficult to obtain from the MT display.
- b. Four pilots felt that the MS VVI was a good design.
- c. Two pilots commented that the LCDSR was better than the LCDFR for approaches.
- d. Two pilots did not like the ratcheting effect of the LCD pointer and found it distracting. Two pilots felt the ratcheting attracted attention to a change in the periphery and provided a very positive indication of change.
- e. Three pilots stated that the displays must be evaluated in turbulent conditions before a final determination can be made for lag.

DISCUSSION

Vertical Velocity Indicators

Although the RMS airspeed and RMS vertical velocity deviation data showed no performance difference between the MT, MS and LCDSR displays, the greater pitch rate yielded by the MT display indicates a performance benefit with the moving pointer displays (assuming response lag is held constant). These results can be explained in terms of several human factors design deficiencies associated with the MT display.

According to Wickens (1984) a display is optimal if it presents information in a format that is compatible with the user's internal mental representation of the information being displayed; following this principle ensures the minimum amount of mental translation required in reading the display. It is reasonable to assume that the pilot conceptualizes vertical velocity as a continuously varying quantity where increases are associated with upward vertical aircraft movement and decreases are associated with downward vertical aircraft movement. This suggests that a vertical velocity indicator should have the following design characteristics: analog display movement; vertical orientation; a scale ordered so that the upper portion of the scale represents climbing by greater amounts and the lower portion of the scale corresponds to descent; and display movement such that upward motion indicates a climb and downward motion indicates descent.

While the moving pointer display designs generally conform to these guidelines, it is impossible to do so with the moving tape display. Because of the labeling of the scale, increasing rates of climb result in a downward movement of the display. Reversing the scale to allow upward tape movement to indicate climb would require reversal of the display labeling, in which the lower, rather than upper portion of the scale would indicate greater rates of climb.

Only a portion of the scale on the MT is visible at any given time, requiring the pilot to read the values shown, determine his location on the scale (for ascent or descent), and read the values relative to the pointer. In the moving pointer designs, the entire scale is visible at all times, which simplifies reading the display by reducing the need to read specific values; a general indication of vertical velocity can be easily obtained from pointer position. The moving tape display is more difficult to read than the fixed scale designs in dynamic conditions because of scale movement. Not only does this cause difficulty reading the actual vertical velocity at a given time, but also increases the difficulty of extracting trend information from the display.

These factors combined result in a display that lends itself to reading errors, increased time required to interpret the display, and greater difficulty of reading the display under changing conditions. All of these effects could have contributed to increased pitch rates, by requiring a greater reading time and increasing the potential for display reading errors.

Effect of Response Lag

Response time of the display did not impact pitch rate (i.e., LCDSR and LCDFR did not differ on the pitch rate measure) but did influence vertical velocity deviation. A faster response time of the VVI provides a more precise display, provides more accurate trend information, and reduces the pilot's reliance on estimated vertical velocity at a given time. As expected, performance improved with the LCDFR over the LCDSR. This same effect would be expected with the Mechanical semicircular display, if its response were increased. However, this improved performance with a faster response cannot be generalized to the moving tape display with the same level of confidence, because increasing the speed of scale movement may reduce its legibility. Note that the determination of display lag should be made after evaluation in turbulent conditions with the characteristically "noisy" VVI signal under turbulent conditions. The current study results can only provide an assessment of performance with different lags. It cannot determine what lag is acceptable under actual conditions.

ILS Data

As was stated previously, no objective data differences were found during any of the ILS approaches. The lack of statistically significant differences is probably due to the role of the VVI during an approach and landing. During this phase of flight, the VVI is used primarily as a cross-check instrument which may assist in maintaining alignment with the glideslope and localizer bars rather than maintaining a specified VVI. The objective data measures were much more sensitive to differences across VVIs in the rate climbs and descents, which were VVI intensive tasks.

Differences Across Maneuvers

The main effect for maneuver on the pitch rate measure showed that the 750 ft/min runs required higher levels of workload than any of the other rate climb/descent maneuvers. However, vertical velocity deviation showed improved accuracy at maintaining the specified vertical velocity under the same maneuvers. The increased precision provided by all of the displays in the 750 ft/min range may have contributed to the improved accuracy at maintaining 750 ft/min. This greater display accuracy, being more sensitive to deviations from the specified rate of climb or descent, may have resulted in more pitch corrections being input by the pilot.

