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TRISTAR I: Evaluation Methods for Testing Head-Up Display (HUD) Flight Symbology

US Army
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Nomenclature

Acronyms

A/A	Air-to-air
A/G	Air-to-ground
AFB	Air Force Base
ANOVA	Analysis of variance
AOA	Angle of attack
CDL	Climb–dive ladder
CDM	Climb–dive marker
cg	Center of gravity
CGI	Computer generated image
CRT	Cathode-ray tube
DH	Decision height
FOV	Field of view
FPM	Flightpath marker
FSWG	Flight Symbology Working Group
HUD	Head-up display
IC	Initial conditions
ILS	Instrument landing system
IMC	Instrument meteorological conditions
IP	Initial point
KIAS	Knots indicated airspeed
N/R	Not reported
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
RAE	Royal Aeronautical Establishment
RAF	Royal Air Force
RCS	Reaction control system
TLX	Task load index
TRENDS	Tiltrotor engineering database system
UA	Unusual attitude
USA	U.S. Army
USAF	U.S. Air Force
USN	U.S. Navy
VMC	Visual meteorological conditions
VV	Velocity vector

Symbols

az_{VV}	Azimuth component of velocity vector
el_{VV}	Elevation component of velocity vector
$F_{(\,)}$	Forces
F_J	Gross thrust
g	Normal acceleration
G	Quickener gain
h	Altitude
M	Mach number
P_{AMB}	Ambient pressure
P	Roll rate
q	Quickener term
q_1	Quickener term
q_2	Quickener term
Q	Pitch rate
R	Yaw rate
s	LaPlace variable
t	Time
$T_{(\,)}$	Moment
T_{AMB}	Ambient temperature
V	True airspeed, ft/sec
V_{EJ}	Equivalent jet velocity ratio
V_{RW}	True airspeed, knots
V_I	Indicated airspeed, knots
X_{CDM}	X location of CDM (HUD coordinates)
X_{FPM}	X location of FPM (HUD coordinates)
Y_{FPM}	Y location of FPM (HUD coordinates)
Y_{CDM}	Y location of CDM (HUD coordinates)
α	Angle of attack
α_F	Filtered angle of attack
β	Angle of sideslip
Θ	Pitch attitude

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ρ	Air density, slugs/ft^3
τ	Time constant
τ_α	Time constant to filter a
τ_Q	Quickener time constant
ϕ	Roll attitude
Ψ	Heading

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Summary

A piloted head-up display (HUD) flight symbology study (TRISTAR) measuring pilot task performance was conducted at the NASA Ames Research Center by the Tri-Service Flight Symbology Working Group (FSWG). Sponsored by the U.S. Army Aeroflightdynamics Directorate, this study served as a focal point for the FSWG to examine HUD test methodology and flight symbology presentations. HUD climb–dive marker dynamics and climb–dive ladder presentations were examined as pilots performed air-to-air (A/A), air-to-ground (A/G), instrument landing system, and unusual attitude recovery tasks. Symbolic presentations resembled pitch ladder variations used by the U.S. Air Force (USAF), U.S. Navy (USN), and Royal Air Force (RAF).

Investigations were conducted in a NASA fixed-base simulation cab. The cockpit of the simulation cab was configured to resemble a Harrier aircraft cockpit with fast-jet HUD flight symbology dynamics and AV-8B Harrier aerodynamic equations of motion. Six HUD-experienced male fighter and attack pilots from the USAF, USN, and RAF participated in the study.

Time histories of 83 variables were recorded during the simulation. Four task maneuver performance methods were examined and both subjective and objective data were obtained for each task. Subjective questionnaires revealed several interesting trends based upon each task, such as the preference for a quickened climb–dive marker and a variable-compression pitch ladder for A/G tasks. Objective data indicated decreased reaction times and increased spatial awareness with asymmetrical climb–dive ladders (CDLs).

The study was beneficial for working group researchers, providing a mechanism for exchange of test techniques and methods of presentations. Test techniques developed during the TRISTAR I simulation will be used during the TRISTAR II flight symbology evaluation.

Introduction

The head-up display (HUD) is rapidly becoming the primary fixed-wing instrument flight reference for both visual and instrument meteorological conditions (VMC and IMC). This technology medium allows the presentation of flight-critical information in a plethora of formats and creates the potential for new and unique formats by which information critical to flight and mission success can be conveyed to the flight crew.

The HUD is an outgrowth of World War II reflecting gunsights. Gunsights, which had begun as simple iron rings, developed into collimated displays reflected from a semitransparent combiner glass. The benefit of a collimated virtual image for the pilot was that he could focus on both the target and the sight simultaneously. Essential flight information, such as airspeed and altitude, was added to aid the pilot in maintaining an eyes-out orientation, thus creating the HUD. The major advantages of HUDs are reduced pilot workload, increased flight precision, direct visualization of trajectory, and increased flight safety when overall piloting tasks require head-up, outside-the-cockpit flight references.

Since the late 1970s, a number of reports have been published citing significant deficiencies in HUD symbology and installations. The U.S. Air Force (USAF) Instrument Flight Center found HUDs to be limited by serious drawbacks, including a lack of standardization and an increased tendency toward spatial disorientation (ref. 1).

Traditionally, HUDs and the associated symbology have been procured as part of the airframe weapons systems, not as "aircraft instruments." Usually the HUD is

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contractor furnished with little adherence to general military standards and specifications. Symbology drive laws and dynamics documentation are also frequently missing with the HUD delivery. Since the HUD was not considered an "instrument display," no need was seen to establish suitability for use as a flight reference. Consequently, no flight procedures were developed and no training was provided to pilots on how to use the HUD in routine flight (ref. 2).

Purpose

The TRISTAR study grew primarily from the desire of the Tri-Service Flight Symbology Working Group (FSWG) to address HUD flight symbology deficiencies, standardization, issue identification, and test methodologies. The study provided the mechanism by which the USAF, U.S. Navy (USN), Royal Air Force (RAF), and U.S. Army (USA) could focus organizational ideas and differences for comparisons. Specifically, the TRISTAR investigation examined flight symbology issues collectively identified by each organization and attempted to use objective and subjective test methodology and flight tasking proposed by the FSWG.

Facility

Simulator Cab

The TRISTAR investigations were conducted in the NASA Ames R-CAB fixed-base simulator. The R-CAB, shown in figure 1, is a single cab with three windows aligned in front of a centrally located pilot station. The cab also supports a fourth "chin window" that was not used for this simulation. The windows span a field of view (FOV) from +78 to –77 deg in azimuth and –17 to +12 deg in elevation, as shown in figure 2.

Visual Model

The image generator used with the R-CAB in the TRISTAR investigation was the Evans and Sutherland CT-5A. The CT-5A is a three-channel, single-eyepoint image generator; it is a raster-scan system with a 2:1 interlace ratio. The system operates at a field rate of 60 Hz. Each channel has a total of 1,024 raster lines, of which 1,003 are active video lines. Each line is composed of 875 pixels, so the pixel capacity is 877,625 pixels per channel or 3,510,500 total pixels. The visual system is described in detail in reference 3.

The system supports a number of visual databases. The TRISTAR investigation used a combined ocean database with a Napa Valley land area for the low-level and air-to-ground (A/G) task, a MiG-27 target aircraft for the air-to-air (A/A) task, and Seymour Johnson AFB, North Carolina, for the Instrument Landing System (ILS) task. Table 1 summarizes the lighting conditions, special effects, and object models on the visual database.

Cockpit Hardware

The TRISTAR cockpit, shown in figure 3, was designed to simulate a limited number of cockpit instruments found in the Harrier cockpit. The instrumentation was used for the initial simulation setup, but it was later covered during the HUD simulation so the pilots would be forced to use the HUD for flight reference. The exhaust gas temperature, engine rpm, and normal acceleration (g) were available to the evaluation pilots since this essential information was not available on the HUD. Figure 4 shows the view of the instruments and HUD with the flight instruments blocked.

The HUD used in the evaluation was manufactured by Flight Dynamics, Inc., Raleigh, North Carolina. The HUD uses a holographic combiner with a FOV of 30 deg horizontal by 24 deg vertical. The horizontal FOV is symmetrical about a vertical plane through the eye reference point. The vertical FOV is centered on a depression angle of –4 deg. The eyebox is an approximately rectangular parallelopiped with dimensions 2.7 in. (height) × 4.7 in. (width) × 5.0 in. (length).

The collimation is variable and was adjusted to match the simulation visual scene. Figure 5 shows the HUD installation.

A Harrier power management console was installed along with a generic flight control stick and rudder pedals. Switches on the throttle and control stick were used as pilot event markers. The nozzle and flap controls were not active.

A video camera that monitored pilot status was installed on the right side of the cab. Since the cab was kept at a low light level, an adjustable light with a red cover was installed above the camera to provide lighting for the camera.

Aircraft Mathematical Model

The overall simulation software package is independent of aircraft type. The tasks include integration of the equations of motion, a standard atmosphere model, automatic trimming, stability analysis, graphics, and a user interface. The software is designed to allow easy modification of the aircraft model.

The specific airplane model used was an AV-8B Harrier, consisting of the following submodels:

1. Propulsion and reaction control system (RCS) model
2. Aerodynamic model, including ground effects
3. Control system model
4. Weight, center of gravity (cg), and inertia model

The data for the propulsion, RCS, cg, and inertia models are stored in function table format. This allows table lookups of functions of one to three arguments using linear interpolation between breakpoints. The aerodynamic model is implemented in algebraic formulae with all data included in the aerodynamics subroutine. Figure 6 is the block diagram of the airplane model.

The nonlinear model was valid from 0 through 0.9 Mach number. Additional details can be found in reference 4.

Model Validation

The aircraft model (including the HUD formats) was validated by experienced Harrier pilots who flew the simulator through the evaluation tasks and rated the level of fidelity of the simulation compared with the aircraft. During the same period, the validation of the HUD symbology, particularly the quickening algorithms, was conducted by pilots and engineers familiar with the quickening as implemented at the Royal Aeronautical Establishment (RAE) (ref. 5).

(This phase was planned for one week, but actually required more than two weeks.)

HUD Symbology

The basic HUD symbology was adapted from the RAE fast-jet format (ref. 5).

Basic Symbology

The basic symbology is shown in figure 7. The features common to all experimental symbologies are the counter-pointer airspeed and altitude displays, which use a combination of digital readouts and analog needles; a 4:1 compressed heading scale at the top; and a winged and tailed circle showing the climb–dive angle.

The presentation of climb–dive angle is not common in most U.S. aircraft HUDs. It corresponds to a traditional flightpath marker, which is caged (i.e., constrained to the left-right center of the HUD FOV). The actual aircraft flightpath is shown by a small triangular velocity vector (FPM), which is free to move laterally. In figure 7, this FPM symbol can be seen inside the winged and tailed airplane symbol.

For purposes of clarity, the airplane symbol (showing climb–dive angle) will be referred to as the climb–dive marker (CDM). The arrangement of lines showing the angle will be called the climb–dive ladder (CDL).

If the CDM was to be driven from the FOV because of excessive vertical motion, it was constrained to the FOV limits and this was indicated to the pilot by removing the tail.

Variations in HUD symbologies were primarily concerned with the pitch ladder, although the quickening concept was also studied.

Climb–Dive Ladder Variations

Several variations on construction of the CDLs were evaluated. These included the length of the lines, the orientation of the lines, and the use of vertical asymmetry.

All CDLs were constructed with solid lines above the horizon and dashed lines below. All lines displayed the angle on the left side only slightly above and inboard from the end. Leading minus signs were shown for below-horizon angles.

The lines incorporated horizon-pointing "ticks" to enhance spatial awareness. The location of the ticks was an experimental variable.

Four line arrangements were tried:

1. Tapered lines in which the lines decreased in length as the angle from the horizon increased. Two variations were examined with ticks at the inboard ends of the lines (TI) or at the outboard ends (TO);

2. Straight lines in which all lines were the same length. The ticks were located at the outboard ends of the lines (SO);

3. Bent lines in which the lines were angled to form a "V" as the angle from the horizon increased. The lines were rotated at an angle one-half of the angle from the horizon. The ticks were located at the inboard ends of the lines (BI);

4. Vertically asymmetric lines in which the lines below the horizon were bent as in (BI) and the lines above the horizon were straight (SO). The ticks were located at the inner edges below and the outer edges above the horizon. This CDL arrangement was denoted as VA.

The location of the ticks was varied because it was assumed, a priori, that the inboard tick location would enhance any effect of the bent lines and that the outboard location would enhance any effect of the tapered lines.

Figure 8 shows the CDL with the tapered lines (TO) and figure 9 shows it with bent lines (BI).

Two ladder scalings (compressions) were evaluated: a full-time, 1:1 in which the ladder remained conformal to the real world. In this case, the line spacing remained 5 deg throughout. A variable compression was also tried in which the compression was 1:1 for angles within 5 deg of the horizon with a linear change to 4.4:1 when the climb–dive angle equals ±90 deg. With variable compression, the line spacing was every 5 deg up to ±30 deg and every 10 deg thereafter.

Fixed Versus Moving Scales

Since one of the experimental variables was to be quickened versus non-quickened CDM/FPM, it was necessary to ensure that motion of the scales would not influence this variable. Normally, the scales moved with the CDM. If this were permitted with the nonquickened CDM, there was concern that the nonquickened motion of the scales might make their influence too difficult to read. For this reason, the scales were to be fixed whenever the CDM and FPM were not quickened.

This configuration, however, introduced another variable: relative motion within the display. To accommodate this, a set of quickened-CDM, but fixed scales was included in the experimental matrix.

HUD symbologies were denoted by the abbreviation for the line construction (TO, TI, SO, BI, or VA), a colon, the compression ratio (1:1 or variable), and a description of the quickening and scale motion (QM, QF, or NQF). For example, HUD 1 can be described as TO: 1:1 QM. It has a tapered CDL with outboard ticks, 1:1 compression, a quickened CDM, FPM, and moving scales. This is shown in table 2.

Quickening and Caging Equations

The quickening and caging equations were adapted from the RAE fast-jet equations (ref. 5).

Velocity vector– The velocity vector was positioned in HUD axes by

$$Y_{FPM} = el_{VV} \cdot \cos(\phi) + az_{VV} \cdot \sin(\phi) + q \quad (1)$$

$$X_{FPM} = az_{VV} \cdot \cos(\phi) + el_{VV} \cdot \sin(\phi) \quad (2)$$

where el_{VV} and az_{VV} are the elevation and azimuth components of the aircraft velocity vector with respect to the Earth (expressed in nonroll-resolved aircraft axes), ϕ is the roll attitude, and q is the quickener term described later.

Climb–dive marker– The CDM was positioned in HUD axes by

$$Y_{CDM} = el_{VV} \cdot \cos(\phi) + \alpha_F \cdot \sin^2(\phi) + q \quad (3)$$

$$X_{CDM} = 0 \quad (4)$$

where α_F is the filtered angle of attack (AOA).

Angle of attack– The filtered AOA α_F is given by

$$\alpha_F = \alpha/(1 + \tau_\alpha s) \quad (5)$$

where α is the angle of attack, τ_α is determined as the best compromise between noise suppression at large values of ϕ and the retention of horizon correlation in dynamic pitching maneuvers at moderate values of ϕ, and s is a LaPlace variable. After preliminary screening, a value of 0.04 sec was used. The filter is required to suppress noise on the display at large bank angles in turbulence.

Quickener– The quickener, q, is equal to q_1 for pitch attitudes, $|\Theta| < 10$ deg blending linearly with Θ to be equal to q_2 for $|\Theta| > 30$ deg.

$$q_1 = G \cdot \cos(\phi) \cdot [\tau_Q s/(1 + \tau_Q s)] \cdot \Theta \quad (6)$$

$$q_2 = G \cdot [\tau_Q/(1 + \tau_Q s)] \cdot Q \quad (7)$$

where the quickener gain G = 0.7 and Q is the pitch rate in aircraft body axes. The quickener time constant, τ_Q, varies with flight condition and must be matched to the wing loading, handling characteristics, and avionics fit of the specific aircraft. For the Harrier,

$$\tau_Q = 0.2252 + 1.1112/(V \cdot \rho) \quad (8)$$

where V is the true airspeed and ρ is the air density.

ILS Symbology

The guidance symbology used for the approach and landing task was an ILS cross-pointer needle display as shown in figure 10. The needles were referenced to the CDM. In the vertical axis, full-scale deflection represented ±1.4-deg glideslope deviation. In the horizontal axis, full-scale deflection represented ±6.0-deg localizer deviation. The pitch ladder used had one-to-one scaling. The only HUD variable evaluated during the ILS task was quickening/ nonquickening of the CDM.

Subjective Data Collection Techniques

A questionnaire summarizing pilot experience was administered to each evaluation pilot at the beginning of his participation. In addition to general pilot experience, the questionnaire asked for a summary of HUD experience and current qualifications.

After each task, the evaluation pilot also completed a specific rating form designed to clarify differences in the HUD variables. A final debriefing questionnaire and interview were administered at the conclusion of each evaluation pilot's participation.

In addition, pilots completed task load index (TLX) questionnaires developed by NASA Ames (ref. 6). These questionnaires measure the subjective mental, physical, and temporal task demands, the task performance, and the levels of effort and frustration caused by the task.

Copies are shown in appendix A. This appendix includes the subject questionnaire.

Objective Data Collection Techniques

A total of 84 variables were recorded during the simulation. These were recorded directly from the simulation equations during each computational frame (a sampling interval of 33 msec. The variables are listed in table 3. These variables were the superset of all variables requested for each flight task to be studied. Additional variables (such as pitch rate and pitch rate acceleration) were included for validation and debugging purposes.

The variables were recorded in real time on magnetic tapes and stored in a VAX disk pack located on the Neptune VAX computer at Ames Research Center.

The large amount of data recorded required the use of a database management tool. The NASA TRENDS (Tilt-rotor engineering database system) program was used. TRENDS was developed to manage the data obtained in rotorcraft flight testing and it has been used in a variety of flight and simulation test activities (refs. 7 and 8). One of the advantages of TRENDS is that all analysts, regardless of location, could access the recorded data via telephone connections.

Both the objective data (from the VAX disk pack) and the subjective data (via transcription) were listed in the TRENDS TRISTAR database. This allowed the data analyst to review, for example, all A/A tasks flown by evaluation pilot 1 using HUD 5. Short flight segments, defined by variables being within certain limits, could be examined or plotted on hard copy. TRENDS also allowed the analyst to use conventional statistical programs to determine if significant differences existed between HUD formats.

Appendix B shows the TRENDS database output.

Conduct of the Experiments

Subjects

Six HUD-experienced, male fighter pilots from the USAF, USN, and RAF served as evaluation pilots for this study. They had an average total flight time of 2,880 hours. The evaluation pilots' experience is summarized in table 4.

Each evaluation pilot was given a thorough briefing on the task to be performed and the rating forms to be used. Copies of the briefing materials for each task are shown in appendix C.

Maneuvering

Air-to-air tracking–

Task description: Each evaluation pilot "flew" 14 different HUD symbol sets. The primary task was to track a target aircraft through a set of acrobatic maneuvers similar to those required in A/A combat. The target, a computer generated image (CGI) silhouette of a MiG-27, moved in a cloverleaf type of pattern within the visual field. Movement was varied enough to be unpredictable to the evaluation pilot. The evaluation pilot was instructed to fly the simulator (own-ship) and keep the gun cross on the CGI target at all times. The HUD-referenced aiming symbol (gun cross) was a set of cross hairs resembling the aiming reference of an F-16 aircraft.

Both the target and own-ship commenced maneuvers around 15,000-ft indicated altitude, 300 knots indicated airspeed, and a northerly heading. The own-ship was situated about 2,000 ft directly behind and slightly below the target. Once the evaluation pilot acknowledged a state of readiness, the tracking task began. The target smoothly began a climb to about a 45-deg nose-up pitch attitude. Upon reaching this pitch attitude, the target would begin a gradual roll to an inverted position while tracking a path approximately 90 deg to the left or right (west or east) of the original northerly heading. Ideally, if the evaluation pilot completed a perfect track behind the target, the own-ship would now be in an inverted flight condition, 90 deg from the starting heading, about 2,000 ft behind the target and slightly above, since both would be in an inverted position.

The target would continue with a downward pull through the vertical (similar to a split-S maneuver) and complete the first leaf of the cloverleaf at an upright position about 90 deg of heading change from the beginning of the pull-up (or 180 deg from the inverted flight heading). If accomplished correctly, the conditions at this point should be similar to the beginning conditions (15,000 ft and 300 knots), except for the heading change of approximately 90 deg.

The difficulty with the task, as with any tracking task, was that the evaluation pilot did not know when the target would begin to climb, which direction the target would roll, nor how tight the target was pulling. Therefore, the target could very easily be changing flight parameters (i.e., loosening the pull either during the pull-up or during the pull-through), and transition below a predetermined minimum altitude (11,000 ft) or a predetermined minimum airspeed (200 knots).

The evaluation pilot was required to recognize when the minimum conditions were violated by activating a trigger button on the control stick. Once the aircraft returned above the predetermined conditions, the same button would be activated again. This process would record event markers on the time history tape, thereby producing reaction time intervals that could be used to suggest the best design for inflight aircraft performance awareness. Some of the cloverleaf quarter-section loops were accomplished within parameters, requiring no action by the evaluation pilot, thereby keeping him unsure of the next desired response. The tracking task was briefed as primary, whereas the monitoring and recognizing task was secondary.

