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PILOT ERRORS INVOLVING HEAD-UP DISPLAYS (HUDs), HELMET-MOUNTED DISPLAYS (HMDs), AND NIGHT VISION GOGGLES (NVGs)

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January 1992

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Having become aware of difficulities with night vision and display equipment in helicopters and fixed-wing aircraft, IDA staff members collected pertinent literature, interviewed aircrews, aeromedical research people, and cockpit designers, and then carried out display simulations. They found serious safety problems associated with the newer techniques of displaying information to aircrews. At highly task-loaded moments, pilots are often so stressed that they channelize attention and ignore indications of trouble. Thus, human-factors problems cancel the technological advances being introduced into modern aircraft cockpits. To help solve those problems, the investigators undertook to: appraise the reality and severity of shortcomings in display instrumentation and its use; arrange for specific laboratory research by the Army and the Air Force, followed by tests and demonstrations. They presented their findings and recommendations to the Air Staff and the Air Force Scientific Advisory Board, as well as the Army Deputy Under Secretary for Operations Research and the Commander of the Army Aviation Center and his aeromedical staff at Fort Rucker.

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FOREWORD

There is reason to believe that some serious safety problems are associated with some of the newer techniques of displaying information to aircrews. During combat missions and at other high-stress moments, pilots are often highly task loaded. There exist much firm and more anecdotal data that during such times pilots often fail to notice important safety-related information provided them through their displays or headphones. In these situations, human-factors problems often negate the technological advances being introduced into modern aircraft cockpits.

No body of data exists on how to ensure the intrusion of necessary information into a pilot's awareness. The present state of understanding of human-factors issues related to displaying information to aircrews is insufficient to cope with many of the newer concepts of a "glass cockpit" comprising head-up displays (HUDs), helmet-mounted displays (HMDs), and panel-mounted liquid crystal color displays. Work is needed to address a wide variety of human-factors and display issues through experiments and trials in suitable visual flight simulations and, finally, in flight demonstrations.

In view of the above, the authors of this report suggested to IDA management that these problems appeared sufficiently serious to justify a preliminary survey that, coupled with some cooperative research with both Army and Air Force activities, could lead to important formal recommendations to the military services.

This report, done with IDA funding as a Central Research Project, presents the findings and recommendations resulting from a preliminary survey of Army and Air Force information sources. Comparable Navy sources have not yet been surveyed.

ACKNOWLEDGMENTS

This paper brings together existing research results, flight experiences compiled by people concerned with the subject matter, personal conversations and interviews, and recent original research at IDA and the service laboratories. The Display Laboratories of Hughes Aircraft provided major assistance in the form of literature surveys and reviews. A principal source of information was Colonel Grant B. McNaughton, USAF, retired, who was a deeply involved and concerned flight surgeon before his retirement. We have drawn from his written work and conversation, as we have also from those of Colonel William Berkeley, USAF, a flight surgeon with the Armstrong Laboratory's Aircrew Training Research Division.

Conversations with Dr. Conrad L. Kraft, formerly of Boeing, provided much insight into the problems of visual transition from instrument flight to through-the-windshield viewing.

The publications of Mr. Alton Boyd of the Army Safety Center, and Dr. Isaac Behar *et al.* of the Army Aeromedical Research Laboratory, Fort Rucker, provided the data on rotary-wing problems to a degree not available to us from any other source.

The cooperation and resultant experimental programs of the Air Force Armstrong Laboratory, Wright-Patterson Air Force Base, helped substantially in achieving a better understanding of some basic problems, such as errors in the visual estimation of distance to an object, and the effects of fields of view on human performance in tasks associated with pilotage.

We acknowledge the informative and helpful reviews, some parts of which we have included in the final text, by: Dr. Wallace Prophet; Dr. Penrose C. Albright, of IDA; Dr. Jay Enoch, of the University of California, Berkeley; Dr. Brian Tsou, of the Armstrong Laboratory; Mr. Robert Sendall, of the Hughes Aircraft Company; Dr. Jerome Seeman, of the McDonnell Douglas Helicopter Company; Dr. Robert T. Hennessy, of Monterey Technologies; and Dr. Dan Fulgham, of the Southwest Research Institute.

The synthetic imagery representing views through a HUD was prepared by Miss Lynn Drake, of IDA.

ABSTRACT

Having become aware of difficulties with night vision and display equipment in helicopters and fixed-wing aircraft, IDA staff members collected pertinent literature, interviewed aircrews, aeromedical research people, and cockpit designers, and then carried out display simulations. They found serious safety problems associated with the newer techniques of displaying information to aircrews. At highly task-loaded moments, pilots are often so stressed that they channelize attention and ignore indications of trouble. Thus, human-factors problems cancel the technological advances being introduced into modern aircraft cockpits. To help solve those problems, the investigators undertook to

- Appraise the reality and severity of shortcomings in display instrumentation and its use
- Arrange for specific laboratory research by the Army and the Air Force, followed by tests and demonstrations.

They presented their findings and recommendations to the Air Staff and the Air Force Scientific Advisory Board, as well as the Army Deputy Under Secretary for Operations Research and the Commander of the Army Aviation Center and his aeromedical staff at Fort Rucker.

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GLOSSARY

ADI	Attitude Direction Indicator
AFB	Air Force Base
AFWAL	Air Force Wright Aeronautical Laboratories
AGL	Above Ground Level
AL	Armstrong Laboratory (Air Force)
ALT	Altitude
ANVIS	Aviator's Night Vision Imaging System
AOA	Angle of Attack
ASI	Airspeed Indicator
ATC	Air Training Command
ATF	Advanced Tactical Fighter
CCNVEO	CECOM Center for Night Vision and Electro-Optics
CECOM	Communications-Electronics Command (Army)
CFIT	Controlled Flight Into Terrain
CPG	Copilot/Gunner
CRT	Cathode-Ray Tube
DED	Data Entry Display
DME	Distance Measuring Equipment
EO	Electro-optical
FC	Fire Control
FLIR	Forward-Looking Infrared
FOV	Field of View
FPM	Flight Path Marker
FPS	Flight Path Scales
FTIT	Fan Turbine Inlet Temperature
FY	Fiscal Year

GCI	Ground-Controlled Interception
GLC	G-Induced Loss of Consciousness
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HDU	Helmet Display Unit
HMD	Helmet-Mounted Display
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
HUD-VTR	HUD Video Tape Recorder
IDA	Institute for Defense Analyses
IFC	Instrument Flight Center
IFF	Identification, Friend or Foe
IHADSS	Integrated Helmet and Display Sighting System
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Instructor Pilot
IPD	Interpupillary Distance
LIFT	Link Intellectual Function Tester
MANPRINT	Manpower and Personnel Integration
MSL	Mean Sea Level
NVD	Night Vision Device
NVGs	Night Vision Goggles
PDAD	Primary Dedicated Attitude Display
PNVS	Pilot Night Vision System
R&D	Research and Development
RPV	Remotely Piloted Vehicle
RTU	Replacement Training Unit

SAI	Standby Attitude Indicator
SDO	Spatial Disorientation
S&L	Straight and Level
SPO	System Program Office
TACAN	Tactical Air Navigation
TDY	Temporary Duty
T.O.	Takeoff
TV	Television
UFC	Up Front Control
UPT	Undergraduate Pilot Training
USAARL	U.S. Army Aeromedical Research Laboratory
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnirange

EXECUTIVE SUMMARY

Early aircraft pilots flew with few, if any, aids other than white scarfs, goggles, and the seats of their pants. As aircraft became less creations of technology and more vehicles of commerce, communications and instruments in the form of round, mechanical gauges and meters were gradually added. Later, electronics made possible the gathering and displaying of information, resulting in a myriad of additional gauges for navigation and flight control functions.

Then the cathode-ray tube (CRT) enabled new cockpit displays such as radar images and scrolling maps. As cathode brightness increased, small tubes were used to project information onto a "combining glass," a semitransparent mirror that allowed a military pilot to look through it at the world before him and simultaneously observe information projected by the CRT, i.e., he could see the world with his various sources of important information superposed without having to take his eyes away from the windshield.

This combining-glass-and-CRT combination was called a head-up display, or HUD. It was invented in an attempt to maintain a pilot's situational awareness without his ever having to take his eyes off something embedded in the scene before him--for example, a target embedded in terrain. Later in this paper, Colonel Grant B. McNaughton describes a situation in which a young pilot, fearful of losing contact with his flight leader in the dark of night, never took his eyes off his HUD and, not realizing he had become inverted, instead of climbing some 10,000 feet, dove 10,000 feet to a fatal impact with the terrain.

The anecdotal evidence is full of stories of *suspected* HUD-caused fatalities, but only three such stories are documentable, because "dead men tell no tales." On October 8-10, 1985, Colonel McNaughton held an Aircraft Attitude Awareness Workshop, a forum for what to an outsider was a collection of horror stories about the factors that cause a pilot to lose any sense of where he is and how he is oriented.

Interviews show major divergences between pilots and the engineers responsible for modern cockpit display technology and data transfer. Task-loaded pilots complain that there is so much talk on their radios, and so much symbology or text on their displays, that they cannot hear or see information intended for them.

Not all of the problem is due to technological overload. Much blame can be laid to the fact that the new cockpit layouts and displays do not recognize the fundamental difference in performance of the right and left halves of the human brain. For example, situational awareness data are now being presented digitally, which requires left-brain interpretation, whereas situational awareness is normally a right-brain function.

In the workshop mentioned above, General Albert L. Pruden strongly recommended getting rid of most, if not all, digital displays and getting back to analog presentations like the old round meters and "ribbon" displays, where ribbon length means something instantly grasped with no need to read alphanumeric data with one half of the brain and interpret it for the other half. For example, where two parallel vertical ribbons denote the speeds of two engines, if both ribbon tops are at the same height, the engine speeds are equal. There is no need to read three or four significant figures and then compare the values! As another example, where a columnar gauge like a thermometer represents altitude, a G-loaded pilot has no need to read the fine print of a digital display.

Although the Air Force teaches its new pilots that they *must* rely on conventional instruments for such details as which side is up, most young fighter and attack aircraft pilots are trained to fly by their HUDs; as a result, some die by them.

Almost universally, the high-performance aircraft pilots we spoke with complained about insufficient training in the use of instruments in poor weather or at night. Further, there seems to be a pattern of training a young pilot in an early model of an aircraft, and then sending him to an operational post where he gets an advanced model with different instrument displays and display positions.

There seems to be no standard location or representation of the functions a pilot needs to use in times of crisis. There does seem to be a move to high-resolution digital displays that are based upon technology rather than pilots' needs. New cockpits tend to be designed by engineers, not pilots. After the fact, human-factors people seem to be called in to try to eliminate the troubles caused by the engineers' lack of understanding of how pilots get their information.

Thus, the present study was undertaken as an IDA Central Research Project to determine whether there really are problems with cockpit displays and information transfer and, if so, to try to determine just what they are. In his review of a previous draft of this paper, Wallace Prophet drew the following succinct conclusions:

- HUDs, HMDs, and night vision goggles (NVGs) present some serious questions for the researcher and designer concerning information display content and format. There are numerous areas where we should be concerned over flight safety questions. HUDs are here to stay and have become an integral part of flight operations, and HMDs and NVGs are not far behind in their pervasive use in military aircraft.
- Misaccommodation is likely a minor problem and of no great significance.
- Field of view (FOV) certainly is a concern. Determination of the relationships between FOV and various performatory indices would be desirable so that we do not spend foolishly in pursuit of FOV beyond the point of diminishing performance returns.
- Divided attention raises some important concerns. The HUD alone does not cause attentional tunneling. Any number of factors can bring about this sort of attentional demand. Certainly, the HUD may be a significant contributor, but as with other attentional demands, some training may be the most significant part of the answer to this problem. This must be investigated.
- The discussion of spatial disorientation by McNaughton is important. The combination of sensory information is complex--something we take for granted until some element of it gets out of order.
- The question concerning overlaying imagery with symbology and alphanumerics requires much attention. Attention to the alphanumeric data causes the visual scene to fade in perception. Is it not the case that a focus (focal mode) of attention on any one element (symbology, alphanumerics, or a detail of the visual scene) causes the rest of the scene (visual field) to "fade in perception"? For example, if you focus on the water tower low in the upper left quadrant of Figure 4b (p. 19), you not only no longer see the alphanumerics, but you also no longer see the large building to the immediate right of and below the water tower. Again, the answer may be in a rigorous training of the pilot and, to use that old dictum of the flight instructor, an active cross-check.

Is this really important? Alton Boyd (1991) lists the accidents in just rotary-wing aircraft from FY 1984 through FY 1989 as shown in Table S-1. Though we believe these numbers represent a very small fraction of total flights, the absolute numbers are sufficient to justify an immediate program to acquire an understanding of the problems discussed throughout this report and to correct them as soon as they are sufficiently well understood.

Table S-1. Flight Accidents of Rotary-Wing Aircraft and the Fatalities and Costs Involved, FY 1984-1989: Totals, At Night, At Night Due to Crew Errors, and At Night Due to "Aided" Crew Errors

(Absolute Numbers and Percentages of Totals)

			Night Crew Error	
	All	Night	All	Aided
Accidents	626 (100%)	145 (23%)	119 (19%)	83 (13%)
Fatalities	199 (100%)	82 (41%)	70 (35%)	50 (25%)
Cost ($M)	506.8 (100%)	193.3 (38%)	159.0 (31%)	138.4 (27%)

The argument that the problems are recognized but their solutions are too costly (e.g., new cockpit lighting for aircraft employing night vision goggles) is simply no excuse for inaction. If, for example, an aircraft with a goggles-equipped crew is indeed unsafe for night flight because of cockpit lighting, the lighting should be fixed, the crew should be trained further, or the aircraft should be grounded for night flying that requires the use of goggles.

I. INTRODUCTION

In the early days of aviation, pilots and aircrews got most of their flight information from the seats of their pants and from clear, unaided, relatively unrestricted views of their aircraft and the world around them. Since then, as aircraft speed, complexity, and flyability in bad weather have increased, instrument-panel gauges--first mechanical, then electric, then electronic--have served the ever increasing need for flight information.

The still growing amount of instrumentation in aircraft cockpits has led to a search for ways of providing pilots with the most important, and often critical, pieces of information in readily usable form. Such information, some of which at times includes imagery of the "outside world" under dark nighttime conditions, was first presented on panel-mounted displays. However, use of panel-mounted displays requires a pilot to look away from the outside through-the-windscreen view, thereby tending to cause loss of the perceptual whole situation that is often called "situational awareness."

With progress in electronic and optical technology, small, very bright CRTs became available, and these CRTs with projection optics and a transparent combining glass allowed pilots to view "dashboard information" on the combining glass, through which they could view the outside world. Because that arrangement allows a pilot to see instrument information superimposed on his combining glass without having to look down at panel-mounted instruments, such systems are called head-up displays (HUDs).

HUDs have some restrictions on field of view that pilots find annoying. Means were thus developed to provide the most important, and often critical, pieces of information to a pilot's eyes without requiring a shift in the visual field away from the outside through-the-windscreen scene. This was accomplished through the use of either (1) HUDs that provide the pilot with graphic or alphanumeric information projected on the aircraft's windscreen but have seriously restricted fields of view or (2) helmet-mounted displays (HMDs) that project the same sorts of information on a visor or visorlike transparent (but partially reflecting) surface mounted at eye level on the pilot's helmet.

The past decade produced a series of HMDs in which a pilot's head position controls sensor orientation, so that the pilot sees a scene on his HMD corresponding to what he might see with unaided vision when looking in a given direction.

Such HMDs first were used with simple aiming reticles. Later the fire control information previously shown on a HUD was displayed on the HMD. More recently, switching and combining circuits have been introduced to overlay multiple sources of data for use by the aircrew.

The most recent HMD designs are complex. One example cited in *Aviation Week* (11 November 1991, p. 78) is an HMD proposed by the team of GEC and Ferranti (Fig. 1). This HMD contains a pair of image intensifiers and a pair of cathode-ray tubes to project HUD-like images into a pilot's eyes by reflection from his visor. According to *Aviation Week*, "a pilot will see essential flight information and night vision images projected onto the helmet's visor--in a system to be called Crusader--and overlaid on his direct view of the outside world no matter which way he looks. With the HUD information constantly in view, a pilot should be able to concentrate on his mission without having to look back into the cockpit to scan flight instruments." We believe this is indicative of a trend that would make any pilot accident prone, for reasons discussed later in this paper.

HUDs and HMDs typically present their symbolic or alphanumeric data superimposed on the image of the external scene. In daylight use, the external scene is viewed *through* the HUD, with the symbology or textual information projected to infinity.[1] Thus, there is no *optical* need for the pilot to refocus or change accommodation when shifting attention or view from the external scene to in-cockpit HUD-presented information, or vice versa. HUDs have been introduced into many aircraft cockpits and are now essentially standard in all military combat aircraft. Some manufacturers are now proposing the use of HUDs in automobiles.

Several applications of HUDs utilize projected imagery and projected alphanumeric information together with complex symbology intended to convey: an understanding of where the combat pilot is relative to both the earth and his threats; advice about the positions of his intended targets or refueling aircraft; and related intelligence about the battle.

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1 At night, many of the aircraft using HUDs or HMDs show both an image and superposed text or symbology, both projected to appear at infinity. These night vision devices are discussed later in this report.

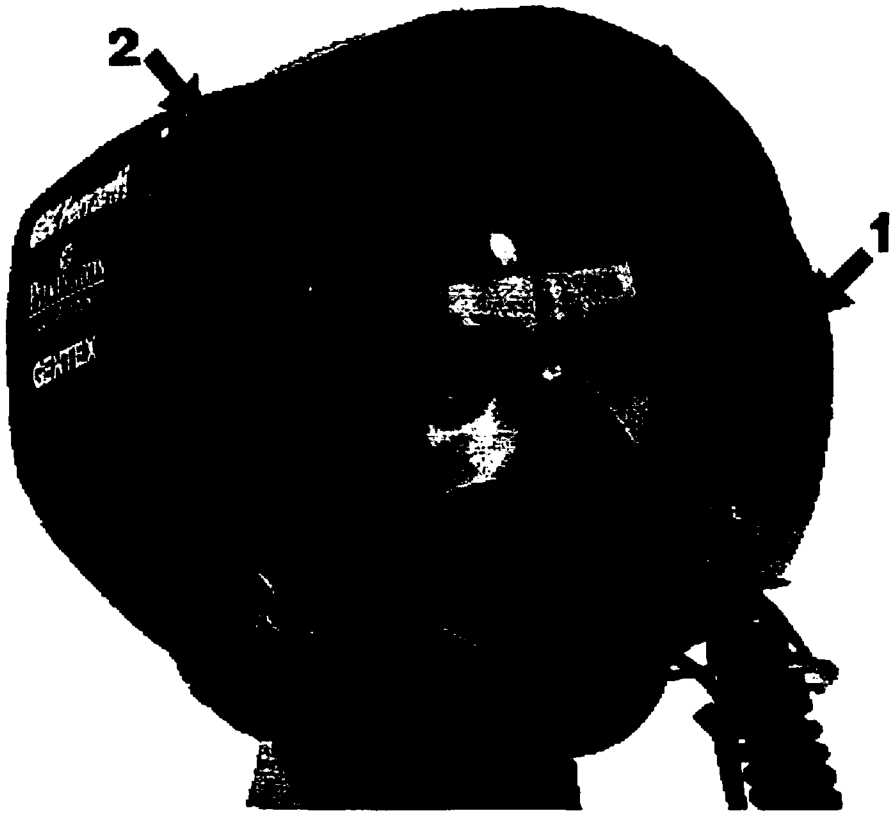

Figure 1. In a helmet under development by a GEC/Ferranti-led team, symbols from two projectors (Arrow 1) will show head-up display information as well as night vision enhancement from built-in image intensifiers (Arrow 2), projected onto the pilot's visor. (Source: *Aviation Week*, 11 November 1991, p. 78)

Unfortunately, a pilot is limited by well-understood problems associated with his cerebral organization and his resultant divided visually related perception. Overly simplified, this can be explained as follows. The pilot sends information on his position relative to his immediate world to the right half of his brain; he sends information requiring reading skill and reasoning processes to the left half of his brain. He does one or the other and switches back and forth unless he become preoccupied with one function, in which case he completely or almost completely ignores the other half of his brain. Thus, the pilot may well become so engrossea with his target that he fails to read a message or symbology telling him of impending disaster. IDA has performed pictorial experiments, discussed later in this document, illustrating that this sort of behavior can occur while one is simply looking at a picture or a book. Some workers in the field call this "channelizing" of information. It is a serious problem and should be avoided wherever possible.

Reports of "problems" have increased with increases in the use of HUDs and HMDs. These have ranged from reports of pilot complaints of fatigue and headache, found to occur through the use of misfocused devices,[2] to allegations of serious HUD- or HMD-associated aircraft accidents. The entire problem area is being addressed with some vigor not only by U.S. Army researchers but also by U.S. Air Force researchers in the Armstrong Laboratory's elements at both Wright-Patterson Air Force Base, Ohio (formerly the Aerospace Medical Research Laboratory), and Williams Air Force Base, Arizona (formerly the Operations Training Division of the Air Force Human Resources Laboratory).

The use of HMDs and night vision goggles (NVGs) has caused a series of problems such as eye pain, eyestrain, and headaches, while HUDs, recent panel-mounted displays, and HMDs have been accused of causing loss of spatial orientation.

Pilot problems associated with use of such displays indicate confusion, overload, or disorientation. This topic is discussed in Chapter II. Problems arising from superposition of symbology and text onto imagery are discussed in Chapter III. Operational problems resulting from the above are discussed in Chapter IV, and conclusions and recommendations for experiments and research topics are outlined in Chapter V.

Appendixes A and B contain excerpts from the proceedings of a workshop on aircraft attitude awareness that relate to the topic of this paper. Appendix C discusses the theory and fabrication of image intensifiers for proximity focused image intensifier goggles (night vision goggles). Appendix D, on night vision device (NVD) preflight adjustment and focusing procedures, is an example of the NVD training material currently available.

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2 For example, Major General R.T. Travis, Army Medical Research and Development Command, in a letter to the Deputy Under Secretary of the Army for Operations Research, dated 20 February 1991, wrote in part: "..A recently published USAARL Technical Report (90-15) revealed that slightly more than 50 percent of the Apache aviators reported some vision complaint while using their HDU...[but] we showed that there were no long-term visual effects secondary to HDU experience. However, our aviators were, on average, misfocusing their HDU by more than two diopters, which required them to physiologically compensate by accommodating a like amount. This problem was created by a poorly engineered design and a training error which has since been corrected..."

II. REVIEW OF RESEARCH ON HUD- AND HMD-RELATED PROBLEMS

In an early, and perhaps the initial, open-literature allegation of "trouble" with HUDs and HMDs, Roscoe (1987a) observed that, "For better or for worse, virtual imaging displays are with us in the form of head-up narrow-angle combining-glass presentations (HUDs) and head-mounted projections of wide-angle sensor-generated or computer-animated imagery (HMDs)." He called for "...an investigation and analysis of their problems, and a search for realistic alternatives." He summarized the then current status of such displays as follows:

> ...all of our currently operational tactical fighter aircraft are equipped with HUDs. Helicopters are navigated and controlled and their weapons delivered with a variety of imaging displays including, in addition to HUDs, both panel-mounted and head-mounted image intensifiers and forward-looking infrared (FLIR) and low-light TV displays. Even some strategic aircraft and a few commercial airliners contain virtual imaging displays. A new generation of remotely piloted vehicles (RPVs) are intended to be flown by reference to wide-angle but relatively low-resolution sensor imagery presented stereoscopically by head-mounted binocular displays. And Detroit is about to offer HUDs for cars.

Roscoe (1987a) proposed several display alternatives, especially direct-view displays, and called for additional R&D (and R&D support) along such lines, ending with an appeal in these words:

> ...Unfortunately, our sole dependence on virtual imaging displays for tactical missions (HUDs now and HMDs in the future) has resulted in almost total suppression of research and development of more easily optimized direct-view displays of sufficient angular size to provide the needed fields of view with appropriate magnification.

Roscoe's view has not gone unchallenged, nor have the challenges been ignored (see Roscoe, 1987b).[3] Weintraub (1987) summarized his several points by pointing out that "neither virtual-image displays nor head-down CRT displays nor direct viewing of the

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[3] In his rebuttal to the challenges, Roscoe (1987b) proposes several "short-run fixes" and a "long-run fix." The latter suggests that "trying to combine synthetic imagery with contact visibility compromises both," and goes on to make a case for "distributing operational functions and information sources between an 'inside' pilot and an 'outside' pilot" (p. 5).

environment can be considered immune to idiosyncrasies of the visual system." He suggested that as the number of visual-aid options grows, "the research issues of *display* selection and integration plus *information* selection and integration continue to multiply," and he observed further that "HUDs and HMDs are useful tools of the trade. They are here to stay. The knotty questions concern how best to utilize and improve them." Silverstein and Wilbert (1987) also took issue with Roscoe, as did Newman (1987), who concluded that:

> Whatever shortcomings head-up displays may have, the benefit of a properly designed HUD flown by a properly trained pilot will show a significant improvement in both performance and flight safety. This is not to suggest that no further research is required or that a head-up display will be the panacea for all aircraft problems. HUDs have definite limitations, but a properly designed HUD still represents a worthwhile addition to most aircraft from both a performance and a flight safety point of view .

A. MISACCOMMODATION

Roscoe (1987a) attributed much (or all) of these HUD- and HMD-related problems to phenomena related to accommodation, or rather misaccommodation, of the eyes of the pilots flying with HUDs or HMDs. He stated that when viewing collimated virtual images at optical infinity, our eyes do not focus at infinity but at a resting accommodative distance of "about arm's length, on average."

> ...The perceptual consequence of [such] positive misaccommodation is that the whole visual scene shrinks in apparent angular size. This shrunken appearance causes distant objects to be judged farther away than they are, and anything below the line of sight, such as the surface of the terrain or an airport runway, appears higher than it really is relative to the horizon (Roscoe, 1984, 1985, 1987a).

Other factors implicated by Roscoe (1987a) as possible causes of HUD- and HMD-related problems, especially through interaction with the hypothesized misaccommodation, include (a) a strong positive correlation between accommodation and apparent (perceived) size (r is greater than 0.90), (b) optical minification resulting from a limited HUD or HMD display area relative the external view, and (c) relatively poor image quality.

There is some evidence that Roscoe's point is valid--that misaccommodating the collimated alphanumerics or symbology to reading distance changes the focal length of the eye so that all images are seen as smaller. Therefore, the scene itself is perceived to be more distant. As Roscoe claims, this would then result in a pilot's estimating objects to be farther away than they really are, thus leading to some kinds of accidents. However, at most this effect is quite small. Several internationally noted scientists in vision and visual factors in piloting were asked to comment independently on Roscoe's (1987a) accommodation (or misaccommodation) explanation after reading the initial series of relevant papers (including: Roscoe, 1987a; Weintraub, 1987; Newman, 1987; Silverstein and Wilbert, 1987; Roscoe, 1987b; Iavecchia *et al.*, 1988; and Marsh and Temme, 1990). In personal communications, the readers universally rejected the "accommodation (or misaccommodation) hypothesis" as invalid and supported neither by the data presented nor by any other data in their experience. The readers were Drs. Jay Enoch, Dan Fulgham, Conrad Kraft, and Herschel Leibowitz, as well as Dr. Wallace Prophet as quoted on p. S-3.

More recent work by personnel at AL (Wright-Patterson AFB) shows that even if misaccommodation is a problem, it is both a small effect and a small part of the distance judgment errors that are prevalent.

B. FIELD OF VIEW LIMITATION

In a helmet-mounted display, there are several fields of view (FOVs):

- The FOV of each eye.
- The overlap of the fields of each eye (nasal overlap).
- The total FOV--the total FOV for the divergent case is the angle between the left outer edge of the FOV of the left eye to the right outer edge of the FOV of the right eye. The total FOV for the convergent case is the total angle between the inner edge of the FOV of the right eye and the inner edge of the FOV of the left eye (see Fig. 2). This is equal to the sum of the fields of each eye less the nasal overlap.
- The field of regard--the total possible angular coverage by the eye FOV, including rotation of the head and neck.

Because the field of regard has the component due to the FOV of each eye through its displayed field and the rotation of these fields, as the sensor follows head motion and looks where the pilot's head position indicates, a large number of combinations yielding geometrically equivalent coverages could be used, but these would certainly not be equally acceptable.