The greater vertical velocity deviation found for the 1500 ft/min maneuvers was unexpected. On all of the displays, the 1500 ft/min graduation mark was at or near the transition point from one scaling to another. Given a constant rate of change of vertical velocity, the speed of pointer movement changes as it crosses from one scaling to another. This noncontinuity in pointer movement may have increased the difficulty of obtaining trend information when approaching the 1500 ft/min mark, resulting in lower accuracy.

Subjective Data

The subjective data supported the performance data. General display design and layout features as well as the precision provided were generally acceptable to most pilots for all displays. Differences in preferences were more evident when pilots were asked about display dynamics and trend information, on which the MT was least preferred. There also appeared to be a slight but consistent trend of preference for the MS display over the LCD displays for use under dynamic conditions, quality of trend information, and ability to enhance aircraft control. Furthermore, overall ratings and rankings showed the MS to be the most preferred and the MT to be the least preferred, with both LCD configurations falling in between. This pattern of results may be due to the discrete pointer movement on the LCD, which causes a slight degradation in the display of trend information.

These subjective results are in agreement with a previous similar study (Dudley, Hassoun and Gavern, 1988), in which a landing task was used to evaluate performance and subjective differences between a moving pointer, vertical scale VVI and the current F-16C/D moving tape VVI. Although no performance differences were found, pilots preferred the moving pointer display over the moving tape configuration.

The subject evaluation of acceptability of response lag provided interesting results. Even though the MT, MS and LCDSR had identical lags, six pilots indicated the MT response was too slow, six pilots indicated the LCDSR response was about right, and nine pilots responded that the MS response was about right. All of the pilots felt the LCDFR response was about right. These results suggest that different lags may be optimal for different display configurations. In particular, a greater lag may be acceptable in a display that provides high quality trend information (such as the MS display) than is acceptable in a display that provides relatively poor trend information (e.g., the MT display).

Of specific interest to the LCD display were pointer legibility, pointer mechanization, contrast, and the ability to set the brightness to a comfortable level. The LCD pointer moves in discrete steps across the display scale, rather than in a continuous fashion. Therefore, trend information and display accuracy are both slightly degraded. As discussed above, this characteristic of the LCD display appeared to have a small influence on the subjective ratings of interpretability in dynamic conditions. However, the majority of pilots indicated that the LCD displayed sufficient accuracy and that the pointer mechanization was acceptable. Display contrast and brightness adjustments were both acceptable as currently designed.

Other Results

In addition to addressing the goals described previously, the study provided an opportunity to identify potential problems with the prototype LCD display design that would need to be addressed prior to its incorporation into an aircraft. The prototype unit used in the study exhibited two problems. Occasionally, several pointers would actuate simultaneously, causing a fanning effect

on the display that obscured the actual displayed value. Second, the pointer would sometimes disappear in certain portions of the display during operation. Through in-house troubleshooting and discussions with Litton personnel, it appeared that the physical stress on the display housing (when mounted into the cockpit) may have been the cause of the problems. Litton has been able to reproduce the effect on other test items and is working towards a solution.

Generalizing Current Results to the Operational Setting

The current study was designed to be VVI-intensive in order to be sensitive to the effects of different displays on performance. As a result, these same performance differences may not be realized with the typical operational application of the VVI, where it is primarily used as a cross-check instrument, as an alternative to the HUD vertical velocity display, or in the case of a HUD failure. The lack of significant differences during the ILS approaches exemplifies this issue.

CONCLUSIONS

The current study found a performance decrement for the current moving tape display when the display response is held constant; various human factors design deficiencies contributed to this result. No differences between the various moving pointer displays were found when display lag was held constant. A faster display response time in the LCD moving pointer display improved accuracy at maintaining a specified vertical velocity, but did not affect workload (as measured by pitch rate). The same effect would be expected with the mechanical moving pointer design, but this result cannot be generalized to the moving tape design without further verification. Note that the same performance differences may not be replicated in an operational setting, since the tasks in the current study were more VVI-intensive than most operational uses of the display.