In addition to the altitude and airspeed limitations, the target was programed to occasionally disappear, leaving the evaluation pilot with an unusual (and unexpected) spatial orientation problem to resolve. When this occurred, the evaluation pilot was instructed to orient the aircraft to another pitch and bank condition as soon as the target disappeared. The evaluation pilot would promptly orient the own-ship to the desired position. When the recovery was completed and the new position established, the evaluation pilot acknowledged the recovery and the chase continued. The target was programmed to disappear five times during each sortie, these times being unknown to the evaluation pilot. These procedures produced a flight profile unpredictable to the evaluation pilot, yet somewhat realistic in an A/A scenario. Successful completion was defined as achievement of an attitude within 20 deg in bank and 5 deg in pitch of the predetermined attitude. Response time to the first stick input was measured as well as the overall reaction time to complete attitude change.

Subjects were occasionally distracted from these tasks by a third task designed to measure the evaluation pilot's attitude awareness. In this task, each evaluation pilot had a card located on his kneeboard that resembled a bingo game card. The card consisted of lettered columns and numbered rows, shown in table 5. Within the matrix were letter pairs. The evaluation pilot was asked to respond to a letter–number combination with a letter pair from the matrix. For example, in response to the experimenter's saying "A3," the evaluation pilot would respond with the letter pair in column A, third row (in this case, SL). While the evaluation pilot was completing the task, the HUD display was frozen. Upon completion of the distraction task, the experimenter would ask the evaluation pilot to look at the HUD and report the attitude. The response was recorded in the logbook by the experimenter. The rationale behind this task was that the greater the evaluation pilot's attitude awareness, the more accurate his response to the attitude recognition task would be.

These variables (minimum altitude, minimum airspeed, and attitude recognition), when incorporated into a realistic simulated inflight task like the A/A scenario, made for a perfect situation to test the evaluation pilot's ability to recognize, recover, and maintain attitude awareness. Since there were no other instrument displays that the evaluation pilot could use for recovery (the traditional panel instruments were covered), the speed of the trigger response and correctness of recoveries produced with the HUD were considered a good indication of display design improvements. The experimental design should have elucidated the HUD symbology features that provide the pilot with the best overall performance (a part of overall situation awareness).

The pilots practiced until they felt comfortable with the tracking task and confident that they could control the simulator throughout the entire flight profile. The study was originally designed as a completely crossed factorial arrangement. The intent was that all evaluation pilots would complete all the tasks with each HUD. Unfortunately, because of time constraints and programming problems, the original plan had to be modified. Each evaluation pilot performed some of the tasks with some of the HUD configurations. The frequency and presentation order of the secondary task stimuli were equivalent for all HUD configurations.

Subjective data analysis: Questionnaires were administered to the evaluation pilots at the end of the A/A portion of the experiment. The pilots were asked to indicate their preferences for each aspect of the HUD configuration. The summary of the preferences is shown in figure 11. Although a sufficient amount of survey data to perform an analysis of variance (ANOVA) did not exist, the pilots' responses were averaged and several interesting trends were revealed. The results of the survey indicated that, on average, the evaluation pilots had at least slight preferences for the following HUD characteristics:

1. Bent climb–dive ladder lines
2. Vertical asymmetry
3. Variable compression
4. Quickening

Objective data analysis: Three of the recorded variables were airspeed, altitude, and an event marker triggered by the evaluation pilot's pressing the event button on the throttle in response to the secondary task. By measuring the elapsed time from when the airspeed and altitude limits were exceeded to when the event marker was triggered, a reaction time for recognition of an event was obtained. The mean reaction times are shown in figure 12.

An examination of the data points revealed that a number of excursions never received a response. The reason for these errors was not determined, but it was assumed that the pilot did not recognize that a limit had been exceeded. In addition, other trials had abnormally long reaction times (some as long as 60 sec), which suggested that the evaluation pilot might have been pressing the event button in anticipation of exceeding a limit or he might have been pressing the button to respond to some other unknown event. Therefore, only trials with a reaction time of less than 18 sec (a time limit determined by subject matter experts) were used in the analysis.

An ANOVA was performed on the data to determine if there was any difference caused by the 14 different HUD configurations. The ANOVA was marginally significant ($p = 0.06$). Duncan's range test revealed that the reaction times with HUD configurations 1 (TO: 1:1 QM) and 3 (BI: 1:1 QM) were significantly longer than reaction times with HUD configurations 4 (VA: 1:1 QM) and 6 (TO: V QM). Also reaction times with HUD configurations 1, 3, and 10 (SO: V QM) were significantly longer than with HUD configuration 4. These data suggest that vertical asymmetry may be a useful tool for enhancing a pilot's awareness of the state of the aircraft, i.e., may make him less likely to fall victim to spatial disorientation.

Results: Because of the experimental design modifications discussed above, there were missing data points resulting in an unbalanced design that made the statistical analysis difficult. Because of the missing data, the statistical tests used were less likely to detect differences between conditions if differences did exist.

Technical difficulties with the simulator and the data reduction process resulted in the loss of additional data points.

Discussion: The tasks were much more challenging than expected. The evaluation pilots had a difficult time keeping adequate spacing. Often the evaluation pilot overran the target, generating an unwanted unusual attitude (UA) recovery. This problem can be corrected in future simulations by fixing the distance between the target and the evaluation pilot's simulated aircraft. In addition, the task itself should be modified to include a low-level flight segment and fewer over-the-top maneuvers. This would simulate a profile more characteristic of a wide variety of fighter aircraft, and not detract from the realism already established in the profiles. The third task, attitude awareness with the letter pairs, seemed to cause the most confusion and produce the least amount of usable information. This task was therefore deleted from the study.

Low-level air-to-ground tracking–

Task description: The scenario used for this part of the study was a relatively simple pop-up maneuver culminating in the release of weapons on two fixed ground targets. The following paragraphs describe the scenario; they are taken from the evaluation pilot instructions.

> Initial setup is 420 knots indicated airspeed (KIAS), 200-ft altitude, heading 355 deg. When the bay becomes visible off to the left, maneuver over to follow the bay and fly up the river. The river will end at a dam with a house shortly beyond.
>
> Cross the end of the river at 420 KIAS, 200 ft, heading 350 deg. With the gun cross abeam the house, go to mil thrust and make a moderately aggressive 4-g pull up to a 40-deg climb angle. At 6000 ft, roll 180 deg and pull 2–3 g down to a wings-level 40-deg dive (thus a straight pop-up and roll-ahead).
>
> As the aircraft reaches 360 KIAS, reduce the throttle to idle and track the first target (house along road) with the CDM. With the CDM on the first target, press the pickle button passing through 4,500 ft.
>
> Then roll left and put the CDM on the center of the large tanks (second target) and pickle at 1,500 ft and 420 KIAS with the CDM on the tanks.

Points of interest in A/G HUD symbology work are the ability to capture and hold predetermined profiles, precisely execute maneuvers, and identify ground targets against a cluttered background through using HUD symbology. Figure 13 shows the route followed during the task.

Subjective data analysis: Partial data were obtained for eight evaluation pilots in the A/G tasks, only three pilots testing with all fourteen HUD configurations. The subjective data were obtained from the comments and ratings on the ratings display card completed by each pilot (with the experimenter) after each run.

The overall display rating, Question 1, is summarized in table 6. Also shown in the table is the average of the subjective ratings per display. No conclusions can be drawn for the ratings of HUDs 2, 3, 4, or 5 because of lack of data. Table 7 shows the same results for HUD configurations 1 and 6–14.

Note that for the purposes of data analysis, items marked "0" and "Didn't notice" on the ratings display card were changed to a score of 3.5. This was done to better approximate subjective opinions about the display. Otherwise, the considerable number of ratings of 0 could not be used with the 1 to 7 "Helped to hurt" continuum scale used to rate features of the displays: they would be dropped out. Essentially a "Didn't notice" rating has been equivocated to a "Medium" or a "Did not interfere or help" rating.

Answers to questions 4–6 from the ratings display card were reviewed and tabulated according to whether the pilots "liked" or "did not like" a feature of the display. In an attempt to better manage the data for review, some comments were consolidated. That is, comments that mentioned disliking a certain feature were also counted as a "liked" comment for the opposite feature. For example, there were many comments regarding the quickening of the CDM. Many of the pilots indicated a *dislike* of the nonquickened CDM. Since there were only two options in this study, the dislike of the nonquickened CDM was counted as a "liked" for the quickened CDM.

Figure 14 shows what the evaluation pilots did and did not prefer.

Objective data analysis: One of the primary purposes for this experiment was to test tools and procedures that can be repeated in future studies. Through the course of design and implementation for these simulations, many factors came into play that reduced the effectiveness of the results. Primarily, there are missing data cells, unbalanced combinations of variables, and a small sample size. As a result, it is difficult to determine exactly what features of the display were influencing pilot performance and ratings.

Results: The ratings on questions 1–3 show each of the HUD configurations overall around the center of the "Helped–Hurt" scale (between 3.0 and 4.0).

The responses to questions 4–6 showed that CDM quickening was good or helpful more often than any other feature. The variable-compression CDL had the second-highest number of favorable comments. To a lesser extent, vertical asymmetry in the CDL was rated good. There is ambiguity about the viability of most of the other HUD features.

The 1:1 compression CDL had the largest number of negative comments. The fixed-scale ladder had the second-highest number of negative comments. There is ambiguity about the degree that other HUD features were disliked.

Discussion: With such a small sample size and with missing data, the opinion of just one or two pilots can weight ratings significantly. Therefore, generalization from these data should be done cautiously. Within these original constraints on the data, a quickened CDM and a variable-compression CDL are highly desirable in this pop-up A/G task. A 1:1-scale CDL, nonquickened CDM, and fixed scales were not liked. Some ladder comments concentrated on degree increments: some wanted smaller increments, some larger.

The following paragraphs elaborate on the findings.

1. Climb–dive marker: It was virtually unanimous that the CDM should be quickened. Comments regarding the nonquickened marker were that it was sluggish, it was hard to follow, it required too much anticipation, and it was difficult to use. The opposite was said for the quickened CDM.

2. Fixed scales: Most comments on the desirability of fixed scales were negative, mentioning the undesirable pendulum effect and pitch control and scan difficulty. One evaluation pilot, however, said that the fixed scales did not affect the task much.

3. Vertical asymmetry: The only negative comment on vertical asymmetry was that the evaluation pilot did not really notice it. The other comments were positive, including that this scale "left no doubt whether [I was] in a climb or a dive."

4. Straight lines: Straight lines seemed to be undesirable. Only HUDs 5 and 10 had straight-line CDLs. HUD 5 had a 1:1 ladder and HUD 10 had a variable-compression ladder. Unfortunately, only one pilot flew with HUD 5, so a meaningful comparison between 1:1 and variable compression with straight lines is impossible. From the pilots evaluating straight lines, there were more negative than positive comments, including observation of a laddering effect.

5. Variable-compression ladder: Some negative feelings about variable compression were evident in the fact that there were some positive comments about 1:1 scaling. Most comments were clearly positive about variable-compression scaling.

6. Tick marks: Very few comments were made regarding the tick mark location. Some pilots thought that the tick marks were inconsequential, while some liked them on the outside (saying they emphasized the taper on HUD 1), some suggested tick mark removal, and some thought the inside ticks were undesirable. One evaluator said that he used the ticks mainly to tell if he was "above or below."

To enhance the task, the following changes could be made:

1. Provide a featureless landscape for part of the run-in, e.g., barren desert or ocean;

2. Provide hills and mountains to navigate through during the run-in;

3. Require several heading changes to put the aircraft in position for attack on ground targets and a suitable escape route;

4. Include an "observable ceiling" over which the aircraft can be observed by enemy radar;

5. Provide a time above the observable ceiling to complete the mission before missile launch (serves as an artificial threat, for realism and stress increase);

6. Use an artificial time-to-pop-up cue, such as a tone to ensure that all pilots pop up at the same point in the attack (alternatively, use the point of penetration of the observable ceiling);

7. Modify the actual pop-up maneuver to fit the scenario, to add realism, or to increase the difficulty of the mission.

The following performance measures are recommended for future evaluations using the A/G task:

1. Heading, altitude, and airspeed (fidelity to prescribed values throughout the run);

2. Stick and throttle reversals;

3. Time to visually acquire the target (not necessarily using the piper, a verbal "see target one" and "see target two");

4. Time above observable ceiling;

5. Ability to capture prescribed climb–dive angles and rollover.

ILS approach task–

Task description: The approach and landing task involved a standard ILS approach to a landing or missed approach. The initial conditions (ICs) for the approach were as follows:

Range:	5 n. mi.
Lateral offset:	3,000 ft
Altitude:	1,200 ft
Glideslope:	3 deg
Heading:	Parallel with runway heading

Each pilot made two approaches for each HUD configuration. One approach was terminated with a waveoff at a 200-ft decision height. The second approach was terminated when the aircraft touched down on the runway. The evaluation pilots were instructed to maintain airspeed-AOA and glideslope-localizer deviations.

Both approaches were made during low-visibility conditions. The first approach (to a waveoff) had visibility conditions of 100 ft and 1/4 n. mi. and the second approach (to touchdown) had visibility conditions of 200 ft and 1/2 nm. Both approaches were flown with moderate turbulence levels to increase pilot workload.

Figure 15 shows the approach plate used by the evaluation pilots.

Subjective data analysis: Pilot comments indicated a strong preference for the quickened CDM display.

Objective data analysis: The primary measures of HUD performance during this task were glideslope localizer, airspeed, and AOA deviations; throttle position; and longitudinal and lateral stick positions (used as a measure of pilot physical workload). Both time histories and end-of-run statistics were used to measure pilot performance and physical workload. The following parameters were recorded on time histories: flightpath angle, AOA, airspeed, glideslope deviation, localizer deviation, pitch attitude, bank attitude, throttle position, longitudinal stick position, and lateral stick position. The following parameters were recorded for end-of-run statistics: AOA deviations from approach AOA; airspeed deviations from approach airspeed; glideslope deviation; localizer deviation; and washed-out throttle, longitudinal stick, and lateral stick positions. The calculations of the throttle and stick parameters are shown below. The AOA, airspeed, glideslope, and localizer deviations were used to measure approach performance. The washed-out throttle and stick positions were used as a measure of pilot physical workload:

$$\text{Throttle and stick position} \longrightarrow \boxed{\frac{0.5s}{(0.5s+1)}} \longrightarrow \boxed{(abs)} \quad \text{Calculate mean and standard deviation} \qquad (9)$$

Results: Only eight precision approaches were completed during the evaluation. This only allowed for the validation of the task itself and the data collection algorithms. No statistically significant data could be obtained from the limited number of approaches made.

Discussion: Pilot comments did indicate strong preference for the quickened CDM display. It allowed more aggressive maneuvers with minimal overshoots and eliminated the disappearance of the display from the HUD field of view during aggressive maneuvers. The task, as described, appears to be suitable for further evaluations of landing symbologies.

Unusual attitude recovery– One of the flying tasks that has been of particular interest to those developing the HUD as a flight reference display is UA recovery. The ability to quickly assess and react to the aircraft's attitude is a critical function of any flight display. In the task of attitude assessment, the HUD has its most significant departure from traditional flight displays. By its very nature, the HUD is unable to display flight attitude as unambiguously as a head-down attitude indicator. This is the major reason behind the reluctance of the USAF to qualify the HUD as a primary flight display.

The development of an evaluation technique that can evaluate the ability of a given display to convey flight attitude information to the pilot was a major objective of the FSWG. The bulk of past research has relied on a single technique to evaluate UA recoveries. In this technique, the evaluation pilot is presented with a blank display. Upon command of the pilot, a UA is presented on the display. The pilot then recovers to straight-and-level flight.

Task description: Each evaluation pilot was given a preliminary briefing of each of the HUD configurations to be evaluated, the test procedure, and the performance parameters that were to be collected. Once briefed and positioned in the simulator, the pilots were presented with one of the HUD configurations being evaluated. Each pilot was given an opportunity to fly the simulator with the HUD being flown for that trial block.

When the evaluation pilot indicated he had adequately familiarized himself with the HUD characteristics, the HUD was blanked. The experimenter instructed the pilot about the attitude to which he was to recover: wings level or another assigned attitude.

Upon activation by the evaluation pilot (via the trigger switch), the simulator was reset to the UA with the HUD on. The pilot then initiated the recovery to the preassigned attitude. Once the pilot felt he had achieved the assigned attitude, he terminated the trial by pressing the trigger switch, at which time the HUD would blank. The initial conditions and final conditions are shown in table 8.

This procedure was repeated until all trials for each block were completed.

The HUD symbologies are shown in table 2.

Subjective data analysis: Pilot ratings were obtained from the postflight and final questionnaires. Free-form pilot comments were also obtained.

Objective data analysis: Data parameters analyzed for UA recovery include

reaction time (sec)—the time from initiation to the first correct control input;

recovery time (sec)—the time from initiation until the evaluation pilot presses the trigger indicating recovery;

altitude loss/gain (ft)—maximum altitude deviation from initiation until recovery.

Results: Although the evaluation did not result in a clear pilot preference for any one of the HUD configurations, it did provide valuable information. Based on pilot comments made during the course of the evaluation and responses on posttest questionnaires, a consensus was achieved on some key issues.

First, most of the evaluation pilots felt that asymmetry between nose-up and nose-down was a very desirable characteristic for an attitude display. However, the degree of asymmetry and how it is achieved is open to debate. Several of the evaluation pilots felt that the configuration that maximized asymmetry was most effective for the recovery task, but they expressed some concern with regard to roll assessment with the bent scale lines. This concern has been expressed by other researchers (refs. 9 and 10).

Several of the evaluation pilots commented on the effectiveness of the inboard ticks on the CDL as an effective horizon pointer. At the same time, some commented that these ticks created undesirable clutter in the central portion of the display, which might inhibit or detract from A/A or A/G weapon delivery.

Second, nearly all of the evaluation pilots expressed a preference for the quickened CDM and felt that it increased the stability of the display. Some of the evaluation pilots commented that the movement of the scales with the quickened CDM was a distraction and did not improve cross-check patterns.

Third, opinions of the evaluation pilots were split on the effectiveness and desirability of CDL compression. The purpose of compression is to reduce the rate of ladder movement during highly dynamic maneuvering. Two pilots commented that they used the rate of ladder movement as a gauge of pitch rate and gravity pull. They found that, as the rate of apparent motion decreased or increased, they increased or decreased the stick input to attempt to maintain a constant motion of the CDL.

Discussion: One objective of the experiment was to develop and refine effective measurement techniques for each of the tasks. For UA recovery, there is a well established technique. One of the concerns is the need to determine if the pilot can assess his attitude, not merely recover to wings level. For this reason, the task of recovering to a different, non-wings-level attitude was added. This addition was based on the idea that, for a pilot to efficiently maneuver to a different attitude, he must first accurately assess his initial attitude rather than simply determine the direction to the horizon.

In practice, this task proved to be more complicated than anticipated. It was discovered that careful selection of initial and final conditions and analysis of the control inputs is required.

Conclusions

This study served as a focal point for the FSWG and provided an instrument for exchange of information and ideas on flight symbology and test methods. For this initial study, 14 variations of HUD symbology were studied with respect to the CDL presentation, CDM quickening, and altitude and airspeed positioning. Four specific maneuver scenarios were flown by six experienced pilots. Tested HUD symbologies represented commonly used symbologies found in the USAF, RAE, and USN cockpits. Likewise, the pilots were from the same organizations. The simulator used was the NASA Ames R-CAB fixed-base simulator. This initial study proved to be logistically difficult to manage since it involved both tri-service and international agreements, travel, and assignments without direct simulation funding by each organization. Nevertheless, the simulations were successful, and the findings are summarized as follows:

1. A/A tracking

a. In subjective analysis the pilots expressed preferences for

1) bent climb–dive ladder lines

2) vertical asymmetry

3) variable compression

4) quickening

b. Objective data collected during the A/A tracking task indicated that pilot reaction times were significantly faster with asymmetrical CDLs, which may indicate enhanced pilot awareness when performing an attitude awareness task.

2. Low-level A/G tracking

a. The subjective data showed that the pilots preferred the quickened CDM, and disliked the nonquickened CDM.

b. The objective analysis shows pilot preference for CDM quickening, variable-compression CDL, and, to a lesser extent, vertical asymmetry in CDL when performing the low-level A/G tracking task. Other factors in HUD features produced statistically ambiguous results.

c. The objective data showed that a negative pilot rating was given to the 1:1-compression CDL and the fixed-scale ladder for this task.

3. ILS approach

a. Subjective data analysis indicated strong pilot preference for a quickened CDM display.

b. Only eight precision approaches were completed and no statistically valid data were presented for this maneuver.

4. UA recovery

Subjective data show the following:

a. Pilots preferred asymmetry between nose-up and nose-down HUD presentations. (The amount of asymmetry needed was not evaluated in this study.)

b. Pilots expressed concern with interpreting roll attitude when using bent scale lines.

c. Pilots preferred inboard ticks on CDL, but they commented that the ticks cause clutter in the center of the display.

d. Pilots again preferred quickened CDM.

e. Movement of the pitch line scales with the quickened CDM was a distraction.

f. The effective measurement techniques of UA for the pilot to assess initial position proved to be too difficult to evaluate in this simulation. More carefully controlled initial and final conditions will be needed for future studies.