Since the number of resolved elements is limited by the sensor and/or the display, the theoretically best picture would be presented by a small FOV, i.e., the available number of resolved elements, say 500, yields a resolution of (FOV/500). Thus, the smaller the FOV, the finer the resolution.

Very small FOVs cause difficulty because of inability to see the background about the central point of interest. Often these problems are called tunnel vision, or seeing the world through a soda straw. Such small fields necessitate excessive head motion for scanning or tracking.

As FOVs become small, head motion becomes excessive and neck muscle fatigue becomes a problem. If FOVs become larger to relieve head motion, the fixed number of elements projectable by the present generation of miniature CRTs and the projection optics limit the real system resolution, and images of small targets tend to be poorly resolved.

A definite program is necessary to study FOVs necessary for a pilot's situational awareness of his implemented visual field, as is the follow-on development of miniature CRTs to achieve sufficient resolution to match realistic fields of view determined by the previous experiments.

Finally, we need a demonstration of the "specific optimized" FOV presented to a pilot by a pair of CRTs, each of which, one for each eye, is also optimized to cover that "specific optimized" FOV. This is necessary to demonstrate that pushing the CRTs and optics to cover wider fields, thus presenting more data, does not compromise the resolution and contrast performance of the HMD that supposedly is now a better conveyer of information.

C. CONVERGENT VERSUS DIVERGENT FIELDS OF VIEW

There are two ways of getting total FOVs with acceptable nasal overlap: convergent or divergent FOVs of each eye. These are shown in Fig. 2 for equal coverage, along with a parallel arrangement of individual-eye FOVs as is usual in binoculars. In Fig. 2 the convergent and divergent arrangements require about 50 percent overlap of the fields of each eye.

Note that the three methods can achieve similar or identical coverage. Note, however, that the divergent and parallel schemes allow one to see an object coming in from the left side first with the left eye, as in normal vision. With the convergent scheme, an object coming into the field from the left appears first in the right-eye FOV, quite the opposite to normal vision. We do not as yet know if this causes perceptual problems or disorientation.

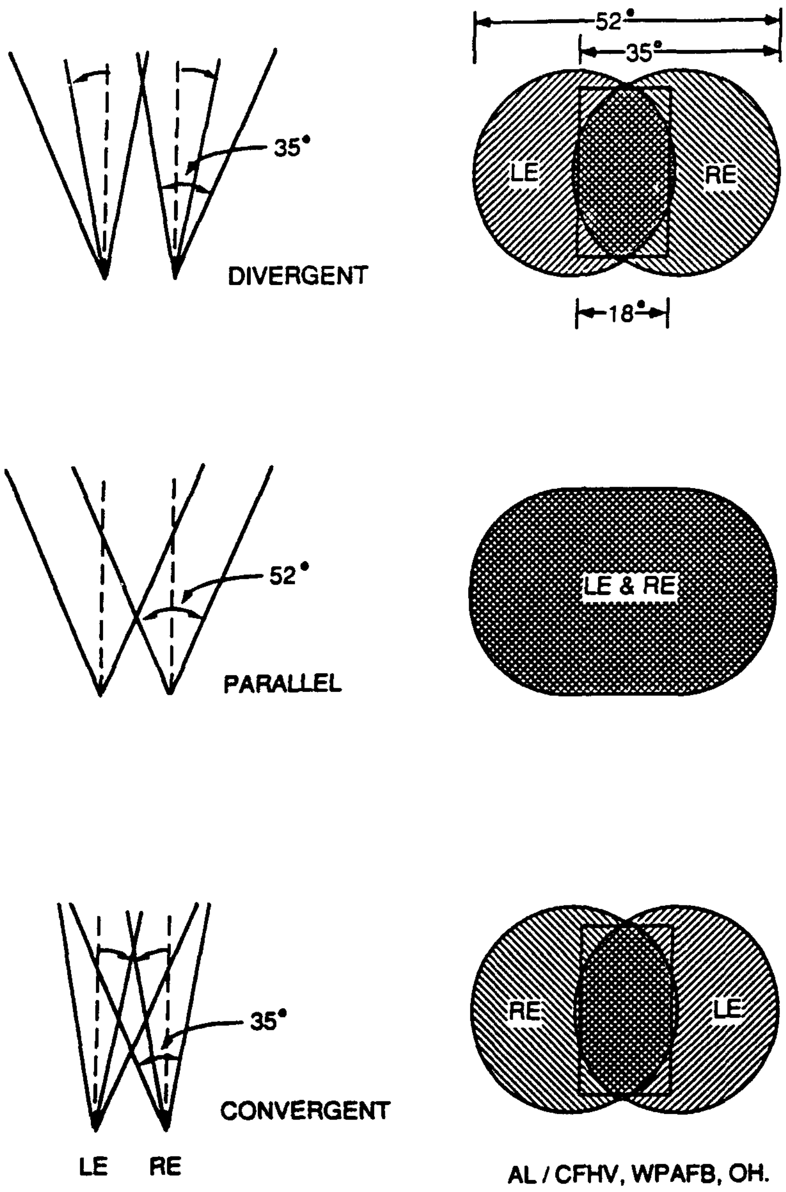

Figure 2. Examples of divergent, parallel, and convergent HMD fields of view.

Currently, some HMDs in final engineering development have a convergent design.

Since most components and designs available today for single-sensor, single-CRT displays for two-eyed viewing cannot cover a desired FOV with adequate resolution and contrast, designs have been put forth that use two CRTs, each independently feeding an eye with adequate imagery. These two images are then fed so that their images each cover a different FOV, arranged so there is some central overlap, allowing the total FOV to cover the sum of the two individual fields less an amount allowed for overlap. Thus, if the CRTs and optics were sufficiently good, the two independent 60 deg fields with a 30 deg overlap could cover 120 – 30 deg, or a 90 deg FOV.

D. DIVIDED ATTENTION

In a recent paper, Larish and Wickens (1991) indicate that there are repeated anecdotal and experimental reports that pilots' fixations on their HUDs' symbology degrade their scanning and their ability to detect events in the external visual scene. Moreover, citing Fisher, Haines, and Price (1980), they hypothesize that high levels of stress or workload (as are typical during normal takeoffs and landings) facilitate a "tunneling of attention or vision on the display so that unexpected, but critical or highly salient, events are either not perceived or not perceived as quickly (even by experienced commercial pilots) as during flight with conventional instrumentation."

Regardless of the fact that we do not fully understand the cause of the problem, substantiating evidence that a serious problem exists is accumulating.

The principal advantage of HUDs and HMDs is that they minimize time spent "head down" looking at cockpit instruments. Instead, flight information is displayed, for a HUD, either directly on the cockpit windshield or on a combiner glass inside the windshield in a collimated image that appears to "float" far outside the cockpit in the same depth plane as the external world. In the case of the HMD, the image is "projected" directly into the pilot's eye or eyes. Optically, collimation allows a pilot to maintain the same focus for extracting information from both the display and the external world, which saves the time that would be spent refocusing in and out of the cockpit.

Larish and Wickens (1991) point out that a key issue revolves around how well pilots can switch their frame of reference between the qualitatively different stimuli represented by the HUD or HMD and the environment; and the extent to which the ability to divide attention between the display and the external scene is affected by superimposition of these information sources in the same depth plane.

E. MISPERCEPTION

Dr. Conrad Kraft suggests that the phenomenon of misperceiving the distance of an external object or point such as a landing zone viewed through a HUD as being farther away than it really is, is a function of *cyclophoria*--a rotation of the eyes when converging, and a counterrotation when diverging, the latter with a time delay on the order of a few seconds, should the eyes be converged when the pilot attends to the HUD's symbology, knowing that it is projected on the aircraft's windscreen.[4] Kraft likens the reported HUD-related distance misjudgment phenomenon to a well-known "duck under" phenomenon in piloting. That is, when breaking out of a cloud cover through which the pilot has been flying with attention on the instrument panel, and going to visual flight rules with a through-the-windscreen view of the landing field, there is an immediate nose-down control movement that is followed in a couple of seconds by a corrective nose-up control movement to a more nearly correct flight path for landing. The nose-down and subsequent nose-up movement is known as a "duck under" to experienced pilots.

F. SPATIAL DISORIENTATION

Grant B. McNaughton, then Chief Aeromedical Advisor to the Life Support SPO, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, in a paper entitled "The Role of Vision in Spatial Disorientation (SDO) and Loss of Aircraft Attitude Awareness by Design," presented at Wright-Patterson AFB in 1985, made a series of separate statements quoted below:

- There are several topics and points I'd like to discuss in this briefing: the role of vision in spatial disorientation (SDO); design features that impact attitude awareness; importance of the attitude indicator; the fact that the HUD is not an ADI, although it could be improved as an attitude reference; and pattern-type displays that take advantage of the fact that the human is basically a pattern recognizer.

- Historically, we've considered SDO to result from a mismatch between vision and the balance organ. We now know that is only part of the story. Just as important is a mismatch within the visual system itself, between its two modes of processing visual information. One of these modes is the all familiar focal mode which focuses, reads the checklist, identifies the bogey, and aims the gun. This mode is highly discriminating and is exclusively visual, in fact, is limited to the central 1-2° of the retina. It requires good lighting and good resolution, and it typically involves conscious attention.

  The other is called the ambient[5] mode because it orients oneself to the ambient environment.

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4 Telephone discussion with C. L. Kraft, Bellevue, Washington, 15 April 1991.

5 Malcom, R., Pilot Disorientation and the Use of a Peripheral Vision Display: The 1983 Annual Harry G. Armstrong Lecture; Aviation, Space and Environmental Medicine, March 1984, p. 233.

This mode is concerned not with object recognition but with object quality, or more correctly, the quality of the surrounds; for example, the "surfaceness" of the surface, "horizonness" of the horizon, or "cockpitness" of an aircraft. It is a quality assessment mode, undiscriminating and uncritical, and it can be easily deceived, which, of course, is part of the problem.

Although this mode involves the entire retina, including central vision, it is by no means exclusively visual. It connects to the same terminals which receive orientation inputs from our organs of balance, proprioception and hearing. Instead of an ambient visual system, we have, in effect, an ambient orientation system, into which vision contributes its share of the inputs along with those from the other senses. When ambulating about on the surface with our eyes open, vision contributes the greatest proportion of orientation inputs, perhaps 90% or more; and of those inputs, the ambient mode provides perhaps 90%, so it supplies the lion's share. If we can see, or think that we can see, vision will dominate as far as orientation inputs are concerned. This mode works at any lighting level:[6] it's the one we use in the dark. Though you cannot read in a dark room, you can orient provided there is a minimum of light.

- Resolution is totally unimportant. You can orient with 20 diopter lenses before your eyes. The ambient mode typically functions at more of a reflex level. Along the scale of evolution, it's the mode that appeared first.[7]
- Firing the Maverick missile involves a multistep procedure requiring the pilot to divide his attention between the stores management panel at lower left, the TV monitor at upper right for final slewing and lock-on, and the HUD to clear his flight path--a potential procedural, attentional and focus trap.
- The problem with digital, symbolic, and alphanumeric displays is that they require the focal mode to read, decode and integrate, and they provide no inherent trending nor limitations information.
- Analog displays generally overcome these objections but can be misread, as illustrated by the old altimeter, which could be misread by 10,000 feet.
- Finally, any display which traps the pilot's attention can kill him.

These remarks are from a McNaughton paper included in Appendix A because of its importance and relative unavailability.

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6 Leibowitz, H.W., Shupert, C.L., and Post, R.B. The Two Modes of Visual Processing: Implications for Spatial Orientation. NASA Conference Publication 2306 - Peripheral Vision Horizon Display - Proceedings of a Conference held at NASA Dryden Flight Research Center, Edwards, CA, 15-16 March 1983, pp. 41-43.

7 Leibowitz, H.W., Shupert, C.L., and Post, R.B., *op. cit.*

In his review of this IDA paper, Dan Fulgham made the following comment:

Obviously, the most glaring failure leading to the perceived inadequacies of cockpit displays has been the failure to use human performance data to guide the design and development of the displays and information format for the military environment. Instead, the display technology was inserted by engineers, simply because it was available and represented something attractive and new (and saleable). Rarely were displays selected on the basis of detailed mission requirements as what the pilot needed to know, and then how to best present it to a human, under those circumstances. Until the horse gets back in front of the cart, human factors specialists are going to continue to spend time and money trying to correct mistakes, instead of making timely design inputs.

III. SUPERPOSITION OF DATA ON IMAGERY

Following McNaughton's remarks about the dual, distinctly different forms of vision, we would like to continue with that topic.

Every driver has experienced the problem of being bothered by the smear of a squashed insect or a pattern created by raindrops on his windshield, when he should be keeping his eyes on the road.

Much has been written about this problem (for example, see McNaughton's remarks in Chapter II) and the tendency to focus at a "resting distance" of a few to several feet when there is little to command attention in the more distant scene. When this happens one tends to see the plane of the windshield clearly and ignore the scene in the distance. This is opposed to the need to see the distant scene well and ignore the squashed bug or the pattern of raindrops.

Here at IDA we have tried to take alphanumerics and create the illusion that they are actually in the plane of the terrain, and thus diminish or delete the two-plane problem in which the alphanumerics appear as if painted on a window through which one looks at a forward oblique scene.

We have created a series of pairs of such scenes using the same forward oblique imagery. We have used perspective rules for the size of the alphanumerics, we have painted a perspective glide path, and we have foreshortened the circular reticle. Two examples of these trials are shown in the two pairs of opposing pictures, Figs. 3a and 3b and Figs. 4a and 4b.

Clearly, in these pairs of photographs all imagery is in the plane of the paper, yet the brain sees the alphanumerics and symbology in a near-vertical plane, while the scene is perceived as if at a long distance in a forward oblique. If one concentrates on the scene, the symbology fades in perception and vice versa.

In spite of the strong efforts made to project symbols and alphanumerics as collimated images that would embed them in distant scenes being viewed by an observer (or a pilot), most observers continued to see the combined images differently.

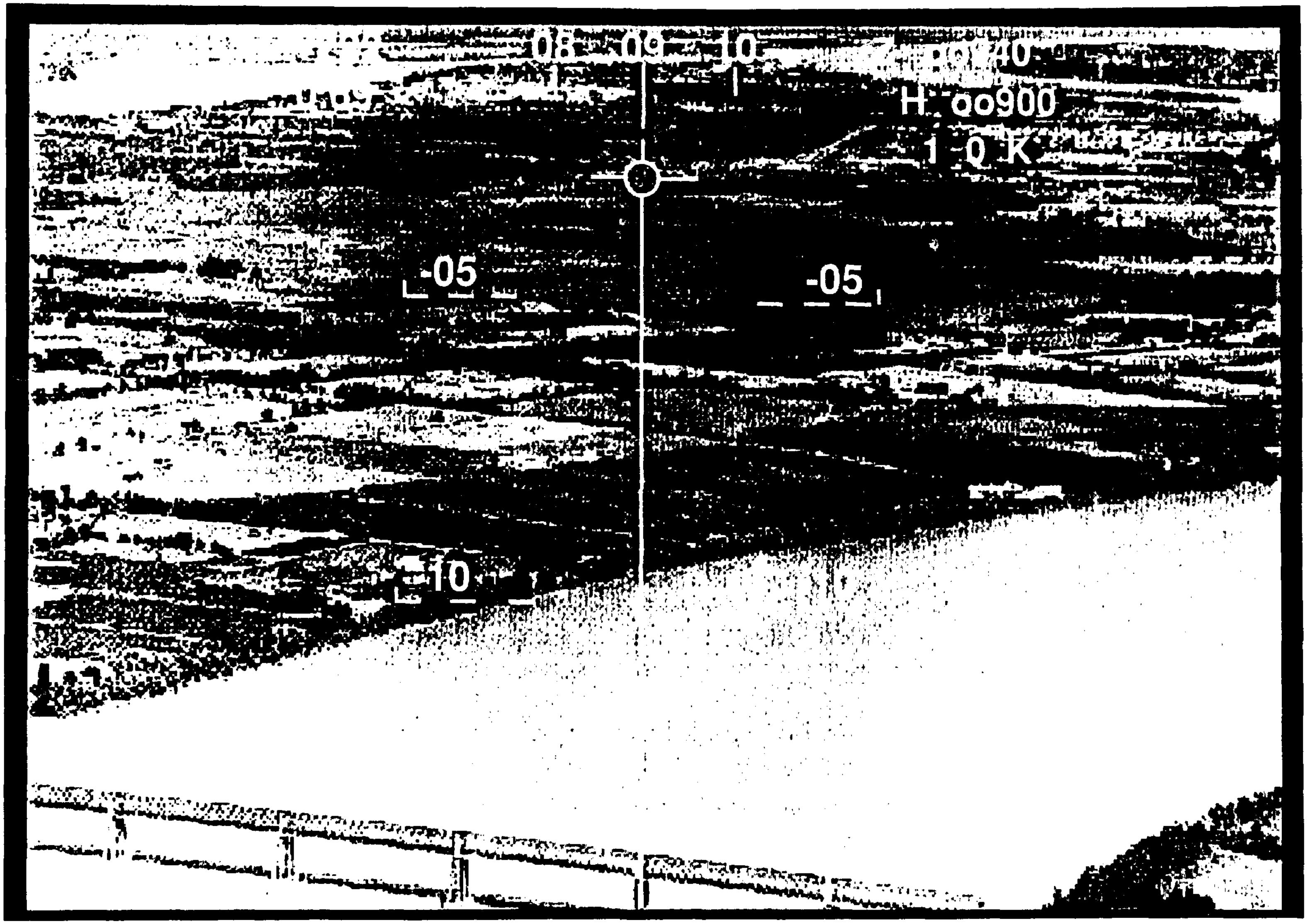

Figure 3a. Text appears in vertical plane, *not* in plane of scene in this figure or in Fig. 3b.

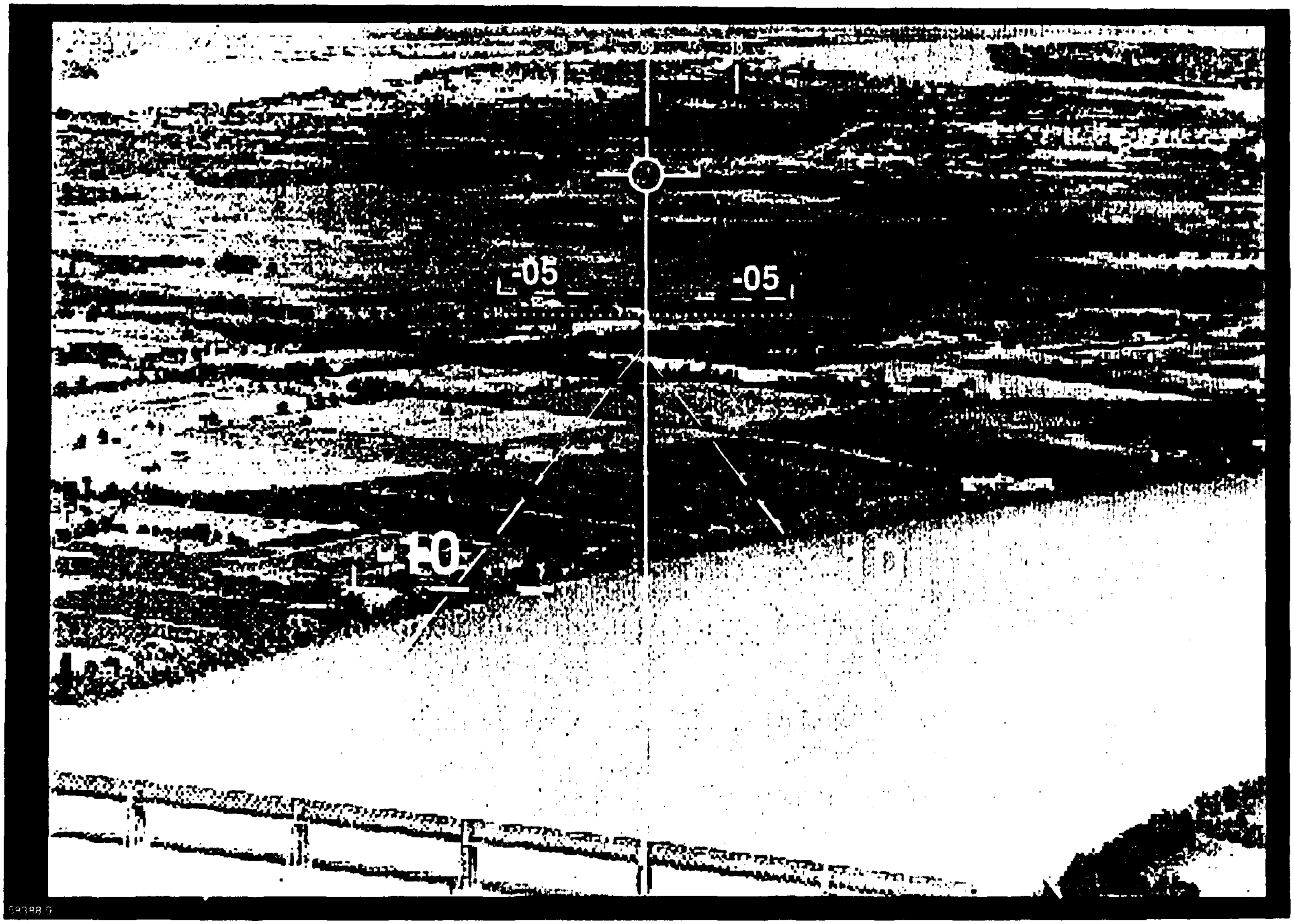

Figure 3b. Text appears in vertical plane, *not* in plane of scene, even though an attempt was made to put symbology in perspective.

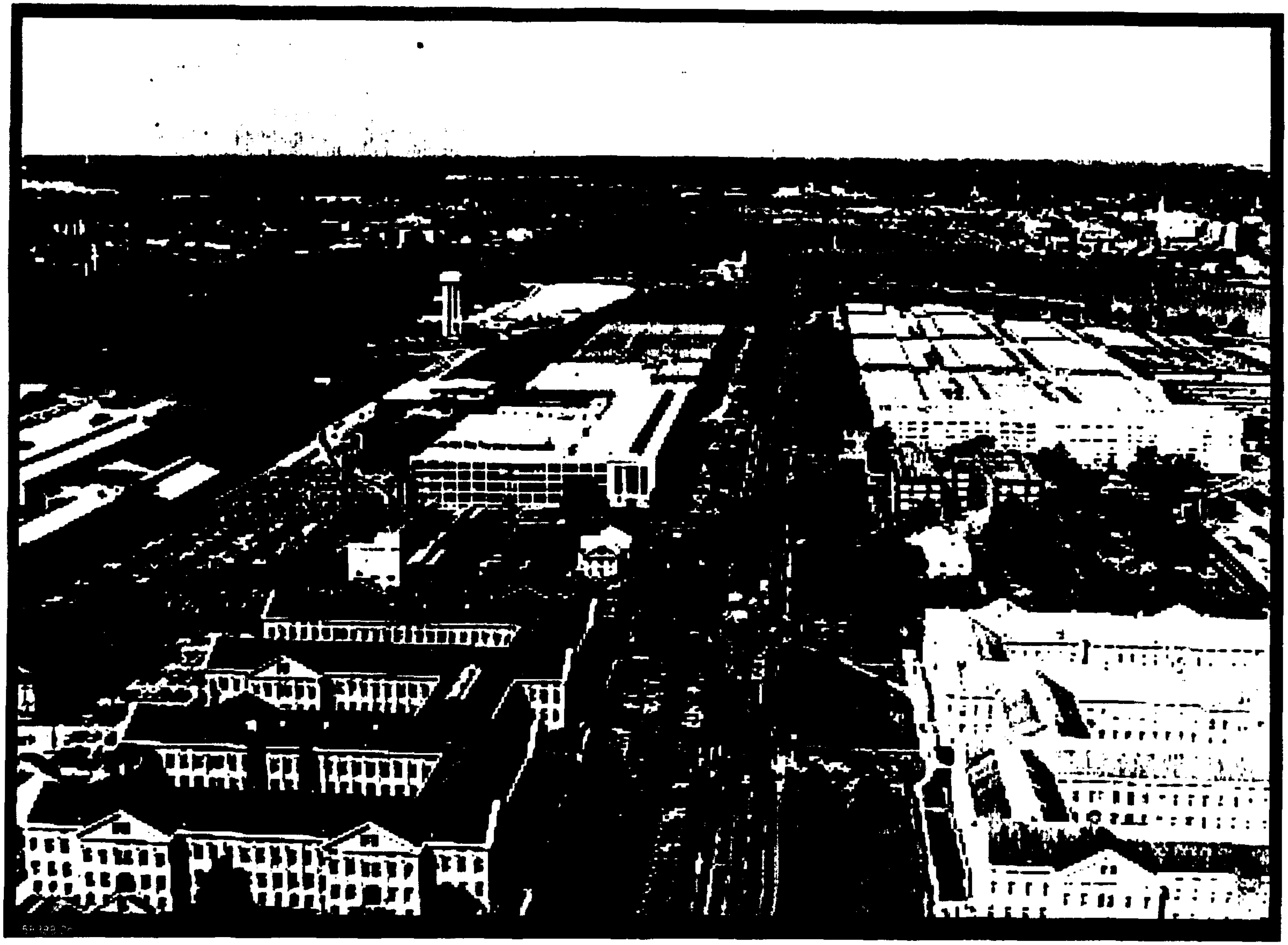

Figure 4a. If one focuses on a small detail, the rest of the scene fades in perception.

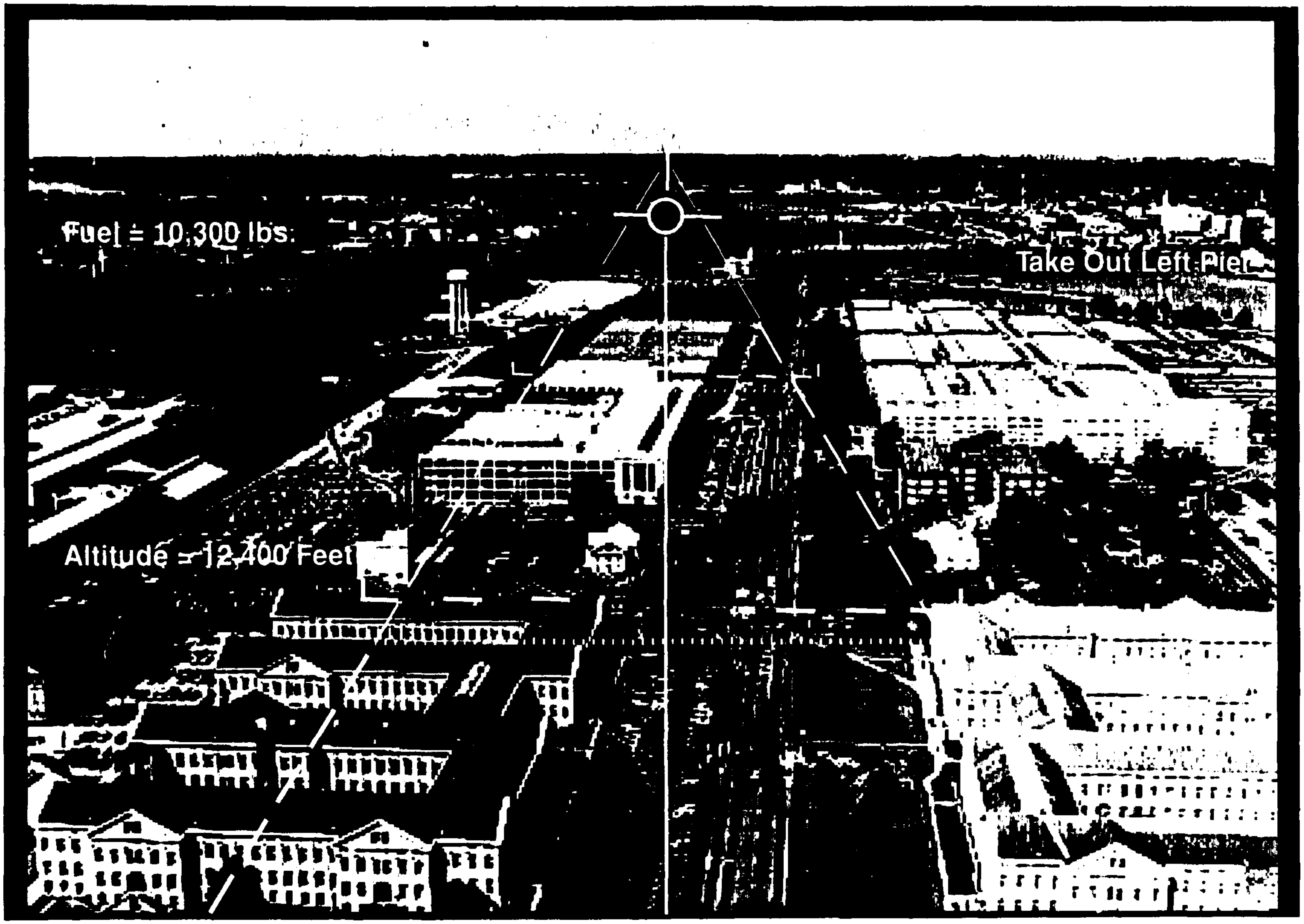

Figure 4b. Perspective of symbology is incorrect; symbology appears in vertical plane, *not* in plane of scene. *Attention to detail in scene effectively eliminates awareness of text.*

HUD-like techniques of projection did not fool the observer, and invariably he saw the scene as a distant scene through a "window" in which alphanumerics and symbology appeared as if written on a transparent windowpane. He thus made a decision to read the alphanumerics (and interpret them with his left brain) or to establish his orientation with regard to the scene (with his right brain). He basically did one thing well while being slightly, if at all, aware of the other.