Subjective data were consistent with these objective results in that the moving tape was the least preferred, particularly for any operational uses that involved interpreting the display under dynamic conditions (e.g., determining trend). However, display legibility, including size and design of markings, display layout, pointer design/visibility and the ability to read the displays under static conditions were generally acceptable for all displays. Display brightness and contrast were also acceptable for the simulator lighting conditions; however, it is emphasized that the current evaluation did not include a comprehensive lighting evaluation. One of the goals of the study was to evaluate possible failure indications for the prototype LCD VVI. Suggestions included (1) removal of the pointer from the display, (2) an "X" displayed on the face, (3) an off flag, (4) actuation of several pointers for a "fan" indication and (5) an INS failure indication.

On the basis of the objective and subjective results, it can be concluded that either moving pointer display would be preferable and would provide equal, if not improved, performance over the current moving tape display. The LCD VVI should not be incorporated until the hardware problems experienced in the study are resolved and display reliability is shown to be acceptable.

RECOMMNDATIONS

- a. Since no differences were found between the LCD and mechanical moving pointer designs, if the F-16 SPO determines the need to replace the current VVI, it is recommended that a moving pointer, semicircular display format be incorporated.
- b. Prior to incorporating an LCD type vertical velocity indicator, such as was evaluated in the current study, efforts should be taken to verify its reliability in a flight test environment.
- c. A thorough lighting evaluation that investigates the acceptability of display luminance and contrast in the entire range of expected operational lighting conditions should be performed prior to incorporating the LCD display into any aircraft.

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- General Dynamics, Fort Worth Division, (1989). *Replace Moving Tape Vertical Velocity Indicator (VVI) with Moving Pointer VVI* (ECP 81755-2185-1604). Fort Worth, Texas.
- Wickens, C. D. (1984). *Engineering Psychology and Human Performance*. Columbus, Oh.: Merrill.

Appendix A
Pilot Questionnaires

Pilot: _____

VVI: Moving Tape

The following questions address various features of the moving tape vertical velocity indicator. Respond to the following questions by checking the blank or providing comments, as appropriate.

PART 1. DISPLAY DESIGN AND OPERATION.

1. Rate the following.

Too large About right Too small

a. Size of numbers:

b. Size of graduation marks:

c. Spacing between graduation marks:

Too high About right Too low

2. Contrast between marking/pointer
and display background

3. Were you able to set display brightness to an acceptable level?

Yes _____ No _____

4. Using the following scale, rate the following items:

A = Completely Acceptable
B = Moderately Acceptable
C = Borderline

D = Moderately Unacceptable
E = Completely Unacceptable

A B C D E

a. Ability to quickly read displayed
value.

b. Overall scaling of display

c. Indication of zero vertical velocity.

5. These questions address display dynamics and operation. Rate the following:

- | | A | B | C | D | E |
|---|---|---|---|---|---|
| a. Ease of interpreting the display under changing conditions. | — | — | — | — | — |
| b. Ease of interpreting the display under relatively static conditions. | — | — | — | — | — |
| c. Quality of trend information. | — | — | — | — | — |
| d. Display's ability to enhance your control of the aircraft. | — | — | — | — | — |
| e. Overall acceptability for use in the F-16. | — | — | — | — | — |
| g. Is the tic mark at -750 fpm useful for approach and landing? | | | | | |

Yes _____ No _____

- h. The display response is: Too fast About right Too slow

— — —

6. Does the display scale present information at sufficient precision?

Yes _____ No _____

If no, explain. _____

7. Provide any comments regarding the operational utility of the display:

Pilot: _____

VVI: Mechanical Semicircular

The following questions address various features of the mechanical semicircular vertical velocity indicator. Respond to the following questions by checking the blank or providing comments, as appropriate.

PART 1. DISPLAY DESIGN AND OPERATION.