Insights and lessons learned during this first FSWG simulation effort will be considered in future deliberations and symbology trials. The experience gained during this collaboration with the three U.S. military services and the RAE has led to changes in test methods, an exchange of ideas, and an understanding and appreciation for the difficulty in obtaining objective performance measures. Also, an appreciation was gained for the requirements for specific symbology presentations for specific aircraft and tasks in order to optimize pilot/vehicle performance.

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Table 1. Effects and object models in the visual database

Effect	Description and comments
Illumination	Three levels: day, dusk, or night conditions
Horizon glow	Available for dusk or night conditions
Hazy horizon	Similar to horizon glow
Ground haze and fog	Visibility controllable from 0 to 20 n. mi.
Patchy fog	Pseudo-random variations in visibility
Clouds	Overcast, scud, and cloud tops available
Smoke	Visibility and color both controllable
Low-level route	A low-level database simulating the Napa Valley. The route followed a river with features such as buildings, roads, and bridges used for navigation, initial points (IPs), and targets
Seymour Johnson AFB	A conventional airport database modeled after Seymour Johnson AFB. Features include runway, taxiways, buildings, and vehicles. The surrounding region contains housing tracts, roadways, and vehicles representing suburban America

Table 2. HUD symbologies tested

No.	Label	Type of lines	Ticks	Compression	Quickening?	Fixed scales
1	TO: 1:1 QM	Tapered	Outside	1:1	Yes	Moving
2	TI: 1:1 QM	Tapered	Inside	1:1	Yes	Moving
3	BI: 1:1 QM	Bent	Inside	1:1	Yes	Moving
4	VA: 1:1 QM[a]	Tapered Bent	Outside Inside	1:1	Yes	Moving
5	SO: 1:1 QM	Straight	Outside	1:1	Yes	Moving
6	TO: V QM	Tapered	Outside	Variable	Yes	Moving
7	TI: 1:1 QM	Tapered	Inside	Variable	Yes	Moving
8	BI: 1:1 QM	Bent	Inside	Variable	Yes	Moving
9	VA: 1:1 QM[a]	Tapered Bent	Outside Inside	Variable	Yes	Moving
10	SO: 1:1 QM	Straight	Outside	Variable	Yes	Moving
11	TO: 1:1 QF	Tapered	Outside	1:1	Yes	Fixed
12	TO: 1:1 QF	Tapered	Outside	1:1	Yes	Fixed
13	TO: 1:1 NQF	Tapered	Outside	1:1	No	Fixed
14	TO: 1:1 NQF	Tapered	Outside	1:1	No	Fixed

[a]Tapered/outside above horizon; bent/inside below.

Table 3. Recorded variables

	Variable	Name	Units
0	Time	Time	sec
1	XNRUN	Run number	
2	XITASK	Task number	= 1: Low level = 2: Air to ground = 3: Air to air = 4: Unusual attitude = 5: Dynamic manuevers = 6: ILS approach
3	XHUDMOD	HUD number	
4	XQUICK	Quickening	Quickening = 1; nonquickening = 0
5	XQ2	(Not used)	
6	XMOVE	Symbols	Scales fixed = 0; move with CDM = 1
7	DTHECB	Stick (pitch)	in.
8	DPHICB	Stick (roll)	in.
9	DPSICB	Rudder input	in.
10	PRLVCB	Power input	Fraction of full stroke
11	TRLVCB	Transition lever	Fraction of full stroke
12	THETJ	Nozzle angle	deg
13	RPMHAR	Engine speed	rpm
14	VEQ	Airspeed	knots
15	VEQERR	Reference airspeed	knots
16	DELTVEQ	Own-target speed	knots
17	VD	Velocity	ft/sec (inertial coordinates)
18	ALT	Barometric altitude	ft
19	HAGLCT5	Radar altitude	ft
20	RALTERR	Radar altitude error	ft
21	PLNERR	Distance error from flightpath	ft
22	PHI	Roll	deg
23	THET	Pitch	deg
24	PSI	Yaw	deg
25	PHID	Roll Euler rate	rad/sec
26	THED	Pitch Euler rate	rad/sec
27	PSID	Yaw Euler rate	rad/sec
28	ALFA	Angle of attack	deg
29	BETA	Angle of sideslip	deg
30	GAMV	Flightpath angle	deg
31	DIVEERR	Dive angle error	deg
32	PIPERR	Pipper error	mrad
33	XRANGE	Range to target	ft
34	GAMH	Flightpath angle	deg (clockwise from north)
35	XCG	X position	ft
36	YCG	Y position	ft
37	HCG	Z position	ft
38	UB	X velocity	ft/sec (body frame)
39	VB	Y velocity	ft/sec (body frame)
40	WB	Z velocity	ft/sec (body frame)
41	UBD	X acceleration	ft/sec
42	VBD	Y acceleration	ft/sec

Table 3. Concluded

43	WBD	Z acceleration	ft/sec
44	PB	Roll rate	rad/sec
45	QB	Pitch rate	rad/sec
46	RB	Yaw rate	rad/sec
47	PBD	Roll acceleration	rad/sec
48	QBD	Pitch acceleration	rad/sec
49	RBD	Yaw acceleration	rad/sec
50	AX	X acceleration	ft/sec (body frame)
51	AY	Y acceleration	ft/sec (body frame)
52	AZ	Z acceleration	ft/sec (body frame)
53	ERSLOC	Localizer error	deg
54	ERSGS	Glideslope error	deg
55	XNUMSEG	Segment number	
56	DELTAS	Own-target speed	knots
57	EVSW1	Event switch 1	
58	EVSW2	Event switch 2	
59	EVSW3	Event switch 3	
60	EVSW4	Event switch 4	
61	EVSW5	Event switch 5	
62	EVSW6	Event switch 6	
63	EVSW7	Event switch 7	
64	EVSW8	Event switch 8	
65	EVSW9	Event switch 9	
66	XTRIG	Trigger	Trigger depressed = 1; not depressed = 0
67	XNOSHOOT	No shoot button	Button depressed = 1; not depressed = 0
68	XWINDO	In shoot envelope	In window = 1; not in window = 0
69	GSERR	Glideslope error	ft
70	AZMTHER	Azimuth error	ft
71	QUICKEN	Quickening term, q_1	See equation (6)
72	QUICKACS	Quickening term, q_2	See equation (7)
73	YHVV	Y velocity vector	mrad (HUD coordinates)
74	XHVV	X velocity vector	mrad (HUD coordinates)
75	YHACS	Y climb-dive	mrad (HUD coordinates)
76	THTHUD	Y pitch	mrad (HUD coordinates)
77	VEQHUD	Aircraft airspeed	knots (HUD signal)
78	ALTHUD	Aircraft altitude	ft (HUD signal)
79	PSIHUD	Aircraft heading	deg (HUD signal)
80	PHIHUD	Aircraft roll	deg (HUD signal)
81	VVEL	Velocity vector, elevation component	deg
82	VVAZ	Velocity vector, azimuth component	deg
83	RVR	Visual range	ft

Table 4. Evaluation pilot experience

ID	Organization	Total	Current aircraft	Using HUD[a]	Test pilot	Current aircraft	Other HUD-equipped aircraft flown
1	RAF	2,000	150	150	Yes	Harrier	Tornado, Jaguar
2	USN	2,500	150	250	No	F-18	Harrier[b]
3	USAF	4,000	800	260	Yes	A-7D, T-38[c]	A-10
4	USN	3,300	1,400	15	Yes	F-14, A-4M	Harrier,[b] F-15, F-18, Mirage
5	USAF	2,600	N/R	N/R	No	T-38[c]	A-10
6	RAF	N/R	1,000	N/R	Yes	Harrier	
7[d]	USAF	2,200	130	N/R	Yes	A-10,T-38[c]	
8[d]	N/R[e]	N/R	N/R	N/R	N/R	N/R	
Average		1,967	205	169	5-Y, 2-N, 1-N/R	9 different HUD-equipped airplanes flown	

[a]Hours using HUD in IMC.

[b]AV-8B.

[c]Not HUD-equipped.

[d]Did not participate in A/A experiment.

[e]Initial questionnaire not available.

Table 5. Workload distraction task: A/A task

	A	B	C	D	E
1	NS	RH	BJ	TG	YK
2	FO	GW	IR	LP	DA
3	SL	QI	ED	PF	OT
4	XV	CE	HB	VD	WM
5	KN	MQ	UX	AC	JY

Table 6. Averages of subjective display ratings: A/G task

	HUD number												
Pilot	1	2	3	4	5	6	7	8	9	10	11	13	14
1	2.7	2.4	2.4	2.5	2.4	1.6	1.8	1.9	1.7	1.9		1.6	2.8
2	3.8					3.1		3.5		3.2	3.3	3.2	3.8
3	3.7					3.5	3.5	3.5	3.3	3.5	3.5	3.5	3.9
4	2.5					2.6	3.4	2.6	2.7	2.7	2.4	2.6	2.5
5	3.6	3.4		3.5		3.2	3.2	3.2	3.2	3.2	3.4	3.5	3.6
6	3.9					3.2	3.1	3.3	3.4	3.4	3.9	3.6	4.3
7	4.4					3.3	3.9	3.4	3.2	3.3	4.6	3.3	3.9
8	3.1					3.1	3.3	3.4	3.3				
Ave	3.5	2.9	2.4	3.0	2.4	3.0	3.2	3.11	3.0	3.0	3.5	3.0	3.5

Table 7. Averages of subjective display ratings: A/G task (reduced data table)

	HUD number										
	1	6	7	8	9	10	11	12	13	14	Ave
Ladder	TO	TO	TI	BI	VA	SO	TO	TO	TO	TO	
Gearing	1:1	Var	Var	Var	Var	Var	1:1	1:1	Var	Var	
Quickening	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	
Fixed	No	No	No	No	No	No	Yes	Yes	Yes	Yes	
1	2.7	1.6	1.8	1.9	1.7	1.9		3.1	1.6	2.8	2.1
2	3.8	3.1		3.5		3.2	3.3	4.4	3.2	3.8	3.5
3	3.7	3.5	3.5	3.5	3.3	3.5	3.5	4.3	3.5	3.9	3.6
4	2.5	2.6	3.4	2.6	2.7	2.7	2.4	2.8	2.6	2.5	2.7
5	3.6	3.2	3.2	3.2	3.2	3.2	3.4	3.5	3.5	3.6	3.4
6	3.9	3.2	3.1	3.3	3.4	3.4	3.9	4.3	3.6	4.3	3.6
7	4.4	3.3	3.9	3.4	3.2	3.3	4.6	5.3	3.3	3.9	3.9
8	3.1	3.1	3.3	3.4	3.3						3.2
Ave	3.5	3.0	3.2	3.1	3.0	3.0	3.5	4.0	3.0	3.5	3.3

Table 8. Unusual attitudes

Unusual attitude	Initial conditions		Final condition [a]	
	Pitch, deg	Roll, deg	Pitch, deg	Roll, deg
1	+50	155 R	+45	60 L
2	–55	60 L	–55	100 R
3	–15	0	+45	45 R
4	+50	45 L	–50	135 L
5	+50	45 L	0	0
6	–55	135 R	0	0

[a]The evaluation pilot was to recover to this attitude.

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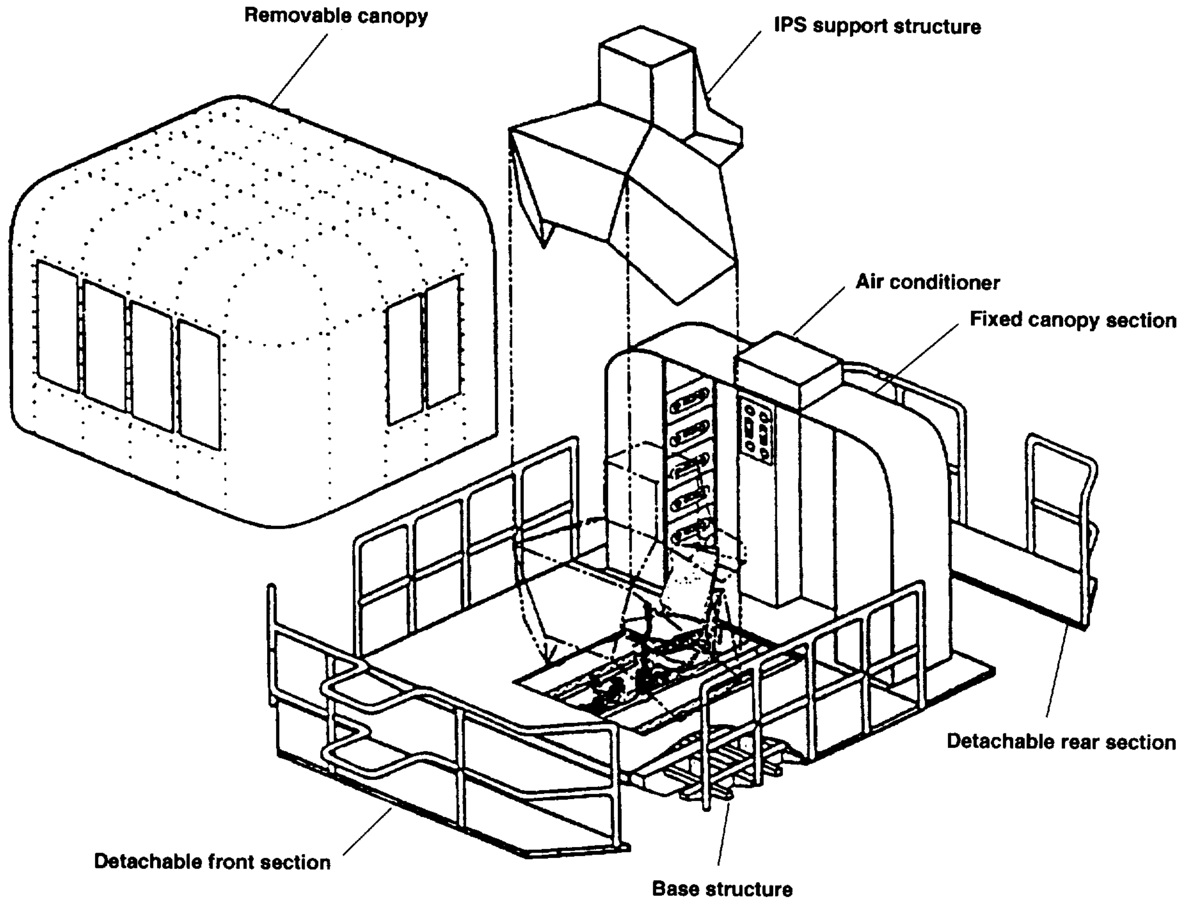

Figure 1. R-CAB cockpit used in simulation (ref. 3). (IPS: image presentation system)

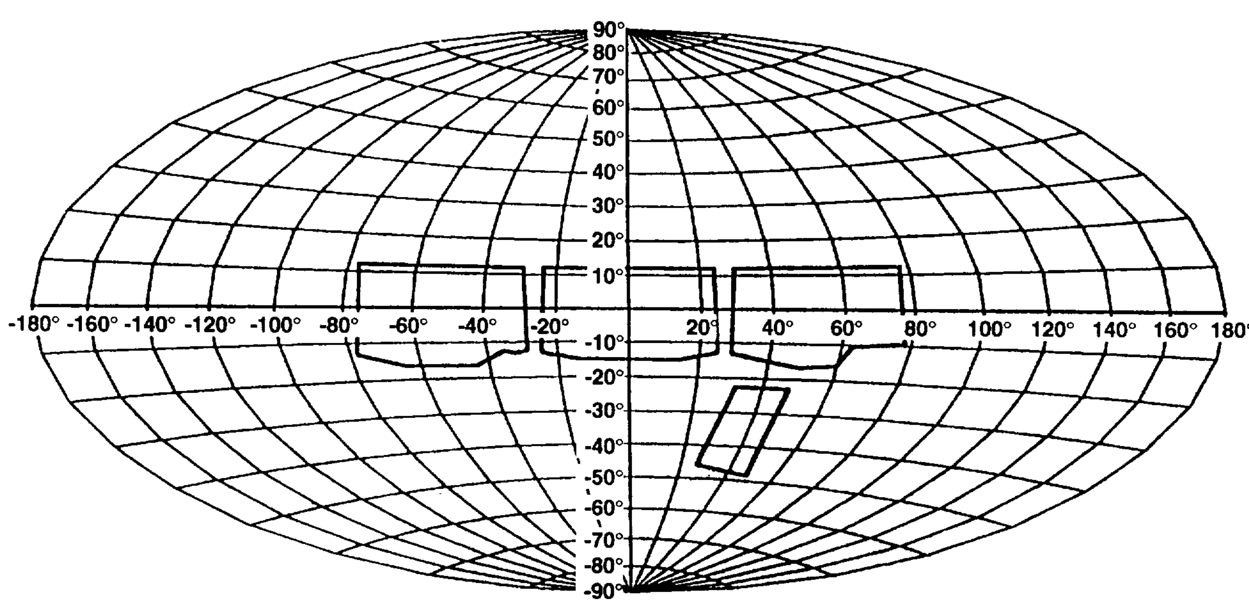

Figure 2. R-CAB field of view (ref. 3).

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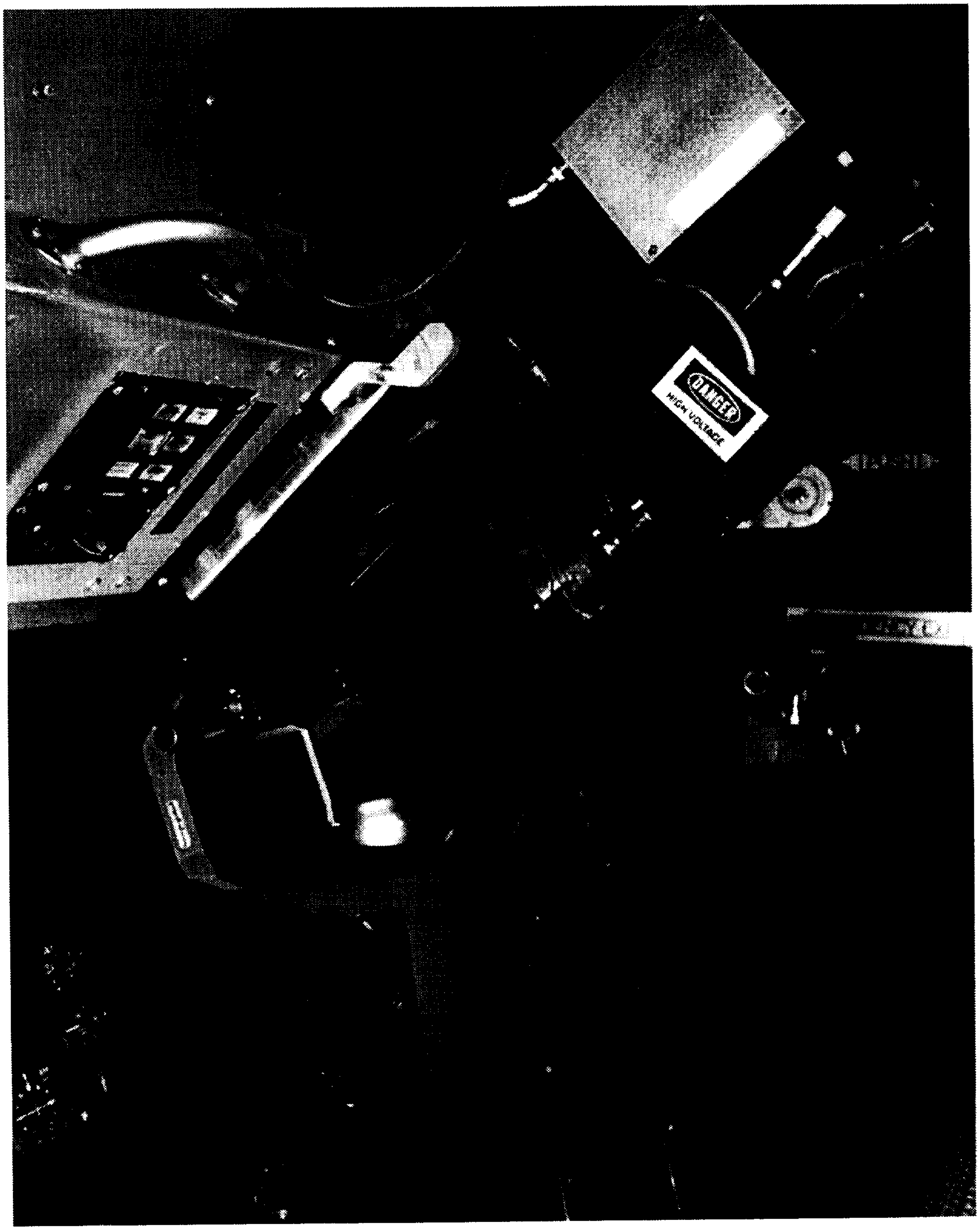

Figure 3. Experimental cockpit (AC90-0115-2).