This holds true whether one is viewing a HUD, an HMD, or a panel-mounted display. Apparently, training from an early age makes one expect and treat alphanumerics and symbology as if they were on a page at reading distance, while one sees the world as a distant scene.

We have about concluded that there is nothing we presently know related to the size/distance relationship that can be used to fool the left-brain/right-brain processing problem. Again we quote McNaughton (1985):

> Another problem arises because HUD symbology is projected into space as virtual imagery. Looking at the virtual imagery of the HUD is like looking at something through the knothole in a fence; various combinations of the pilot's eye position and the FPS position may move it beyond his view. Another point, although the HUD imagery is collimated to infinity, the eye does not necessarily focus to infinity when looking at the HUD. In fact, the eye tends to focus at an intermediate range corresponding to its own resting dark focal length. For many pilots with 20/20 vision, their dark focus (the distance to which they accommodate in the dark) is only 3 or 4 feet.
>
> Another phenomenon regarding HUDs is the tendency to stare at all that symbology and become mesmerized by it, deceiving yourself that you're processing all that information when, in fact, you are not. [There is] even...a name for this: "HUD hypnosis."

IV. OPERATIONAL PROBLEMS ASSOCIATED WITH USE OF NIGHT VISION GOGGLES, HELMET-MOUNTED DISPLAYS, AND HEAD-UP DISPLAYS

A. INTRODUCTION

Roscoe (1987a) cites reported data on operational problems from several sources. For example, about 30 percent of tactical pilots report that using a HUD tends to cause disorientation, especially when flying in and out of clouds (Barnette, 1976; Newman, 1980; Roscoe, 1987a; McNaughton, 1985). Pilots report frequently experiencing confusion when trying to maintain aircraft attitude by reference to a HUD's artificial horizon and "pitch ladder" symbology, especially at night and over water, and there are cases of pilots' being unaware of their aircraft's having become inverted. Also, pilots have reported a tendency to focus on the HUD combining glass rather than on the outside real-world scene (Jarvi, 1981; Norton, 1981; Roscoe, 1987a; McNaughton, 1985); the resulting myopia has been interpreted as a special case of a more general phenomenon known as "instrument myopia" (Hennessy, 1975; Roscoe, 1987a).

Such biased judgments also partially account for the fact that helicopter pilots flying with imaging displays frequently collide with trees and other surface objects. Such biased judgments have also been implicated in certain Air Force mishaps. Between 1980 and 1985 the Air Force attributed 19 mishaps to spatial disorientation; misinterpretation of or confusion by HUD symbology was a definite factor in the mishap of one survivor, and it is strongly suspected in a number of the others. In fact, it was this strong suspicion that gave rise to the 1985 Aircraft Attitude Awareness Workshop at Wright-Patterson AFB, from which we quote extensively. This loss of control is further discussed in Section IV-D, Fixed-Wing Aircraft, and in Appendix B.

Advanced electro-optical imaging and display systems have been integrated into aircraft and especially into rotorcraft operations. These vision-aiding systems permit pilots to fly with increased effectiveness under visibility conditions that often precluded flight just a decade ago. Among these systems are night vision goggles (NVGs) and forward-looking infrared (FLIR) devices. NVGs intensify low-level visible and near-infrared light, such as reflected moonlight. On the other hand, FLIRs typically operate entirely on reemitted and reflected thermal energy in the infrared 8-11 micron band.

These devices do *not* "turn night into day," but rather provide visual displays that differ in important respects from unaided daylight vision. They provide sufficient interpretable visual information to permit rotorcraft pilots, for example, to fly at very low altitudes and avoid obstacles in reduced visibility. The impact on piloting and perception of the differences between the visual scenes presented by night vision devices (NVDs) and unaided daylight vision is generally *not* well understood.[8]

There have been numerous (but largely undocumented) reports of difficulties with the use of NVDs--difficulties including poor resolution, personal discomfort, disorientation, and accidents. Boyd (1991) has recently analyzed crew errors in night rotary-wing accidents and provided outstanding documentation on many aspects of such accidents, including comparisons of unaided-vision versus NVD-aided accident profiles. The data indicate the scope of the problem, at least with regard to rotorcraft piloting.

Except for their special capability of seeing either in very low light levels or by infrared radiation, the displayed data from night vision sensors are quite similar in the variety of visual problems they create. Thus we consider them as a group after first briefly reviewing the night vision goggles widely used in both fixed-wing and rotary-wing aircraft.

B. NIGHT VISION GOGGLES (NVGs)

1. Nature of NVGs

A modern form of NVGs incorporates the proximity focused image intensifier tube. The goggle consists of four component assemblies as follows:

1. A mounting frame or case to hold the components
2. Two channel plate proximity focused image intensifiers, one for each eye
3. Objective lenses with focusing adjustments (to image the scene onto the photocathode of the proximity focused image intensifier)
4. Magnifying eyepieces with focusing adjustments (to allow a viewer to see the intensified image).

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8 But see Kaiser and Foyle (1991), who identify critical human-factors concerns suggested by field data and review empirical studies of performance on flight-relevant perceptual tasks, notably depth and distance perception with NVDs.

The design and use of the objective lens is conventional and needs little explanation, except perhaps to say that its function is similar to that of the objective (front) lenses in a pair of binoculars. The NVG eyepiece is similar to the eyepiece of a good pair of binoculars. The heart of the device is the channel plate proximity focused image intensifier. A brief but detailed description is given in Appendix C.

Use of typical NVGs permits the user to see objects at very low ambient light levels with a resolution on the order of 20/40 visual acuity. Without use of NVGs or other visual aids, acuity at such low light levels would be on the order of 20/400 or worse--that is, worse than "legally" blind. However, night vision devices have been implicated in aircraft accidents, especially the NVGs used with rotary-wing aircraft flights.

In all truthfulness, it must be stated that night flying under the best of conditions is more dangerous than flight in daylight. In the following paragraphs we quote Boyd's statistics for accidents. It is unfortunate that we have no basis for comparison of how many flights were made in the period studied under daytime and nighttime conditions. Thus, we have data on accidents, but we do not know what fractions of flights these represent. Since these were the best data we could obtain, we offer up the numbers. Even without comparison to the total number of flights, they give one sufficient pause to see that some remedial actions are necessary.

2. NVG-Related Accidents in Rotary-Wing Aircraft

Boyd (1991) points out that between FY 1984 and FY 1989 inclusive there were 626 Army rotorcraft (Class A-C) accidents. Of these, 145 (23%) took place at night, and of the night accidents, 119 (82%) were attributable to crew error, 83 (70%) of those while operating with aid of NVGs and 36 (30%) without NVG visual aids. Comparisons of the fatalities resulting from these accidents were even more dramatic: 199 overall, with 82 (41%) occurring in night accidents, and crew error associated with 70 (85%) of these--50 (71%) while using NVGs and 20 (29%) without NVG visual aids. The costs associated with the accidents, like the fatalities, showed the scope of the NVG-aided accidents to be quite large: $506.8M overall, with $193.3M at night and $159.0M (82%) of this attributable to *crew-error-associated night accidents*--$138.4M (87%) while using NVGs and $20.6M (13%) without NVGs as visual aids.

In analyzing the origins of the crew errors, Boyd (1991) was able to categorize the 132 errors into eight types:

1. *Scan*--Improper direction of visual attention inside or outside the aircraft; i.e., too much or too little time on one object/area; scan pattern not thorough or systematic.
2. *Coordinate*--Failure of crewmembers to properly interact (communicate) and act (sequence and timing) in performance of flight tasks.
3. *Maintain/Recover Orientation*--Failure to properly execute procedure(s) necessary to maintain or recover orientation in flight environments known to restrict visibility; e.g., snow, dust, instrument meteorological conditions (IMC), black hole, and over black water.
4. *Plan During Flight*--Improper inflight modification of flight plan or failure to properly modify flight plan in response to unanticipated events or conditions.
5. *Plan Preflight*--Failure to choose appropriate flight options for known conditions and contingencies and develop these into a course of action to maximize probability of mission accomplishment.
6. *Estimate*--Inaccurate estimation of distance between objects or rate of closure with objects.
7. *Detect*--Not identifying obstacles or not recognizing other hazardous conditions; e.g., obstacles in landing area, unsecured equipment, and improper control/switch position.
8. *Diagnose/Respond to Emergency*--Improper identification of, or response to, an actual, simulated, or perceived emergency.

These eight types of error occurred with frequencies as follows: scan (36), coordinate (27), maintain/recover orientation (23), plan during flight (21), plan preflight (11), estimate (8), diagnose/respond to emergency (4), and detect (2). Also, Boyd (1991) was able to assign the origins of these 132 crew errors to various shortfalls or failures (with frequencies) as follows: individual (54), leader (36), standards (20), training (16), and equipment design (6). Thus, the principal sources of crew error were individual (overconfidence, haste), leader, standards, and training. Other conclusions were that no crew-error type was associated more with aided than unaided flight, and none increased over time. However, crew-error types were related to operational factors such as the phase of flight, mission, command, aircraft type, airspeed, and visual obscuration.

In addition, considerable evidence indicates that other factors, such as the training of a user to adjust and calibrate an NVG individually before use, can determine much of the resulting visual capability (and related military performance) of that user.

3. Aircrew Training and NVG Issues[9]

There is a wide variation in NVG skills, even among the most highly experienced NVG pilots. Some are highly competent, but many are using incorrect procedures, and some have received no training at all in the use of NVGs. Some procedural training is given most Army pilots, but such training in the past has appeared to be insufficient for ensuring subsequent correct use of NVGs. Many pilots are actually incorrectly "trained."

Because the equipments necessary for preflight adjustment and assessment of NVGs have generally *not* been available, effective training really has not been possible, and appropriate preflight procedures usually have not been practiced. Moreover, significant deficiencies exist not only in NVG-use training, but also in NVG-maintenance practices and training. Damaged or failing NVGs are sometimes not recognized as being faulty, and maintenance procedures are not always performed correctly. Yet, it is important that every aircrew member be able to assess accurately the condition and operability of his or her NVG before each flight on which it is to be used. The capability to accomplish such an assessment is dependent upon a combination of necessary equipment (or facilities) and skill (or training).

Realizing the need, personnel at the Armstrong Laboratory's Aircrew Training Research Division at Williams AFB, Arizona, among other accomplishments during 1991, (a) developed and evaluated an NVG test lane, (b) established a prototype NVG training facility, (c) developed and validated a prototype NVG course for training, and (d) produced video demonstrations of NVG effects, limitations, and illusions.

The NVG test-lane evaluation procedures were as follows: (a) the available NVGs were screened for performance, (b) experienced NVG pilots were asked to adjust their NVGs for flight with their "usual" methods, (c) visual acuity was measured with a chart calibrated from 20/35 to 20/100, (d) the test subjects were then allowed to readjust their

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9 This section is based primarily on materials obtained during a discussion with Colonel W. Berkley, USAF, at the Armstrong Laboratory, Aircrew Training Research Division, Williams Air Force Base, AZ, 19 June 1991.

goggles using the test lane a ıd test-lane procedures, and finally (e) visual acuity was redetermined.

The results, shown in Fig. 5, can be summarized as follows:

- 8 of the 20 available ANVIS-6 NVGs used in the test could not resolve better than 20/45.
- 20 of the 28 test subjects failed to achieve 20/45 acuity (or better) with their "usual" method.
- Most subjects could not judge the adequacy of their visual acuity (or of the NVG performance) without the test lane, even when acuity was worse than 20/100.

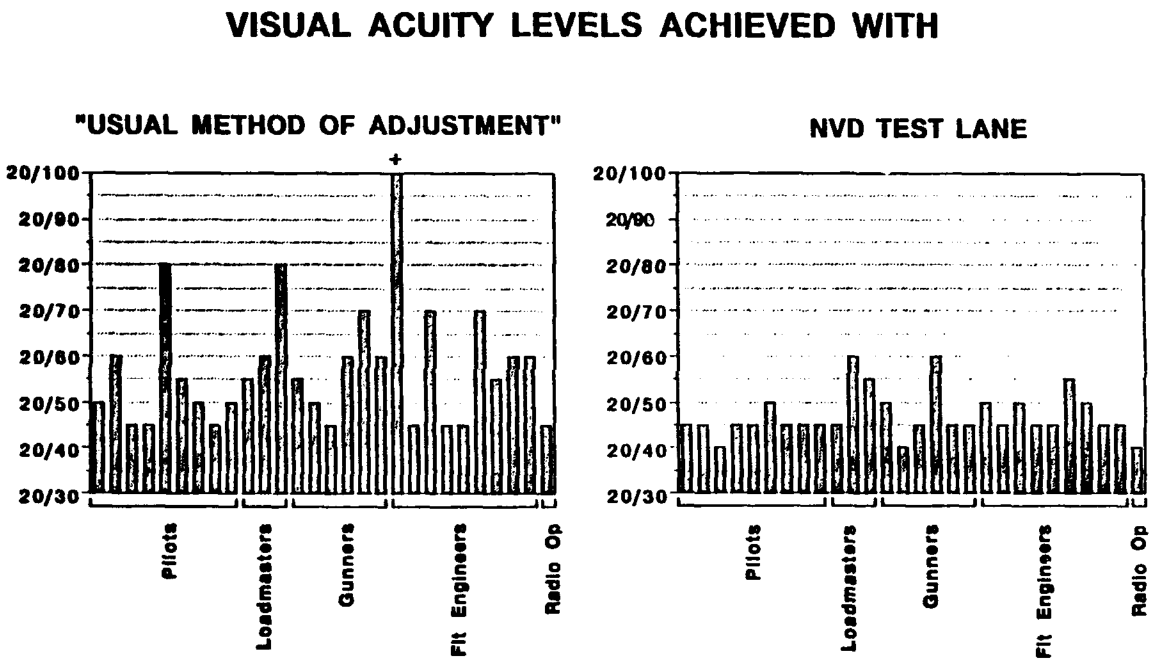

Figure 5. NVD test lane initial evaluation.

The laboratory personnel provided support for Desert Shield and Desert Storm by distributing test-lane equipment to Army, Navy, and Air Force units in the theater of operations, and by training more than 200 pilots, instructor pilots, and flight surgeons. In addition, two video training tapes were made for ongoing in-theater instruction, and the Army made and distributed 300 copies of the resolution chart locally in theater.

Subsequently, a prototype NVG t aining facility has been developed, along with new training media and courseware[10] to support the facility's test and evaluation. The prototype facility is to be situated with an existing NVG training unit at Kirtland AFB, New Mexico, and major command implementation is to occur following completion of a validating evaluation.

4. Cockpit Lighting--An NVG Issue of Concern

The maximum sensitivity of the human eye is to "green" light (505-555 nanometers). Green cockpit lighting is vastly superior to white light, and especially to red light, even when NVGs are not used. That is, cockpit displays are much more legible at lower power levels with green lighting. The use of most white lighting devices at the higher levels of illumination needed for equivalent legibility will reduce the functionality of the NVG because of the red and infrared radiation included in white light, and use of red cockpit lighting will essentially nullify NVG utility.

If NVGs are to be used, it is essential that green cockpit lighting be employed (in accordance with MIL-L-85762A). Any incompatible light sensed by the NVGs will cause a reduction in gain, and therefore decreased NVG performance, with the reduced capability only rarely perceived by a human looking through the device. All new aircraft (or other equipment to be employed with use of NVGs) should call for the green lighting. After nonrecurring engineering, NVG-compatible green cockpit lighting would cost little or no more than white lighting.

Though all these facts are well known by cockpit designers and flight safety people, financial interests continue to defer this important correction to current design practice.

5. Summary--Aircrew Training and NVG Issues

Night operations are inherently more demanding than comparable day operations. Crews (and commanders) should fully understand the limitations of their aircraft, vessels, or vehicles, as well as their weapon systems and human system components, if they are to attain predictable and high levels of performance. High levels of proficiency will help offset but will not eliminate the performance degradations typically associated with

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10 For example, see Appendix D.

nighttime operations, fatigue, and circadian desynchronization. Nor will they eliminate other NVG degradations due to improper ambient lighting, or due to improper adjustment or calibration assignable to poor or inappropriate training.

After the experiences of Desert Storm, it is even more likely that night military operations will receive greater emphasis in the future. Nighttime training, especially in piloting aircraft, will be limited by resources, airspace restrictions, time constraints, and safety considerations. Specialized facilities and simulators for such night-operations training will doubtless be essential.

C. HELMET-MOUNTED DISPLAYS--PROBLEMS WITH THE IHADSS HMD IN THE APACHE HELICOPTER

Between calendar years 1985 and 1989 inclusive, there were 31 serious (Class A to C) display-related accidents in Army AH-64 attack helicopters, 42% (13) of them attributed to IHADSS-pilot factors such as undetected aircraft drift (5), misuse of symbology (3), misjudged aircraft clearance (2), poor helmet fit (1), overconfidence in pilot night vision system (PNVS) (1), and the "waving-grass" illusion (1).[11]

Even if the above operational problems were not alarming, the serious visual symptoms reported by Apache crews require serious attention. The most recent reported data is contained in a USAARL report published in September 1990 (Behar *et al.*, 1990). Because it so clearly indicates not only the seriousness but also the extent of the problem, the few pages of its executive summary are reproduced *in toto.*

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[11] The waving-grass illusion is a false perception of self-motion from the wavelike motions of weeds or grass that can result from the effects of helicopter rotor downwash or strong winds. Rotor downwash or strong winds produce a series of wavelike-appearing motions in weed- or grass-covered terrain, which are similar in nature and cause to the wave motions observed in the ocean whenever significant winds exist. The rotor downwash in a stable no-wind hover forms a circular outflowing pattern from rotor center, modified by rotor lift and height. The shape and centering of the outflow pattern is modified by local winds, and by the attitude and speed of the helicopter. It shifts rearward on takeoff, and shifts forward during the final deceleration stages of landing until the steady hover shape is assumed.

Different false perceptions of self-motion can result whenever a restricted part of the rotor downwash flow pattern is viewed through a restricted-field-of-view imaging device, and even with direct vision whenever the total flow pattern is not evident. Strong winds create a similar but different pattern of wavelike motions in weed/grass-covered surfaces that can move in any direction. Winds also will combine vectorially with rotor downwash patterns to further confuse state perceptions. The flowlike nature of these stimuli almost certainly results in stimulation of spatial-motion-location visual processes, which are known to take precedence over any other sensor or cognitive stimuli. In other words, waving-grass illusory perceptions can be very compelling.--Charles A. Gainer, Chief ARI, Aviation R&D Activity, Fort Rucker, Alabama, personal communications, 17 June and 10 December 1991.

Executive Summary

A study of AH-64 Apache pilots was conducted to address the visual medical concerns associated with flying this aircraft. This study consisted of three parts, each addressing a separate aspect of Apache aviator vision. The first part, accomplished by written questionnaire, was primarily an epidemiological appraisal documenting current visual problems experienced by the Fort Rucker Apache instructor pilot (IP) population. The second part was a clinical and laboratory evaluation of the refractive and visual status of a sample of these aviators. The third part assessed the Apache pilots' adjustment of the dioptric settings of the Integrated Helmet and Display Sighting System (IHADSS). Because the IHADSS is designed to have the virtual imagery appear at optical infinity, incorrect diopter adjustment could result in sustained accommodation, which, in turn, could lead to visual fatigue and subsequent related visual symptomology.

Part 1. Anonymous questionnaire

A brief questionnaire was forwarded to the 14th Aviation Regiment, Fort Rucker, to be distributed to the Apache IP population. A total of 58 were completed and returned. In order to elicit unguarded responses, the questionnaire was completed anonymously.

A. Demographic information:[12]

Years of age:	Mean: 35.8	Range:	26-44	
Years of service:	Mean: 15-3	Range:	4-24	
Total flight hours:	Mean: 3330	Range:	1000-9000	
AH-64 flight hours:	Mean: 664.4	Range:	150-1500	(N=55)
AH-1 flight hours:	Mean: 1707	Range:	150-5000	(N=54)
AH-64 hours within last 30 days:	Mean: 32.3	Range:	2-60	
Percent of recent time at each crew station:	Pilot -- Mean: 20% CPG -- Mean: 80%	Range: Range:	8-96% 10-100%	
Night vision goggle qualified:	Yes: 51 (88%)	No:	7 (12%)	
Eyeglass wearers:	Yes: 20 (34%)	No:	38 (66%)	

[12] N = Number of responses (58 unless noted otherwise).

B. Visual symptoms reported by Apache pilots during and after Apache flight:

More than 80 percent of the pilots registered at least one visual complaint associated with flying or after flying the Apache aircraft. Many of their comments indicated that symptoms occurred during long flights and/or flying with poor quality or out-of-focus display symbology. The most common symptom experienced was that of visual discomfort while flying the aircraft. Fifty-one percent of the pilots indicated that they sometimes experienced visual discomfort while flying; only 28 percent reported a similar problem after flying. About one-third of the aviators reported suffering from occasional headaches and about 20 percent responded that they sometimes experienced either blurred vision and/or disorientation while flying. The percentages of pilots reporting headache and blurred vision remained about the same after flight, while the percentage of those experiencing postflight disorientation decreased to five. About 20 percent of all pilots reported the presence of afterimages following Apache flight. The actual percentages of pilots reporting symptoms are shown in Table 1; a sampling of their pertinent comments follows the table.

Table 1. Percentages of Pilots Reporting Visual Symptoms During and After Apache Flight

	During flight			After flight		
	Never	Sometimes	Always	Never	Sometimes	Always
Visual discomfort	49%	51%	-	70%	28%	2%
Headache	65	35	-	67	32	2
Double vision	86	12	2%	89	9	2
Blurred vision	79	21	-	72	24	3
Disorientation	81	19	-	95	5	-
Afterimages	NA	NA	NA	79	19	2

During flight comments:

-- Occasional eyestrain due to poor FLIR [forward looking infrared] quality on some flights when the system is used extensively (visual discomfort).

-- ...on PNVS flights of more than 3 hours (visual discomfort).

-- If the FLIR image is out of focus, of poor quality, or if the HDU [helmet display unit] is out of focus, severe right eye pain for up to several hours (headache).

-- When using the HDU (day gunnery or night flight), headaches occur followed by vision problems. Problems may be due to my inability to obtain an "infinitv focus" on the HDU symbology or the system not maintaining the focus that I've set (headache).

-- After removing the combiner lens from the right eye things are blurred for 4-5 minutes (blurred vision).

-- Occasional, mild, when switching rapidly between the left (unaided) and right (aided) eyes to resolve an object in the field-of-view (disorientation).

After flight comments:

-- Occasionally, after long PNVS [pilot night vision system] flights of greater than 3 hours, I experience eyestrain or "soreness" in my right eye which persists until I go to sleep (visual discomfort).

-- After 3-4 hours of system flying under PNVS (headache).

-- After flying the night system, my right eye has blurred vision for about 45 minutes (blurred vision).

-- After long flights (>2.5 hours) with poor quality FLIR, some afterimages can occur for up to 2-3 hours after the flight. This is most noticeable in a dark room such as when going to bed after a training day.

C. Additional visual problems:

Fifteen pilots (26 percent of the sample) reported changes in their ability to see or interpret HMD [helmet mounted display] symbology during flight. All but two of those claimed that their abilities worsened. About 70 percent of all pilots used the affirmative categories (Always, Usually, Sometimes) when asked if their vision ever alternated unintentionally between the two eyes either during or after Apache flight. Of the 20 self-reported spectacles-wearers, only 11 responded to the question of whether the use of the modified spectacles interfered with the ability to see HMD symbology; of those, however, 10 responded that the spectacles interfered with viewing and reported significant discomfort from their wear.

D. Additional aviator comments:

Pilots were asked to provide comments on any other visual or ocular symptoms experienced with the Apache IHADSS, apart from those questions contained in the questionnaire. Some of their responses are listed below:

-- After long periods on PNVS operations and consecutive nights, I have problems with focusing distant objects with the right eye.

-- After an extended period of HDU use, the right eye is not night adapted while the left eye is. After rotating the HDU out of the way, you are essentially night blind in the right eye and night adapted in the left eye. This causes slight sensations of imbalance and loss of depth perception until the right eye adapts several minutes later.

-- I've developed the ability to use each eye separately. I am becoming excessively right-eye dominant. I have to close it when not flying to use my left eye.

-- My right eye appears to be having acuity problems and suffering from strain. My guess would be that during flight with the HDU/HMD, I may not be able to distinguish a proper infinity focus as designed, and

I'm continually causing my eye to compensate, causing strain and blurring problems, and causing my acuity to be lost.

Part 2: Laboratory evaluation of 10 Apache aviators

The original design of the study called for two groups of five pilots, one group consisting of individuals who had reported Apache related visual problems to the Flight Surgeon, and a group who had not reported visual problems and were matched in age and in flight experience. Because of temporary duty (TDY) and duty conflicts, and at least one refusal to participate, the individuals identified as having visual problems were by-and-large not available for this study. The sample thus consisted of but a single group of opportunistically selected IPs. They ranged in age from 32 to 44, mean 38.6 years. As a way of distinguishing among the 10 pilots with respect to visual symptoms and complaints, their responses on the questionnaire were tallied. The maximum possible score is 11, and for the present sample the range was from 0 to 4 with a mean of 1.5.

The correlation coefficients for the relationship between the visual complaint score and 32 different measures of visual and ocular status were calculated. None of the correlations were statistically significant. Differences between the right and left eyes on the variety of vision and ocular tests were small in all cases. There was evidence of mild incipient presbyopia in most of the pilots, but this is within expectations for the age group. Binocular ocular motility for the group as a while was found to be lower than expected.

In summary, no significant variation from expected normal values was measured in the ten AH-64 aviators who were subjected to comprehensive visual function testing.

Part 3: Measurement of Helmet Mounted Display (HMD) dioptric focus setting

Twenty Apache aviators served as subjects, 11 students and 9 instructor pilots. Nine subjects were measured under nighttime illumination; the remaining 11 were measured under daytime illumination.

The range of dioptric settings was 0 to –5.25, with a mean of –2.28. The required positive accommodation by the eye to offset these negative focus settings is very likely a source of headaches and visual discomfort during and after long flights. No correlation was found between the focus settings and aviator age or experience; nor were there differences between IPs and students, or day versus night settings.

Prior to the data collection procedure, it was hypothesized that inadequate training in proper procedures for setting the focus of the HMD could very likely result in unnecessarily high negative settings. This is a result of the eye's ability to induce positive power. This hypothesis was borne out by the data and the observed focusing techniques demonstrated by the aviators. The hypothesis was further tested on three subjects by demonstrating to them proper focusing technique and having them repeat the focus setting. The repeat focus settings for all three subjects were between 0 and –1 diopter.

D. FIXED-WING AIRCRAFT

Between 1980 and 1985 the Air Force lost 73 aircraft in clear weather. Of these, 54 mishaps of controlled flight into terrain have been attributed to pilot misorientation, and 19 mishaps have been attributed to disorientation resulting in loss of control. These factors have been addressed quite seriously, and the remarks of three investigators are given below.