1. Rate the following.

Too large About right Too small

- | | | | |
|--------------------------------------|-------|-------|-------|
| a. Size of numbers: | _____ | _____ | _____ |
| b. Size of graduation marks: | _____ | _____ | _____ |
| c. Spacing between graduation marks: | _____ | _____ | _____ |

Too high About right Too low

- | | | | |
|---|-------|-------|-------|
| 2. Contrast between marking/pointer
and display background | _____ | _____ | _____ |
|---|-------|-------|-------|

3. Were you able to set display brightness to an acceptable level?

Yes _____ No _____

4. Rate the following items with the scale below:

A = Completely Acceptable

D = Moderately Unacceptable

B = Moderately Acceptable

E = Completely Unacceptable

C = Borderline

- | | A | B | C | D | E |
|---|-------|-------|-------|-------|-------|
| a. Ability to quickly read displayed value. | _____ | _____ | _____ | _____ | _____ |
| b. Overall scaling of display | _____ | _____ | _____ | _____ | _____ |
| c. Location of number labeling on scale | _____ | _____ | _____ | _____ | _____ |
| d. Indication of zero vertical velocity. | _____ | _____ | _____ | _____ | _____ |
| e. Legibility of pointer | _____ | _____ | _____ | _____ | _____ |

5. These questions address display dynamics and operation. Rate the following:

	A	B	C	D	E
a. Ease of interpreting the display under changing conditions.	—	—	—	—	—
b. Ease of interpreting the display under relatively static conditions.	—	—	—	—	—
c. Quality of trend information.	—	—	—	—	—
d. Display's ability to enhance your control of the aircraft.	—	—	—	—	—
e. Overall acceptability for use in the F-16.	—	—	—	—	—

6. Would a tic mark at -750 fpm be useful for approach and landings?

Yes _____ No _____

7. The display response is: Too fast About right Too slow

8. Does the display scale present information at sufficient precision?

Yes _____ No _____

If no, explain. _____

9. Provide any comments regarding the operational utility of the display:

Pilot: _____

VVI: LCD _____ response

The following questions address various features of the Liquid Crystal vertical velocity indicator with the _____ response. Respond to the following questions by checking the blank or providing comments, as appropriate.

PART 1. DISPLAY DESIGN AND OPERATION.

1. Rate the following.

Too large About right Too small

- | | | | |
|--------------------------------------|-------|-------|-------|
| a. Size of numbers: | _____ | _____ | _____ |
| b. Size of graduation marks: | _____ | _____ | _____ |
| c. Spacing between graduation marks: | _____ | _____ | _____ |

Too high About right Too low

- | | | | |
|---|-------|-------|-------|
| 2. Contrast between marking/pointer
and display background | _____ | _____ | _____ |
|---|-------|-------|-------|

3. Were you able to set display brightness to an acceptable level?

Yes _____ No _____

4. Rate the following items with the scale below:

A = Completely Acceptable
B = Moderately Acceptable
C = Borderline

D = Moderately Unacceptable
E = Completely Unacceptable

- | | A | B | C | D | E |
|---|-------|-------|-------|-------|-------|
| a. Ability to quickly read displayed value. | _____ | _____ | _____ | _____ | _____ |
| b. Overall scaling of display | _____ | _____ | _____ | _____ | _____ |
| c. Location of number labeling on scale | _____ | _____ | _____ | _____ | _____ |
| d. Indication of zero vertical velocity. | _____ | _____ | _____ | _____ | _____ |
| e. Legibility of pointer | _____ | _____ | _____ | _____ | _____ |

5. These questions address display dynamics and operation. Rate the following:

	A	B	C	D	E
a. Ease of interpreting the display under changing conditions.	—	—	—	—	—
b. Ease of interpreting the display under relatively static conditions.	—	—	—	—	—
c. Quality of trend information.	—	—	—	—	—
d. Display's ability to enhance your control of the aircraft.	—	—	—	—	—
e. Acceptability of mechanization of LCD pointer	—	—	—	—	—
f. Overall acceptability for use in the F-16.	—	—	—	—	—

6. Would a tic mark at -750 fpm be useful for approach and landing?

Yes _____ No _____

7. The display response is: Too fast About right Too slow

8. What do you recommend for a failure indication?

8. Does the display scale present information at sufficient precision?

Yes _____ No _____

If no, explain. _____

9. Provide any comments regarding the operational utility of the display:

Pilot: _____

VVI: LCD _____ response

The following questions address various features of the Liquid Crystal vertical velocity indicator with the _____ response. Respond to the following questions by checking the blank or providing comments, as appropriate.