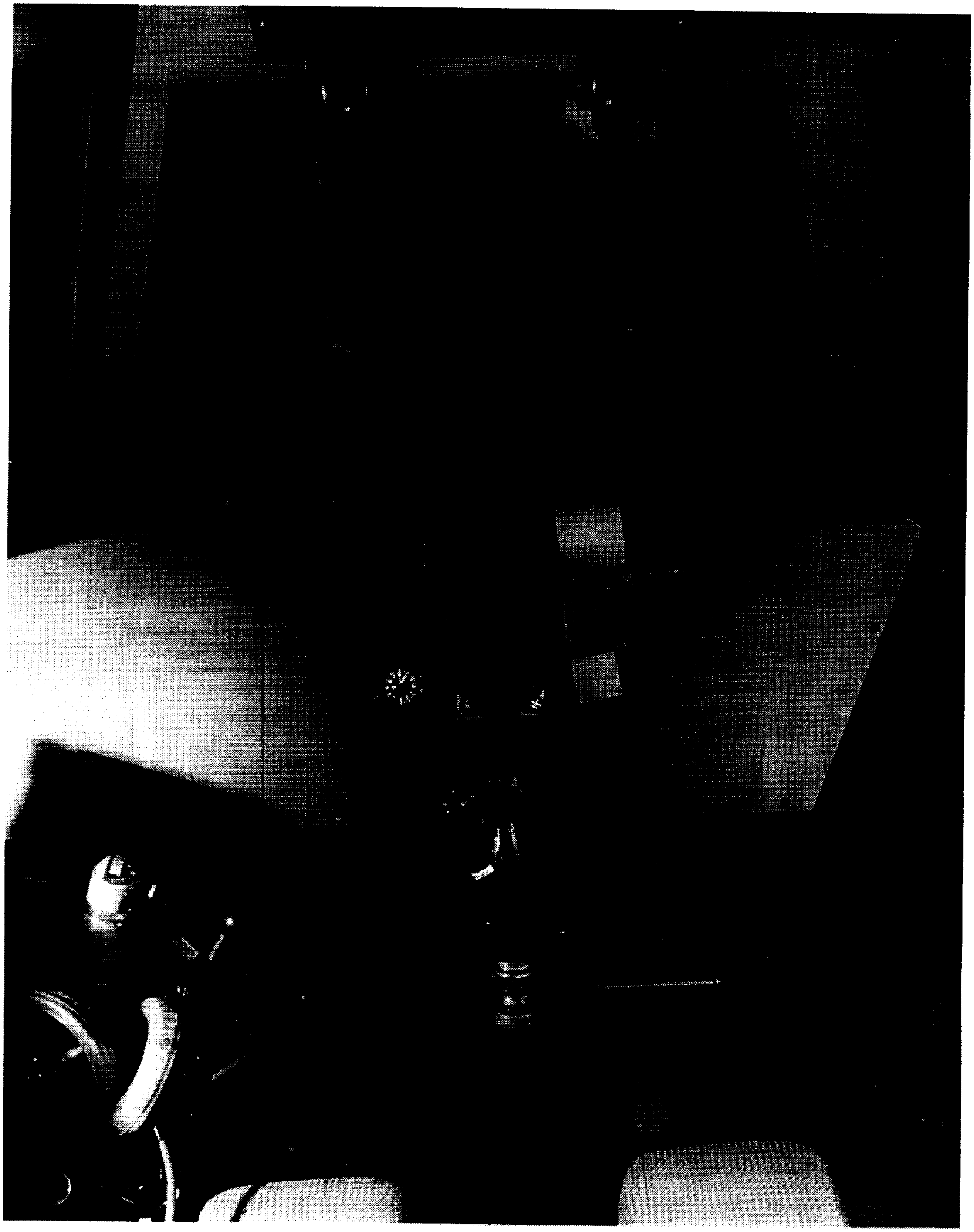

Figure 4. View of HUD and instrument panel (AC90-0178-67).

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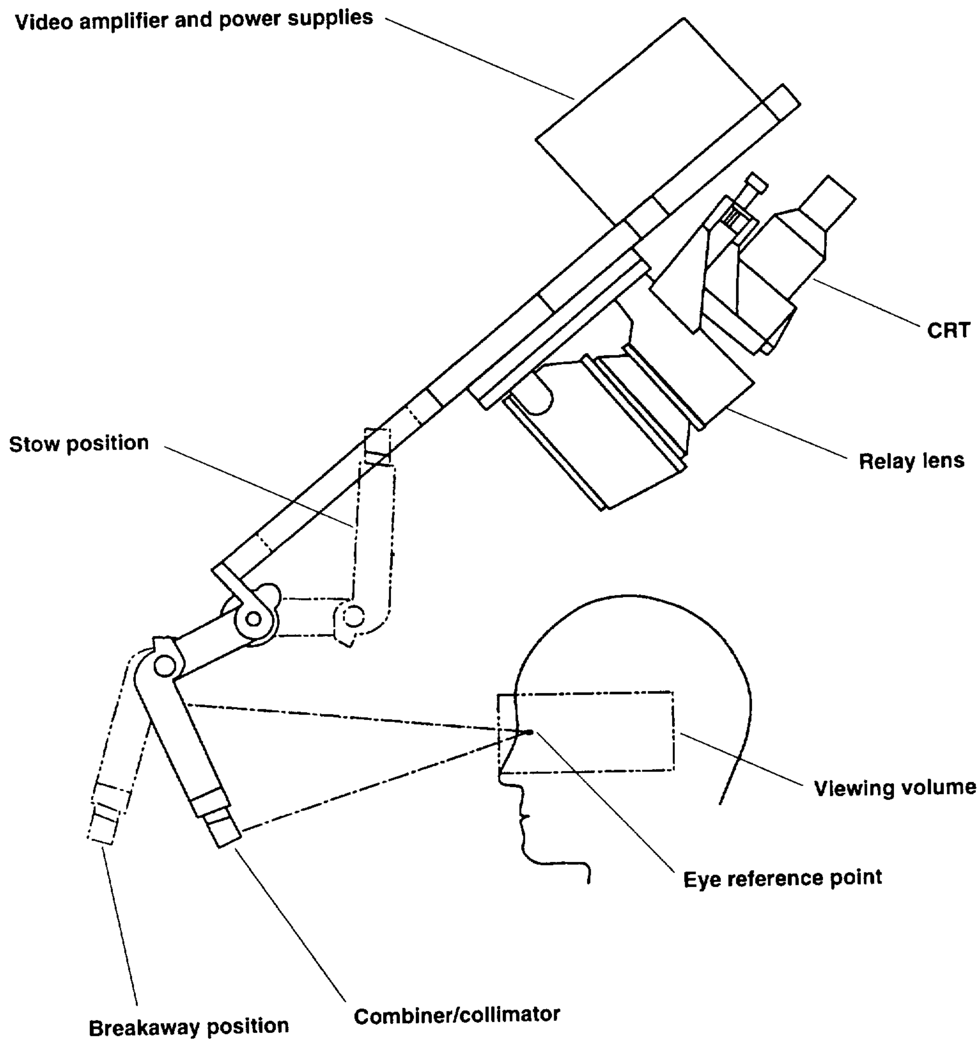

Figure 5. Flight dynamics HUD installation (AC90-0178-65). (CRT: cathode-ray tube)

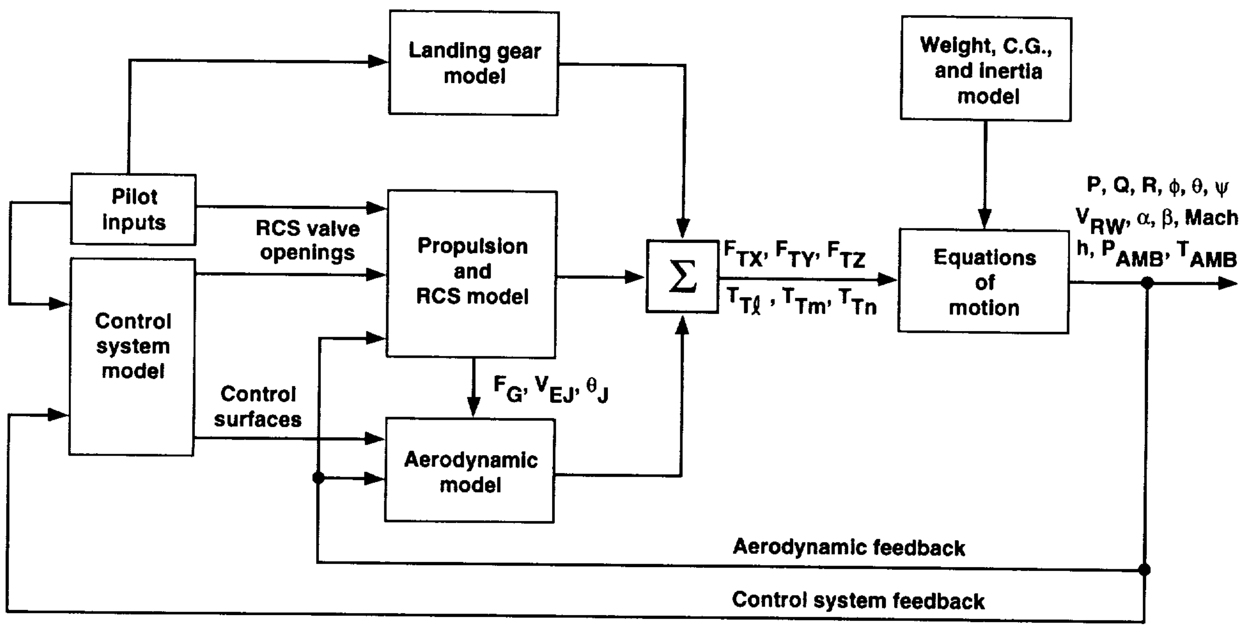

Figure 6. AV-8B Harrier simulation model structure (ref. 4). F_G, nominal gross thrust; θ_J, engine nozzle angle; V_{EJ}, equivalent jet velocity ratio; F_{TX}, F_{TY}, F_{TZ}, total forces in the x-, y-, and z-axes; $T_{T\ell}$, T_{Tm}, T_{Tn}, total torque about the x-, y-, and z-axes.

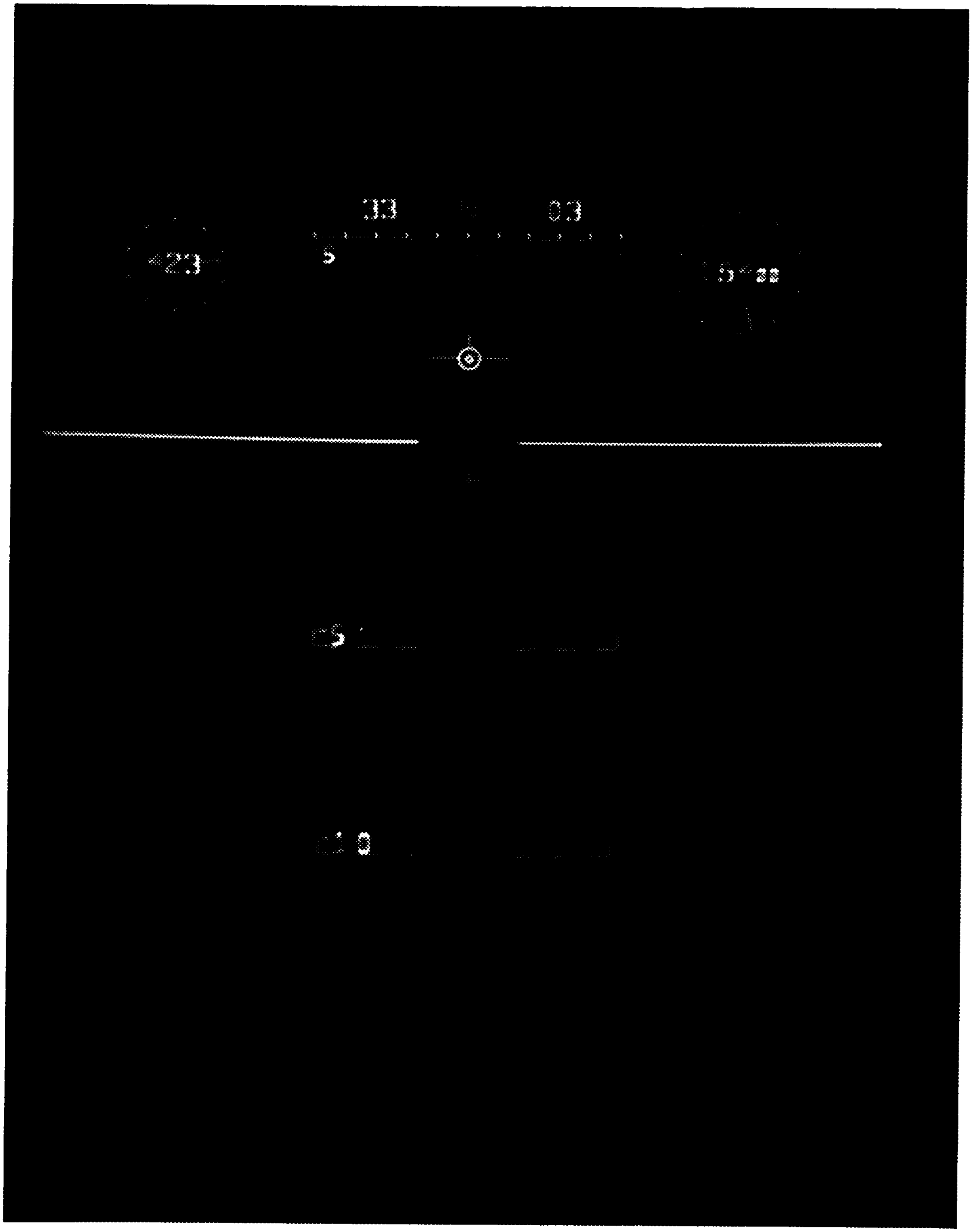

Figure 7. Basic HUD symbology.

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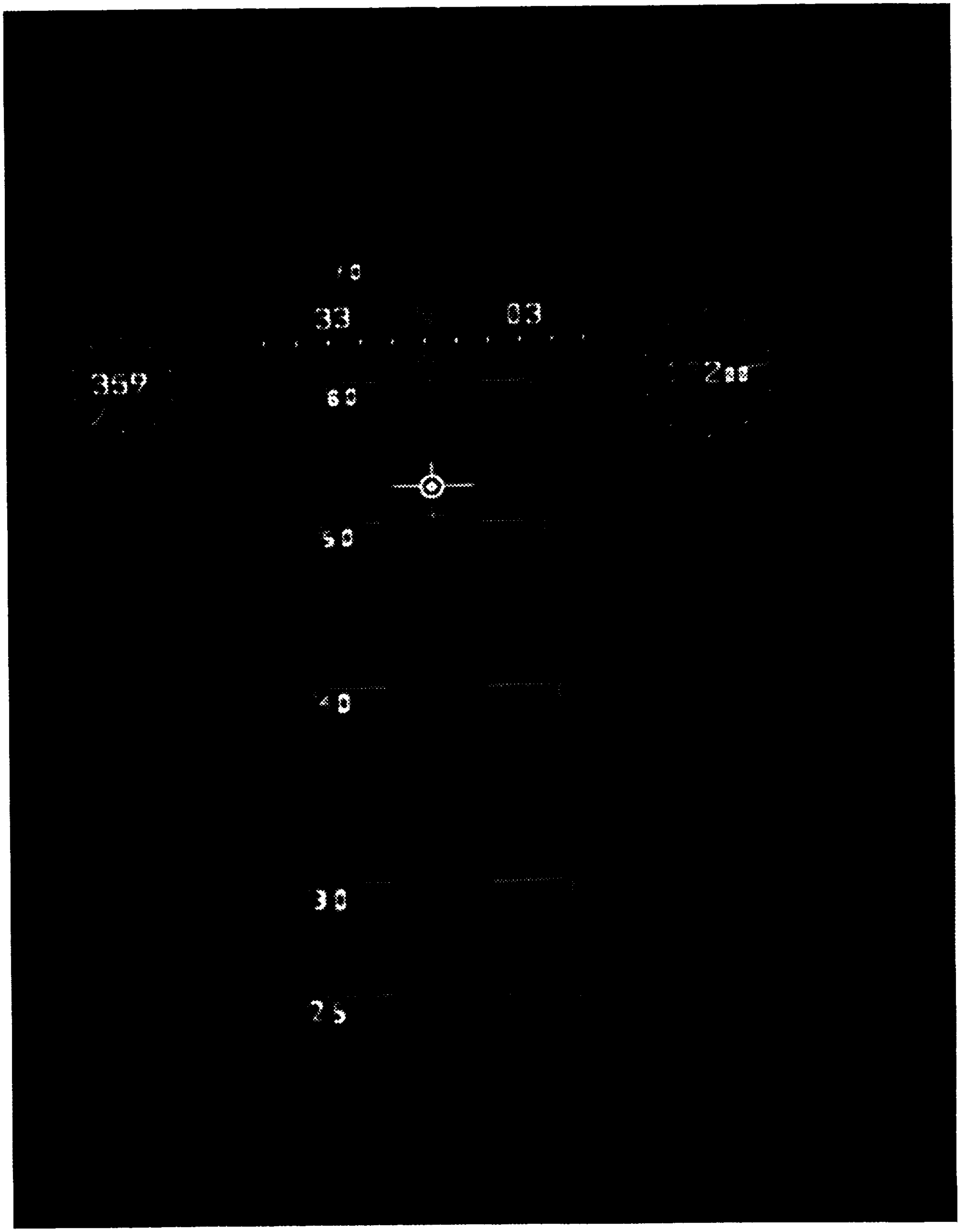

Figure 8. Climb–dive ladder with tapered lines (TO).

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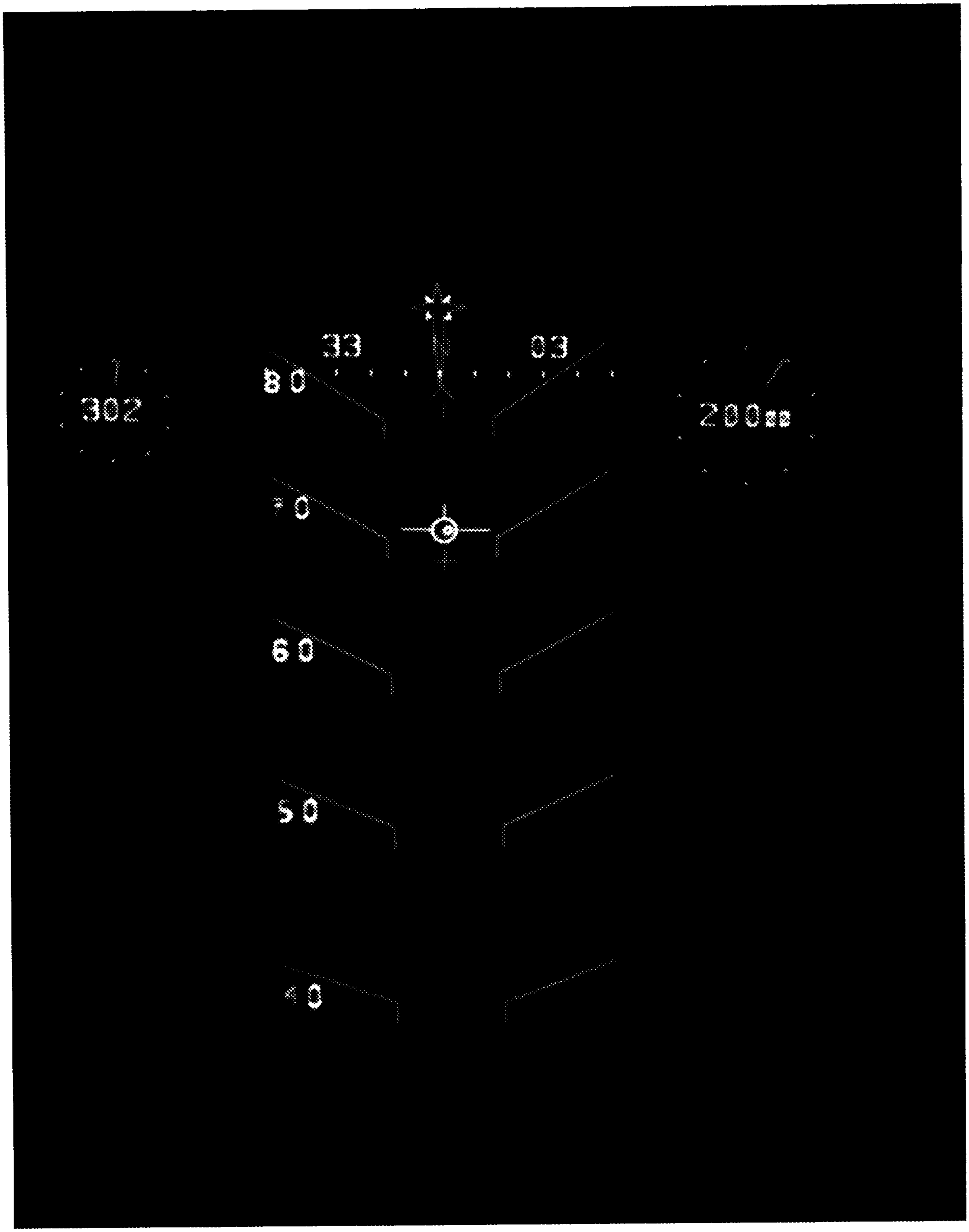

Figure 9. Climb–dive ladder with bent lines (BI).