1. An Investigation of Spatial Disorientation of F-15 Eagle Pilots as Reported by Colonel D. W. Jarvi (1981)

In his report Colonel Dennis W. Jarvi stated:

> F-15 Head-up Display (HUD). A fundamental concern was expressed by some of the F-15 pilots that there exists an overdependence on the HUD in flying the aircraft. This is particularly true when a pilot finds himself either in an unusual attitude or recognizing the symptoms of vertigo. There is a tendency for the pilot to initially look at the HUD to become reoriented and effect recovery. However, the recommended procedure in this situation is to completely ignore the HUD and immediately transition heads down to the cockpit panel instruments. This natural tendency for the F-15 pilots to employ the HUD as the primary instrument display has reportedly at times caused a loss of reference by pilots, which probably can best be described as the experiencing short-term disorientation phenomenon. This effect may occur from either (a) the "rush" of the flight parameters in the HUD, such as the scale displays of altitude, airspeed, heading and pitch attitude, during aircraft maneuvering, or (b) the visual transition from the HUD to the external world scene at night, which is a function of the accommodation and contrast effects on the human visual system during reduced ambient illumination levels. Although the HUD is collimated at infinity, the display tends to cause the pilot's eyes to focus at the near point of the combining glass rather than seeing the symbology superimposed on the external scene. Furthermore, the HUD symbology brightness level cannot be adequately adjusted at night. In order to readily discern the numbers which are displayed in green, the display brightness must be increased to a level where the pilots feel they cannot see out of the cockpit. Thus, when there is a requirement to scan outside the aircraft, the display brightness must be reduced, which only adds to the pilot's workload problems.
>
> Most of the pilots interviewed reported that they flew instruments primarily with the inside panel and utilized the HUD for cross-check purposes and during stabilized flight. Although the pilots indicated that the HUD information provided fairly accurate information, instrument flying with the HUD in actual weather conditions tended to increase the probability of disorientation. Interestingly, the HUD was designed by McDonnell Douglas as a primary flight reference, but the Dash One cautions against using the HUD for this purpose due to inadequate failure warnings. It was suggested that a minimum number of HUD-out instrument approaches should be required in the simulator and in the aircraft in order to reduce the

dependence on the HUD. Although this training requirement would be difficult to enforce, it nevertheless would emphasize the need for pilots to become more familiar and comfortable with HUD-out instrument flying. Newer pilots have not used the instrument group over the HUD to the point where they feel confident, such as older pilots who once had only instrument experience and feel comfortable relying on them. In summary, the pilots find the HUD a very compelling display, presumably because of its information content, prominent location in the pilot's visual field, novel display mode, and the overall integrated relationship of the HUD to flying the aircraft and accomplishing the mission.

F-16 Heads-up Display (HUD). The F-16 HUD is considered a primary reference except for instrument flight. All pilots stated they would go directly to head down instruments when in instrument conditions or disoriented without trying to use the HUD. One pilot commented that the HUD is the worst place to look if disoriented. The only other HUD comment that was expressed concerned the small field of view that requires taller pilots to lean forward or slouch down to view the level flight reference below 300 knots.

Jarvi then made the following recommendations from the conclusions drawn:

Recommend the F-15 pilots be trained to avoid using the HUD as an instrument reference when transitioning from formation flying at night or in instrument conditions, especially in lost wingman situations. Rather, they should be trained to refer to the ADI and primary flight instruments.

Recommend the F-15 pilots practice HUD-out instrument approaches to decrease dependence on the HUD and to permit the pilot to become more familiar with and comfortable at flying instruments without the HUD.

Recommend the HUD symbology brightness control be reviewed for improvement under night flying conditions. A scheme similar to the yellow filter on the A-7 aircraft HUD is suggested for review.

2. Remarks by General A.L. Pruden on Loss of Situational Awareness

Brigadier General Albert L. Pruden, Jr., was director of Inspection at the Air Force Inspection and Safety Center, Norton AFB, in 1984. In a meeting on 8-10 October 1985 at the Flight Dynamics Laboratory, Wright-Patterson AFB, he made a series of statements quoted below:[13]

In 1984, 20 of 41 operator-factor accident reviews cited "loss of situational awareness" as a probable contributory factor.

- 5 of these were inadvertent flights into the terrain (spatial disorientation/misorientation).

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[13] General Pruden's complete remarks are included in Appendix A.

- Other factors commonly noted were task saturation, distraction, and channelized attention.
- This group had a high fatality rate due to ejection out of the envelope or no ejection attempts.
- In 1985, similar patterns.

To date, inadvertent flight into the terrain and G-induced loss of consciousness (GLC) appear to have contributed to half of F-16 operator-factor mishaps.

- Spatial disorientaion (SDO) is an old problem that is very much still with us.
  - -- Less than ideal cockpit for instrument flight.
  - -- Cockpit design concerns include flight instruments, warning systems, and distractions.
  - -- Flight instrument options.
    1. Reduce the number of digital displays.
    2. Improve information display on the HUD.
    3. Review basic efficiency of information transfer through flight instruments. (Instr. Flight Center).
- The trend in spatial disorientation/misorientation mishaps is increasing.
- SDO situations: night aerial refueling or refueling in the weather. Night low level formation approaches: wingman's problems when lead's formation lights do not work.
- Fighting in clear blue sky -- SDO has happened more than once to experienced F-15 pilots.
- HUD dependence -- canted cloud-deck viewed through HUD creates a mismatch (with the normal judgment of what is the true horizontal).

Those flying frequently in actual weather conditions tend to go heads down in weather whereas those who fly less frequently in actual weather tend not to go heads down. But, the real issue is not whether heads up is better than heads down or vice versa.

We need to maximize the technology available to us today to make something that is better than either the HUD or instruments -- or maybe a combination of the two.

3. Remarks by Colonel G. McNaughton on Disorientation

Colonel Grant McNaughton, whose presentation followed that of General Pruden at the same meeting, emphasized the problems of SDO by referring to specific HUD-related problems, some of which we quote below:

The HUD is also an inside-out display with reversed roll-sensing like an ADI, but it is not an ADI. The aircraft symbol, which moves in pitch and yaw (but not in roll) tells not where the aircraft is pointed but where the aircraft is going. It is really an inertially derived flight path marker. (Some HUDs also display a "W" waterline symbol or gun cross indication where the aircraft is pointed; the difference between where the aircraft is going and where it is pointed constitutes angle-of-attack.)

On the HUD, there is no clear distinction between sky and surface--the only difference being the type of lines on the pitch scale: solid for positive, dashed for negative. The overall pattern of the scales is symmetric about the 0° pitch line (horizon line) which, itself, is not much longer and therefore hardly more commanding than any other pitch line. The horizon line in most HUDs is straight, whereas all other pitch scales have "tails" pointing toward the horizon.

In trying to determine one's attitude from the HUD, it is not always immediately apparent whether one is upright or inverted, or climbing or diving, or if so, to what general extent, because the scales all look about the same.

Whereas the ADI gives a 60-110° FOV (the big or macro-picture), the HUD provides only a 14-20° FOV, or in the case of the F-16, 16°. This is the micro-picture; it is like taking a 16° circle out of the ADI, and expanding it over the face of the combiner. It not only magnifies the scale to 1:1 with the outside world, it also magnifies the dynamics of the FPM and, in particular, the Flight Path Scales (FPS, also called pitch scales). Whereas the FPM moves as if on a pendulum, suspended from the gun-cross, the FPS revolves around the FPM. The dynamics are such that at high pitch or roll rates, or in high crosswinds, the FPS can nearly slew off the face of the combiner and may become unreadable. In other words, at rapid roll or pitch rates, the FPS does not hold still for interpretation. Thus, the first step in recovering from an unusual dynamic attitude via the HUD is to first stop the roll or slow the pitch rate so you can read the numbers. This takes some finite amount of time. The next steps are combinations of pulling to the horizon and rolling upright, or rolling upright and pulling to the horizon. There are cues on the FPS's to help you reach the horizon: in the F-16 HUD, the FPS's have horizon pointing tails; in the F-18, the entire FPS is angled like a chevron aimed at the horizon, forming a channel. However, there is still the problem of determining which way is upright. Since there is no clear distinction between sky and surface on the HUD, you must reduce the dynamics sufficiently to tell whether the FPS's are solid (for positive pitch) or dashed (for negative). Again, this takes some finite amount of time. Furthermore, since there's nothing intuitively obvious about the symbology for upright vs. inverted, it's entirely possible to recover to straight and level, inverted, and not recognize it for some time.

The ADI is designed for the recognition of and coping with unusual attitudes. The HUD is not, and such actions can be very difficult on the HUD. This is not to say the HUD could not be improved upon for attitude recognition. As a minimum, two changes would be needed:

a. Since the FPM is so commanding, it would seem reasonable to make it into a roll cue. This could be done by simply adding to it a zenith-pointer.

b. The relative simplicity of pitch scales fails to cue regarding angle from the horizon.

Night combat flying is a difficult stressing task with a HUD or HMD, or without a HUD or HMD. McNaughton illustrated this well in the following:

> Having been at his new base about a month, this pilot was assigned to fly a series of surge sorties, in which he awakened at 0200, briefed at 0300, launched at 0400, flew some intercepts, then landed, flew another sortie or two, then headed back to quarters to try to get some rest for the next early morning go. The mishap occurred on a pitch black night over a pitch black range. This was his fourth morning, so first of all, if he wasn't tired, he should have been (although probably no more so than most of the others). Second, he'd been having difficulty acquiring his target, which was his lead aircraft, so was under some self-imposed pressure to get the talley. When it was his turn to be the interceptor, he thought he saw his target, called "Talley," lost talley, then called "Talley" again from a position where he was belly up to his target aircraft--no way could he have seen it. Over the ensuing 1-1/2 to 2 minutes, he proceeded to lose 11,000 feet, impacting near a lighted train siding. It so happened that a train had passed within several minutes. It's possible that his Doppler locked up the train and that he mistook its light for that of his target. Again, we'll never know. But just suppose that he had decided to check his altitude during that pitch black night (altimeter constitutes a fairly critical instrument on a pitch black night over terrain devoid of height references), and not seen it in the old location, could he have simply deleted it from his cross-check? After all, nothing was alerting him that he was going downhill and he certainly did not want to lose sight of that target again.

An additional anecdotal account of a young pilot's indoctrination into night combat missions, though with happier endings, is related below from a letter[14] strongly suggesting the need for more and better instrument training for pilots of fighter and attack aircraft:

> Make a point for more training--even make a case for overtraining--for instrument flying. I was amused by the account of the young pilot (p. A-12) whose accident was attributed to inadequate instrument flight training and practice, since I had two similar experiences, once in Korea, and again in Vietnam. As a 2LT in 1952, my first combat mission in Korea was flying number 4 in a 4-ship flight (F-84s) on a last-light recce over North Korea. We took off in formation 30 minutes before sunset, climbed into solid clouds at 3,000 feet, flew all the way to the target area in solid weather, let down to visual conditions, dropped two bombs each, rejoined in formation in the dark, flew back to Kunsan in night weather, and recovered in night landings. As of the beginning of that mission, I had had

[14] Personal correspondence from Dan Fulgham, Southwest Research Institute.

no night formation, no weather formation, two night landings in F-84s, a grand total of perhaps four hours of haphazard jet instrument hood time in T-33s, and a total of less than 50 hours flying time in the F-84. Scared doesn't come close!

Fifteen years later, I entered combat in Vietnam in F-4s, but with little or no instrument flight training in that aircraft, although I had 4,000 flight hours and was an instrument instructor and flight examiner, which made a lot of difference. Having the extra pilot on board also helped, very much. Now, here it is 1990s, and pilots are still being short-changed on instrument training, and in aircraft poorly designed for instrument flight. Our student pilots train for 12 months on conventional instrument panels and are then transitioned directly into HUD-equipped aircraft (with poor conventional displays) and expected to tackle night and weather flying with little opportunity to train and practice. It would not take much study to discover that more training and frequent flying would greatly reduce SDO incidents.

V. SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

There are several important and unresolved issues regarding (a) the proper content and format of displayed information, (b) the abatement of associated distortions of visual distance and orientation, and (c) the reduction of failures to note emergency warning signals or messages when aircrews use HUDs, HMDs, or NVGs.

In a 1991 Air Force Scientific Advisory Board summer study of what off-board information should be presented to aircrews,[15] participants became aware that there are problems regarding how such information should be presented, and how crews should be alerted that such information awaits their attention. Aircrews complain that some forms of such off-board transmissions present so much material, including messages that are stale, that the important stuff is often buried in what is to them unimportant miscellany and thus tends to go unnoticed. Certainly, the transfer of such off-board information has to compete with a panoply of on-board information.

A closer examination of problems related to on-board information reveals that cockpit and instrument designs are responsible for a significant number of aircraft accidents and fatalities. Colonel Grant B. McNaughton and General Albert L. Pruden, Jr., quite clearly made these points in a 1985 Air Force workshop on aircraft attitude awareness (Appendixes A, B). In that workshop, much attention was given to the HUD, its information content, and the training of aircrews in its use. Similar issues apply to helicopter piloting because of the increased use of HMDs in Army aviation.

HUDs have become an integral part of flight operations and are undoubtedly "here to stay." HMDs and NVGs are not far behind in the pervasiveness of their use in military aircraft. All three devices--HUDs, HMDs, and NVGs--present questions not only about information content and format, but also about other information display issues of reducing the factors that cause attention tunneling, visual distortions of distance or orientation, and

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[15] Summer study by the Ad Hoc Committee on Off-Board Sensors to Support Air Combat Operations, July 1991.

failures to note emergency warning signals or messages--areas where technology has outpaced human-factors applications to cockpit design.

Out of all the concerns mentioned in this report, spatial disorientation when using the HUD has been documented best in operational settings (Appendixes A, B). In addition, USAARL has reported eye dioptric missetting, uncorrected eye relief setting, and visual discomfort and fatigue using IHADSS in flying Apaches (Behar *et al.*, 1990).

Some of these problems can be corrected through training, and those are therefore viewed primarily as manpower and personnel integration (MANPRINT) issues, not issues of display design. Preliminary exploration of some of these issues has been accomplished recently in simulators or simulated field studies.

Eye fatigue and discomfort related to the use of both NVGs and IHADSS, the only operational helmet-mounted display, remain a big concern.

Further, there are reasons to believe that serious attentional and safety problems are associated with some of the newer techniques of displaying information to aircrews. During combat missions and other highly task-loaded situations, pilots are often stressed to a degree that makes them more subject to channelized attention and thus less likely to notice indications of trouble. There are some firm data, and considerably more anecdotal information, to the effect that during such moments pilots often fail to notice important safety-related information being provided to them through their visual displays or headphones. It can be said about such situations that the human-factors information-display shortcomings essentially negate the advantages of the technological advances being introduced.

Indeed, interviews with pilots and cockpit designers show major divergences between the designs based on state-of-the-art display technology put forward by engineers, and the human-factors technology needs governing the transfer of information to a stressed pilot. For example, pilots tend to report that there is so much talk on their radios, and so much symbology or text on their displays, that they do not hear or see much of the information intended for them.

A. DIGITAL VERSUS SYMBOLIC DISPLAYS

Many new cockpit layouts and displays fail to recognize some of the fundamental findings of cognitive psychology and human-factors studies regarding the use of digital versus symbolic displays and the two modes of human perception (often discussed in terms of left-brain versus right-brain dominance). We paraphrase McNaughton (1985) on these two modes:

> One is the familiar focal mode that focuses, reads a checklist, identifies a bogey, and aims a gun. This mode is highly discriminating and is exclusively visual, limited in fact to the central 1-2 deg of the retina. It typically involves conscious attention and requires good lighting and sharp resolution.
>
> The second is the ambient mode that orients a person to the (ambient) environment. This mode is concerned not with object recognition, but rather with object quality, or more correctly, the quality of the surround--e.g., the "surfaceness" of a surface, the "horizonness" of the horizon, or the "cockpitness" of a cockpit. It is a quality-assessment mode that tends to be both undiscriminating and uncritical, and therefore easily deceived in the sense of providing a "faulty" perception. The degree of visual resolution is unimportant in the ambient mode; one can orient oneself with 20 diopter lenses before one's eyes. The ambient mode typically functions at more of a reflex level. Along the scale of evolution, it is the mode that appeared first.

Much situational-awareness information is now being presented digitally and thus requires interpretation by use of the focal (left-brain) perceptual mode, whereas the demands of situational awareness are normally met by use of the ambient (right-brain) perceptual mode. Indeed, in the 1985 Aircraft Attitude Awareness Workshop, General Pruden strongly recommended getting rid of most, if not all, digital data displayed in aircraft cockpits in favor of getting back to presentations like the old round meters and "ribbon" displays where the *length* of a ribbon means something that can be instantly grasped (Appendix A). An example would be the use of two parallel vertical ribbons denoting two engine speeds. If the ribbon tops are next to each other, the engine speeds are equal--there is no need to read two or three significant figures and then compare the values! Another example would be a thermometerlike representation of altitude making it unnecessary for a G-loaded pilot to read the fine print of a digital display. Contrary to General Pruden's recommendation, however, there seems to be a continuing trend toward high-resolution digital displays based on state-of-the-art technology rather than on the characteristics of the human's perceptual system and pilots' needs.

B. HUD-RELATED ORIENTATION PROBLEMS

The Air Force teaches its new pilots that they *must* rely on conventional instruments for such details as which side is up. However, most young fighter and attack aircraft pilots tend also to learn to fly by their HUDs (and, as a result, some die by them). The natural tendency for an F-15 pilot to employ the HUD as his primary instrument display has been reported at times to have caused a short-term disorientation—or loss of reference—on the part of the pilot.[16]

Although the HUD is collimated (its symbology made to appear as though it were at infinity), both the pilot's knowledge of the nearness of the display and his seeing the symbology as superimposed on the external scene tend to cause him to focus at the near point of the combining glass rather than at infinity (Section II-A, Misaccommodation, p. 6). Such misaccommodation appears *not* to explain adequately the reported disorientation.

The HUD is a very compelling display for a pilot, presumably because of its information content, its prominent location in the pilot's visual field, its novel display mode, and its overall integrated relation to flying the aircraft and accomplishing the mission. It may also be that pilots are better practiced in use of the HUD than in use of the conventional displays. For example, conversations with high-performance aircraft pilots indicate an almost universal complaint about insufficient training in the use of standard instruments in poor weather or at night (see quotation of Dan Fulgham, bottom of p. 37).

Further, there seems to be a tendency for young pilots to be trained in one (earlier) version of an aircraft, and then to be assigned to an operational unit equipped with another (later, more advanced) version with different instrumentation (i.e., different displays and display positions). The importance of standardizing the displays, their positions, and the kinds of information presented on them in a given model of an aircraft is self-evident. Granted, instrumentation advances should not be stopped, but cockpit updating should be more widely practiced, where possible. [Clearly the Global Positioning System (GPS) would not fit into the 1960 concept of aircraft meters and gauges.] Progress in instrumentation continues today at accelerated rates, making a freeze on display technology and location difficult. *Nevertheless, the means of conveying to a pilot a sense of which way is up, where he is, and the status of his aircraft's vital statistics should be consistent and not critically dependent upon which aircraft model or version he is flying*. This was initially an observation that stimulated the birth of the human-factors engineering discipline during World War II, and the "lesson learned" then is not yet being implemented today!

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[16] Some psychologists and human-factors specialists attribute lack of recognition of unexpected events and spatial disorientation to fundamental problems in the human cognitive capabilities, especially when combined with the necessity of using text or symbology embedded in a scene on a display (Fisher, Haines, and Price, 1980).

C. PROBLEMS RELATED TO USES OF HMDs AND NVGs IN AIRCRAFT

Plans abound for future uses of HMDs in aircraft. Unfortunately, there are few data and little definitive guidance regarding fundamental issues such as (a) how much information one should feed to each eye, (b) what the overlap of the fields of each eye should be, (c) what overall field of view is necessary, and (d) how well the separately displayed information for one eye must be aligned with and scaled to that presented to the other eye.

The increasingly wide use of night vision goggles (NVGs) for night flying is a boon to many pilots, but the sensitivity and thus the utility of such goggles are greatly diminished by use of the existing typically white or red cockpit lighting, which seriously reduces NVG performance. The cockpit lighting, including that from the various meters and displays, of those aircraft in which NVGs are to be used must be filtered by removing the red and near-infrared content to permit maximum NVG performance, *or the goggles must not be used for pilotage.* Such proper lighting changes will *not* reduce cockpit visibility for the pilot's *unaided* vision. *Claims that a widespread retrofit of this sort would be too expensive must be reconsidered.*

The performance of the best designed HMDs and NVGs is seriously degraded by inappropriate or haphazard adjustment of the interpupillary distance (IPD) of those devices. Present procedures for self-determination of the IPD are clumsy and usually inaccurate. The optical centers of those instruments *must* be aligned with both pupils of the user. Such a measurement is needed before the best helmet-mounted system can be expected to perform properly. Fortunately, good and simple instruments for such measurements are both inexpensive and easy to use.

Wearers of spectacles typically have a careful measurement of IPD made by a trained oculist before a lens prescription is filled. Each HMD or NVG user should have his IPD measured and recorded, and he should carry it with him, perhaps on his "dog tags," so he will be able to set his equipment correctly. Likewise, individual HMDs or NVGs should have clear, sharp markings to allow a user to check or correct the IPD of the device he is about to use.[17] Thus, improvements are indicated in HMD and NVG hardware and in the training of aircrews for their calibration and use.

D. R&D NEEDED ON ATTENTION CHANNELING AND FAILURE TO RECOGNIZE WARNINGS

The experiments of Larish and Wickens (1991) demonstrated that experienced commercial pilots under high-workload conditions failed to see unexpected events. Specifically, 75 percent of the subject pilots did not see warning messages concerning windshear or another aircraft entering the runway ahead of them. The experiments were conducted under conditions different from those for military aircraft--e.g., different from conditions that could cause a military aircraft pilot to be unaware of a drastic need to abort, or to face an attacker of which he is unaware. A series of experiments needs to be carefully planned to extend the work of Larish and Wickens by employing conditions more representative of military situations. Such experiments might be carried out in a simulation dome or bubble, and could include measures of the speed of response for switching from the focal mode (the left-brain *reading* function) to the ambient mode (the right-brain *location* or *orientation* function). In addition, high-workload conditions should be used in these experiments--e.g., conditions such as conducting a Weasel mission, launching a Maverick, or setting up for a laser-guided weapon. The degree of success in completion of such simulated missions might be used as a criterion for certifying pilots for certain types of duty, or even for their selection or classification as to duties for which they may be best or least suited.

It should be noted that the HUD alone does *not* cause the attentional tunneling that typically occurs with its use. Many factors can influence or even bring about the same sort of attentional demand. Certainly, use of the HUD may be one of the more significant contributors, but as with other attentional demands, appropriate cognitive training could be used to bring about a substantial alleviation of the problem. The characteristics of such

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17 At present there is an adjustment for the IPD on the Aviator's Night Vision Imaging System (ANVIS) goggles. Unfortunately, just about all such goggles we have seen have a scale using tiny black bumps and numbers raised on the black rubber body of the goggles. All future goggles should have the IPD scale and pointer in white or yellow, rather than in black, on a black background. For the present, we suggest that every pair of such goggles be sent to a shop where someone with a young and steady hand using a very fine brush can mark the dots with small dabs of white or yellow paint. Aircrews should be told to check, if necessary adjust, and lock the proper IPD settings, and then adjust their eyepieces to their optimum settings before putting their helmets on. This simple procedure, when based upon careful measurements, should make the aircrews' tasks considerably less stressful.

training, and the conditions and techniques under which it should be presented for optimum effectiveness and efficiency, are yet to be determined.

E. R&D NEEDED ON FIELD-OF-VIEW (FOV) OPTIMIZATION FOR HMDs

The series of experiments recently conducted at the Armstrong Laboratory, Wright-Patterson AFB, Ohio, concerned with optimizing the fields of view of each of the two displays in an HMD need to be extended. The quantification of FOV for each eye and the amount of overlap have been examined for driving race cars over a difficult course and, very recently in December 1991, for flights of a helicopter at Fort A.P. Hill, Virginia. This work needs to be extended to a more realistic series of situations to determine if these choices are good for universal application to all flying tasks or whether the need is mission-class dependent. Obviously, a sound determination of the relations between FOV characteristics and various performatory indices would be desirable to avoid foolish spending in pursuit of FOV sizes beyond the point of diminishing performance returns.

F. R&D NEEDED ON CONVERGENT OR DIVERGENT BINOCULAR FOVs

Current designs for a helicopter pilot's helmet include both helmet-mounted display and night vision goggles, with the goggles being worn widely separated on the helmet so that the usual design to achieve overlapping fields of view for both eyes is difficult. Thus, the current design being implemented uses converging fields of view that allow the left eye to see objects entering the field from the right before the right eye can see them, and objects entering the field from the left are seen first by the right eye. It is not clear that this design does or does not cause confusion. Clearly, this is a topic to be clarified before the design process enters the final phase.

Use of an HMD increases the HUD's field of regard, but its instantaneous FOV is quite often restricted by resolution and weight requirements. How much FOV is sufficient in such situations is a "million dollar question." An engineering solution to enlarge the FOV while maintaining finer resolution is to overlap the binocular FOV partially. Then, the question becomes not merely "How much *overall* FOV is necessary?" but "How much *binocular* FOV is necessary?" Experiments are being carried out to address this issue, including current ones at the Air Force Armstrong Laboratory, Wright-Patterson AFB, Ohio, and others in collaboration with researchers at the Army's CECOM Center for Night Vision and Electro-Optics (CCNVEO), at Fort A.P. Hill, Virginia.

Currently some HMDs are being designed on principles that have never been proven suitable for operational use in aircraft. Additional R&D, including appropriate testing before production, seems imperative in this area.

G. R&D NEEDED ON THE PRESENTATION OF INFORMATION TO AIRCREWS

Issues regarding overlaying imagery with symbology and alphanumerics require serious R&D attention. Visual-lobe theory predicts that a pilot's attention to alphanumeric data causes the rest of the visual scene to fade in his perception. It is well known that a focus of strong attention (focal mode) on any one element of a visual scene (symbology, alphanumerics, or a detail) causes the rest of the scene (visual field) to "fade in perception." For example, if one focuses on the water tower low in the upper left quadrant of Fig. 4b (p. 19), one no longer sees not only the alphanumerics, but also the large building to the immediate right of and below the water tower.

There are similar R&D issues concerned with the best ways to alert aircrews, on a variety of missions, that an important message regarding their mission is coming in from off-board sources. The most appropriate methods--tactile, audible, or visual--for displaying the information in such situations are yet to be determined, as are also the optimum instruments and signals to be used in such displays.

H. MAJOR CONCLUSIONS

The major conclusions supported by the findings of this study are as follows:

- There is ample reason to believe that serious safety problems are associated with some of the newer techniques of displaying information to aircrews.
- The present state of understanding of human-factors issues related to displaying information to aircrews is insufficient to cope with many of the newer concepts of the "glass cockpit"--including HUDs, HMDs, and panel-mounted liquid crystal color displays.
- No definitive body of data exists on signal conspicuity or on how to ensure the intrusion of necessary information into a pilot's awareness.
- R&D is needed to address a wide variety of human-factors and display issues through experiments, trials in visual flight simulators, and finally in actual aircraft-flight demonstrations.

I. MAJOR RECOMMENDATIONS

Our major recommendations are as follows:

- Lighting in older combat aircraft must be updated so as not to degrade night vision goggle (NVG) performance, or NVGs must not be used.
- Each user of NVGs or binocular helmet-mounted displays (HMDs) should have his interpupillary distance (IPD) measured and recorded, and should carry it with him, perhaps on his "dog tags." Individual HMDs or NVGs should have clear, sharp markings to allow the user to check or correct the IPD of the device he is about to use. Presently there is an adjustment for the IPD on the Aviator's Night Vision Imaging System (ANVIS). Unfortunately, most have a scale using tiny black bumps and numbers raised on the black rubber body of the goggles. All future goggles should have the IPD scale and pointer in white or yellow, rather than in black, on a black background. Every pair of such goggles should be sent to a local shop where someone using a very fine brush can mark the dots with white or yellow paint.
- Before each flight, aircrews should check, if necessary adjust, and lock the IPD settings, and only then should they adjust their eyepieces to their optimum settings and put their helmets on.
- The service laboratories should initiate R&D on in-flight information requirements to prevent overloading HUDs or HMDs with peripheral data. Data presentation management is critical and must be under crew control. The kind of information displayed must be crew and mission selectable.
- Flight schools should increase emphasis on training combat pilots to avoid using HUDs or HMDs as instrument references, especially when transitioning from formation flying at night or in instrument-flight conditions. Rather, train them to refer to the ADI and primary flight instruments.
- Aircraft displays--including their formats and locations--should be standardized. Acknowledge that there are problems with standardization and freezing of designs. Nevertheless, the means of conveying to a pilot a sense of which way is up, where he is, and the status of his aircraft's vital statistics should be consistent and not critically dependent upon which aircraft model he is flying.
- Apply similar measures to the designs of the forthcoming "all-glass cockpit."
- Pursue R&D related to the noted human-factors and display issues through experiments, trials in visual flight simulators, and finally actual aircraft-flight demonstrations.