1. Rate the following items with the scale below:

A = Completely Acceptable

B = Moderately Acceptable

C = Borderline

D = Moderately Unacceptable

E = Completely Unacceptable

	A	B	C	D	E
a. Ability to quickly read displayed value.	_____	_____	_____	_____	_____
2. These questions address display dynamics and operation. Rate the following:					
a. Ease of interpreting the display under changing conditions.	_____	_____	_____	_____	_____
b. Ease of interpreting the display under relatively static conditions.	_____	_____	_____	_____	_____
c. Quality of trend information.	_____	_____	_____	_____	_____
d. Display's ability to enhance your control of the aircraft.	_____	_____	_____	_____	_____
e. Acceptability of mechanization of LCD pointer	_____	_____	_____	_____	_____
f. Overall acceptability for use in the F-16.	_____	_____	_____	_____	_____

3. The display response is:

Too fast

About right

Too slow

4. Provide any comments regarding the operational utility of the display:

PART 2. COMPARISON

1. Rank the displays in order of overall ease of interpretation. (1=most preferred, 4=least preferred).

Moving Tape _____

Mechanical Semicircular _____

LCD (slow response) _____

LCD (increased response) _____

2. Considering everything, rank the displays. (1=most preferred, 4 = least preferred).

Moving Tape _____

Mechanical Semicircular _____

LCD (slow response) _____

LCD (increased response) _____

3. Provide any other comments on the displays.

Appendix B
Pilot Comments

F-16 Vertical Velocity Indicator Evaluation

Pilot Comments

1. General:

Pilot 1. The moving tape gives the best feel for climbs and descents. The only enhancement might be for adding the altitude in round numbers at the bottom in a display similar to the F-111. However, I think it works just fine the way it is. I felt very comfortable with the moving tape during three years instrument flying at Ramstein.

Pilot 2. The tape lighting appears to be better than in the actual aircraft.

Pilot 5. LCD display was just as good as mechanical if it had more of an analog movement versus the incremental one tested. The continuous analog movement provides better trend information.

Pilot 6. Need larger ADI to properly use high fidelity ADI.

Pilot 7. The mechanical semicircular display is very nearly as good as the LCD - in a way it is better in that it can display increments between tic marks in the low vertical velocity regions. An aspect of the LCD I liked was the discrete movement of the pointer. This called attention to change in vertical velocity, where analog movement may be slow and insidious.

Pilot 8. 750 fpm is rarely exactly what's required anyway. Probably just used to round gage anyway.

Pilot 9. The mechanical semicircular was the smoothest movement display and easiest to use for this test. It was the easiest for precision and trend information.

Moving Tape VVI:

Pilot 1. One improvement would be to put a separate digital display at the bottom of the VVI to show whole numbers representing thousands of feet.

Pilot 2. With the current dampening, the tape is excellent.

Pilot 3. Too much lag.

Pilot 4. Chasing the lag was a nuisance.

Pilot 5. In static conditions, read a VVI value is very easy. In dynamic situations it is much harder. Trend information is very difficult to obtain from tape. Pilot must look at instrument [directly whereas trend can be picked up in the periphery with a moving pointer type display]

Pilot 6. Between 0-1500 fpm need a larger scale.

Pilot 7. The tape didn't provide good global situation awareness of vertical velocity. I felt forced to only look to it for a sort of digital assessment of stable vertical velocity. It was confusing to look at while it was moving.

Pilot 9. Overall moderately acceptable for instrument conditions; however, the pilot still has to focus on the actual display and the numbers instead of noting a relative indication in the peripheral field of view as in standard VVIs.

Pilot 10. Using the tape was stressful to the eyes with the AOA tape moving, ADI moving and VVI tape moving. In a tight spot I could foresee a problem with misinterpretation of the ADI. With vertigo induced the eyes would probably get into a fluttering (unable to focus) that may not be recoverable.