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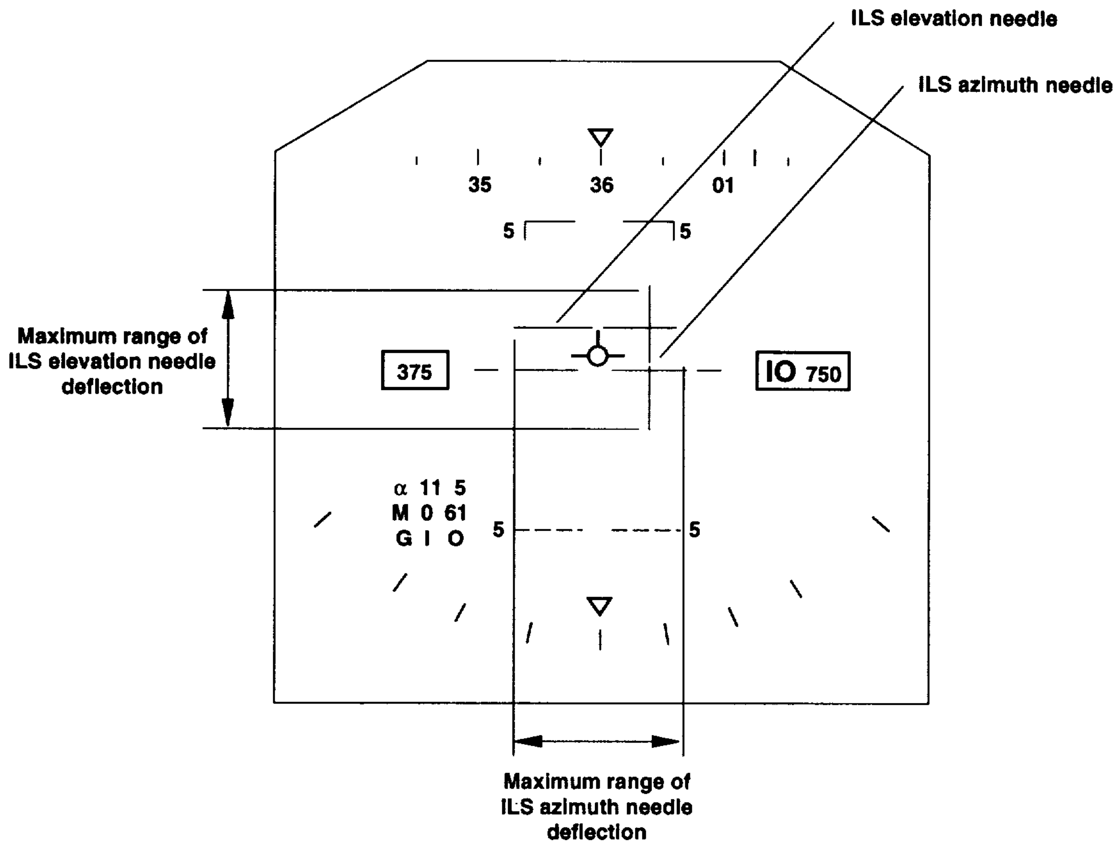

Figure 10. ILS guidance symbology.

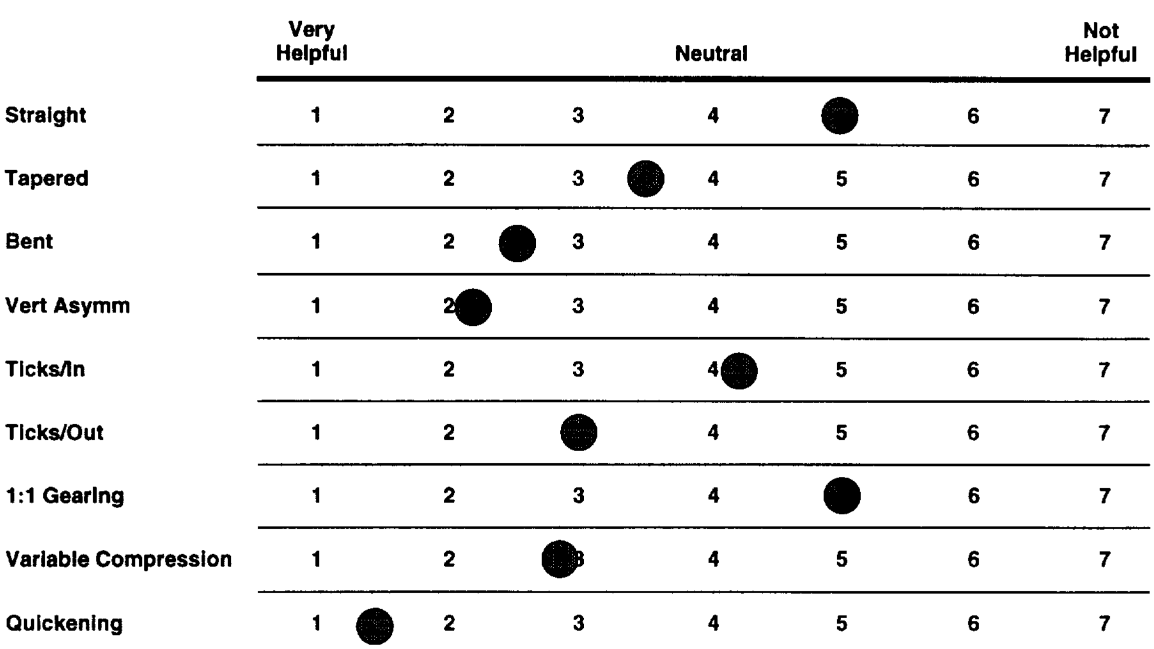

Figure 11. Subjective questionnaire responses averaged across subjects: A/A task.

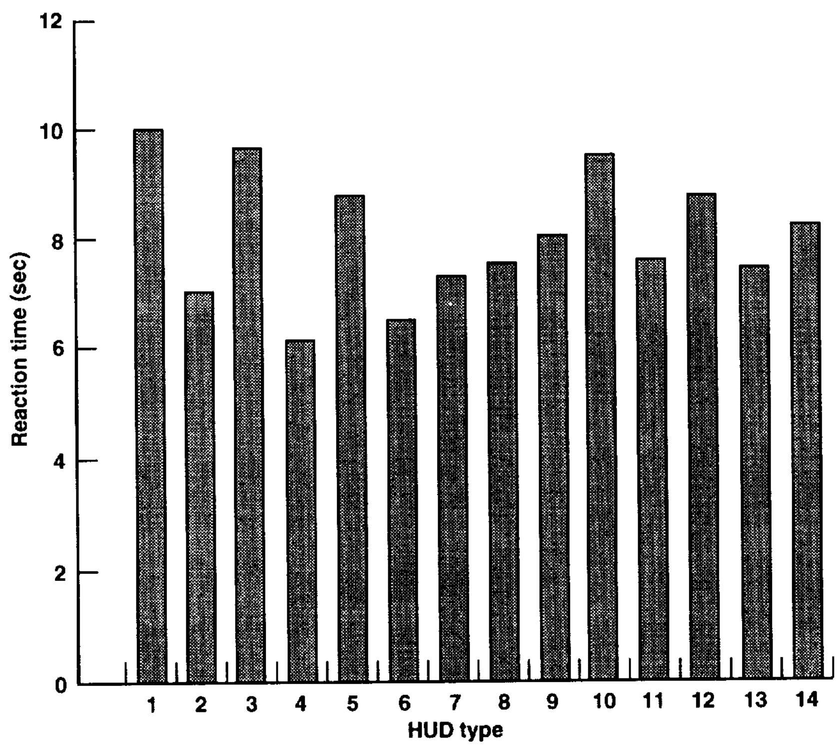

Figure 12. Reaction time as a function of HUD types: A/A task.

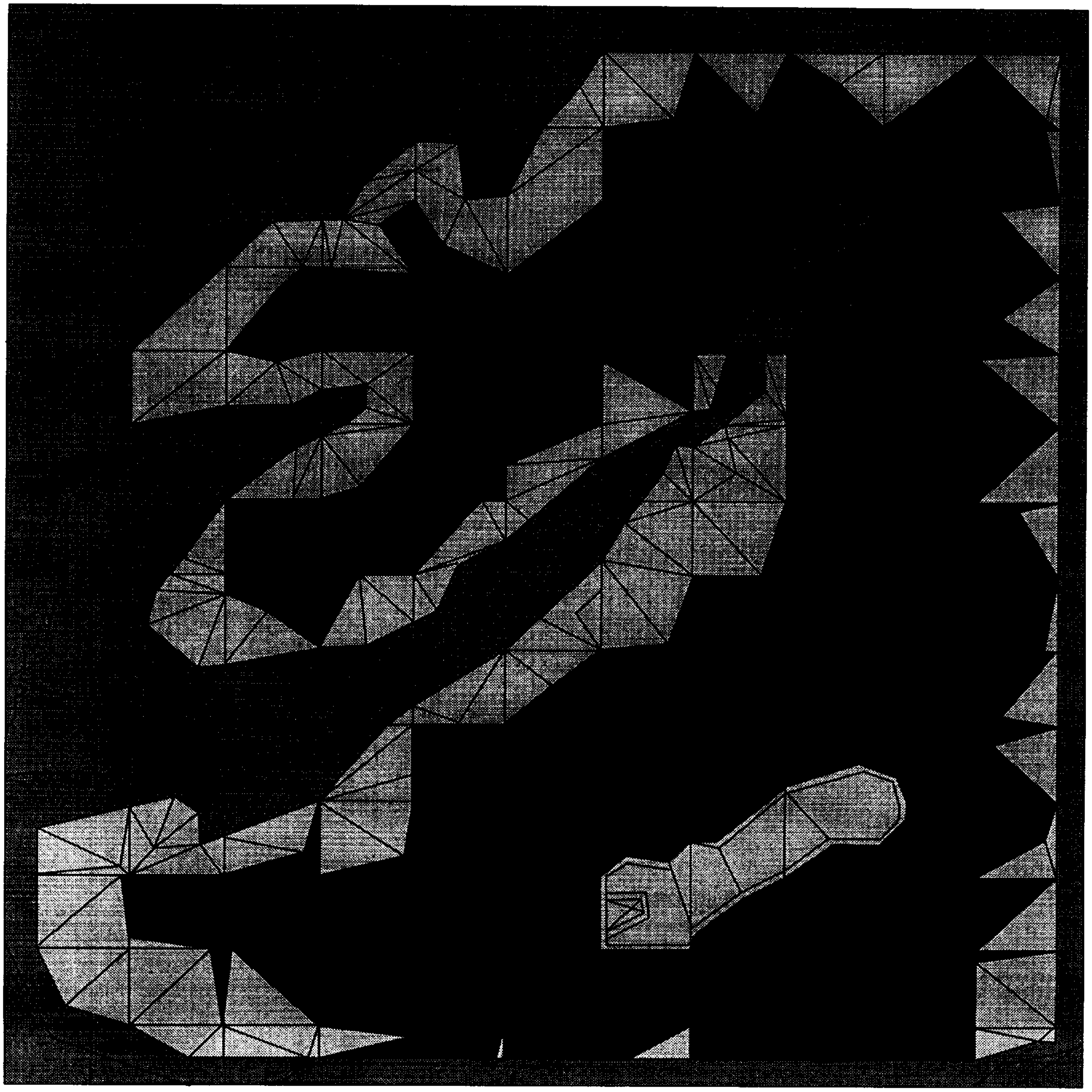

Figure 13. Map of low-level route.

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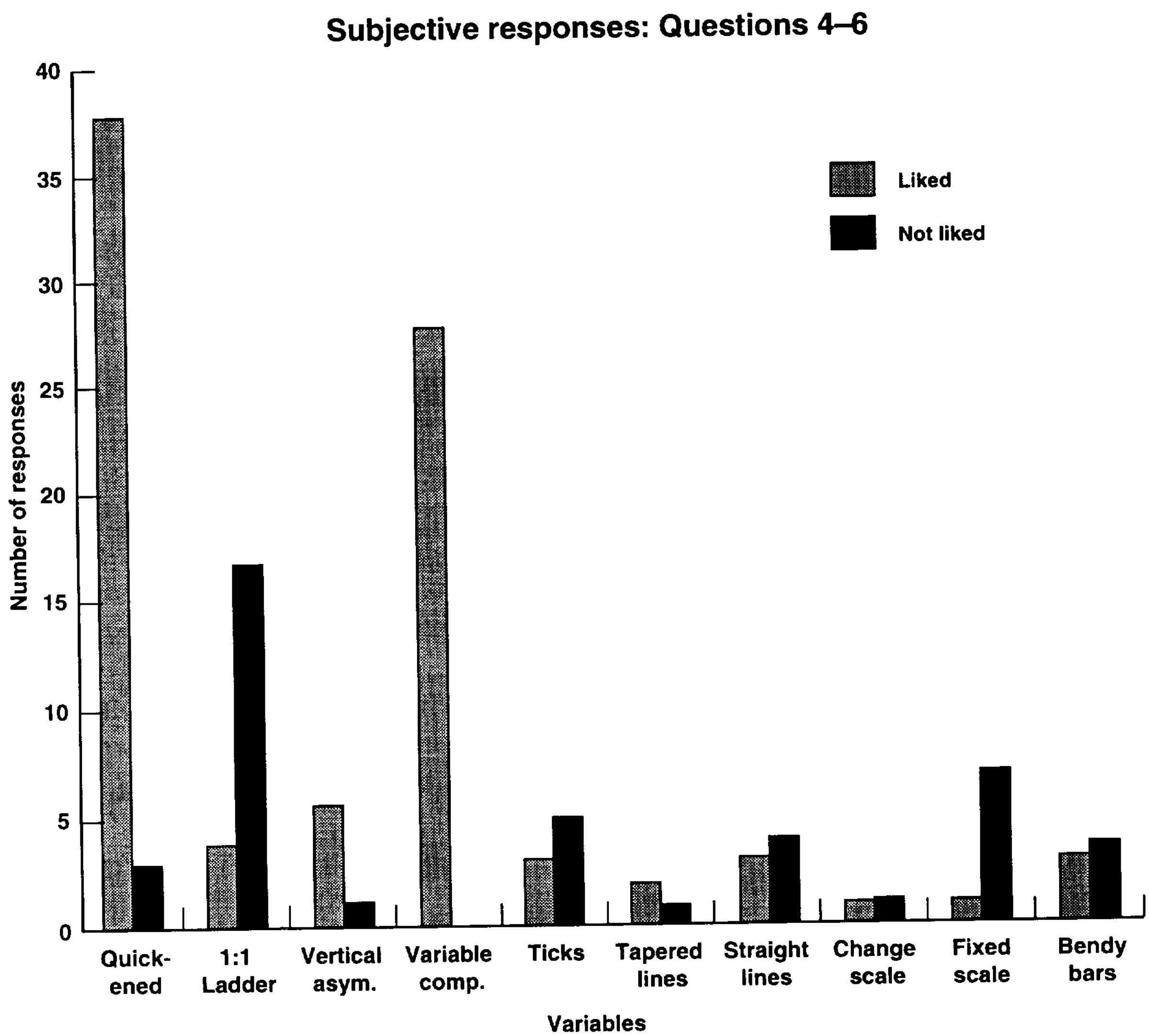

Figure 14. Subjective responses: A/G task.

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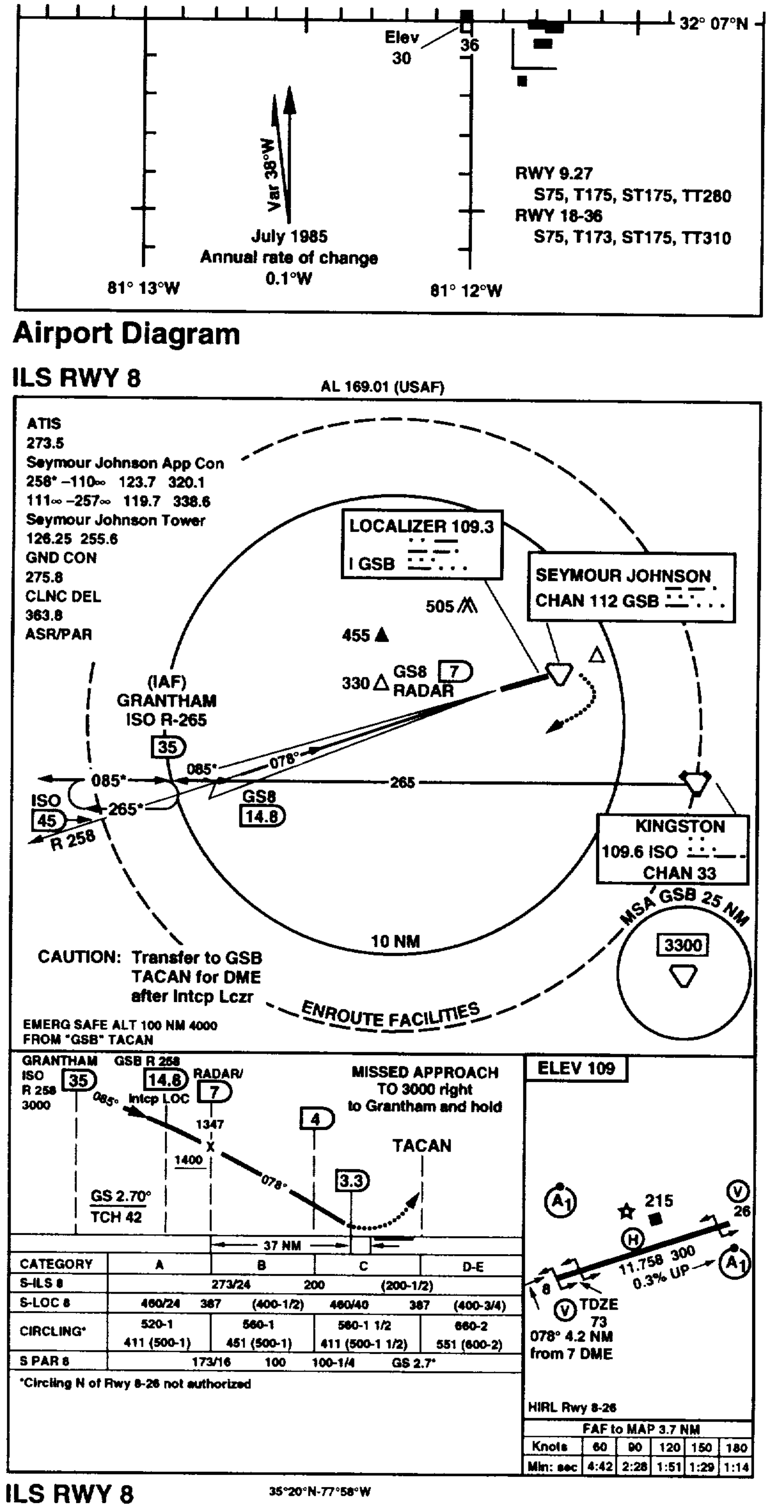

Figure 15. Approach procedure flown during ILS task.

Appendix A
Subjective Questionnaires

Background

One of the objectives of the TRISTAR simulations was to develop a methodology for display evaluation. It is clear that subjective pilot ratings play a key role in any such evaluation. Historically, pilot ratings have been patterned after one of two forms: The Cooper-Harper Pilot Rating (ref. 11) or a traditional "rate the difficulty on a scale of (e.g.) one to seven."

The Cooper-Harper ratings scale uses a decision tree to allow the pilot to "walk through" a series of dichotomous alternatives answering questions, such as "Is [the airplane] controllable?"; "Is adequate performance attainable with a tolerable workload?"; and "Is it satisfactory without improvement?" Following these dichotomies, the pilot makes a choice of at most three subalternatives.

Traditional rating scales either ask the pilot to rate the difficulty on a continuum of easy to hard or force him to make choices such as "Very Easy," "Easy," "Medium," "Hard," or "Very Hard." Examples of this type of scale are the NASA TLX workload rating scales (ref. 6). Similar ratings have been used in previous HUD simulations. The chief advantage for traditional scales is the ease with which a subject can learn them.

One disadvantage of such scales is the reluctance of subjects to use extreme values, and another is the reluctance of most pilots to use "difficult" ratings unless the display is quite bad. As a result, a seven point scale tends to becomes a three point scale.

The main advantage of the Cooper-Harper approach is that the logic tree involved produces consistent results, particularly with trained evaluators. This is evident in the area of aircraft handling qualities ratings. The difficulty is the time that an evaluator must spend learning the logic tree. When Cooper-Harper ratings are used with untrained evaluators, often a copy of the logic diagram is provided.

Display Evaluation

Two aspects of flight displays must be considered: Can the pilot determine the value of a specific parameter (such as airspeed)?; and Can the display be used to control that variable? As we have said, these two questions must be answered in the context of a specific mission scenario.

Because of the widespread acceptance of the Cooper-Harper rating scale in the flight-test community, two logic trees were constructed to rate the "readability" and the "flyability" of the display. These two decision trees are shown in figures A-1 and A-2. The readability rating indicates whether or not the pilot can determine the value of a specific parameter using the information display. The controllability rating follows the original Cooper-Harper decision tree closely. The difference between the display controllability rating and a Cooper-Harper handling qualities rating is the requirement that the evaluation pilot consider aircraft control **using the display for information**. This is essentially a Cooper-Harper rating of the airplane handling qualities in series with the display control laws.

Note that it is possible to have a readable display that is uncontrollable as well as an unreadable display that is controllable.

It is necessary for the pilot to consider every significant variable in turn to develop his display rating. This means that he must, for example, rate the readability and controllability of airspeed information, altitude information, etc. Of course he should rate the display on an overall basis.

It is imperative that any rating be taken in the context of a specific mission segment flown by a typical operational pilot. Cooper and Harper emphasized this requirement in their report, but it applies to all aircraft control-display evaluations as well. For this reason, the evaluation pilot must have a clear understanding of the performance criteria for the task to be performed. These criteria were provided to each evaluation pilot with his task briefing materials.