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APPENDIX A

INTRODUCTION AND SUMMARY, SELECTED FINDINGS AND RECOMMENDATIONS, AND SELECTED PRESENTATIONS FROM PROCEEDINGS OF AIRCRAFT ATTITUDE AWARENESS WORKSHOP[A-1]

CONTENTS

[A-1] G. B. McNaughton, ed., *Proc. Aircraft Attitude Awareness Workshop*, held at Flight Dynamics Laboratory, Bldg. 146, Rm. 203, Wright-Patterson Air Force Base, 8-10 October 1985, Life Support SPO, Deputy for Aeronautical Equipment, Aeronautical Systems Division, and Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. 8 April 1987, pp. XI to XV, 1-2-1 to 1-2-6, and 1-3-1 to 1-3-53.

INTRODUCTION AND SUMMARY

Several of our newer state-of-the-art fighter-attack aircraft, while well-suited to the day VMC role, create significant problems for the pilot when flown at night or in IMC. Much of the problem stems from the fact that designers have not taken into consideration how the pilot functions or what he needs in order to maintain basic attitude awareness. Thus on one hand, these aircraft contain features which tend to mislead, confuse, or disorient the pilot, while on the other hand they fail to provide adequate references for coping - for maintaining or regaining aircraft attitude awareness.

It is our responsibility to analyze these problems, to determine whether cost-effective remedies exist for our current fleet, but perhaps even more importantly, to insure that these problems not be perpetuated in future aircraft. For, unless the priorities are properly established, many of these ultra-expensive aircraft and their crew will needlessly be lost in training mishaps. the first priority is aircraft control, the ingredients of which are awareness of attitude, altitude, airspeed, and vertical velocity.

This workshop considered aircraft attitude awareness not only in the context of spatial disorientation, in which the pilot is aware of an orientation problem, but also in the context of spatial "misorientation," in which the aircraft has subtly attained an attitude of which the pilot is unaware. Furthermore, in view of the preponderance of mishaps due to Controlled-Flight-Into-Terrain (CFIT), considerable attention was devoted to altitude awareness, collision warning and avoidance systems, automatic recovery systems, and G limiter override capability.

The workshop developed a number of findings and recommendations summarized below:

To avoid collisions with the surface, the pilot needs inputs to sensory channels other than the focal visual system. Properly designed auditory and proprioceptive interfaces have the potential to redirect the pilot's attention to his flight path in time to initiate correction. Failing this, the aircraft should attempt to auto-recover.

To maintain or regain aircraft attitude awareness, the pilot requires visual displays that are dedicated and properly integrated within the cockpit. There are currently three basic components: the primary and standby attitude indicators, and the head-up display (HUD); and there is potential for emerging technologies such as helmet mounted displays and possibly three-dimensional sound. The hub of aircraft attitude awareness is a large primary dedicated attitude display (PDAD) centered high in the instrument panel and located just beneeth the HUD. Its purpose is to provide continuously and instantly the immediate big attitude picture to the pilot's basic orientation channel, the ambient visual mode. It should be visible when the pilot's attention is directed to the HUD. The second component is the head-down attitude display (formally the Standby Attitude Indicator or SAI). This should also be in the midline and sufficiently low to permit its use in the presence of ambient visual mode distractions, such as moving glare and reflections off the canopy, or false horizons. The third component providing attitude information is the HUD, yet the HUD is not an attitude indicator. The potential exists to improve the HUD as an attitude alerting device, directing the pilot to refer to the PDAD. Suggested improvements included the addition of a zenith pointer to the Flight Path Marker to provide a better roll cue, and radically altering the pattern between positive and negative Flight Path Scales to provide better pitch cues.

Current fighter/attach aircraft are poorly suited to the enhanced night role. Remedies must consider the compromised nature of the pilot who flies at night. As a minimum, aircraft need better attitude references, to include a large PDAD, critical control parameters formatted for instant unequivical recognition, improved cockpit and instrument lighting, less canopy glare and reflections, better formation lighting, and no false horizons.

Several training issues emerged: basic instruments, the use of the HUD's as instruments, the use of attention and the proper use of vision. The USAF/IFC should be supported in the acquisition of a training aircraft equipped with a programmable HUD for instrument research and training.

Virtual displays projected onto the visor as helmet mounted displays offer great potential for a variety of purposes, especially aircraft attitude awareness. This technology should be pushed vigorously.

There have been several instances in F-15's where the recovery from a spatial disorientation incident required the pilot to over-G his aircraft. At least one F-16 might similarly have been saved had the pilot had access to every G available. Consideration should be given to the incorporation of a G-limiter by-pass as an emergency override in aircraft such as the F-16.

The enormous information processing capability of sensory channels such as the ambient visual mode, hearing, and proprioception is underutilized. This thrusts the task of maintaining awareness of critical aircraft control parameters upon the focal visual mode, tending to overload it. Strong emphasis should be placed upon displays which can be processed by non-focal visual mode sensory channels.

An innovative audio-technology known as three-dimensional sound appears to offer promise in such areas as warnings and alerts, localization of objects in space, and possibly aircraft attitude awareness. Research and development should be pushed.

The noise in modern cockpits is commonly such as to hamper effective communications and potentially helpful auditory cues. A technology is currently under development that can effectively reduce relatively steady state background noise by a significant amount, improving the audio environment for sounds that matter. Research and development efforts in this area should continue.

There are times when a pilot requires certain information yet does not want to look away from his primary task to obtain it. A voice call out of such information upon command would be very useful, and could include parameters such as attitude, altitude, airspeed, VVI, fuel state, rounds count, weapons mode selected, etc.

SELECTIONS FROM WORKSHOP FINDINGS AND RECOMMENDATIONS[A-2]

1. ALTITUDE AWARENESS

Current fighters commonly lack adequate warnings and alerts to altitude; i.e. altitude awareness is even more critical than attitude awareness, in view of the preponderance of controlled-flight-into-terrain (CFIT) mishaps (Fig 1). These mishaps are due primarily to lack of awareness, failure to monitor flight path, distraction, etc, though they may often be set up by misperception of altitude AGL or of vector convergence with terrain. The pilot needs something to wake him up, to redirect his attention to his flight path, as well as an absolute height gauge.

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2. ATTITUDE DISPLAYS

Attitude Displays are inadequate. They are too small and too deep in the cockpit. Under suboptimal lighting, they may be subject to misinterpretation. Current configuration delays to rapid transition from outside to inside and inhibits the wingman from sneaking a peek during close formation. It hampers the pilot from maintaining his own big attitude awareness picture, especially when his attention is focused on the head-up display (HUD). It impedes the recognition of unusual attitudes (in cases of unrecognized spatial disorientation or misorientation). Furthermore, it impairs coping with spatial disorientation (SDO) and unusual attitudes. The obvious solution is to utilize the space below the HUD (presently the up front control panel) for a large, prominent primary dedicated attitude display. Several methods for accomplishing this were suggested: one involved the projection of an attitude depiction onto the up front control panel (UFC). Others were to take advantage of emerging flat panel technologies for the PDAD, and consider touch sensitive overlays for the UFC, or consider displacing the UFC to the left side of the HUD container for access by the pilot's left hand.

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[A-2] For figures called out, please see source document.

3. HUD IMPROVEMENTS

The HUD is not an attitude indicator, nor should it ever be, although it does provide some information regarding attitude. What the HUD needs to be able to do regarding attitude, is alert the pilot when to refer to the primary dedicated attitude display (PDAD) which, ideally, should be located immediately below the HUD. To improve the HUD as an attitude alert requires at least two changes: one to the Flight Path Marker (FPM) and the other to the pitch scales, (Figs 4 & 5).

The basic problems with the HUD, as far as attitude is concerned, are that it does not tell the pilot, at a glance, whether he is upright or inverted, or whether he is pitched above or below the horizon, or to what general extent he is pitched. Humans are basically patterned recognizers, and since the general pattern of the pitch scales are symmetric about the horizon, it is possible to confuse an inverted dive for an upright climb (Fig 3).

This was recently illustrated in the full mission F-16 LANTIRN simulator by subjects participating in a certain study. The intention of the subjects was to perform a pop-up pull-down delivery (by popping, rolling inverted, pulling down, and rolling out upright to bomb the target). In repeated instances, subjects would become so engrossed in the target that they would forget they had rolled out upright. Attempting to sort it our by looking at the HUD was of no help. The flight path scale provided no innate sense of up. Besides, it was moving too rapidly for interpretation. In these instances, thinking himself to still be inverted, the subject would roll again (to inverted) and pull into the ground. It is to avoid just such errors that we should strive to provide a roll cue on the Flight Path Marker, such as a Zenith or Vertex Pointer (Figure 4).

Another most dangerous aspect is that the HUD does not instantly distinguish between climbs and dives. The problem lies with the global symmetry of the flight path scales (FPS), i.e. both the positive and negative FPS's have the same general shape with horizon-pointing tails in the same location. Though generally a useful cue, the solid line for positive pitch and dashed for negative pitch does not always register, especially in a dynamic situation, but also occasionally in a static one as well. For example, it is possible to confuse an inverted dive for an upright climb. Angling the FPS's like chevrons forming a channel toward the horizon helps locate the horizon, but if the global pattern remains symmetrical, it is still possible to confuse an inverted dive for an upright climb. For this reason, it is urged that attempts be made to maximize the differences in the overall FPS pattern between positive and negative. For suggestion see Fig 5.

RECOMMENDATION 3: Improve HUD as an attitude alerting device by:

- FPM: add vertex pointer (e.g. Fig 4)
- Pitch scales: radically change pattern from positive to negative and within negative (e.g. Fig 5); consider color as a redundant cue.

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4. NIGHT-WEATHER ROLE CONSIDERATIONS

The night-weather role requires special considerations, both for the pilot and for the aircraft. For the pilot, fatigue is a given; reactions are slowed, perceptions impaired, and the pilot is more subject to illusions, particularly those of false motion and those of false horizons; he is more susceptible to disorientation, distraction, channelized attention, and loss of the sense of the passage of time. Regarding aircraft considerations, present single-seat fighters are not adequate for the night-weather role. Their bubble-shaped canopies gather glare and reflections, movement of which across the canopy creates distractions, or worse, the disorienting sensation of self motion (vection illusion or Star Wars effect, Fig 6). At night, the glare and reflections impede outside viewing, impair the acquisition of a valid external orientation cue (true horizon or surface), and hamper the ability to distinguish false horizons (Fig 7). Quite commonly, the light sources for the glare and reflections are from within the cockpit, where little, if any, attempt has been made at proper shielding. The routes of information transfer regarding critical control parameters such as attitude, airspeed, and altitude are inadequate. Visual displays are not always formatted for instant unequivocal interpretation, nor are they adequately illuminated, lacking individual rheostats. Thus they promote spatial disorientation, or worse, a more subtle form of unrecognized disorientation (misorientation), more lethal because it fails to alert the victim that anything is amiss. Yet they fail to provide the information necessary for recognition and coping in a quickly recognizable, unmistakable format.

Inadequacies in lighting apply not only to the cockpit and instruemtns, but very much so to formation lights. Present schemes deny the wingman adequate recognition of lead's distance, relative heading and relative attitude. Proper attention has not always been paid to the hazardous aspects of certain external lights, e.g. the aerial refueling light generating a false horizon.

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9. NON-FOCAL VISUAL MODE SENSORY CUES

The enormous processing capability of non-focal visual mode sensory systems are presently under-utilized.

- Auditory & Tactile cues

Current aircraft lack adequate tactile and auditory cues to airspeed making it easy to inadvertently get too slow, into stalls, or into sink rates unawares. Feel of the aircraft is no longer available as a portion of the critical triangle of agreement regarding basic aircraft control; nor are audio inputs. Auditory cues are considered necessary for airspeed (and aircraft) control, especially in aircraft lacking such tactile cues, such as the F-16. The same applies to certain instances of flight control activity; eg. the speed brakes on the A-10 provide no tactile nor auditory cue when deployed, with serious implications for situations of reduced thrust.

RECOMMENDATION 9-1: Incorporate auditory/tactile cues to critical parameter controls.

- Ambient mode displays

Present displays are designed to be processed only by the focal visual mode thus tending to overload it. Better use of the processing capability of the ambient visual mode could be made by the proper formatting of displays: eg. patterned analog format for parameters such as airspeed and altitude. Such parameters lend themselves well to the moving tape format (Fig 10 A & B). For suggestions see Figs 11 & 12.

RECOMMENDATION 9-2: Press for development of displays for critical parameters (airspeed, altitude) that can be processed by the ambient visual mode.

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LOSS OF AIRCRAFT ATTITUDE AWARENESS: IMPACT ON THE USAF NEW TECHNOLOGY - OLD PROBLEMS

Brig. General Albert L. Pruden, Jr.

INTRODUCTION

In 1984, 20 of 41 operator-factor accident reviews cited "loss of situational awareness" as a probable contributory factor.

-- 5 of these were inadvertent flight into the terrain (spatial disorientation/misorientation).

-- Other factors commonly noted were task saturation, distraction, and channelized attention.

-- This group had a high fatality rate due to ejection out of the envelope or no ejection attempts.

-- In 1985, similar patterns.

THE IMPACT OF AWARENESS ON TWO OF OUR HUMAN FACTOR PROBLEMS IN NEWER AIRCRAFT

To date, inadvertent flight into the terrain and G-induced loss of consciousness (GLC) appear to have contributed to half of F-16 operator-factor mishaps.

-- Spatial Disorientation (SDO) is an old problem that is very much still with us.

  -- Loss of feedback through stick, rudder, throttle, visual and auditory channels; (a good sportscar is good because of "road feel").

  -- Overconfidence or "euphoria" is subtle. (Magic visibility and smmmoooothness).

  -- Less than ideal cockpit for instrument flight.

-- GLC represents a recently recognized threat and is an example of good results of increased awareness.

  -- G onset rate may be more rapid in fly-by-wire.

  -- Confidence in the G-limiter contributes to abrupt pulling.

  -- Body position basic to effective straining.

  -- Period of incapacitation (>12-15 seconds).

GLC prevention measures stress pilot awareness and are in progress, including centrifuge training.

- -- Mental and physical preparation, early and effective straining, body position (especially checking 6), adequate duration.
- -- So far in 1985, only one GLC (4 in 1984).

Potential measures to counter the SDO threat include both training and design concerns.

- -- Training (not always preventive, but rather to enhance recognition and recovery proficiency).
  - -- We can increase emphasis on instrument training in UPT/RTU programs (SEL rewriting ATC chapter on SDO).
  - -- We are making improved training films on SDO.
  - -- We can more widely apply low altitude awareness training type approaches (teaches attention management).
  - -- We have the VERTIFUGE, but can we design a trainer adequate to simulate unrecognized SDO?
- -- Cockpit Design concerns include flight instruments, warning systems, and distractions.
  - --- Flight instrument options.
    1. Reduce the number of digital displays.
    2. Improve information display on the HUD.
    3. Review basic efficiency of information transfer through flight instruments. (Instr. Flight Center)
  - -- Reduce cockpit distractions.
    1. Continue to pursue traditional control/switch position, and glare/reflection issues.
    2. Exploit automatic processing of orientational cues such as peripheral vision or auditory.

    As we proceed, let's be more aware of cues robbed from the pilot ... and if he still fails;
  - -- Warning system options.
    1. GPWS.
    2. Can we build a system for automatic recovery?

CONCLUSION

Teamwork, the integration of multiple brands of expertise will move us ahead on the awareness issue more efficiently.

-- Starts for safety with the whole mishap board asking the right questions.

-- Regular, recurrent human factors working groups between appropriate USAF agencies have begun.

-- Continue focused working groups such as this one as specific needs become apparent.

-- We must continue the study of human information processing and its limits.

We will progress. We've seen some on GLC and are moving on SDO. We will make some on situational awareness. We will find out where to best invest our resources to prevent mishaps. New technology has given us fine equipment. We can bring a helpful perspective to that activity, a new technology of our own. Let's pull ahead together.

Editor's Note

Brig. Gen Pruden also included the following in his remarks:

o The trend in spatial disorientation/misorientation mishaps is increasing - hope the F-16 C/D will be better.

o SDO situations: night aerial refueling or refueling in the weather. Night low level formation approaches: wingman's problems when lead's formation lights do not work.

o Fighting in clear blue sky - SDO has happened more than once to experienced F-15 pilots.

o HUD dependence - canted cloud-deck viewed through HUD creates a mismatch.

o Recent F-16 RTU graduate hit an ILS stanchion making a night approach out of low overcast. His UPT was at Williams AFB (Arizona) where his instrument flying was all in simulators; LIFT was ACBT only with no instrument training; RTU was learning to deliver ordinance, no instrument training. Now at his operational base, he is making his first actual night weather approach, ever. We need to improve that.

o ATF should be a great leap forward in Aircraft Attitude Awareness, taking advantage of past mishaps history and all the new technology in displays and the Pilot Vehicle Interface. There's lots of new technology and we're in a position to make it happen.

o We need to test our systems using new as well as old fighter pilots.

Those flying frequently in actual weather conditions tend to go heads down in weather whereas those who fly less frequently in actual weather tend not to go heads down. But, the real issue is not whether heads up is better than heads down or vice versa.

We need to maximize the technology available to us today to make something that is better than either the HUD or instruments - or maybe a combination of the two.

THE ROLE OF VISION IN SPATIAL DISORIENTATION AND
LOSS OF AIRCRAFT ATTITUDE AWARENESS BY DESIGN

by
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Chief Aeromedical Advisor, Life Support System Program Office
Deputy for Aeronautical Equipment, Aeronautical Systems Division
Air Force Systems Command
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There are several topics and points I'd like to discuss in this briefing: the role of vision in spatial disorientation (SDO); design features that impact attitude awareness; importance of the attitude indicator; the fact that the HUD is not an ADI, although it could be improved as an attitude reference; and pattern-type displays that take advantage of the fact that the human is basically a pattern recognizer. We'll first talk about spatial disorientation (SDO) and how the man-machine interface and other inputs can lead to a loss of attitude awareness in some of our state-of-the-art fighters. Though Dr. Leibowitz will discuss the two modes of visual processing in more detail this afternoon, I need to explain something about it to provide some relevant background for this talk.

Historically, we've considered SDO to result from a mismatch between vision and the balance organ. We now know that is only part of the story. Just as important is a mismatch within the visual system itself, between its two modes of processing visual information. One of these modes is the all familiar focal mode which focuses, reads the checklist, identifies the bogey, and aims the gun. This mode is highly discriminating and is exclusively visual, in fact, is limited to the central 1-2° of the retina. It requires good lighting and good resolution, and it typically involves conscious attention.

The other is called the ambient mode because it orients oneself to the ambient environment. To demonstrate to yourself the orienting capability of the ambient mode, just try this little test popularized by Dr. Malcolm.[1]

- Place your feet in a tandem (heel-toe) position, close one eye, cover the open eye with your fist through which you've made an aperture sufficient to maintain central or focal (or foveal) vision while blocking inputs from the periphery, and determine how long you can maintain your balance.

- Now try the converse of that test by clenching the fist to block focal vision but move your fist an inch or so away from your open eye so as to permit peripheral inputs. You should find you can hold your balance considerably longer, if not indefinitely, because your orientation inputs are going straight from your primary orientation sensor to the core of your balance centers.

This mode is concerned not with object recognition but with object quality, or more correctly, the quality of the surrounds; for example, the "surfaceness" of the surface, "horizoness" of the horizon, or "cockpitness" of an aircraft. It is a quality assessment mode, undiscriminating and uncritical, and it can be easily deceived, which, of course, is part of the problem.

Although this mode involves the entire retina, including central vision, it is by no means exclusively visual. It connects to the same terminals which receive orientation inputs from our organs of balance, proprioception and hearing. Instead of an ambient visual system, we have, in effect, an ambient orientation system, into which vision contributes its share of the inputs along with those from the other senses. When ambulating about on the surface with our eyes open, vision contributes the greatest proportion of orientation inputs, perhaps 90% or more; and of those inputs, the ambient mode provides perhaps 90%, so it supplies the lion's share. If we can see, or think that we can see, vision will dominate as far as orientation inputs are concerned. This mode works at any lighting level[2]: it's the one we use in the dark. Though you cannot read in a dark room, you can orient provided there is a minimum of light (Figure 1).

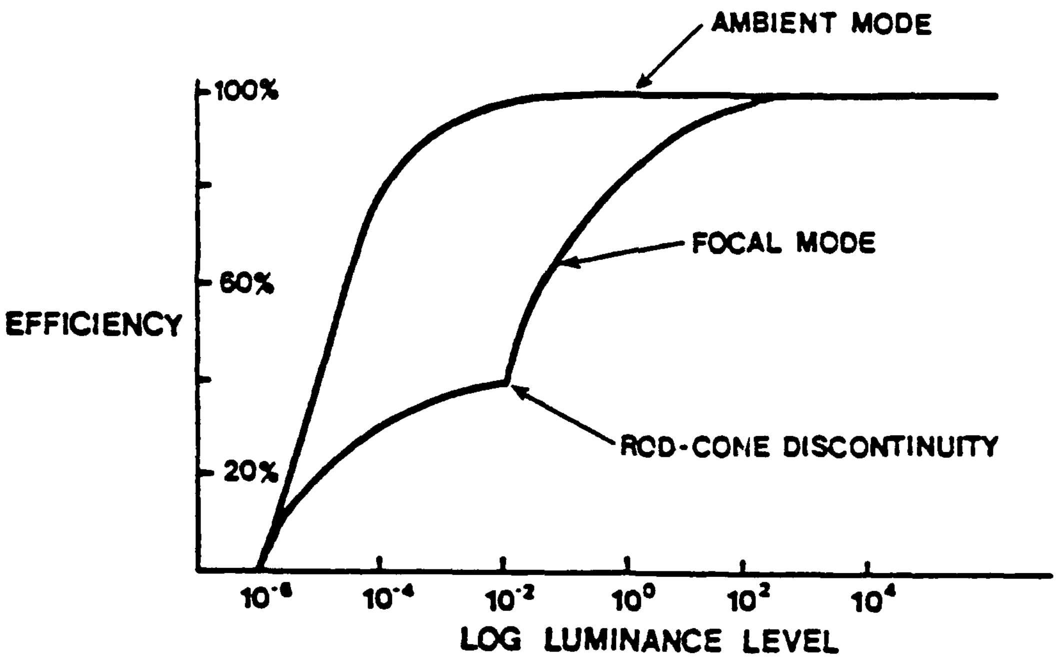


Figure 1: Focal vs. Ambient Visual Mode Efficiency - Effect of Decreasing Illumination.

Resolution is totally unimportant (Figure 2). You can orient with 20 diopter lenses before your eyes. The ambient mode typically functions at more of a reflex level. Along the scale of evolution, it's the mode that appeared first.[1]

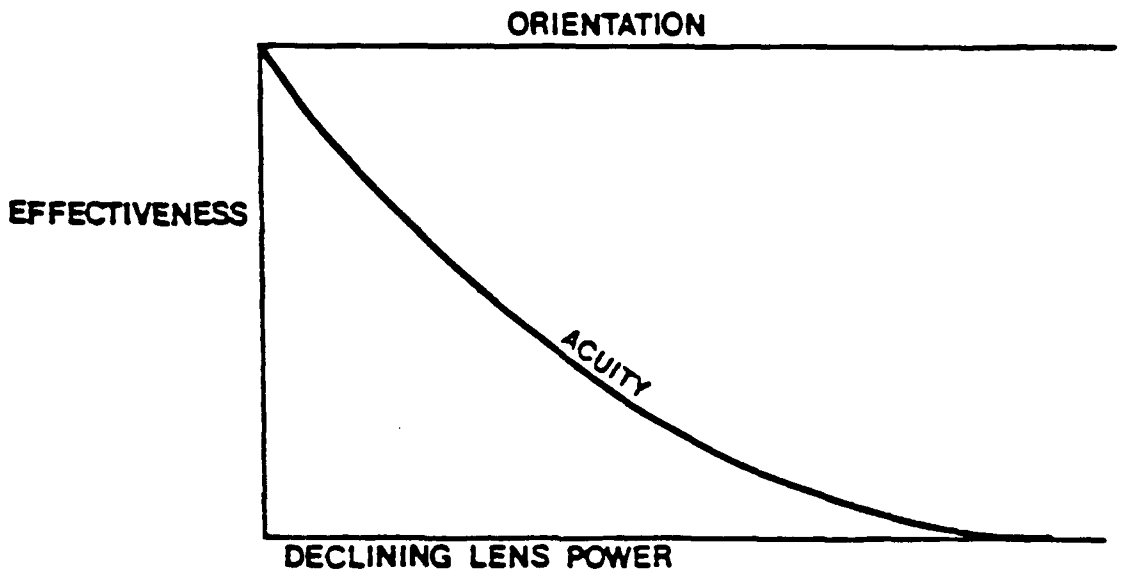
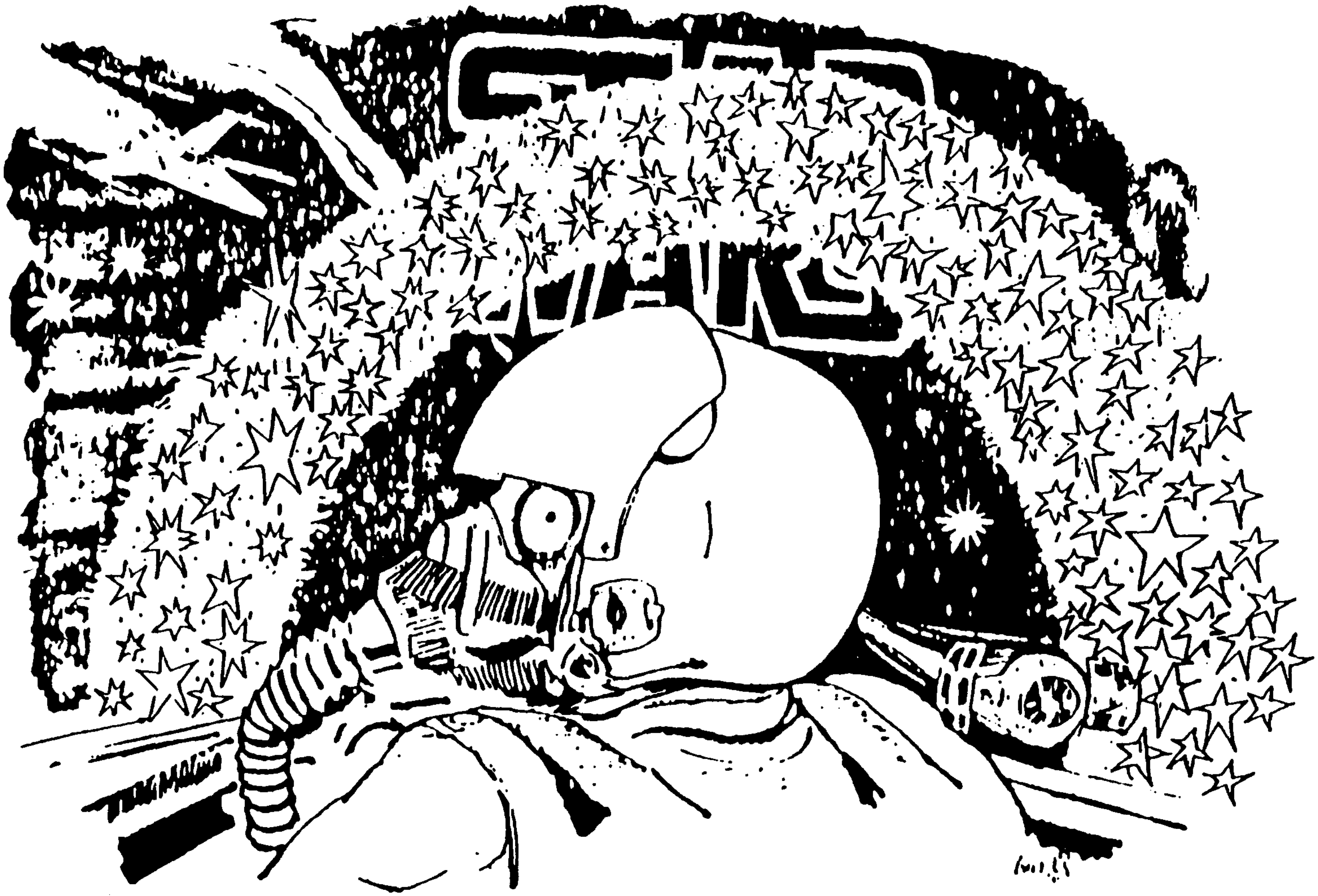


Figure 2: Focal vs. Ambient Visual Mode - Effect of Decreasing Resolution.