2. Mechanical Semicircular VVI:

Pilot 2. Needs more light at the zero mark.

Pilot 3. Needs faster reaction.

Pilot 4. This seemed very responsive and accurate.

Pilot 5. Grad marks are small but OK for intended purpose.

This true analog was better than digitally presented analog display. A turbulent study should be made. Even though this is slow response, it seemed better [than the LCD] because of true analog movement versus digital incremental movement.

Pilot 6. Excellent VVI.

Pilot 7. Given lighting didn't allow truly precise reading of the display. If lighting were improved, I think I would score the display higher/more acceptable.

Pilot 8. [sufficient precision is provided] If looking for only moderate precision as is normally the case in an aircraft - no, if you really want to nail at +/-3000 fpm (only good for +/- 200 fpm in that range).

Pilot 9. I really liked this display and the analog movement of the pointer. It was very easy to read and interpret.

Pilot 10. It really needs better backlighting to be an effective instrument. I had to use map light to flood it for use.

3. LCD (General):

Pilot 1. Pointer should go away for failure indication.

Pilot 2. Once you capture a desired climb/descent point, any deviation is much more quickly recognized due to the jump in the needle. Requires less concentration on VVI. Lighting is more uniform because of back lighting. The numbers are easier to read.

Failure Indication: LCD pointer blanking out of view or an X midway along LCD pointer.

Pilot 3. Need smaller scale up to 1500 feet per minute

Provides intuitive display of control/performance relationship. I set something and the VVI goes to a position-- fits with a computerized model.

Pilot 4. The clicking between points doesn't seem to allow for precision. You ask for 750 fpm, do I set it at 700 or 800 fpm?.

Spacing between graduation marks too small at higher numbers.

Failure indication should be Loss of needle.

Pilot 5. At smaller VVI reading - a bit hard to read exact graduation. Prob. close enough though. 750 is not a magic number with different loadings and approach speeds of F-16s. Failure indication should be off flag like ADI.

Pilot 6. INS failure light for failure indication.

The pointer is on backwards. Shouldn't the small end be the "pointer" end?

Pilot 7. Failure indication: Turn off the needle or turn on the XXX needles.

Pilot 8. Failure indication. flag covering display or maybe a "fan indication"

[Sufficient precision] except if you want to nail a high rate of climb/descent.

Pilot 9. Failure indication. Total blank indicator or a bar or X through the display.

Pilot 10. Failure indication. Pointer disappears if possible or the entire LCD goes blank.

4. LCD (Slow Response) VVI:

Pilot 1. I like the quicker response better.

Do not like ratcheting.

Pilot 5. I like this much better than the original tape of the F-16. The faster response was much better. Took too long to settle, however, should be evaluated in turbulence for final determination. Analog display is good. The response time is the only question I have. Must evaluate this option in turbulence to get final answer.

Pilot 7. The difference between this and fast response display is slight in this simulator, given that both are very good, the slower display may be the most useful.

Pilot 8. Probably better than the fast rate for approaches.

Pilot 9. The discrete movement of the pointer from one value to another was initially distracting, but after a couple minutes, I didn't notice it as much. Tough to do 750 fpm when you only have 700 or 800 to choose from.

Pilot 10. I felt trend information was too slow even though I liked the positive indications. It also being slower didn't catch my eye as quickly as the previous [LCDFR] indicator (it was quick and very positive, which match my control inputs.)

5. LCD (Fast Response) VVI:

Pilot 3. Much better with faster response.

Pilot 5. Display should be looked at in turbulence to evaluate response time.

Pilot 6. I found the display readable while I was watching the ADI. This is a good display.

Pilot 8. May be too sensitive during approaches in turbulence.

Pilot 9. The discrete movement from one value to another initially got my attention, but then was less noticeable after a few minutes. Good display. There was a good point to the ratcheting and that was when I noticed it moving, it gave me a good indication that something had changed which required an action on my part.

Pilot 10. I think the way this is mechanized (it shows a very positive change) is good. I can very easily adjust 100 fpm and set it.