The rating card is shown in appendix A–1. Copies of the logic trees and performance criteria were also provided to the evaluation pilots.

Need for Pilot Comments

No display rating (or any aircraft rating for that matter) can tell the whole story with a single number (or pair of numbers). It is essential for the pilot to tell why he made the rating. In handling qualities, a pilot might rate two airplanes as "6" in roll. One airplane might be much too responsive and easily overcontrolled while the other might be extremely sluggish in its response. Clearly, a single "6" does not tell the whole story.

Space on the rating card for pilot comments was provided.

It is essential that the evaluating pilots be acquainted with the vocabulary of display ratings. They should be aware of pilot compensation in the form of leads or lags (or both). It would be well for them to be given some opportunity to practice their ratings on standard displays.

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Need for Validation

The NASA TLX workload rating scale was used as a validating "traditional scale" for all mission segments except the UA recovery. For this task, the questionnaire used in the previous UA study was used, and it is shown in appendix A–2.

The NASA TLX workload rating scale form is shown in appendix A–3.

Subject Qualification Questionnaire

Each evaluation pilot completed a brief questionnaire describing his experience, including HUD experience. This questionnaire, patterned after those used in previous studies, is shown in appendix A–4.

Postexperiment Questionnaire

Each evaluation pilot completed a postexperiment questionnaire. This questionnaire is shown in appendix A–5.

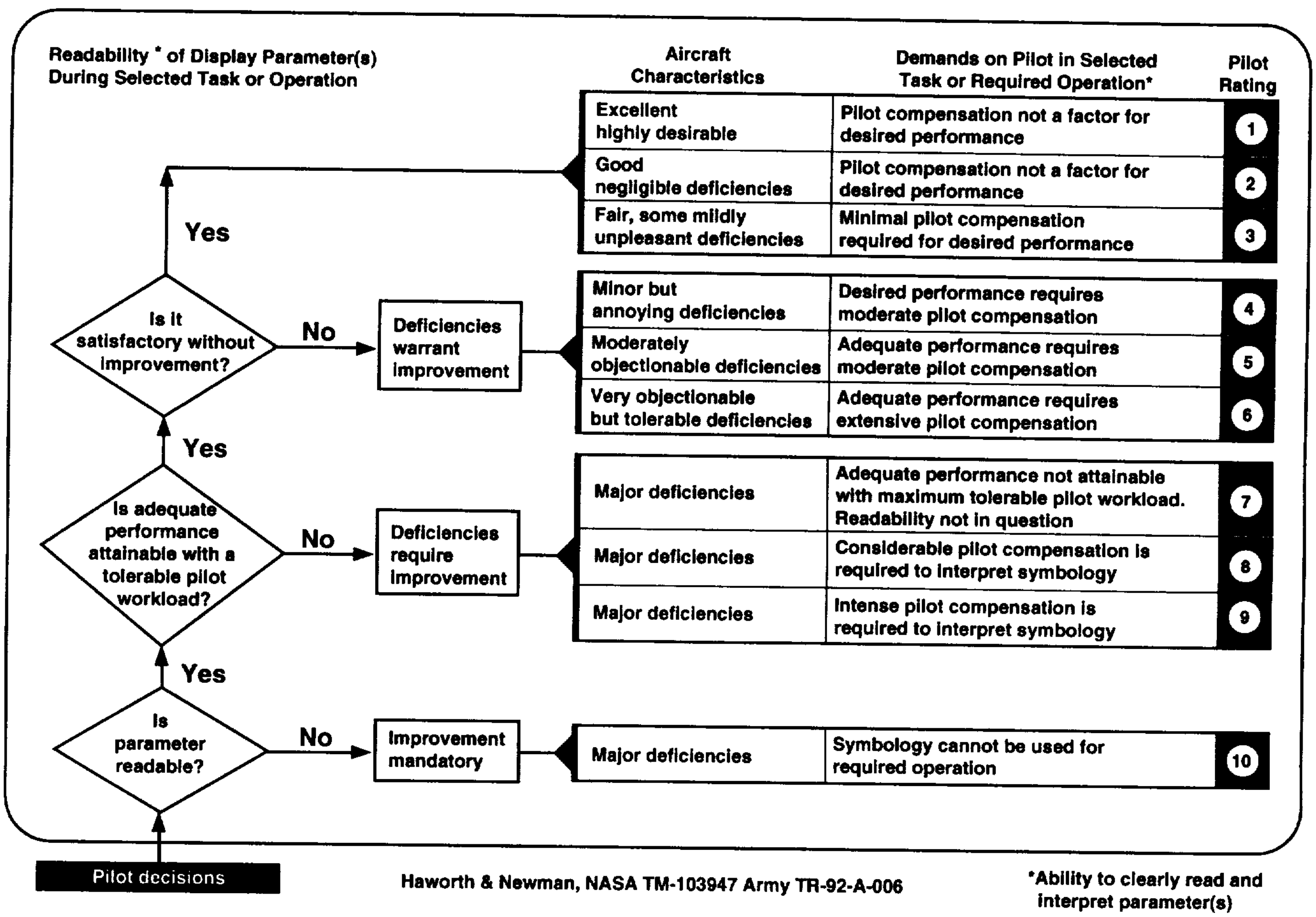

Figure A-1. Readability rating.

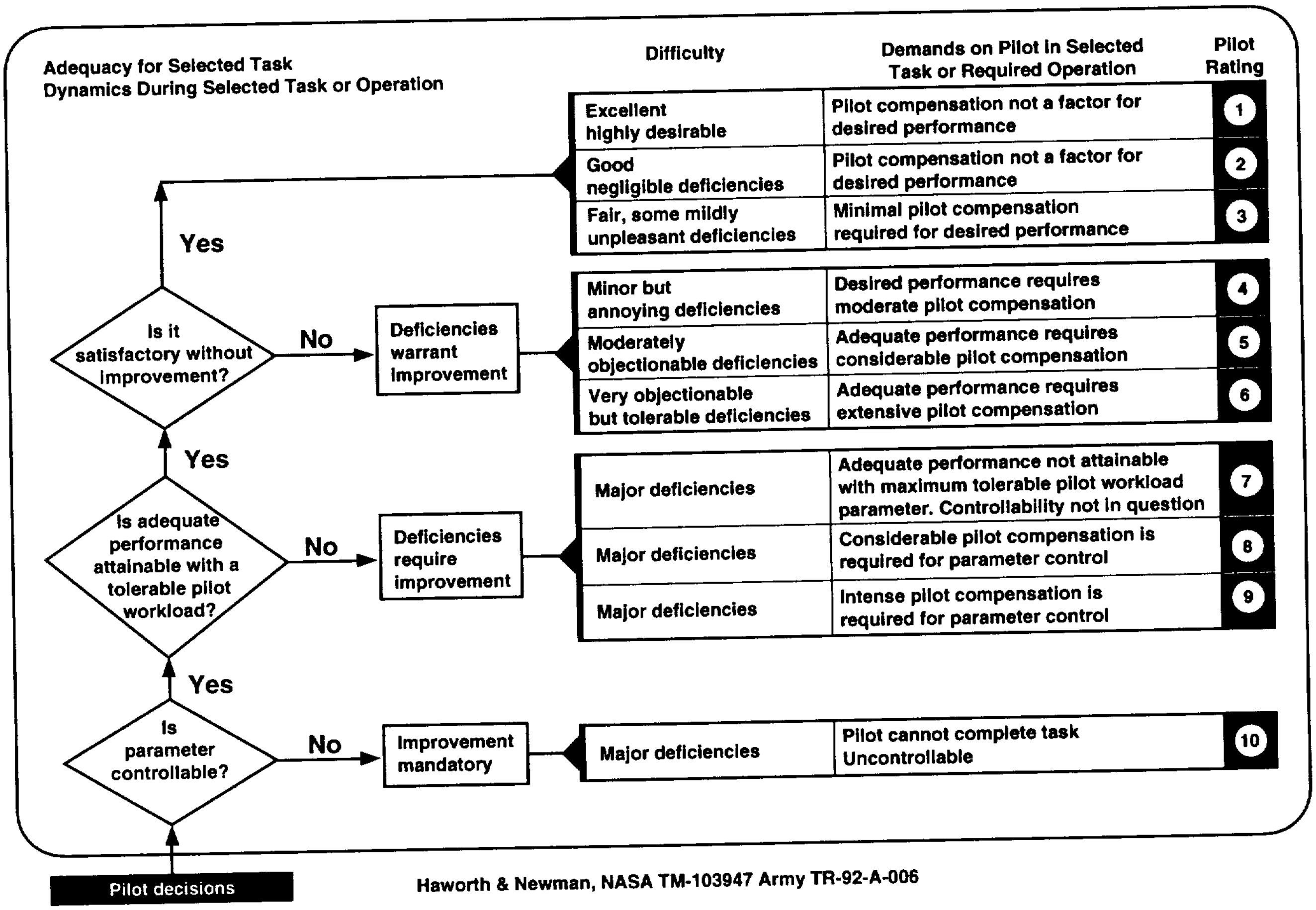

Figure A-2. Flyability rating.

Appendix A–1
Pilot Rating Card

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Name:________________________

Display:________________

Mission:________________

Sortie:___ Date:________

DISPLAY PARAMETER	READA-BILITY RATING	CONTROL-LABILITY RATING	REMARKS (include estimate of precision, need for parameter, reason for rating, etc.
Pitch Attitude			
Bank Angle			
Airspeed			
Altitude			
Flight Trajectory			
Ground Track			
OVERALL ORIENTAT'N		/////////	
OVERALL CONTROL	/////////		

Additional Comments:

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Appendix A–2
Rating Card Used in UA Task

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POST-FLIGHT QUESTIONNAIRE

Name: ______________________ Date: ______________________

Display: ______________________ Sortie: ______________________

1. How easy was it to fly using this display?

	Very Easy			Med-ium			Very Hard
Unusual Attitude Recovery	1	2	3	4	5	6	7

2. How easy was it to maintain orientation using this display?

	Very Easy			Med-ium			Very Hard
Unusual Attitude Recovery	1	2	3	4	5	6	7

3. What is your over all rating of this display?

	Very Easy			Med-ium			Very Hard
Unusual Attitude Recovery	1	2	3	4	5	6	7
What do you think it would be in your operations?	1	2	3	4	5	6	7

4. What do you like about this display?

5. What problems do you see in using this display?

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Name: ______________________________ Display: ______________________

6. Are there any changes you might recommend to this display to make it more acceptable?

7. Any other comments or suggestions?

Appendix A–3
NASA TLX Rating Card

Subject ID: ______________ Task ID: ____________________

RATING SHEET

MENTAL DEMAND

Low — High

PHYSICAL DEMAND

Low — High

TEMPORAL DEMAND

Low — High

PERFORMANCE

Good — Poor

EFFORT

Low — High

FRUSTRATION

Low — High

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

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Appendix A–4
Initial Questionnaire

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INITIAL QUESTIONNAIRE

Name:____________________________ Date:____________________

1. What type aircraft and HUD are you presently flying?

Aircraft: HUD:

2. What are your present flight qualifications?

( ) Instructor Pilot
( ) Flight Lead
( ) Aircraft Commander
( ) Other (please specify)

3. Indicate your flight experience.

	All Aircraft	Current Aircraft
Total flying time:	---------	---------
As Instructor Pilot	---------	---------
Actual Instrument	---------	---------
Actual instrument (using HUD)	---------	---------

4. Have you flown other HUD-equipped airplanes? If so, what airplanes and how much time?

5. Have you noticed any tendency towards disorientation when flying by reference to the HUD? If so, please describe.

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Appendix A–5
Final Questionnaire

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FINAL QUESTIONNAIRE

Name: ______________________________ Date: ____________________

1. Which of the following features would you feel would be beneficial in future HUDs?

	Very Helpful			Neutral			Not Helpful
Tapered Pitch Ladder:	1	2	3	4	5	6	7
Slanted Pitch Ladder (F-18):	1	2	3	4	5	6	7
Slanted and Tapered P. L.:	1	2	3	4	5	6	7
Slanted below horizon, Straight above	1	2	3	4	5	6	7
Full-time 2:1 Compression	1	2	3	4	5	6	7
Variable Pitch Compression	1	2	3	4	5	6	7
Automatic 2:1 Compression:	1	2	3	4	5	6	7
Elimination of precession "over the top"	1	2	3	4	5	6	7

2. Pitch compression, if installed, could be different for different HUD modes -- i. e. 1:1 for ILS approaches or air-to-ground weapon delivery and compressed for other modes (such as cruise). Would this influence your answers to question 1?

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Name:______________________ Display:____________________

3. Do you feel any tasks require 1:1 pitch scaling?
If so, which ones?

4. Do you foresee any problems with using different pitch scalings for different HUD modes?

5. Automatic "upset modes" have been suggested for unusual attitude recovery. Do you feel that the following automatic mode switching could be of benefit?

	Very Helpful			Neutral			Not Helpful
Automatic declutter:	1	2	3	4	5	6	7
Automatic pitch: compression	1	2	3	4	5	6	7
Automatic declutter and compression	1	2	3	4	5	6	7

6. What should trigger such pitch scale compression?

Excessive bank angle	( )	what value?
Excessive pitch attitude	( )	what value?
Combination of pitch and bank	( )	what values?
Stick-mounted paddle switch, i. e. pilot selected.	( )	
Automatic, but with stick mounted paddle switch to cancel	( )	

Name:____________________________ Display:________________________

7. Do you have any comments regarding "upset modes"?

8. Were your instructions and questionnaires clear?

9. Were there any problems with the simulator?

10. Any other comments, suggestions, criticisms, etc. will be welcome.

Appendix B
Tristar Trends Database Output

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Appendix B–1
Wordscan Output Example

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WORDSCAN OUTPUT FOR TRISTAR DATABASE

SCAN.TRXTS1 5-SEP-90 14:15:13

			Pilot Comments	Duration	Tzero
FLT	3 CTR	21	HUD01/UA01:+50,155R:+45, 60L	12.00	0:00:00.024
FLT	3 CTR	22	HUD01/UA02:-55, 60L:-55,100R	5.50	0:00:00.024
FLT	3 CTR	23	HUD01/UA03:-15, 0R:+45, 45R	10.87	0:00:00.024
FLT	3 CTR	26	HUD01/UA06:+50, 30L:-50,135L	13.85	0:00:00.024
FLT	3 CTR	27	HUD01/UA07:+50, 45L: 0, 0	10.99	0:00:00.024
FLT	3 CTR	28	HUD01/UA08:-55,135R: 0, 0	9.50	0:00:00.024

			Pilot Comments	Duration	Tzero
FLT	4 CTR	29	HUD02/UA00:PRACTICE	56.16	0:00:00.024
FLT	4 CTR	30	HUD02/UA02:-55, 60L:-55,100R	4.73	0:00:00.024
FLT	4 CTR	32	HUD02/UA06:+50, 30L:-50,135L	13.85	0:00:00.024
FLT	4 CTR	33	HUD02/UA08:-55,135R: 0, 0	9.14	0:00:00.024
FLT	4 CTR	34	HUD02/UA01:+50,155R:+45, 60L	7.06	0:00:00.024
FLT	4 CTR	35	HUD02/UA03:-15, 0R:+45, 45R	9.65	0:00:00.024
FLT	4 CTR	37	HUD02/UA07:+50, 45L: 0, 0	16.49	0:00:00.024

			Pilot Comments	Duration	Tzero
FLT	5 CTR	38	HUD04/UA00:PRACTICE	46.90	0:00:00.024
FLT	5 CTR	39	HUD04/UA03:-15, 0R;+45, 45R	10.66	0:00:00.024
FLT	5 CTR	40	HUD04/UA06:+50, 30L:-50,135L	13.82	0:00:00.024
FLT	5 CTR	41	HUD04/UA01:+50,155R;+45, 60L	8.76	0:00:00.024
FLT	5 CTR	43	HUD04/UA07:+50, 45L: 0, 0	12.26	0:00:00.024
FLT	5 CTR	44	HUD04/UA02:-55, 60L:-55,100R	6.62	0:00:00.024
FLT	5 CTR	46	HUD04/UA08:-55,135R: 0, 0	8.16	0:00:00.024

			Pilot Comments	Duration	Tzero
FLT	7 CTR	57	HUD06/AA00:PRACTICE	29.86	0:00:00.024
FLT	7 CTR	58	HUD06/AA00:PRACTICE	58.92	0:00:00.024
FLT	7 CTR	59	HUD06/AA1A:+20, 20R:+20, 45L	0.00	0:00:00.000
FLT	7 CTR	60	HUD06/AA1B:+50, 45L:+20, 45R	0.00	0:00:00.000
FLT	7 CTR	62	HUD06/AA1D:+70,160L:+30, 45L	0.00	0:00:00.000
FLT	7 CTR	63	HUD06/AA1E:-20, 20L:-20, 45L	0.00	0:00:00.000
FLT	7 CTR	65	HUD06/AA1D:+70,160L:+30, 45L	0.00	0:00:00.000
FLT	7 CTR	66	HUD06/AA2A:+70,160L:+30, 45L	0.00	0:00:00.000

			Pilot Comments	Duration	Tzero
FLT	8 CTR	69	HUD02/AA4E:+20, 20R:+20, 45L	0.00	0:00:00.000
FLT	8 CTR	70	HUD02/AA3B:+50, 45L:+20, 45R	0.00	0:00:00.000
FLT	8 CTR	72	HUD02/AA2A:+70,160L:+30, 45L	0.00	0:00:00.000
FLT	8 CTR	73	HUD02/AA4C:+70,150L:+30, 45L	0.00	0:00:00.000
FLT	8 CTR	74	HUD02/AA2E:+50, 45L:+20, 45R	0.00	0:00:00.000
FLT	8 CTR	75	HUD02/AA1A:+20, 20R:+20, 45L	0.00	0:00:00.000
FLT	8 CTR	76	HUD02/AA3C:+70,160R:+30, 45R	0.00	0:00:00.000
FLT	8 CTR	77	HUD02/AA4B:+50, 45R:+50, 20L	21.91	0:00:00.024
FLT	8 CTR	79	HUD02/AA3D:-20, 20R;-40, 20R	0.00	0:00:00.000
FLT	8 CTR	80	HUD02/AA1D:+70,160L:+30, 45L	0.00	0:00:00.000
FLT	8 CTR	82	HUD02/AA1E:-20, 20L;-20, 45L	0.00	0:00:00.000
FLT	8 CTR	83	HUD02/AA2C:+20, 20R:+20, 45L	0.00	0:00:00.000
FLT	8 CTR	84	HUD02/AA2A:+70,160L:+30, 45L	0.00	0:00:00.000
FLT	8 CTR	85	HUD02/AA2D:-20, 20R;-40, 20R	0.00	0:00:00.000

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Appendix B–2
Item Definitions

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TRISTAR PARAMETER DEFINITIONS

ITEMS.TRXTS1 5-SEP-90 14:20:08

ML Mnemonic-ordered list

Seq	Item	Description	Units	Item-Code	Grp	Fltr Freq	Input Rate/Dec
1	ALFA	ANGLE OF ATTACK	DEG		TC		
2	ALT	BAROMETER ALTITUDE	FEET		TC		
3	ALTHUD				TC		
4	AX	X-ACCEL AIRCRAFT CG	RAD/S2		TC		
5	AY	Y-ACCEL AIRCRAFT CG	RAD/S2				
6	AZ	Z-ACCEL AIRCRAFT CG	RAD/S2		TC		
7	AZMTHER	AZIMUTH ERROR	FEET		TC		
8	BETA	SIDESLIP ANGLE	DEG		TC		
9	DELTAS	OWN TARGET SPEED	KNOTS		TC		
10	DELTVEQ	OWN-TARGET SPEED	KNOTS		TC		
11	DIVEERR	OWN DIVE ANGLE	DEG		TC		
12	DPHICB	ROLL INPUT	INCHES		TC		
13	DPSICB	YAW INPUT	INCHES		TC		
14	DTHECB	PITCH INPUT	INCHES		TC		
15	DURTIME	LENGTH OF RUN IN SECONDS	SEC		TC		
16	EPSGS	GLIDE SLOPE ERROR	DEG		TC		
17	EPSLOC	LOCALIZED ERROR	DEG		TC		
18	ETRVR	ELAPSED TIME FROM RVR=0	SEC		ΔΔ		
19	EVSW1						
20	EVSW2						
21	EVSW3						
22	EVSW4						
23	EVSW5						
24	EVSW6						
25	EVSW7						
26	EVSW8						
27	EVSW9						
28	E_TLX	EFFORT - RATING SHEET	%		PR		
29	F_TLX	FRUSTRATION - RATING SHEET	%		PR		
30	GAMH	FLT ANGLE CLOCKWISE FROM NORTH	RAD		TC		
31	GAMV	FLIGHT PATH ANGLE	RADS		TC		
32	GSERR	GLIDE SLOPE ERROR	FEET		TC		
33	HAGLCT5	RADAR ALTITUDE	FEET				
34	HCG	Z-POSITION OF AIRCRAFT	FEET		TC		
35	HHGS	GLIDE SLOPE ERROR	FEET		TC		
36	HUD10DEF	SO:STRA.OUT VAR QM:QUICK.MOVE			HD		
37	HUD11DEF	TO:TAPER.OUT 1:1 QF:QUICK.FIX			HD		
38	HUD12DEF	TO:TAPER.OUT 1:1 NQF:NOQUI.FIX			HD		
39	HUD13DEF	TO:TAPER.OUT VAR QF:QUICK.FIX			HD		
40	HUD14DEF	TO:TAPER.OUT VAR NQF:NOQUI.FIX			HD		
41	HUD1DEF	TO:TAPER.OUT 1:1 QM:QUICK.MOVE			HD		
42	HUD2DEF	TI:TAPER.IN 1:1 QM:QUICK.MOVE			HD		
43	HUD3DEF	BI:BENDY.IN 1:1 QM:QUICK.MOVE			HD		
44	HUD4DEF	VA:VERT ASYM 1:1 QM:QUICK.MOVE			HD		
45	HUD5DEF	SO:STRA.OUT 1:1 QM:QUICK.MOVE			HD		
46	HUD6DEF	TO:TAPER.OUT VAR QM:QUICK.MOVE			HD		
47	HUD7DEF	TI:TAPER.IN VAR QM:QUICK.MOVE			HD		