There are three consequences of ambient mode reactions of concern to pilots: the distraction potential, the vection illusion, and the tendency to orient to false horizons.

First, the brain contains receptors that are specifically tuned to the components of motion, both velocity and direction. An object whose motion is detected by the eye will trigger a neuron or clump of neurons to fire. If the velocity changes, it will fire a different neuron or clump, and if the direction changes, still a different neuron or clump. There is thus an architectural basis for responsiveness to perceived motion.[4] And after all, pilots are cocked to spot bogeys and avoid midair collisions and will likely snap glance to any movement. If the snap glance results in a substantial enough head motion, that may tumble their gyros causing vertigo. Thus, any motion can distract, even the slewing motion of the pitch scales on the HUD.



THE VECTION ILLUSION

Figure 3: Vection Illusion

The same can apply to anything appearing out of place, such as bug spots on the windscreen: one experienced fighter pilot admitted to breaking for a bug spot, then breaking again within minutes for the same bug spot.

Whereas a small motion in the periphery may be interpreted as object motion, more of the periphery that moves will be interpreted as self-motion. You've all experienced this sensation while sitting at a stop light: as the car next to you begins to roll backwards, your impulse is to slam the brakes on your motionless car. This sensation is known as vection. It can be true or illusory, and it is the principle upon which full visual simulators are based. The sensation of motion created by these devices is sufficiently commanding that the motion bases are unnecessary and have commonly been deactivated.

Design features that potentiate distraction and disorientation include a wide area canopy, bubble-shaped like a "fishbowl"; a head position high up in this "fishbowl" subjecting the ambient mode to maximum bombardment with glare, reflections and false motions; light sources that cause glare and reflections off the canopy, that impede outside viewing, that impede the acquisition of a valid orienting phenomenon (horizon or surface), or that cause systematic motions such as described by A-10 pilots flying over a lighted runway at night. These reflections running from aft to forward up the canopy make it appear as though an airliner is passing overhead. They dub this the "Star Wars Effect" and admit that it's a real attention getter (Figure 3). Furthermore, the ambient mode is adequately activated by the low spatial frequencies, such as fuzzy shadows and reflections, typically stimulating large areas of the visual field.[2] The vection illusion can be exceptionally deceiving as well as disorienting.

Another finding of interest is the fact that the brain cortex subserving ambient vision contains receptors specifically responsive to lines and to edges. This has actually been mapped out in the brains of cats by Hubel and Weisel at Harvard, 1962,[3] and is probably true as well in humans. Since the human can't tolerate a sense of disorientation and since the ambient mode is uncritical, it will likely accept anything with the quality of "horizoness" as a valid horizon. There appears to be a sort of mass rule operating here: the larger, the more commanding. That may explain in part, at least, the commanding nature of phenomena such as sloping cloud decks, sloping terrain, a haze or fog-depressed horizon, the Northern Lights, or surface features resembling a horizon.

A particularly lethal combination is a night take-off across a lighted shoreline. Since the balance organ cannot distinguish between acceleration and a climb, as what appears to be the horizon passes beneath his wingline, the pilot becomes convinced he's doing a loop, and his tendency is to dump the nose and fly into the water.

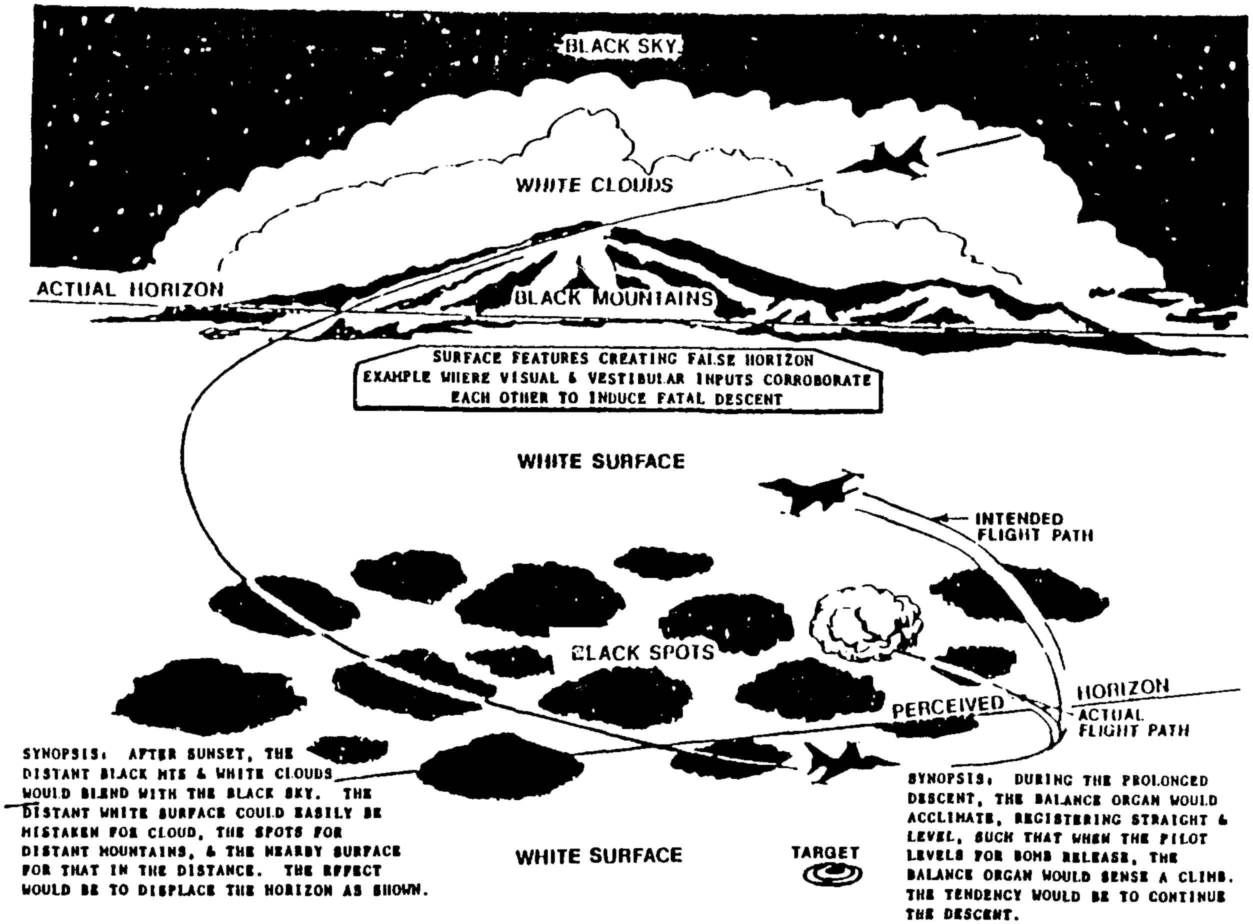


Figure 4: Misplaced Horizon on Night Bomb Drop

We think that surface features resembling a horizon have been responsible for a number of our mishaps. One involved an experienced fighter pilot flying an F-16 on a night bomb drop. The sun had just set, and from his orbit at 17,000 feet MSL, looking west, he could see in order, rapidly blackening sky, white clouds, black mountains, white terrain, black circular discontinuities through the white terrain, then more lighter terrain beneath him (Figure 4). As he descended toward bomb release ("pickle") altitude, he stabilized in his track sufficiently for his balance organ to register straight and level, such that when he levelled to pickle, his balance organ registered a climb. In want of better visual information, his tendency would be to continue the descent. Visually, while inbound to the target, he had the lights of a large city on the eastern horizon to enable orientation, but once he turned to downwind, he was confronted with a lightless, black hole. From his new viewpoint, the mountains and clouds both blended with the black sky, making the more distant white terrain appear as the cloud, the black discontinuities as the distant mountains, and the nearby light terrain as that in the distance. The effect was to displace the horizon downward 35-40°.

There were two additional factors impacting this pilot. One, the bomb failed to spot (i.e., it failed to flash) and troubleshooting a possible malfunction trapped his attention. And two, he was pickling that bomb at about his normal bedtime, so he probably wasn't as sharp as usual. These, coupled with the corroborating false vestibular and visual cues provided him the comfortable premise of a climb to downwind as intended, and he probably never bothered to cross-check his instruments.

With that background on the role of vision in SDO, let's discuss some problems with current fighter attack aircraft. I see them as:

- o Failing to provide adequate attitude references, both external references and instruments.
- o Failing to provide critical control parameters such as airspeed and altitude in a quickly digestible format.
- o Confusing, disorienting, and misorienting the pilot.
- o Providing inadequate tactile and/or auditory cues.

A number of human factors problems are exposed in the A-10 (Figure 5). First, the angled canopy rail denies the pilot a reference to the horizontal, and the stubby nose denies him a ready motion cue, either in the vertical or the lateral planes. Because this aircraft is so highly maneuverable, it is easy to inadvertently over bank it, in which case it will fly a descending flight path. If the pilot fails to catch that nose dropping through the

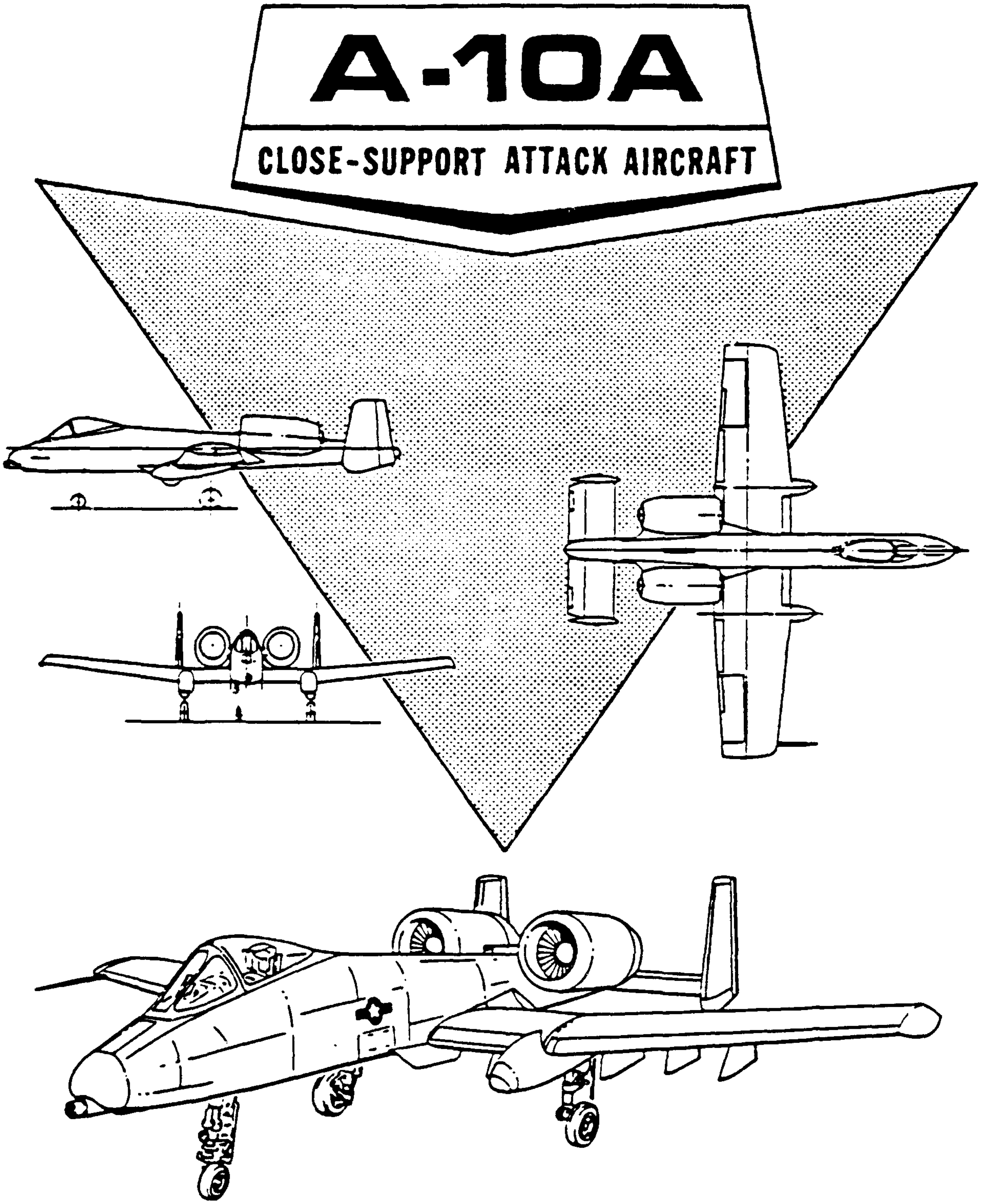


Figure 5: A-10

horizon early, he's committed to a dive recovery for which he may have insufficient altitude. That's important for this aircraft because of the low altitude where it operates. It also has no radar altimeter or ground proximity warning system.

From the cockpit (Figure 6), one can appreciate that the view out the front is cluttered: HUD supports, windscreen brace, and canopy bows can mask birds and aircraft. There are some potential attention traps: some of the avionics needed for flying in IMC, e.g., the radios, TACAN, and INS are located down on the side consoles, constituting potential head-down attentional/vertigo traps. Firing the Maverick Missile involves a multi-step procedure requiring the pilot to divide his attention between the stores management panel at lower left, the TV monitor at upper right for final slewing and lock-on, and the HUD to clear his flight path--a potential procedural, attentional and focus trap. The engine instruments are stacked left-right-left-right so that in the event of a mismatch, it's not always immediately apparent which engine's at fault.

The aircraft exhibits flight control characteristics which has created problems for pilots. Whereas most aircraft buffet before they stall, generating a reliable tactile cue that pilots ingrain and come to rely upon, the A-10 stalls before it buffets. We lost a number of them before breaking that code.

Another area where tactile cueing could stand improvement is the speed-brake. There is no cue, tactile or auditory, to remind the pilot that his speed brakes are deployed. Of course, he can see them if he thinks to look for them (split ailerons), but under pressure of an emergency, he may not think about them. This is important because, whereas the aircraft has a relatively ineffective propulsion system, it has a very effective speed brake, such that if an engine is retarded without retracting the speed-brake, the aircraft will not maintain altitude. We have lost several aircraft because the-pilot did just that; shut down an engine, failed to retract the speed brake, and was unable to figure out why he could not maintain altitude in sufficient time to avoid having to eject. In at least two of these instances, the pilots were in IMC, and just maintaining attitude while coping with the emergency absorbed all their attention.

The F-15 will be discussed in more detail by Major Merrill Beyer, but let me point out just two design features impacting attitude awareness:

First, the considerable amount of prime real estate taken up by the radio, transponder and HUD control panel (Figure 7). This has forced the location of the ADI, which is only 3" in diameter, down over 35° below the design eye line. It is not easy for the wingman to simultaneously fly formation and maintain his own attitude awareness. He must turn his head considerably to the side in order to fly good formation; the result can be an angular difference between the outside formation references and the line of

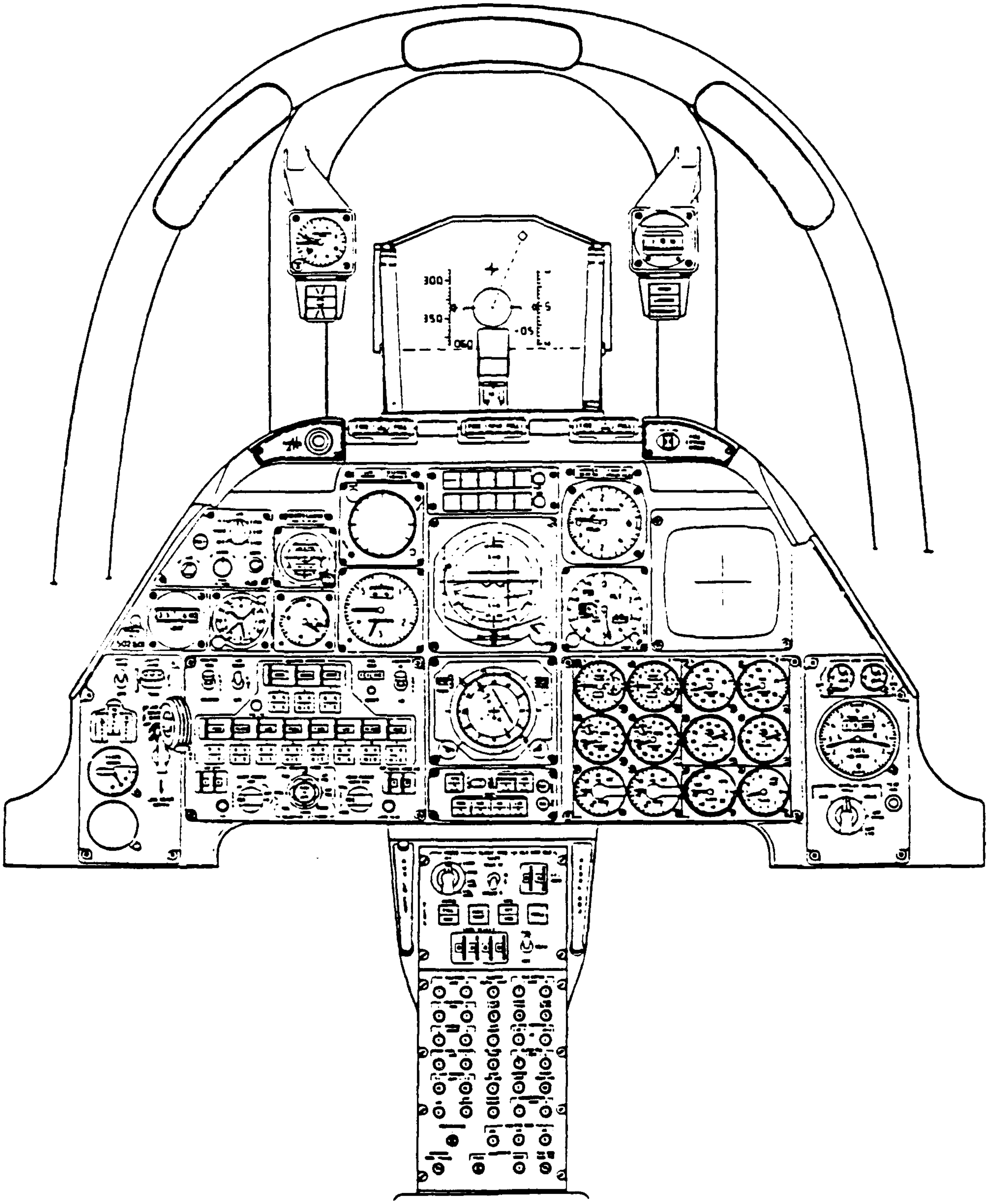


Figure 5: A-10 Instrument Panel

MAIN PANEL

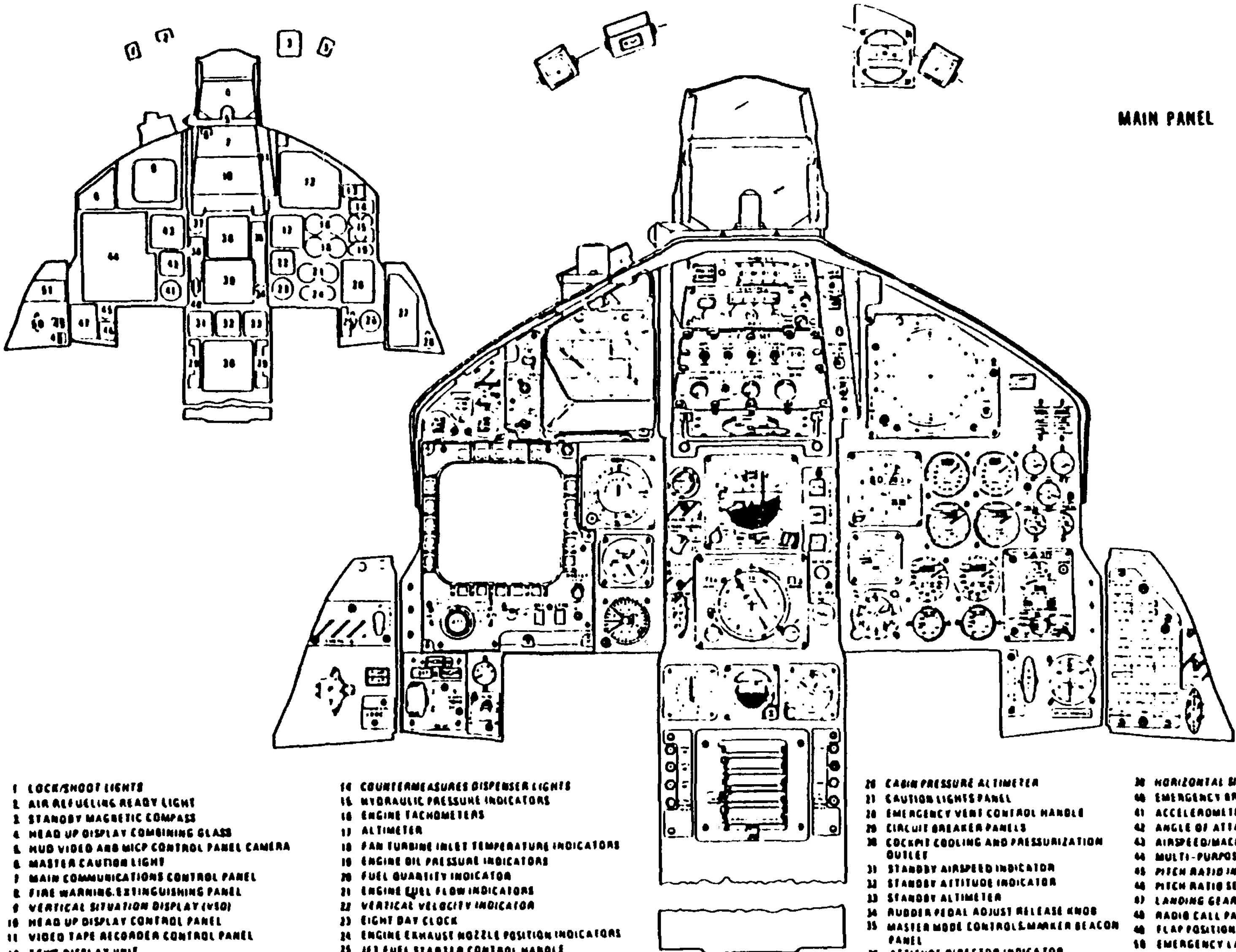


Figure 7: F-15 Instrument Panel

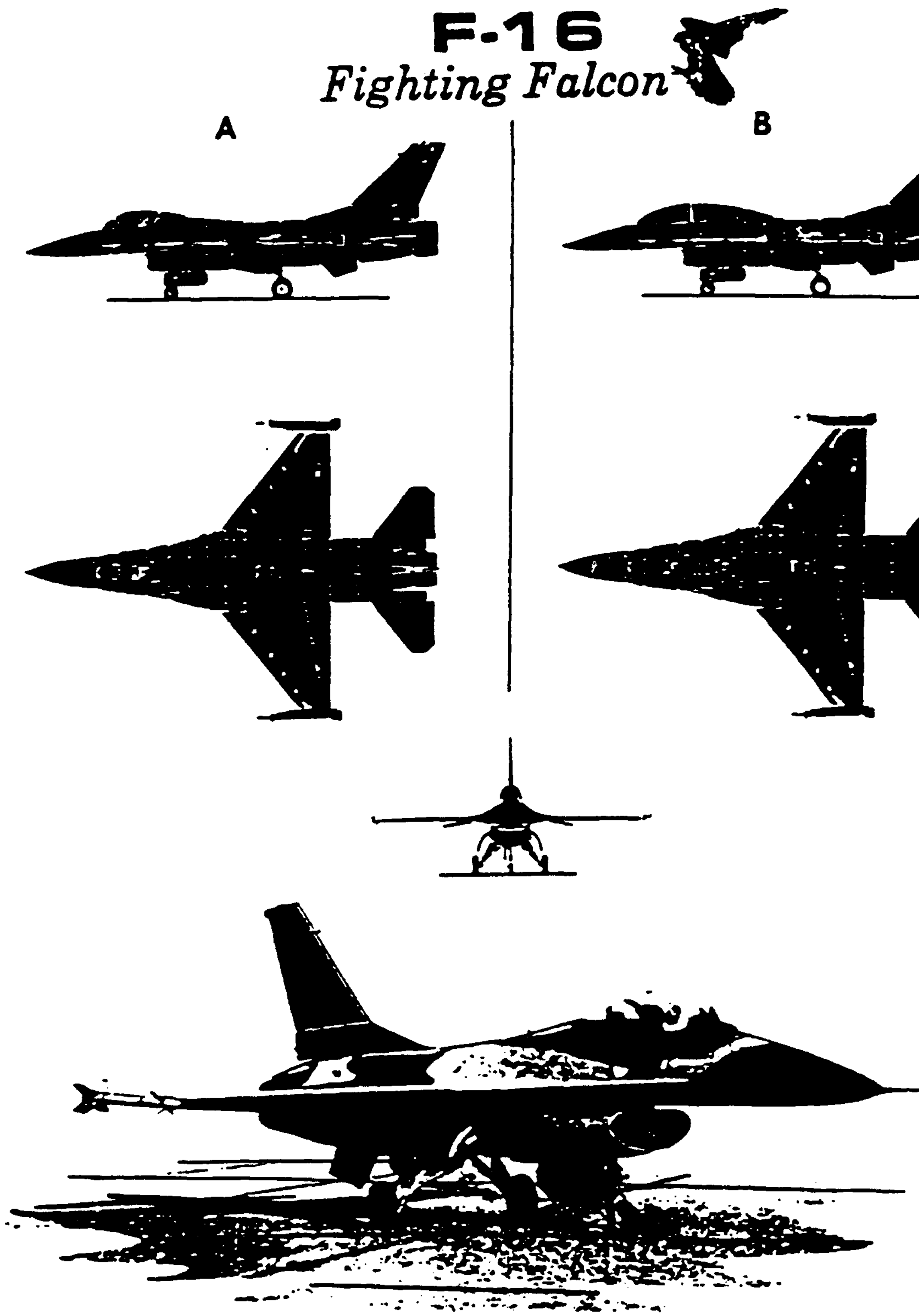


Figure 8: F-16 Planform

sight to his HUD or ADI by as much as 60°. This requires him to make significant head movements whenever he wishes to cross-check his cockpit instruments. Pilots know that large head movements in the cockpit can produce vertigo. In order to minimize these head movements, the wingmen prefer to slide down and back from the normal formation position. However, if the wingman drops too far down and in toward lead during intense weather formation flight, the wingman's aircraft wing overlaps the horizontal stabilizer of the lead aircraft. Not only is this somewhat dangerous, but it also can interfere with the normal flight dynamics of the lead aircraft to the extent that lead can "feel" when the wingman is in too tight. Pilots have also reported that they lose the F-15 when flying formation during day weather conditions more than any other tactical fighter they have flown. This is due to the gray paint scheme of the F-15 which minimizes color contrast with gray backgrounds, enabling the aircraft to easily blend into weather.[4]

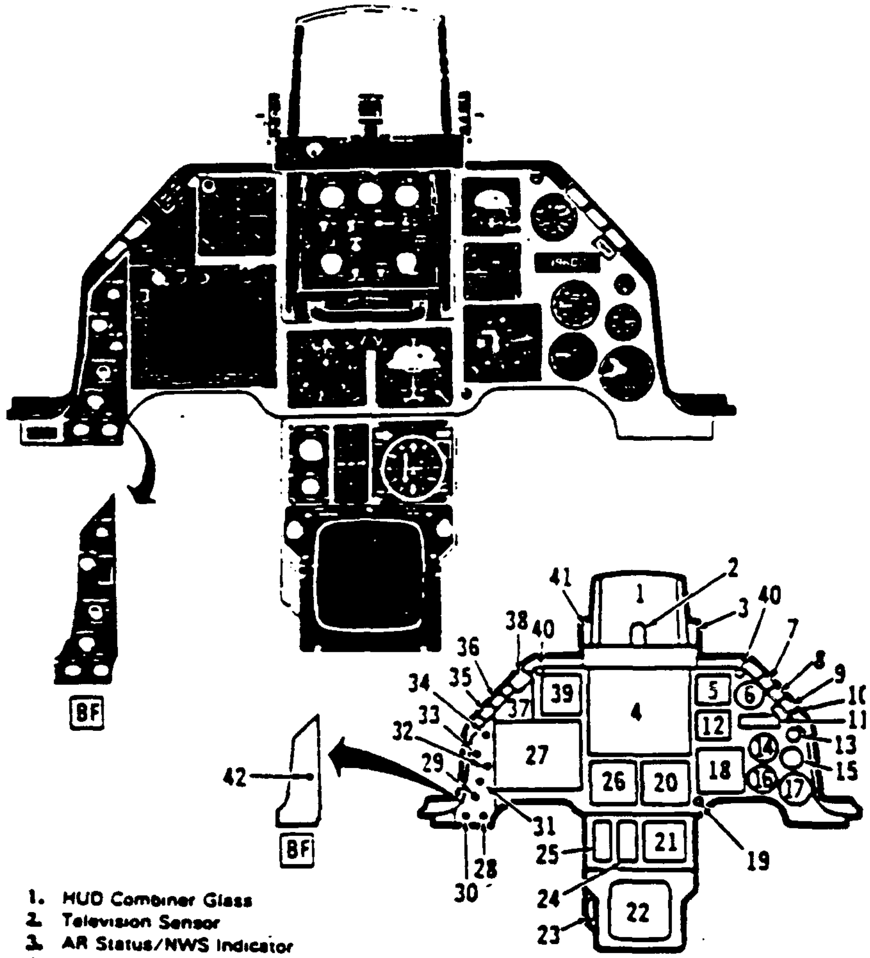
The other feature is the location of the Standby Attitude Indicator (SAI). It is deeper yet than the primary ADI, and it is behind the stick; it requires moving the stick (or leaning way forward) to view it.

The F-16 (Figure 8) was originally built as a day VFR lightweight fighter concept demonstrator, and as a day VFR dog-fighter, it is probably unparalleled. But it was not designed for the night-weather role, and when flown in such conditions, it generates its share of human factors problems (to be discussed later by Major Arthur Fowler), not the least of which are canopy glare and reflections from cockpit and instrument lights and from the radar scope. In addition, canopy reflections from clipboards, helmets, and other cockpit items occur about 30° forward of the pilot's ear line and prove distracting. Pilot's helmets were painted gray to decrease such reflections.

The F-16 aircraft lacks natural attitude references. From his seated position, the pilot may not be able to see much or any of the aircraft. The canopy bow is behind the pilot where some claim it blocks their view to the rear. Most pilots love the unsurpassed visibility, however, and would resist any change. Yet the pilot may get the feeling of being "on" the aircraft or suspended above it, like being on the nose of a dart or on a "magic carpet." That, coupled with the spectacular performance and lack of cues, has led to a feeling of unwarranted contentment or complacency, dubbed by a former F-16 Wing Commander, "F-16 Euphoria."[5] What impact it may have on one's time sense, cross-check, or situational awareness, if any, has not been formally studied, but we've had instances of inattention to critical parameters for excessive periods of time, resulting in thousands of feet of altitude loss and crashes.

This aircraft was built as a visual aircraft to keep the eyes out. It does not cue the pilot that anything has changed or that it's time to transition back inside, and when it is time to transition back inside, the aircraft presents a challenge. This begs the question as to what the pilot needs to transition back inside. If confronted with situations of false

INSTRUMENT PANEL [A] [BF]



1. HUD Combiner Glass
2. Television Sensor
3. AR Status/NWS Indicator
4. HUD Control Panel
5. Standby Attitude Indicator
6. Fuel Flow Indicator
7. DUAL FC FAIL Warning Light (Red)
8. HYD/OIL PRESS Warning Light (Red)
9. CANOPY Warning Light (Red)
10. ENGINE Warning Light (Red)
11. Radio Channel/Frequency Indicator
12. Vertical Velocity Indicator
13. Oil Pressure Indicator
14. RPM Indicator
15. Nozzle Position Indicator
16. FTIT Indicator
17. Fuel Quantity Indicator
18. Altimeter
19. MRK BCN Light
20. Attitude Director Indicator
21. Horizontal Situation Indicator
22. Radar/EO Display
23. Rudder PEDAL ADJ Knob
24. AOA Indicator
25. Instrument Mode Select Panel
26. Airspeed Mach Indicator
27. Stores Control Panel
28. Autopilot ROLL Switch
29. AUTOPILOT Switch
30. Autopilot PITCH Switch
31. MASTER ARM Switch
32. ALT REL Button
33. SMS PWR Switch
34. IFF IDENT Button
35. ENG FIRE Warning Light (Red)
36. T.O./LAND CONFIG Warning Light (Red)
37. THREAT WARNING Controls and Indicators
38. MASTER CAUTION Light (Amber)
39. THREAT WARNING Azimuth Indicator
40. Spotlight
41. AOA Indexer
42. [BF] OVRD Light

Figure 9: Instrument Panel
Block 10 Aircraft

motions, false horizons or no horizon; i.e., if he lacks God's big outside horizon, the pilot needs man's horizon, and the bigger the better. Whereas it may be permissible to miniaturize some instruments, miniaturization does not apply to the ADI. The ADI represents one instance where BIG is definitely BETTER, ideally big enough to see out the corner of the eye, as in flying formation.

But what in the way of an ADI does the F-16 provide (Figure 9)? Like the F-15, the large HUD control panel forces the primary ADI deeply into the cockpit, over 25° below the design eye line. Under certain lighting conditions, the top half may appear uniform, allowing the pilot to miss the fact that he's in a descent. The ADI is small; it's barrel is less than 2" in diameter, and depending upon how the seat is adjusted, could be anywhere from 25-33" from the eye, such that it fails to subtend a large angle or a large area at the eye; it is not particularly commanding. Finally, wide separation between the primary ADI and SAI precludes the immediate recognition of a mismatch between the two and upsets one's composite cross-check if required to switch. Although the SAI is less reliable than the primary ADI, its proximity to the eye line has resulted in its use to the exclusion of the primary ADI with disastrous results when it (the SAI) was in error.

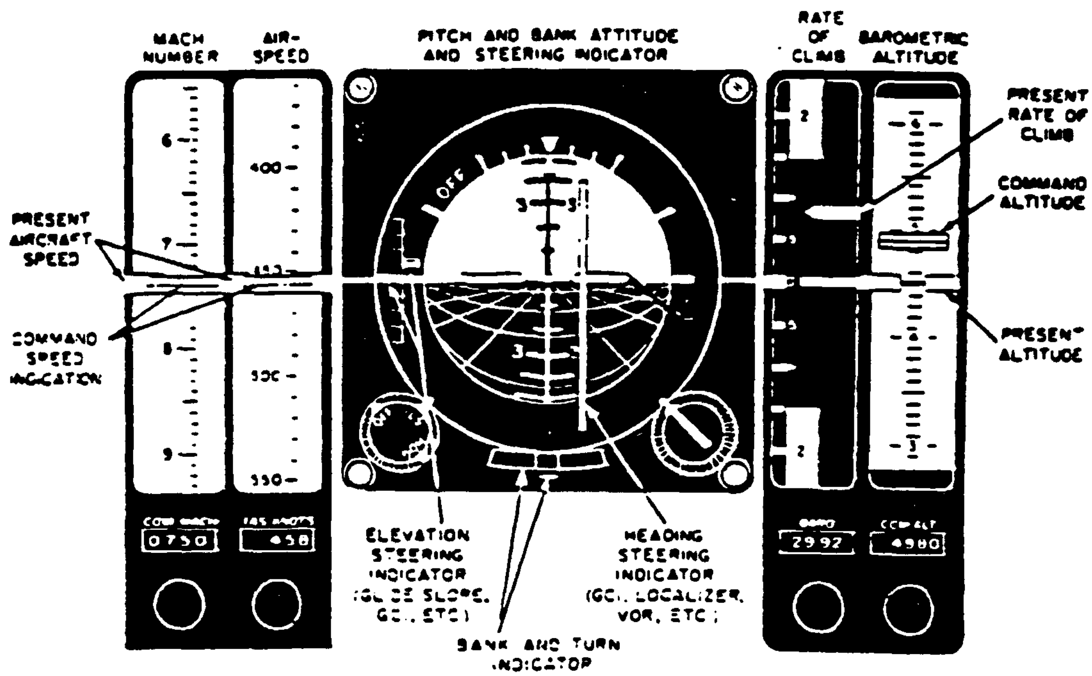
I'd like to discuss a mishap illustrating the attitude instrument problem in this aircraft. The mission involved a day formation departure into a low overcast; the lead pilot was inexperienced, the wingman highly experienced, and as they departed, the wingman was on the right wing. Upon entering the overcast, the lead became disoriented, and after some gyrations, exited the clouds in a steep dive at a steep left bank. At this point, the wingman had moved to the left wing, so he was looking up at lead. As soon as they broke out, lead saw the trees, rolled and pulled hard, hitting some trees but getting the aircraft back. Wingman was just a millisecond too late.

This mishap illustrates two points. One, lead was unable to transition from outside to inside in a timely, positive manner; and two, despite his experience, the wingman could not simultaneously fly formation and maintain his own attitude awareness, because of the small size and deep location of the ADI.

Again, the importance of the attitude indicator: it's the hub of the cross-check. Studies have shown that pilots flying in IMC spend between 70-90% of their eye time dwelling on the ADI. It should be large, high, centrally located, and prominent enough to see out the corner of the eye: to facilitate the transition from outside to in; to enable the wingman to sneak-a-peek while flying formation; to facilitate maintaining one's own aircraft attitude awareness; to speed recognition of unusual attitudes, and to facilitate coping with unusual attitudes.

We haven't always had small ADI's, as illustrated by the instrument cluster developed at AFWAL by former Luftwaffe Colonel Siegfried Knemeyer

(Figure 10). At the hub of this cluster, which was near eye level in the F-105 and F-106 was an ADI, the sphere of which measured a full 3" in diameter. (The same integrated flight instruments are currently used in the F-111, C-5 and C-141, and were also used in the B-70.)



[illegible]

Figure 10: Integrated Instrument Display

The "forward-looking" portion of the panel is planned to provide a single frame of reference in interpreting instrument indications by providing a common center line that extends across all instruments in the row (see Fig. 13. 6). When the aircraft goes into a climb, for example, changes in all the rate and displacement indications (displayed side by side) are consistently related to the center reference line and to the pilot's control movement. Insofar as possible, scale displacements are in a single direction. Note also that actual performance data and desired performance values are displayed so that the pilot does not have to remember specific values. Instead, he flies the aircraft so as to keep the indices aligned across the reference line.

(Extract from "Vision in Military Aviation" Wulfeck et al 1958. WADC-TR-58-399 p. 285)

There was another popular feature: the moving tape formats for airspeed and altitude. By the use of cursors shaped like Captain's Bars, one could mark some preselected parameter sufficiently to not require foveation; i.e., could monitor it with peripheral vision. The numbers on the tapes were such that the smaller airspeed was at the top and vice versa for altitude. While flying straight and level, the cursors formed an even line with the ADI's horizon. If one drifted off, however, say inadvertently entered a descent, as airspeed increased, the left (airspeed tape) cursor would move up as the higher airspeed came into view; the horizon line would move up as attitude changed; and the altimeter cursor would move up as altitude was lost and the lower altitude moved into view. The opposite would happen for an ascent. This provided a very nice redundant cue to attitude and facilitated the cross-check. Once pilots learned how to interpret and use the moving tape format, they generally preferred it to round dials. Mr. Pete Lovering may discuss this device tomorrow.

Another approach is that of Dr. Richard Malcolm, in his Peripheral Vision Horizon Display, an attitude indicator projected onto the instrument panel that is wide enough to be monitored out the corner of the eye. It enables attitude awareness by the ambient mode thus freeing up the focal mode for tasks requiring focal mode processing; this has significant potential not only for reducing spatial disorientation but also for reducing cockpit workload. Dr. Gillingham has formally tested this device in the lab and demonstrated an improvement in instrument approaches.

There's a second source of attitude information--the SAI--about which we'll hear more tomorrow from Mr. Dick Geiselhart. There are some issues regarding the position of this instrument relative to the primary ADI, as well as basic reliability.

Before proceeding to the third source of attitude information, I'd like to digress a moment on the characteristics of man versus displays, and make some remarks about attitude depiction. As you'll hear from Dr. Malcolm and others this afternoon, man is basically a pattern recognizer, from birth on. The more that you can organize information for him visually, the faster he can acquire and understand it, which is why a picture is worth a thousand words. When a pilot looks at a display, he usually wants to know only whether the parameter it represents has changed, and if so, in which direction, how much and how fast; i.e., he wants trending information. He also likes limitations cues--whether the parameter is too low, too high or right on.

The problem with digital, symbolic and alpha-numeric displays is that they require focal mode to read, decode and integrate, and provide no inherent trending nor limitations information. Analog displays generally overcome these objections but can be misread, as illustrated by the old altimeter which could be misread by 10,000 feet. Finally, any display which traps the pilot's attention can kill him.

Instrument Modes (Typical)

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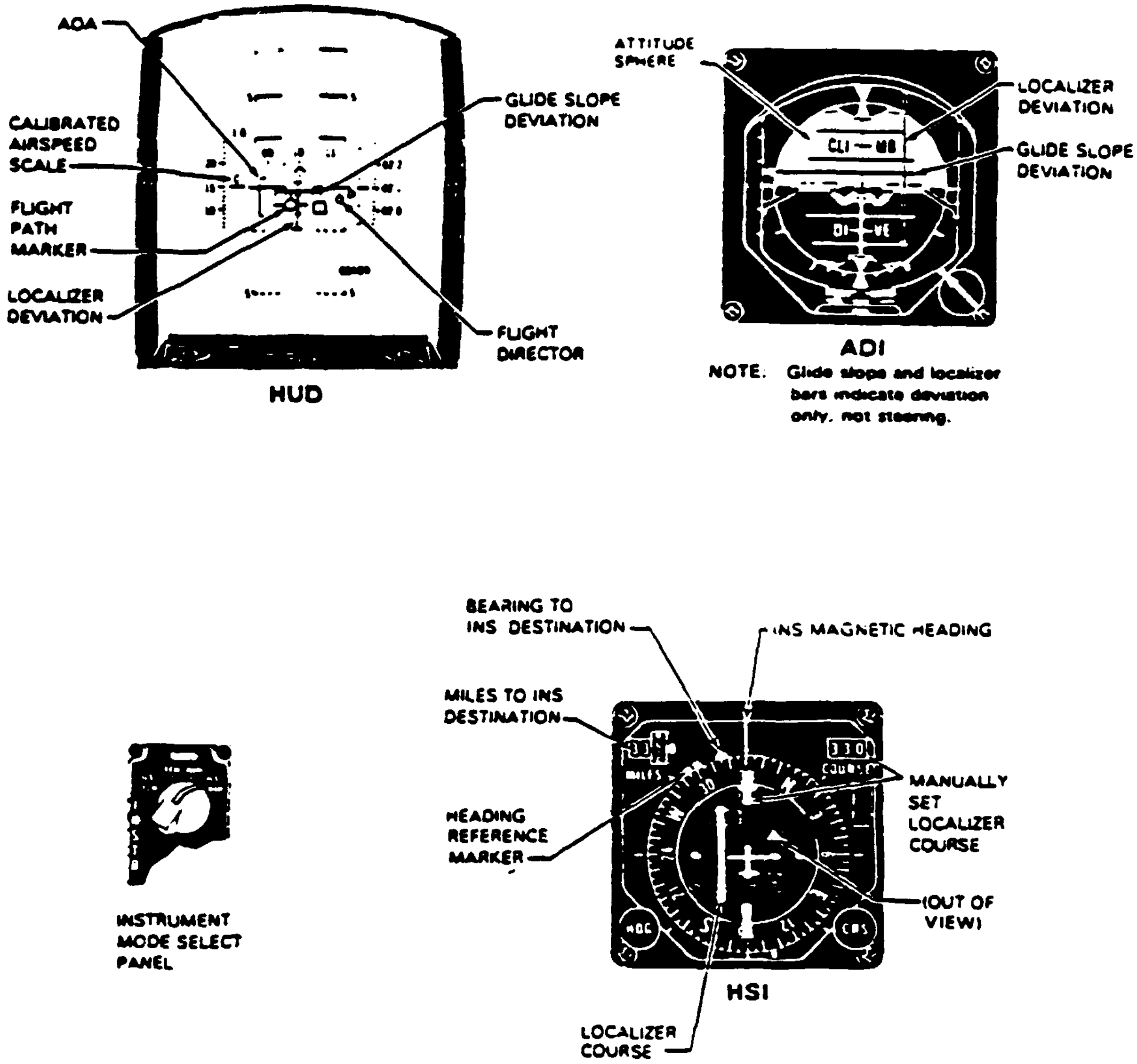


Figure 11: ADI and HUD

Now, let's talk a moment about attitude depiction in general (Figure 11). The way we depict attitude generates an important human factors problem: reversed roll-sensing. The most commanding part of the ADI is the part that moves - the horizon. In order to "level" the horizon, you must move the stick in the direction opposite to its desired motion. This reversed roll-sensing is one reason it takes so long for a pilot to learn to fly instruments, so that the correct response becomes automatic. Still, this is an unnatural act, and even test pilots with over 2500 hrs in fighters have confided that when coping with an unusual attitude, they must first tweak the stick to see which way the ball moves before initiating recovery. So for some, perhaps most of us, if truth be known, the response never does become automatic. Those who learn to cope successfully often do so by imagining themselves inside the aircraft, looking out at the world through a porthole the size of the ADI window, which is why it's called an "inside-out" display.

At least the ADI is an attitude indicator. The little "W" (waterline symbol) which is fixed, tells where the aircraft is pointed relative to the horizon, which moves. On the sphere, the sky is blue, surface brown and horizon unmistakably depicted, and the field of view approximates 90^{o}-110^{o} of the sphere.

This brings us to the third source of attitude information, which is on the HUD. The HUD is also an inside-out display with reversed roll-sensing like an ADI, but it is <u>not</u> an ADI. The aircraft symbol, -○-, which moves in pitch and yaw (but not in roll) tells not where the aircraft is pointed but where the aircraft is going. It is really an inertially derived flight path marker. (Some HUDs also display a "W" waterline symbol or gun cross indicating where the aircraft is pointed; the difference between where the aircraft is going and where it is pointed constitutes angle-of-attack, Fig 12A.)

On the HUD, there is no clear distinction between sky and surface--the only difference being the type of lines on the pitch scale: solid for positive, dashed for negative. The overall pattern of the scales is symmetric about the 0o pitch line (horizon line) which, itself, is not much longer and therefore hardly more commanding than any other pitch line. The horizon line in most HUD's is straight, whereas all other pitch scales have "tails" pointing toward the horizon.

In trying to determine one's attitude from the HUD, it is not always immediately apparent whether one is upright or inverted, or climbing or diving, or if so, to what general extent, because the scales all look about the same.

Whereas the ADI gives a 60-110° FOV (the big or macro-picture), the HUD provides only a 14-20° FOV, or in the case of the F-16, 16°. This is the micro-picture; it is like taking a 16° circle out of the ADI, and expanding it

WHERE AIRCRAFT IS POINTED VS WHERE AIRCRAFT IS GOING

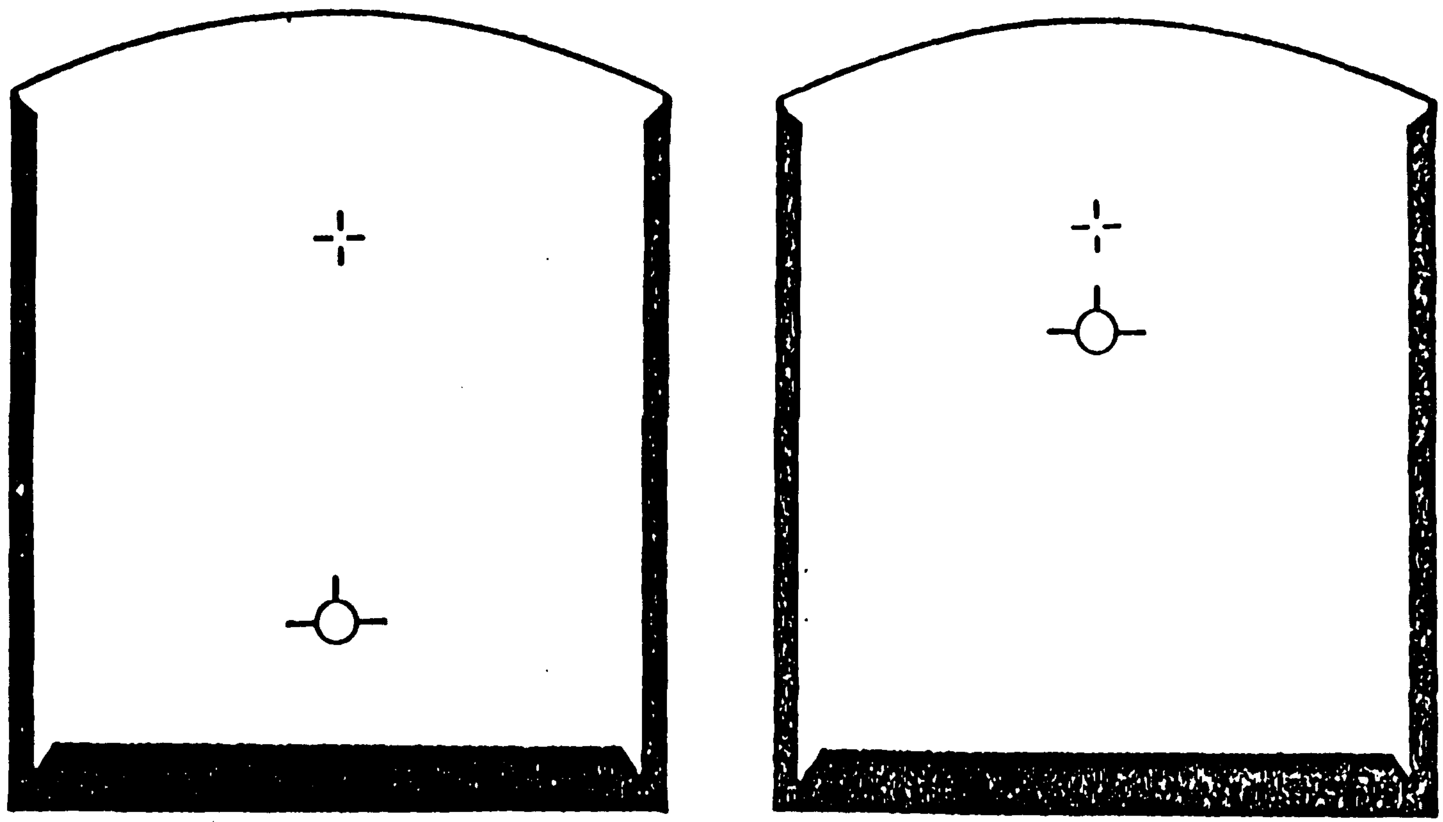


Figure 12A: HUD depicting gun-cross (where aircraft is pointed) versus Flight Path Marker (-O- , where aircraft is going)

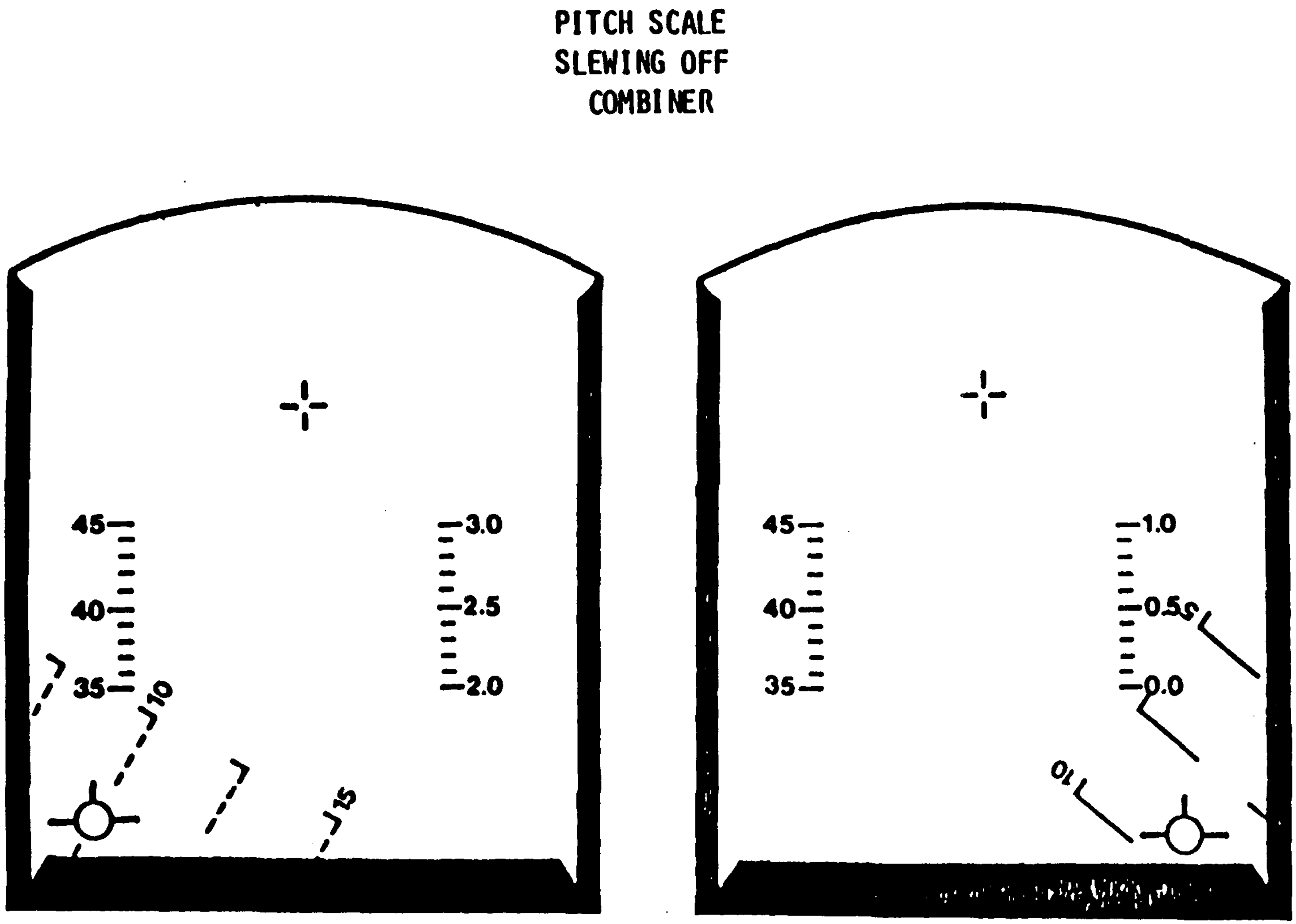


Figure 12B: HUD Pitch Scale slewing off face combiner

F/A-18A Navigation HUD Display

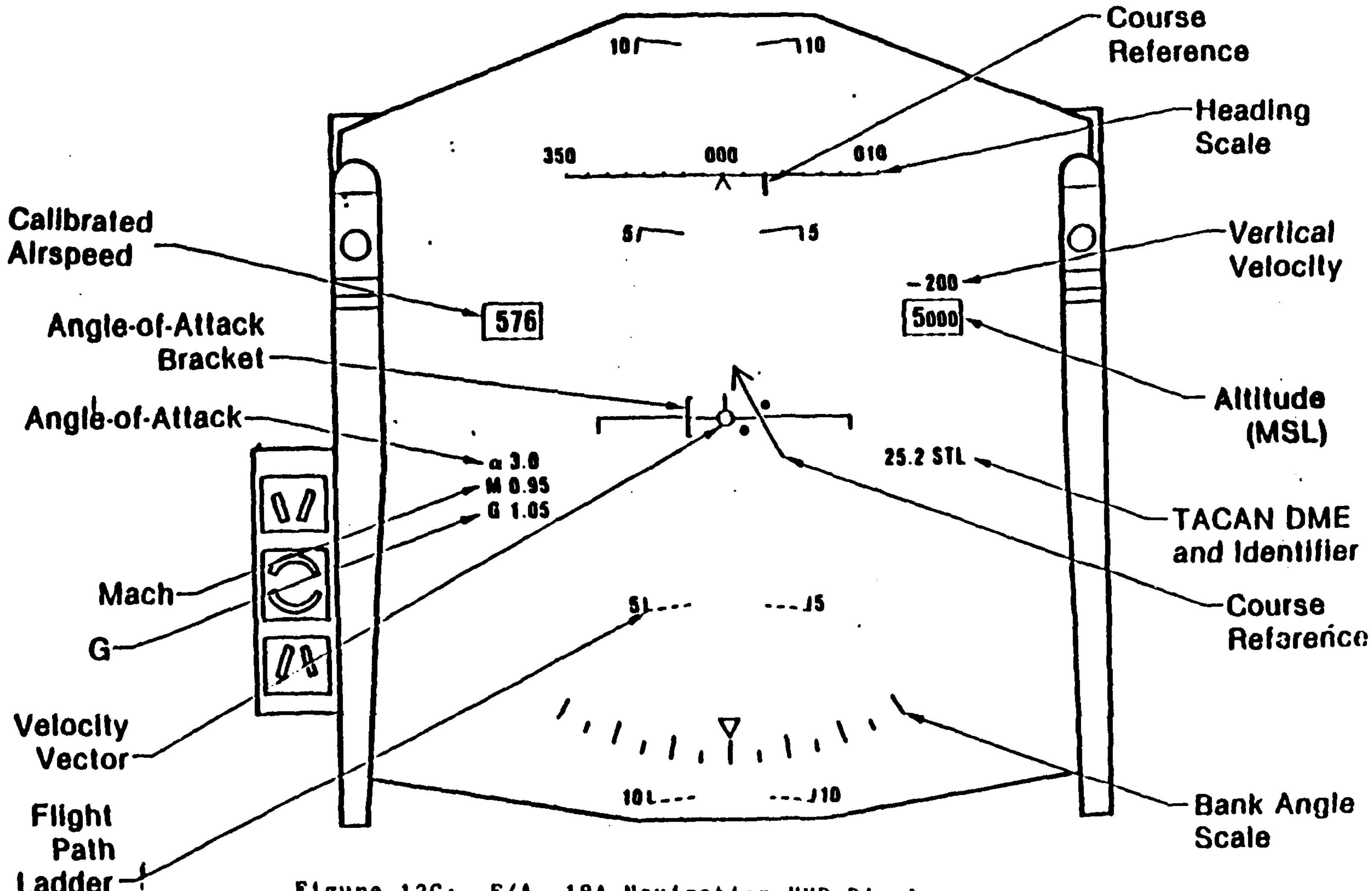


Figure 12C: F/A -18A Navigation HUD Display over the face of the combiner. It not only magnifies the scale to 1:1 with the outside world, it also magnifies the dynamics of the FPM and, in particular, the Flight Path Scales (FPS, also called pitch scales). Whereas the FPM moves as if on a pendulum, suspended from the gun-cross, the FPS revolves around the FPM. The dynamics are such that at high pitch or roll rates, or in high cross winds, the FPS can nearly slew off the face of the combiner (Fig 12B) and may become unreadable. In other words, at rapid roll or pitch rates, the FPS does not hold still for interpretation. Thus, the first step in recovering from an unusual dynamic attitude via the HUD is to first stop the roll or slow the pitch rate so you can read the numbers on the FPS! This takes some finite amount of time. The next steps are combinations of pulling to the horizon and rolling upright, or rolling upright and pulling to the horizon. There are cues on the FPS's to help you reach the horizon: in the F-16 HUD, the FPS's have horizon pointing tails; in the F-18, the entire FPS is angled like a chevron, (Fig 12C), aimed at the horizon, forming a channel. However, there is still the problem of determining which way is upright. Since there is no clear distinction between sky and surface on the HUD, you must reduce the dynamics sufficiently to tell whether the FPS's are solid (for positive pitch) or dashed (for negative). Again, this takes some finite amount of time. Furthermore, since there's nothing intuitively obvious about the symbology for upright vs inverted, it's entirely possible to recover to straight and level, inverted, and not recognize it for some time (Fig 12D).