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48	HUD8DEF	BI:BENDY,IN VAR QM:QUICK,MOVE			HD
49	HUD9DEF	VA:VERT ASYM VAR QM:QUICK,MOVE			HD
50	IQ2	QUICKENING=1 NON-QUICKENING=0			TC
51	MD_TLX	MENTAL DEMAND - RATING SHEET	%		PR
52	PB	ROLL RATE (BODY FRAME)	RAD/S		TC
53	PBD	ROLL ACCEL (BODY FRAME)	RAD/S2		TC
54	PD_TLX	PHYSICAL DEMAND - RATING SHEET	%		PR
55	PHI	OWNSHIP ROLL	DEG		TC
56	PHID	ROLL EULER RATE	RAD/S		
57	PHIHUD				TC
58	PIPRER	PIPPER ERROR	MRADS		TC
59	PLNERR	DIST ERROR FROM FLIGHT PATH	FEET		TC
60	PRERVR	TIME BERFORE RVR=0	SEC		ΔΔ
61	PRLVCB	POWER INPUT			TC
62	PSI	OWNSHIP YAW	DEG		TC
63	PSID	YAW EULER RATE	RAD/S		
64	PSIHUD				TC
65	P_TLX	PERFORMANCE - RATING SHEET	%		PR
66	QB	PITCH RATE (BODY FRAME)	RAD/S		TC
67	QBD	PITCH ACCEL (BODY FRAME)2	RAD/S2		TC
68	QUICKEN				TC
69	QUIKACS				TC
70	RALTERR	OWN-REF RADAR ALT	FEET		
71	RB	YAW RATE (BODY FRAME)	RAD/S		TC
72	RBD	PITCH ACCEL (BODY FRAME)	RAD/S2		
73	RC_1OT	OVERALL - RATING CARD	1-7		PR
74	RC_1PT	PRESENT TASK - RATING CARD	1-7		PR
75	RC_2A	MOTION HUD TO READ WORLD	0-7		PR
76	RC_2B	MOTION OF PITCH LADDER/HORIZ	0-7		PR
77	RC_2C	MOTION OF SCALES	0-7		PR
78	RC_2D	MOTION OF AIRPLANE SYMBOL	0-7		PR
79	RC_2E1	MOTION V/V DIAMOND STRAIGHT	0-7		PR
80	RC_2E2	MOTION V/V DIAMOND EASY TURNS	0-7		PR
81	RC_2E3	MOTION V/V DIAMOND HARD TURNS	0-7		PR
82	RC_3P	EASE OF MAINTAINING PITCH	0-7		PR
83	RC_3R	EASE OF MAINTAINING ROLL	0-7		PR
84	RPMHAR	RPM			
85	RVR	VISUAL RANGE	FEET		TC
86	THED	PITCH EULER RATE	RAD/S		
87	THET	OWNSHIP PITCH	DEG		TC
88	THETAJ				
89	THTHUD				TC
90	TRLVCB				
91	T_TLX	TEMPORAL - RATING SHEET	%		PR
92	UB	X-VEL FORWARD (BODY FRAME0	FPS		
93	UBD	X-ACCEL FORWARD (BODY FRAME0	FPS2		TC
94	VB	Y-VEL FORWARD (BODY FRAME0	FPS		
95	VBD	Y-ACCEL FORWARD (BODY FRAME0	FPS2		
96	VD	OWN VELOCITY TO EARTH CENTER	FPS		
97	VEQ	OWNSHIP AIRSPEED	KNOTS		TC
98	VEQERR	OWN REFERENCE SPEED	KNOTS		TC
99	VEQHUD	HUD AIRSPEED	KNOTS		TC
100	VVEL				TC
101	VVEL2			VVEL	

102	WB	Z-VEL FORWARD (BODY FRAME0	FPS	TC
103	WBD	Z-ACCEL FORWARD (BODY FRAME0	FPS2	TC
104	XCG	X-POSITION OF AIRCRAFT	FEET	TC
105	XHUDMOD	HUD MODEL NUMBER	1-14	TC
106	XHVV	X-VELOCITY VECTOR		TC
107	XITASK	TASK NUMBER	1-6	TC
108	XMOVE	SIDESCLS FIXED=0		TC
109	XNRUN	RUN NUMBER		TC
110	XNUMSEG	SEGMENT NUMBER		TC
111	XOSHOOT	NO SHOOT DEPRESSED=1		TC
112	XQ2	QUICKENING=1,NON-QUICKENING=0		TC
113	XQUICK	QUICKENING=1,NON-QUICKENING=0		TC
114	XRANGE			TC
115	XTRIG	TRIGGER DEPRESSED=1		TC
116	XWINDO	IN WINDOW=1,NOT IN WINDOW=0		TC
117	YCG	Y-POSITION OF AIRCRAFT	FEET	TC
118	YHACS			TC
119	YHVV	Y-VELOCITY VECTOR		TC

Appendix B–3
Flight Descriptions

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EXAMPLE OF FLIGHT DESCRIPTIONS

```
FLIGHTS.TRXTS1                                5-SEP-90  14:21:52

          FLIGHTS: Show Flight Descriptions
          *********************************

$ Enter BRIEF, NOTES or FULL :
+F

$          LOOK FOR:
+*

$ Enter flight(s) of interest :
+200-225


 ******************************************************************************


   AIRCRAFT:  TS1             UNUSUAL ATTITUDE - HUD 2
     FLIGHT:  200            LOCATION: VMS
   FLT DATE: 16 MAR 90       COUNTERS:  1013- 1016
   DIRECTOR:                   PILOTS:

 1.  OVERALL RATING             Very Good             Medium          Very Poor
     ------------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task      ..............3.5
              Overall                  ..............3.5

 2.  APPARENT MOTION         Didn't
     (HELP OR HINDER)        Notice  Helped            Medium              Hurt
     -------------------------0-------1-----2-----3-----4-----5-----6-----7--
   A  HUD-motion wrt real world
   B  Pitch motion ladder/horizon
   C  Motion of scales
   D  Motion of airplane symbol
   E  Motion of V/V diamond in:
   E1 straight flight
   E2 easy turns
   E3 hard turns

 3.  EASE OF MAINTAINING ORIENTATION
                                Very Good             Medium          Very Poor
                 ------------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation        ............3
              Roll orientation         ......2

   Rating Sheet
   ------------>        Mental demand   50%    Physical Demand   60%   Temporal     40%
              Performance     40%     Effort              50%  Frustration  40%

 4.  Liked:----- 1:1 apparent tapering effect is less.
 5.  Problems:-- Cues for extreme pitch attitude are reduced.
 6.  Changes?:--
```


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  AIRCRAFT:  TS1              UNUSUAL ATTITUDE - HUD 7
    FLIGHT:  201             LOCATION: VMS
  FLT DATE: 16 MAR 90        COUNTERS:  1016- 1023
  DIRECTOR:                    PILOTS:

1.  OVERALL RATING              Very Good              Medium         Very Poor
    ------------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task      ........2.5
              Overall                  ........2.5

2.  APPARENT MOTION           Didn't
    (HELP OR HINDER)          Notice  Helped           Medium              Hurt
    --------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon
  C  Motion of scales
  D  Motion of airplane symbol        .................4
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                Very Good              Medium         Very Poor
              ----------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation        ......2
              Roll orientation         ......2

  Rating Sheet
  ------------>       Mental demand   45%    Physical Demand   40%   Temporal      40%
              Performance     30%    Effort            40%   Frustration  40%

4.  Liked:-----
5.  Problems:-- Scan pattern could add to workload so should fix scales to CDA.
6.  Changes?:--


****************************************************************************

  AIRCRAFT:  TS1              UNUSUAL ATTITUDE - HUD 14
    FLIGHT:  202             LOCATION: VMS
  FLT DATE: 16 MAR 90        COUNTERS:  1024- 1027
  DIRECTOR:                    PILOTS:

1.  OVERALL RATING              Very Good              Medium         Very Poor
    ------------------------------------1-----2-----3-----4-----5-----6-----7--
```

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```
              During present task      ..............................6
              Overall                  ..............................6

2.  APPARENT MOTION          Didn't
    (HELP OR HINDER)         Notice  Helped           Medium           Hurt
    -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon
  C  Motion of scales                  ..............................6
  D  Motion of airplane symbol
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                              Very Good           Medium         Very Poor
          ----------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation
              Roll orientation         ......2

  Rating Sheet
  ------------>        Mental demand   50%   Physical Demand   60%  Temporal   50%
              Performance      60%     Effort           70%  Frustration  75%

4.  Liked:-----
5.  Problems:-- Scan pattern became enormous, so unsat. -setting att. more diff.
6.  Changes?:--
```

****

```
  AIRCRAFT:  TS1              AIR TO GROUND - HUD 6
    FLIGHT:  203              LOCATION: VMS
  FLT DATE: 16 MAR 90         COUNTERS:  1029- 1030
  DIRECTOR:                     PILOTS:

1.  OVERALL RATING            Very Good           Medium         Very Poor
    ---------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task      ......2
              Overall                  ......2

2.  APPARENT MOTION          Didn't
    (HELP OR HINDER)         Notice  Helped           Medium           Hurt
    -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon
  C  Motion of scales
  D  Motion of airplane symbol
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns                              ..................4
```

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E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

```
                         Very Good              Medium         Very Poor
          ----------------------1-----2-----3-----4-----5-----6-----7--
          Pitch orientation      ......2
          Roll orientation       ......2
```

Rating Sheet

```
------------>       Mental demand   50%    Physical Demand   50%   Temporal    5(
            Performance      40%    Effort            50%   Frustration  30%
```

4. Liked:-----
5. Problems:-- Straight pitch bar good since accurate attitude.
6. Changes?:--

****

```
AIRCRAFT:  TS1              AIR TO GROUND - HUD 1
  FLIGHT:  204              LOCATION: VMS
FLT DATE: 16 MAR 90         COUNTERS:  1031- 1033
DIRECTOR:                     PILOTS:
```

1. OVERALL RATING

```
                            Very Good              Medium         Very Poor
 ----------------------------------1-----2-----3-----4-----5-----6-----7--
          During present task    ............3
          Overall                ............3
```

2. APPARENT MOTION (HELP OR HINDER)

```
                        Didn't
                        Notice  Helped          Medium              Hurt
 -----------------------0-------1-----2-----3-----4-----5-----6-----7--
A  HUD-motion wrt real world
B  Pitch motion ladder/horizon
C  Motion of scales
D  Motion of airplane symbol
E  Motion of V/V diamond in:
E1 straight flight
E2 easy turns                              ..................4
E3 hard turns
```

3. EASE OF MAINTAINING ORIENTATION

```
                         Very Good              Medium         Very Poor
          ----------------------1-----2-----3-----4-----5-----6-----7--
          Pitch orientation      ..................4
          Roll orientation       ......2
```

Rating Sheet

```
------------>       Mental demand   60%    Physical Demand   60%   Temporal    60
            Performance      40%    Effort            50%   Frustration  40%
```

4. Liked:-----

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5. Problems:-- (?)
6. Changes?:--

****

AIRCRAFT: TS1 — PRECISION APPROACH HUD 6
FLIGHT: 205 — LOCATION: VMS
FLT DATE: 16 MAR 90 — COUNTERS: 1034- 1035
DIRECTOR: — PILOTS:

1. OVERALL RATING . Very Good — Medium — Very Poor

---1-----2-----3-----4-----5-----6-----7--

During present task 5
Overall 5

2. APPARENT MOTION (HELP OR HINDER) — Didn't Notice — Helped — Medium — Hurt

---0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world
B Pitch motion ladder/horizon
C Motion of scales
D Motion of airplane symbol
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good — Medium — Very Poor

---1-----2-----3-----4-----5-----6-----7--

Pitch orientation
Roll orientation

Rating Sheet
------------> Mental demand 70% Physical Demand 50% Temporal 50%
Performance 40% Effort 60% Frustration 40%

4. Liked:-----
5. Problems:-- ILS display should stay fixed relative to pitch bar. Smaller gearing of heading scale.
6. Changes?:--

****

AIRCRAFT: TS1 — PRECISION APPROACH HUD 7
FLIGHT: 206 — LOCATION: VMS
FLT DATE: 16 MAR 90 — COUNTERS: 1036- 1037
DIRECTOR: — PILOTS:

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```
1.  OVERALL RATING               Very Good              Medium        Very Poor
   -----------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task       .......................5
              Overall                   .......................5

2.  APPARENT MOTION          Didn't
   (HELP OR HINDER)          Notice  Helped             Medium             Hurt
   --------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon
  C  Motion of scales
  D  Motion of airplane symbol
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                 Very Good              Medium        Very Poor
              -----------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation
              Roll orientation

  Rating Sheet
  ------------>       Mental demand   70%   Physical Demand   50%  Temporal    50%
              Performance      40%    Effort            60%  Frustration  45%

4.  Liked:-----
5.  Problems:-- Tabs on inside add a little clutter when CDA gets to -5 dive.
6.  Changes?:--


****************************************************************************


  AIRCRAFT:  TS1               PRECISION APPROACH HUD 13
    FLIGHT:  207              LOCATION: VMS
  FLT DATE: 16 MAR 90         COUNTERS:  1038- 1039
  DIRECTOR:                     PILOTS:

1.  OVERALL RATING               Very Good              Medium        Very Poor
   -----------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task       .............................6
              Overall                   .............................6

2.  APPARENT MOTION          Didn't
   (HELP OR HINDER)          Notice  Helped             Medium             Hurt
   --------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon
  C  Motion of scales
  D  Motion of airplane symbol
```

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E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good ... Medium ... Very Poor

----------------------1-----2-----3-----4-----5-----6-----7--

Pitch orientation
Roll orientation

Rating Sheet
------------> Mental demand 80% Physical Demand 50% Temporal 60%
Performance 40% Effort 70% Frustration 60%

4. Liked:-----
5. Problems:-- Scan pattern is enormous and with heading being important makes task difficult.
6. Changes?:--

****

AIRCRAFT: TS1 PRECISION APPROACH HUD 14
FLIGHT: 208 LOCATION: VMS
FLT DATE: 16 MAR 90 COUNTERS: 1040- 1041
DIRECTOR: PILOTS:

1. OVERALL RATING Very Good ... Medium ... Very Poor

----------------------------------1-----2-----3-----4-----5-----6-----7--

During present task 6.5
Overall 6.5

2. APPARENT MOTION (HELP OR HINDER) Didn't Notice ... Helped ... Medium ... Hurt

-------------------------0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world
B Pitch motion ladder/horizon
C Motion of scales
D Motion of airplane symbol
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good ... Medium ... Very Poor

----------------------1-----2-----3-----4-----5-----6-----7--

Pitch orientation
Roll orientation

Rating Sheet

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```
------------>        Mental demand   80%    Physical Demand   60%   Temporal     70%
             Performance      60%    Effort              75%  Frustration  65%
```

4. Liked:-----
5. Problems:-- Scan still enormous. FPM much harder to control: overcontrolling made task harder.
6. Changes?:--

****

```
  AIRCRAFT:  TS1              PRECISION APPROACH HUD 13
    FLIGHT:  209             LOCATION: VMS
  FLT DATE: 16 MAR 90        COUNTERS:  1042- 1043
  DIRECTOR:                    PILOTS:
```

```
1. OVERALL RATING                 Very Good            Medium         Very Poor
   ------------------------------------1-----2-----3-----4-----5-----6-----7--
             During present task     ..................4
             Overall                 ..................4

2. APPARENT MOTION          Didn't
   (HELP OR HINDER)         Notice  Helped            Medium              Hurt
   -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world        ......2
  B  Pitch motion ladder/horizon
  C  Motion of scales                 ..................4
  D  Motion of airplane symbol        ......2
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3. EASE OF MAINTAINING ORIENTATION
                                  Very Good            Medium         Very Poor
             ------------------------1-----2-----3-----4-----5-----6-----7--
             Pitch orientation
             Roll orientation
```

```
  Rating Sheet
  ------------>        Mental demand   60%    Physical Demand   40%   Temporal     60%
             Performance      20%    Effort              50%  Frustration  20%
```

4. Liked:-----
5. Problems:-- Would like A/S closer.
6. Changes?:--

****

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```
AIRCRAFT:  TS1                PRECISION APPROACH HUD 14
  FLIGHT:  210               LOCATION: VMS
FLT DATE: 16 MAR 90          COUNTERS:  1044- 1045
DIRECTOR:                      PILOTS:

1.  OVERALL RATING               Very Good              Medium          Very Poor
   ----------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task      ..................4
              Overall                  ..................4

2.  APPARENT MOTION            Didn't
    (HELP OR HINDER)           Notice  Helped           Medium               Hurt
    -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world         ......2
  B  Pitch motion ladder/horizon
  C  Motion of scales                  ......2
  D  Motion of airplane symbol         ......2
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                 Very Good              Medium          Very Poor
              -----------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation
              Roll orientation

  Rating Sheet
  ------------>        Mental demand   50%    Physical Demand   50%   Temporal     60%
              Performance      30%     Effort          40%  Frustration  20%

4.  Liked:-----
5.  Problems:--
6.  Changes?:--
```

```
*******************************************************************************
```

```
AIRCRAFT:  TS1                PRECISION APPROACH HUD 7
  FLIGHT:  211               LOCATION: VMS
FLT DATE: 16 MAR 90          COUNTERS:  1046- 1047
DIRECTOR:                      PILOTS:

1.  OVERALL RATING               Very Good              Medium          Very Poor
   ----------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task      ........2.5
              Overall                  ........2.5

2.  APPARENT MOTION            Didn't
    (HELP OR HINDER)           Notice  Helped           Medium               Hurt
    -------------------------0-------1-----2-----3-----4-----5-----6-----7--
```

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```
  A  HUD-motion wrt real world           ......2
  B  Pitch motion ladder/horizon
  C  Motion of scales                    1
  D  Motion of airplane symbol           ......2
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                   Very Good            Medium        Very Poor
               -----------------------1-----2-----3-----4-----5-----6-----7--
             Pitch orientation
             Roll orientation

  Rating Sheet
  ------------>        Mental demand   50%    Physical Demand   40%   Temporal      60%
             Performance      20%    Effort               40%  Frustration  10%

4.  Liked:-----
5.  Problems:-- Task does not require pilot to monitor scales.  Task which
             required pilot to monitor Alt. would be better.
6.  Changes?:--


******************************************************************************


  AIRCRAFT:  TS1              PRECISION APPROACH HUD 6
    FLIGHT:  212             LOCATION: VMS
  FLT DATE: 16 MAR 90        COUNTERS:  1048- 1049
  DIRECTOR:                    PILOTS:

1.  OVERALL RATING                Very Good            Medium        Very Poor
    -------------------------------------1-----2-----3-----4-----5-----6-----7--
             During present task        ......2
             Overall                    ......2

2.  APPARENT MOTION           Didn't
    (HELP OR HINDER)          Notice  Helped           Medium              Hurt
    ---------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world          ......2
  B  Pitch motion ladder/horizon
  C  Motion of scales                   ......2
  D  Motion of airplane symbol          ......2
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                  Very Good            Medium        Very Poor
               -----------------------1-----2-----3-----4-----5-----6-----7--
```

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Pitch orientation
Roll orientation

Rating Sheet
------------> Mental demand 40% Physical Demand 40% Temporal 50%
Performance 10% Effort 35% Frustration 10%

4. Liked:-----
5. Problems:--
6. Changes?:--

****

AIRCRAFT: TS1 AIR TO AIR - HUD 1
FLIGHT: 213 LOCATION: VMS
FLT DATE: 19 MAR 90 COUNTERS: 1051- 1055
DIRECTOR: KESSLER/LH PILOTS:

1. OVERALL RATING Very Good Medium Very Poor
----------------------------------1-----2-----3-----4-----5-----6-----7--
During present task 4
Overall 4

2. APPARENT MOTION Didn't
(HELP OR HINDER) Notice Helped Medium Hurt
-------------------------0-------1-----2-----3-----4-----5-----6-----7--
A HUD-motion wrt real world
B Pitch motion ladder/horizon 6
C Motion of scales
D Motion of airplane symbol
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION
Very Good Medium Very Poor
----------------------1-----2-----3-----4-----5-----6-----7--
Pitch orientation 5
Roll orientation 2.5

Rating Sheet
------------> Mental demand 80% Physical Demand 65% Temporal 60%
Performance 30% Effort 60% Frustration 30%

4. Liked:-----
5. Problems:-- Ladder effects with pitch rates. (would get worse with higher pitch rates)
6. Changes?:-- Gear it. Eliminate multiple righting of the pitch bars.

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```
  AIRCRAFT:  TS1                AIR TO AIR - HUD 6
    FLIGHT:  214               LOCATION: VMS
  FLT DATE: 19 MAR 90          COUNTERS:  1056- 1063
  DIRECTOR: KESSLER/LH           PILOTS:

1.  OVERALL RATING              Very Good              Medium          Very Poor
    ----------------------------------1-----2-----3-----4-----5-----6-----7--
               During present task      ........2.5
               Overall                  ........2.5

2.  APPARENT MOTION          Didn't
    (HELP OR HINDER)         Notice  Helped              Medium               Hurt
     -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon        ..................4
  C  Motion of scales
  D  Motion of airplane symbol
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                Very Good              Medium          Very Poor
               -----------------------1-----2-----3-----4-----5-----6-----7--
               Pitch orientation        ......2
               Roll orientation         ........2.5

  Rating Sheet
  ------------>         Mental demand    70%     Physical Demand   60%   Temporal     60%
               Performance      15%     Effort              50%   Frustration  20%

4.  Liked:-----
5.  Problems:-- Doesn't display ladder effects.  Compressed gearing.  Slightly
               abnormal motions of pitch ladder occasionally.
6.  Changes?:--
```

****

```
  AIRCRAFT:  TS1                AIR TO AIR - HUD 5
    FLIGHT:  215               LOCATION: VMS
  FLT DATE: 19 MAR 90          COUNTERS:  1064- 1068
  DIRECTOR: GK/LH                PILOTS:

1.  OVERALL RATING              Very Good              Medium          Very Poor
    ----------------------------------1-----2-----3-----4-----5-----6-----7--
               During present task      .......................5
```

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Overall 5

2. APPARENT MOTION (HELP OR HINDER)

Didn't Notice — Helped — Medium — Hurt

--------------------------0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world
B Pitch motion ladder/horizon 6
C Motion of scales
D Motion of airplane symbol
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good — Medium — Very Poor

-----------------------1-----2-----3-----4-----5-----6-----7--

Pitch orientation 5.5
Roll orientation 3

Rating Sheet
------------> Mental demand 80% Physical Demand 60% Temporal 50%
Performance 60% Effort 75% Frustration 30%

4. Liked:----- Nothing
5. Problems:-- Multiple writing in pitch bars. Coarse indication of (?). No analog feedback of pitch attitude. Must read numbers. Used to 10 degree markings.
6. Changes?:--

****

AIRCRAFT: TS1 AIR TO AIR - HUD 10
FLIGHT: 216 LOCATION: VMS
FLT DATE: 19 MAR 90 COUNTERS: 1069- 1074
DIRECTOR: GK/LH PILOTS:

1. OVERALL RATING

Very Good — Medium — Very Poor

----------------------------------1-----2-----3-----4-----5-----6-----7--

During present task 3.5
Overall 3.5

2. APPARENT MOTION (HELP OR HINDER)

Didn't Notice — Helped — Medium — Hurt

--------------------------0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world
B Pitch motion ladder/horizon
C Motion of scales
D Motion of airplane symbol
E Motion of V/V diamond in:
E1 straight flight

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E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

```
                       Very Good              Medium           Very Poor
 ------------------------1-----2-----3-----4-----5-----6-----7--
Pitch orientation        ...............3.5
Roll orientation         ............3
```

Rating Sheet

```
------------>        Mental demand   40%    Physical Demand   60%   Temporal   50%
           Performance     30%      Effort             60%  Frustration  20%
```

4. Liked:----- Don't suffer from laddering. Like crispness of pitch ladder.
5. Problems:-- Awful lot of writing of bars. Very evident in this display.
6. Changes?:-- Better analog information from this display. Needs tapers.

****

```
AIRCRAFT:  TS1             UNUSUAL ATTITUDE - HUD 4
  FLIGHT:  217             LOCATION: VMS
FLT DATE: 19 MAR 90        COUNTERS:  1075- 1078
DIRECTOR: GK/LH              PILOTS:
```

1. OVERALL RATING

```
                          Very Good              Medium           Very Poor
 ------------------------------------1-----2-----3-----4-----5-----6-----7--
During present task      ............3
Overall                  ............3
```

2. APPARENT MOTION (HELP OR HINDER)

```
                          Didn't
                          Notice  Helped              Medium              Hurt
 -------------------------0-------1-----2-----3-----4-----5-----6-----7--
A  HUD-motion wrt real world
B  Pitch motion ladder/horizon       ....................4.5
C  Motion of scales
D  Motion of airplane symbol
E  Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns
```

3. EASE OF MAINTAINING ORIENTATION

```
                       Very Good              Medium           Very Poor
 ------------------------1-----2-----3-----4-----5-----6-----7--
Pitch orientation        ........2.5
Roll orientation         ..............3.5
```

Rating Sheet

```
------------>        Mental demand   60/65%  Physical Demand   50%   Temporal   50%
           Performance     50%      Effort             50%  Frustration  20%
```

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4. Liked:----- Very obvious whether you're above or below horizon.
5. Problems:-- Laddering. Looks like 2 different displays above or below hor. Window problems - left bank & pulling. Numbers on pitch bars are late coming into display.
6. Changes?:--

****

AIRCRAFT: TS1 — UNUSUAL ATTITUDE - HUD 9
FLIGHT: 218 — LOCATION: VMS
FLT DATE: 19 MAR 90 — COUNTERS: 1079- 1082
DIRECTOR: GK/LH — PILOTS:

1. OVERALL RATING

	Very Good		Medium			Very Poor
	1	2	3	4	5	6	7

During present task 3
Overall 3

2. APPARENT MOTION (HELP OR HINDER) — Didn't Notice 0, Helped 1 — 2 — Medium 3 — 4 — 5 — 6 — Hurt 7

A HUD-motion wrt real world
B Pitch motion ladder/horizon
C Motion of scales
D Motion of airplane symbol
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION — Very Good 1 — 2 — Medium 3 — 4 — 5 — 6 — Very Poor 7

Pitch orientation 2
Roll orientation 3

Rating Sheet
------------> Mental demand 60% Physical Demand 50% Temporal 50%
Performance 30% Effort 50% Frustration 20%

4. Liked:----- Good analog info. about below and above horizon.
5. Problems:-- Less happy about 0 below horizon. Error of +/-20 degs. of roll. Using different techniques for attitudes below & above horizon.
6. Changes?:--

****

AIRCRAFT: TS1 — AIR TO AIR - HUD 5

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```
  FLIGHT:  219              LOCATION: VMS
FLT DATE: 19 MAR 90         COUNTERS:  1083- 1091
DIRECTOR: GK/LH               PILOTS:

1.  OVERALL RATING               Very Good             Medium         Very Poor
    ------------------------------------1-----2-----3-----4-----5-----6-----7--
               During present task      ..................4
               Overall                  ..................4

2.  APPARENT MOTION           Didn't
    (HELP OR HINDER)          Notice  Helped           Medium               Hurt
     -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon        ..................4
  C  Motion of scales                   ..................4
  D  Motion of airplane symbol          ..................4
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                 Very Good             Medium         Very Poor
                ----------------------1-----2-----3-----4-----5-----6-----7--
               Pitch orientation        ............3
               Roll orientation         ............3

  Rating Sheet
  ----------->         Mental demand   40%    Physical Demand   40%   Temporal      40%
               Performance     60%    Effort              40%  Frustration  40%

4.  Liked:----- Similar to what he's used to.
5.  Problems:-- Not used to A/S & attitude, but better than what he's used to.
6.  Changes?:--


*******************************************************************************


  AIRCRAFT:  TS1              AIR TO AIR - HUD 10
    FLIGHT:  220            LOCATION: VMS
  FLT DATE: 19 MAR 90       COUNTERS:  1093- 1096
  DIRECTOR: GK/LH             PILOTS:

1.  OVERALL RATING               Very Good             Medium         Very Poor
    ------------------------------------1-----2-----3-----4-----5-----6-----7--
               During present task      ..............................6
               Overall                  ..............................6

2.  APPARENT MOTION           Didn't
    (HELP OR HINDER)          Notice  Helped           Medium               Hurt
     -------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
```

... POOR QUALITY

B Pitch motion ladder/horizon 6
C Motion of scales 6
D Motion of airplane symbol 6
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good ... Medium ... Very Poor

----------------------1-----2-----3-----4-----5-----6-----7--

Pitch orientation 6
Roll orientation 6

Rating Sheet
-----------> Mental demand 60% Physical Demand 40% Temporal 70
Performance 80% Effort 70% Frustration 50%

4. Liked:-----
5. Problems:-- Didn't like this HUD. Logrithmic representation was not liked. Don't like since linear nose track not shown with variable. Felt like nose track was slowing down.
6. Changes?:--
7. Comments:-- First impression when he saw the top or bottom - not used to it. On 1:1 cannot see number well, but number on bars not important.

****

AIRCRAFT: TS1 AIR TO AIR - HUD 4
FLIGHT: 221 LOCATION: VMS
FLT DATE: 19 MAR 90 COUNTERS: 1097- 1102
DIRECTOR: GK/LH PILOTS:

1. OVERALL RATING Very Good ... Medium ... Very Poor

---------------------------------1-----2-----3-----4-----5-----6-----7--

During present task 3
Overall 3

2. APPARENT MOTION (HELP OR HINDER) Didn't Notice ... Helped ... Medium ... Hurt

-------------------------0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world
B Pitch motion ladder/horizon 3
C Motion of scales 3
D Motion of airplane symbol 3
E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

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```
                       Very Good            Medium       Very Poor
               -----------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation       ............3
              Roll orientation        ..................4

 Rating Sheet
 ------------>      Mental demand   30%    Physical Demand   30%  Temporal    30%
              Performance     40%    Effort            30%  Frustration  20%
```

4. Liked:----- Liked the best since better sense of above or below.
5. Problems:-- Bridged information better for pitch attitude. Lack of compression requires symbology below horizon to give sense of urgency.
6. Changes?:--

****

```
 AIRCRAFT:  TS1            AIR TO AIR - HUD 9
   FLIGHT:  222            LOCATION: VMS
 FLT DATE: 19 MAR 90       COUNTERS:  1103- 1108
 DIRECTOR: GK/LH             PILOTS:

1.  OVERALL RATING         Very Good            Medium       Very Poor
    ------------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task     ............3
              Overall                 ............3

2.  APPARENT MOTION        Didn't
    (HELP OR HINDER)       Notice  Helped       Medium              Hurt
    -------------------------0-------1-----2-----3-----4-----5-----6-----7--
 A  HUD-motion wrt real world
 B  Pitch motion ladder/horizon       ............3
 C  Motion of scales                  ............3
 D  Motion of airplane symbol         ............3
 E  Motion of V/V diamond in:
 E1 straight flight
 E2 easy turns
 E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                       Very Good            Medium       Very Poor
               -----------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation       ........................5
              Roll orientation        ..................4

 Rating Sheet
 ------------>      Mental demand   40%    Physical Demand   35%  Temporal    40%
              Performance     60%    Effort            45%  Frustration  40%
```

4. Liked:----- Increased sense of urgency in steep dive angles - bending bars.
5. Problems:-- Tougher for roll orientation at high pitch attitudes, but roll orientation not that important

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6. Changes?:--

****

```
AIRCRAFT:  TS1              UNUSUAL ATTITUDE - HUD 2
  FLIGHT:  223             LOCATION: VMS
FLT DATE: 19 MAR 90        COUNTERS:  1109- 1113
DIRECTOR: GK/LH              PILOTS:

1.  OVERALL RATING                 Very Good              Medium          Very Poor
    ------------------------------------1-----2-----3-----4-----5-----6-----7--
              During present task      ........................5
              Overall                  ..................4

2.  APPARENT MOTION            Didn't
    (HELP OR HINDER)           Notice  Helped             Medium               Hurt
     ---------------------------0-------1-----2-----3-----4-----5-----6-----7--
  A  HUD-motion wrt real world
  B  Pitch motion ladder/horizon       ..................4
  C  Motion of scales                  ..................4
  D  Motion of airplane symbol         ..................4
  E  Motion of V/V diamond in:
  E1 straight flight
  E2 easy turns
  E3 hard turns

3.  EASE OF MAINTAINING ORIENTATION
                                   Very Good              Medium          Very Poor
                ------------------------1-----2-----3-----4-----5-----6-----7--
              Pitch orientation        ........................5
              Roll orientation         ........................5

  Rating Sheet
  ------------>        Mental demand   40%    Physical Demand   35%   Temporal     40
              Performance     65%      Effort            50%   Frustration  45%
```

4. Liked:-----
5. Problems:-- Rapid pitch changes at several nose down attitudes. Taper too subtle in FOV of HUD needs more. Since it wasn't compressed, he had a hard time with rapid pitch attitude change.
6. Changes?:-- Compression would help for this task.

****

```
AIRCRAFT:  TS1              UNUSUAL ATTITUDE - HUD 7
  FLIGHT:  224             LOCATION: VMS
FLT DATE: 19 MAR 90        COUNTERS:  1114- 1117
DIRECTOR: GK/LH              PILOTS:
```

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1. OVERALL RATING Very Good Medium Very Poor

---------------------------------1-----2-----3-----4-----5-----6-----7--

During present task 3

Overall 3

2. APPARENT MOTION (HELP OR HINDER) Didn't Notice Helped Medium Hurt

--------------------------0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world

B Pitch motion ladder/horizon 4

C Motion of scales 4

D Motion of airplane symbol 4

E Motion of V/V diamond in:

E1 straight flight

E2 easy turns

E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good Medium Very Poor

------------------------1-----2-----3-----4-----5-----6-----7--

Pitch orientation 3

Roll orientation 4

Rating Sheet

------------> Mental demand 25% Physical Demand 20% Temporal 25%

Performance 40% Effort 25% Frustration 20%

4. Liked:----- Good display.

5. Problems:--

6. Changes?:--

****

AIRCRAFT: TS1 UNUSUAL ATTITUDE - HUD 11

FLIGHT: 225 LOCATION: VMS

FLT DATE: 19 MAR 90 COUNTERS: 1118- 1121

DIRECTOR: GK/LH PILOTS:

1. OVERALL RATING Very Good Medium Very Poor

---------------------------------1-----2-----3-----4-----5-----6-----7--

During present task 4

Overall 4

2. APPARENT MOTION (HELP OR HINDER) Didn't Notice Helped Medium Hurt

--------------------------0-------1-----2-----3-----4-----5-----6-----7--

A HUD-motion wrt real world

B Pitch motion ladder/horizon 4

C Motion of scales 4

D Motion of airplane symbol 4

E Motion of V/V diamond in:
E1 straight flight
E2 easy turns
E3 hard turns

3. EASE OF MAINTAINING ORIENTATION

Very Good Medium Very Poor

------------------------1-----2-----3-----4-----5-----6-----7--

Pitch orientation 5

Roll orientation 4

Rating Sheet
------------> Mental demand 35% Physical Demand 30% Temporal 35:
Performance 45% Effort 40% Frustration 40%

4. Liked:-----
5. Problems:-- Needs compression in this display.
6. Changes?:--

$ Enter flight(s) of interest :

$ Enter BRIEF, NOTES or FULL :

Appendix C
Evaluation Pilots' Briefing Materials

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C–1 A/A Dynamic Maneuvering Task

Each evaluation pilot "flew" 14 different HUD symbol sets. The primary task was to track a target aircraft through a set of acrobatic maneuvers similar to those required in A/A combat. The target, a CGI silhouette of a MIG-27, moved in a cloverleaf type of pattern within the visual field. Movement was varied enough to be unpredictable to the evaluation pilot, who was instructed to fly the simulator (own-ship) and keep the gun cross on the CGI target at all times. The HUD-referenced aiming symbol (gun cross) was a set of cross hairs resembling the aiming reference of an F-16 aircraft.

The evaluation pilot did not know when the target would begin to climb, which direction the target would roll, nor how tight the target was pulling. Therefore, the target could very easily be changing flight parameters (i.e., loosening the pull either during the pull up or during the pull through), and transitioning below a predetermined minimum altitude (11,000 ft) or a predetermined minimum airspeed (200 knots).

C–2 Low-Level and A/G Task

Initial setup is 420 KIAS, 200-ft altitude, heading 355 deg. When the bay becomes visible off to the left, maneuver over to follow the bay and fly up the river. The river will end at a dam with a house shortly beyond.

Cross the end of the river at 420 KIAS, 200 ft, heading 350 deg. With the gun cross abeam the house, go to mil thrust and make a moderately aggressive 4-g pull up to a 40-deg climb angle. At 6,000 ft, roll 180 deg and pull 2–3 g down to a wings-level 40-deg dive (thus a straight pop-up and roll ahead).

As the aircraft reaches 360 KIAS, reduce the throttle to idle and track the first target (house along road) with the CDM. With the CDM on the first target, press the pickle button passing through 4,500 ft.

Then roll left and put the CDM on the center of the large tanks (second target) and pickle at 1,500 ft and 420 KIAS with the CDM on the tanks.

C–3 ILS Approach Task

The approach and landing task involved a standard ILS approach to a landing or missed approach. The ICs for the approach were as follows:

Range	5 nm
Lateral offset	3,000 ft
Altitude	1,200 ft
Glideslope	3 deg
Heading	Parallel with runway heading

Each pilot made two approaches for each HUD configuration. One approach was terminated with a waveoff at a 200-ft decision height (DH). The second approach was terminated to maintain airspeed/angle of attack and glideslope/localizer deviations.

Both approaches were made during low visibility conditions. The first approach (to a waveoff) had visibility conditions of 100 ft and 1/4 nm and the second approach (to touchdown) had visibility conditions of 200 ft and 1/2 nm. Both approaches were flown with moderate turbulence levels to increase pilot workload.

C–4 UA Recovery Task

Each evaluation pilot was given a preliminary briefing of each of the HUD configurations to be evaluated, the test procedure, and the performance parameters that were to be collected. Once briefed and positioned in the simulator, the pilots were presented with one of the HUD configurations being evaluated. Each pilot was given an opportunity to fly the simulator with the HUD being flown for that trial block.

When the evaluation pilot indicated he had adequately familiarized himself with the HUD characteristics, the HUD was blanked. The experimenter instructed the pilot to the attitude to which he was to recover: wing-level or another assigned attitude.

Upon activation by the evaluation pilot (via the trigger switch), the simulator was reset to UA with the HUD on. The pilot then initiated the recovery to the pre-assigned attitude. Once the pilot felt he had achieved the assigned attitude, he terminated the trial by pressing the trigger switch, at which time the HUD would blank.

This procedure was repeated until all trials for each block were completed.

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C–5 Performance Standards

Task	Parameter	Acceptable performance	Desirable performance
Low level	Maintain airspeed	±20 knots	±10 knots
	Maintain radar altitude[a]	±100 ft	±50 ft
	Maintain track	±1/4 nm	±1/2 nm
A/G	Maintain sight picture[a]	±10 mr	±5 mr
	Maintain airspeed	±10 knots	±5 knots
	Release altitude	±100 ft	±50 ft
	Sighting error at release	±5 mr	±21/2 mr
A/A	Maintain sight picture[a]	±10 mr	±5 mr
	Fire within roll constraint	±60 deg	±60 deg
	Minimum altitude	10,000 ft	10,000 ft
	Recovery heading	±10 deg	±5 deg
	Recovery altitude	±100 ft	±50 ft
	Recovery airspeed	±10 knots	±5 knots
UA recovery	First control input	<2 1/2 sec	<1 1/2 sec
	Control reversals	One	None
	Altitude loss	2,500 ft	1,000 ft
	Recovery heading	±10 deg	±5 deg
	Recovery altitude	±100 ft	±50 ft
	Recovery airspeed	±10 knots	±5 knots
Dynamic maneuver	Pitch at key points	±10 deg	±5 deg
	Recovery altitude	±200 ft	±100 ft
	Recovery airspeed	±10 knots	±5 knots
	Recovery heading	±10 deg	±5 deg
ILS	Maintain airspeed	±5 knots	±2 knots
	Maintain localizer	±2 dot	±1/2 dot
	Maintain glide slope	±1 dot	±1/2 – 0 dot
	Call decision height	±20 ft	±10 ft

[a]Fifty percent of the time.

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13. ABSTRACT *(Maximum 200 words)*

The first in a series of piloted head-up display (HUD) flight symbology studies (TRISTAR) measuring pilot task performance was conducted at the NASA Ames Research Center by the Tri-Service Flight Symbology Working Froup (FSWG). Sponsored by the U.S. Army Aeroflightdynamics Directorate, this study served as a focal point for the FSWG to examine HUD test methodology and flight symbology presentations. HUD climb-dive marker dynamics and climb-dive ladder presentations were examined as pilots performed air-to-air (A/A), air-to-ground (A/G), instrument leanding system (ILS), and unusual attitude (UA) recovery tasks. Symbolic presentations resembled pitch ladder variations used by the U.S. Air Force (USAF), U.S. Navy(USN), and Royal Air Force (RAF). The study was initiated by the FSWG to address HUD flight symbology deficiencies, standardization, issue identification, and test methodologies. It provided the mechanism by which the USAF, USN, RAF, and USA could integrate organizational ideas and reduce differences for comparisons. Specifically it examined flight symbology issues collectively identified by each organization and the use of objective and subjective text methodology and flight tasking proposed by the FSWG.

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