Although the Flight Path Scale yaws and rolls (and, of course, scrolls up and down in pitch) over and off the combiner, there is a considerable quantity of symbology and scale that does not move: for example, the airspeed, heading and altimeter scales as well as the digits for G and mach, and other symbols for avionics, radar and weapons modes are fixed; and being fixed, they constitute a stationary frame of reference. With the preponderance of evidence to the eye being that nothing is moving up there, motions of the FPS may not even register, especially if off center or nearly out of view. (Motion of the FPS will, of course, register as motion, but not necessarily as aircraft motion.) In some cases, the FPS can actually generate more "quality of horizoness" when rotated 90° (Fig 12E), so for all these reasons, HUDs are less than optimal attitude instruments.

Another problem area of the HUD is attention allocation--the effectiveness of information transfer and the potential to trap attention. Digital formatting aggravates this because of tying up the focal mode. Furthermore, your span of focus is too narrow to read more than one parameter at a glance. If you want 4 or 5 different parameters, you must make as many eye stops and then you still must decode and integrate it. So, despite the clustering of information, it doesn't invariably speed up the cross-check. As a matter of fact, many pilots feel there's too much stuff up there (Fig 12F) and the first thing they reach for is the declutter switch.

RECOVERY TO
S&L INVERTED
WITHOUT REALIZING IT

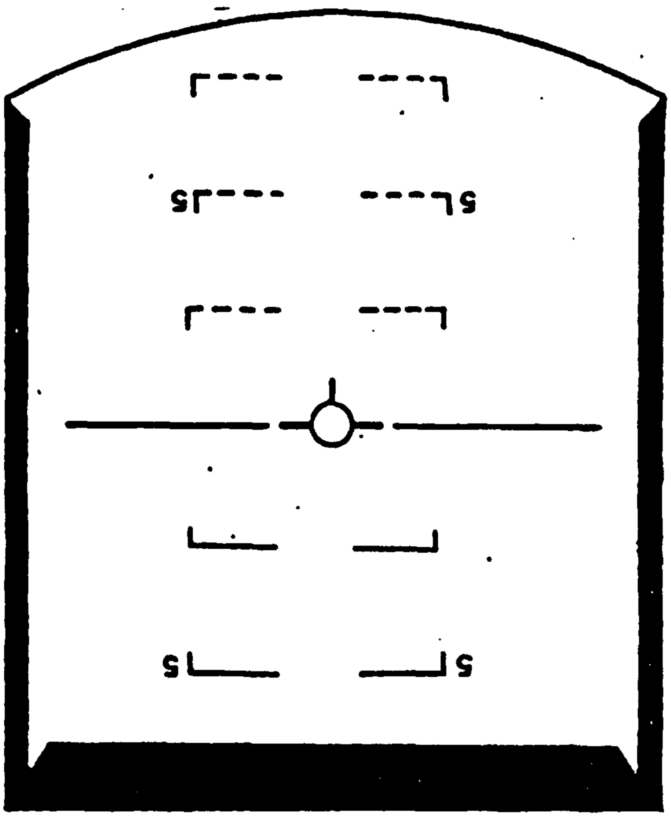


Figure 12D: HUD depicting recovery to straight and level inverted without realizing it

PITCH SCALE =
MORE QUALITY OF
"HORIZONESS" WHEN
ROTATED 90°

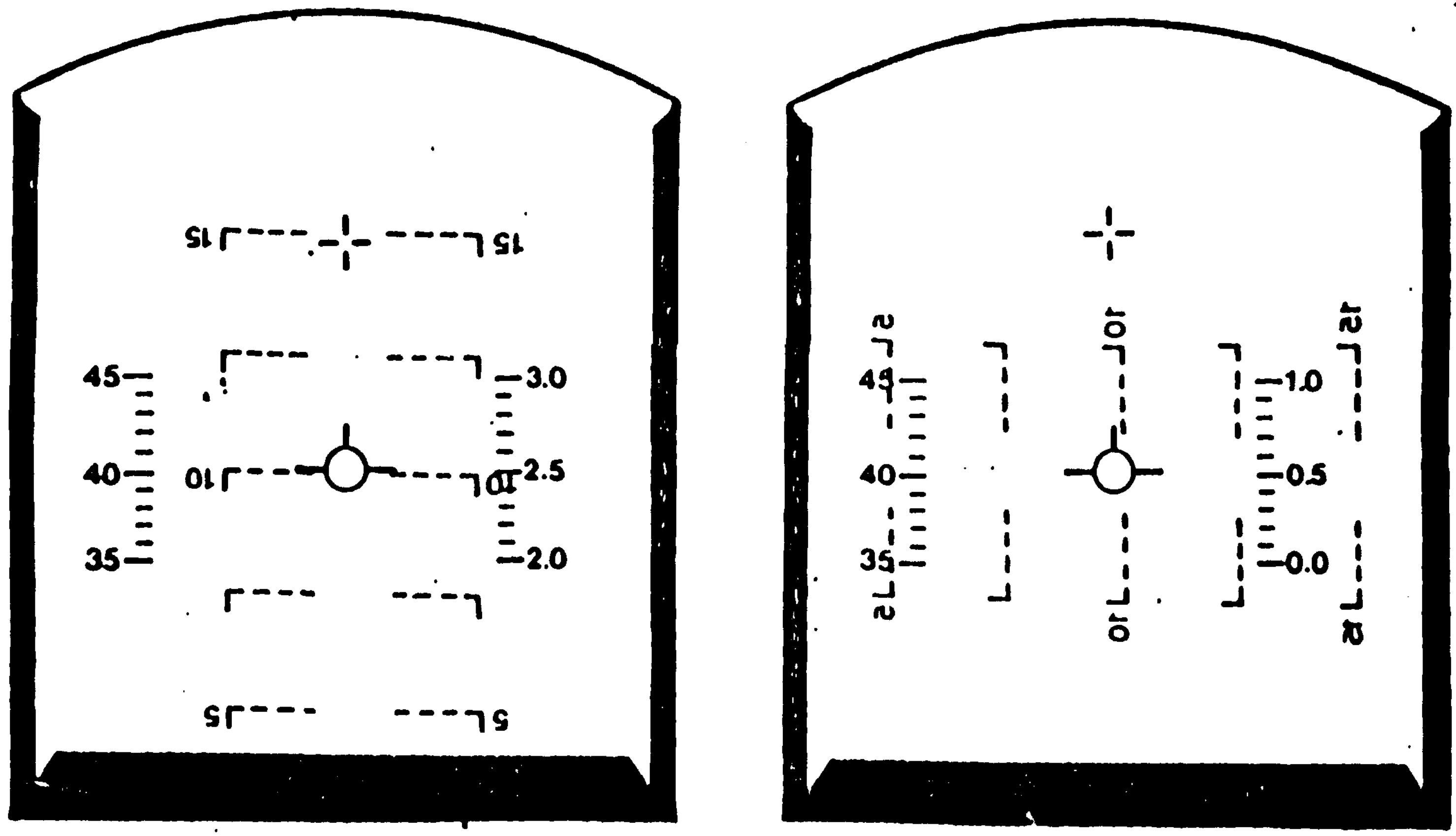


Figure 12E: HUD Flight Path Scale showing more "quality of horizoness" when rotated 90°

HUD DISPLAYS

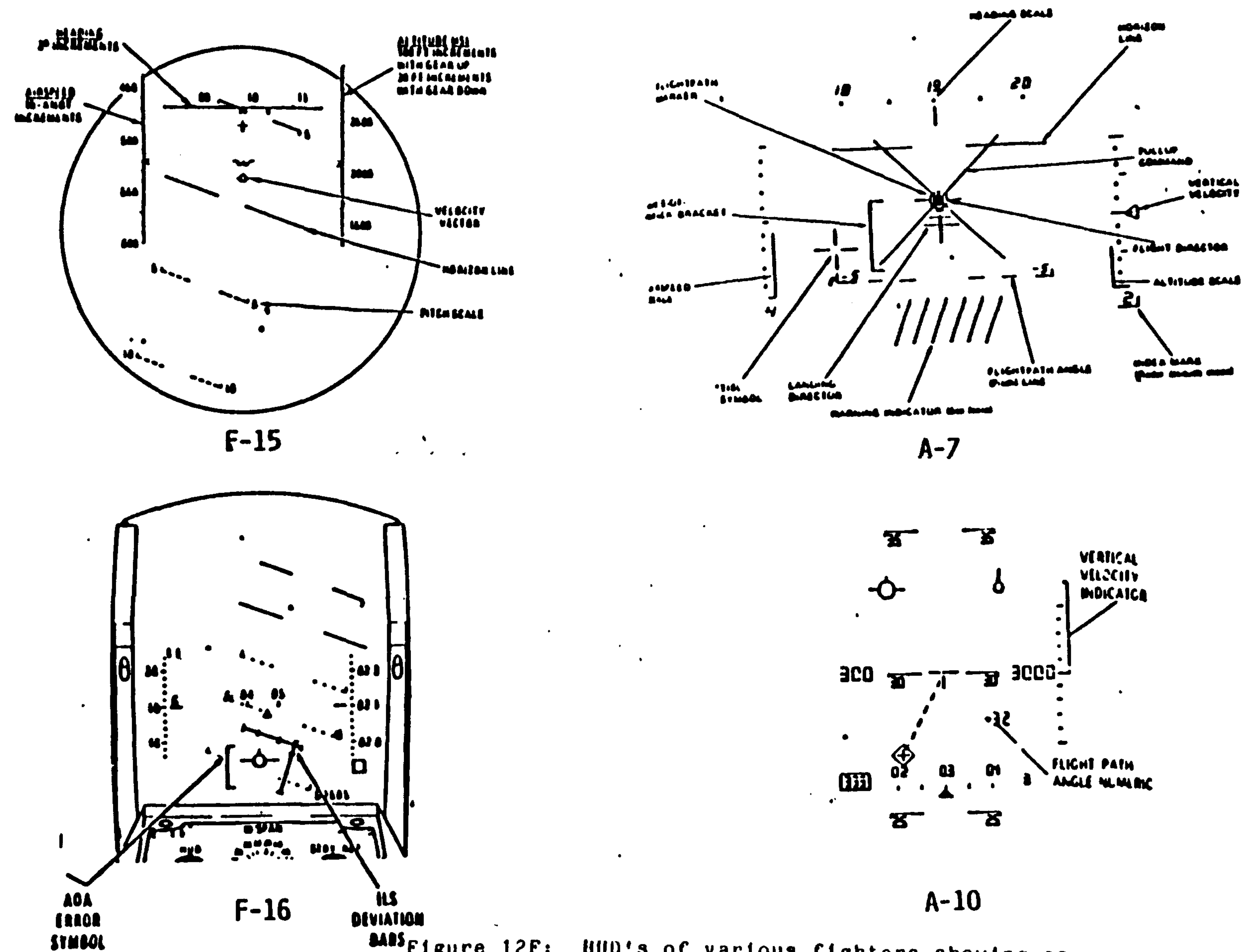


Figure 12F: HUD's of various fighters showing some

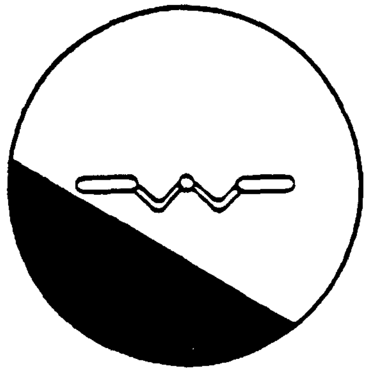
Another phenomenon regarding HUDs is the tendency to stare at all that symbology and become mesmerized by it, deceiving yourself that you're processing all that information when, in fact, you are not. They even have a name for this: "HUD Hypnosis."

Another problem arises because HUD symbology is projected into space as virtually imagery. Looking at the virtual imagery of the HUD is like looking at something through the knothole in a fence; various combinations of the pilot's eye position and the FPS position may move it beyond his view. Another point, although the HUD imagery is collimated to infinity, the eye does not necessarily focus to infinity when looking at the HUD. In fact, the eye tends to focus at an intermediate range corresponding to its own resting dark focal length. For many pilots with 20/20 vision, their dark focus (the distance to which they accommodate in the dark) is only 3 or 4 feet. As you will hear from Joyce Iavecchia and Stan Roscoe, this has implications for clearing the flight path.

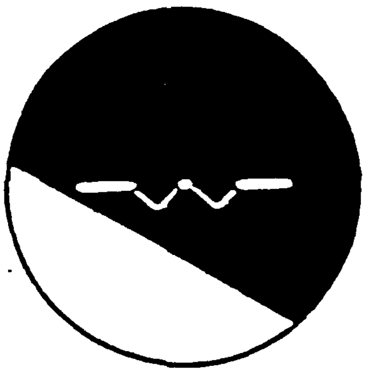
Finally, looking through the HUD in visible precipitation or moving lights can create a disorienting vection sensation.

This is not to say that you can't fly instruments on the HUD or recover from unusual attitudes. You can fly an entire mission on the HUD or an entire airshow on only the HUD--including loops, rolls and all sorts of aerobatics, <u>provided you keep up with the maneuver</u>. What's difficult is attempting to go from some unknown, unrecognized or misperceived attitude to the HUD to recognize the problem, sort it out and cope. The HUD is simply not designed for that. The HUD evolved from the gunsight and is designed specifically to enable maneuvering against a visual scene, which it, in effect, calibrates. It's ideal for precision ordnance delivery or for clearing terrain. Because the Flight Path Marker (FPM) organizes so much information for you, you simply keep the FPM above the obstructions. Or even precision approaches: to shoot a 2.5° glide-slope, simply keep the FPM at -2.5°, and you're wired. But the HUD was not designed nor intended for the recognition of or recovery from unanticipated, unusual attitudes.

The following mishap illustrates the confusion potential of the HUD. It involved a student pilot on his third night ride, a bomb drop on a pitch black range. The mission was uneventful till just following bomb release, when the student established an upright left climb and flew into an unforecast cloud. Within 30-40 seconds of entering that cloud, he rolled from an upright left climb, 180° to an inverted right dive, and impacted with no further call nor attempt to eject. The Mishap Investigation Board suspected a distraction, and sure enough, a warning light requiring him to throw a certain switch was found to have been illuminated at the time of the crash. Though we'll never know what was going on in his mind, it's likely his attention was trapped in coping with this "emergency".



At the moment the aircraft entered IMC, the ADI would have looked something like this.



At the moment of impact, the ADI would have looked like this... The barrel of the ADI is less than 2" in diameter, as in this figure. It is located between the knees, 24" to 34" from the Design Eye Point. Could it be possible to confuse these indications, such as at night, with canopy reflections?

Note: Horizon line subtends an angle of only 3.4 to 4.8 at the eye - not particularly commanding.

Figure 13: ADI's Depicting Upright Left Climb & Inverted Right Dive

Suppose he'd looked at his ADI the instant he entered that cloud and again the instant before hitting the ground (Figure 13). Is it possible, with the glare and reflections, that he could have confused depictions, or even made a roll-reversal?

But suppose he'd glanced at his HUD at the same instant, realizing that in the ordnance delivery mode (which he was using) the pitch scale slews over the combiner and would not necessarily be centered as depicted in Figure 14. Since this aircraft does not "talk" to the pilot nor alert him of any change, he may not have been suspecting that anything had changed--he could easily become a victim of the element of expectancy, see what he expects or wants to see, and simply misinterpret the depiction. We think he could have been a victim of this more subtle and insidious form of spatial disorientation, more lethal because it fails to alert its victims to even question attitude, hence, they delay cross-checking attitude till it's too late. Some refer to this as "spatial misorientation."

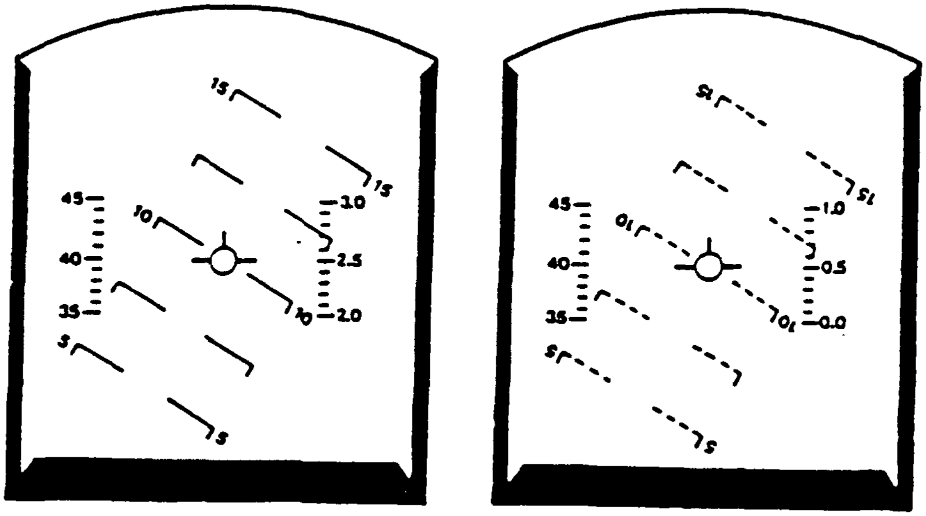


Figure 14: HUD's Depicting Upright Left Climb & Inverted Right Dive

In some HUDs, the pitch scales are angled, like chevrons, pointing toward the horizon. While this may improve orientation toward the horizon, as long as the pattern is symmetric about the horizon, it does not necessarily avoid the confusion of upright-inversion, as per Figure 15.

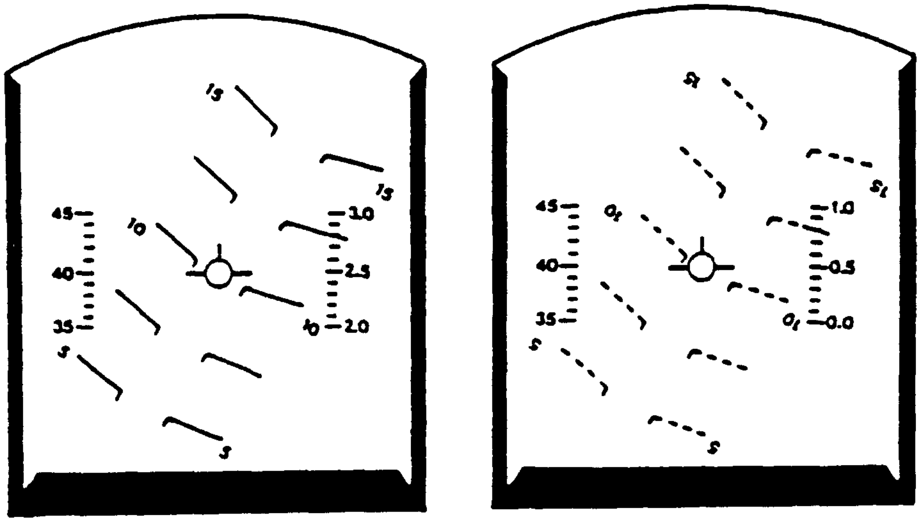


Figure 15: HUD's with Angled Flight Path Scales, Depicting Upright Left Climb & Inverted Right Dive

To reiterate: The ADI is designed for the recognition of and coping with unusual attitudes. The HUD is not, and such actions can be very difficult on the HUD.

This is not to say the HUD could not be improved upon for attitude recognition. As a minimum, two changes would be needed:

a. Since the FPM is so commanding, it would seem reasonable to make it into a roll cue. This could be done by simply adding to it a zenith-pointer, as per Figures 16 A,B,C. The star is Dr. Malcolm's idea--to add "innateness" to the cue (stars are up, in the sky).

b. The relative simplicity of pitch scales fails to cue regarding angle from the horizon, at least when the pitch lines are straight. Admittedly, using chevrons with angles increasing with offset from

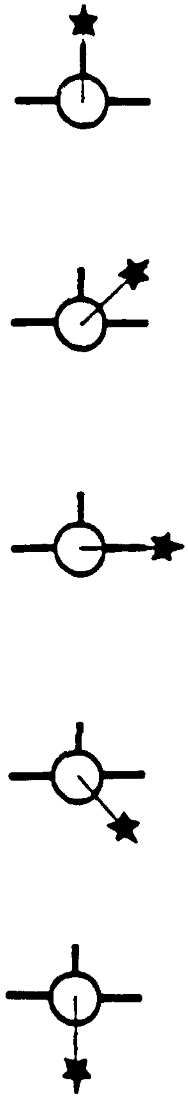


Figure 16A: HUD Flight Path Marker Showing Zenith Pointer

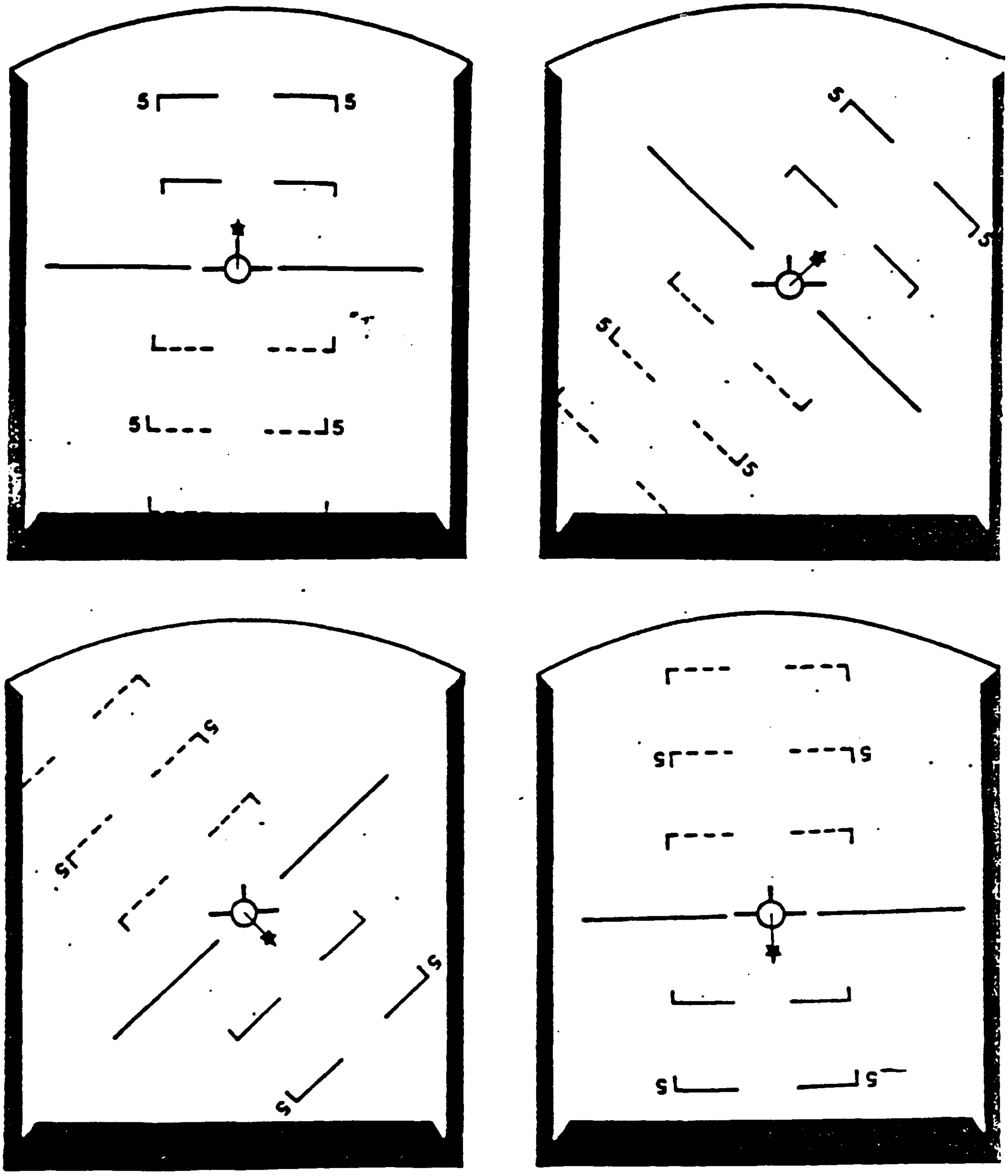


Figure 16B: HUD FPM showing (clockwise) S&L Upright, 45° Left Bank S&L Inverted, 135° Left Bank

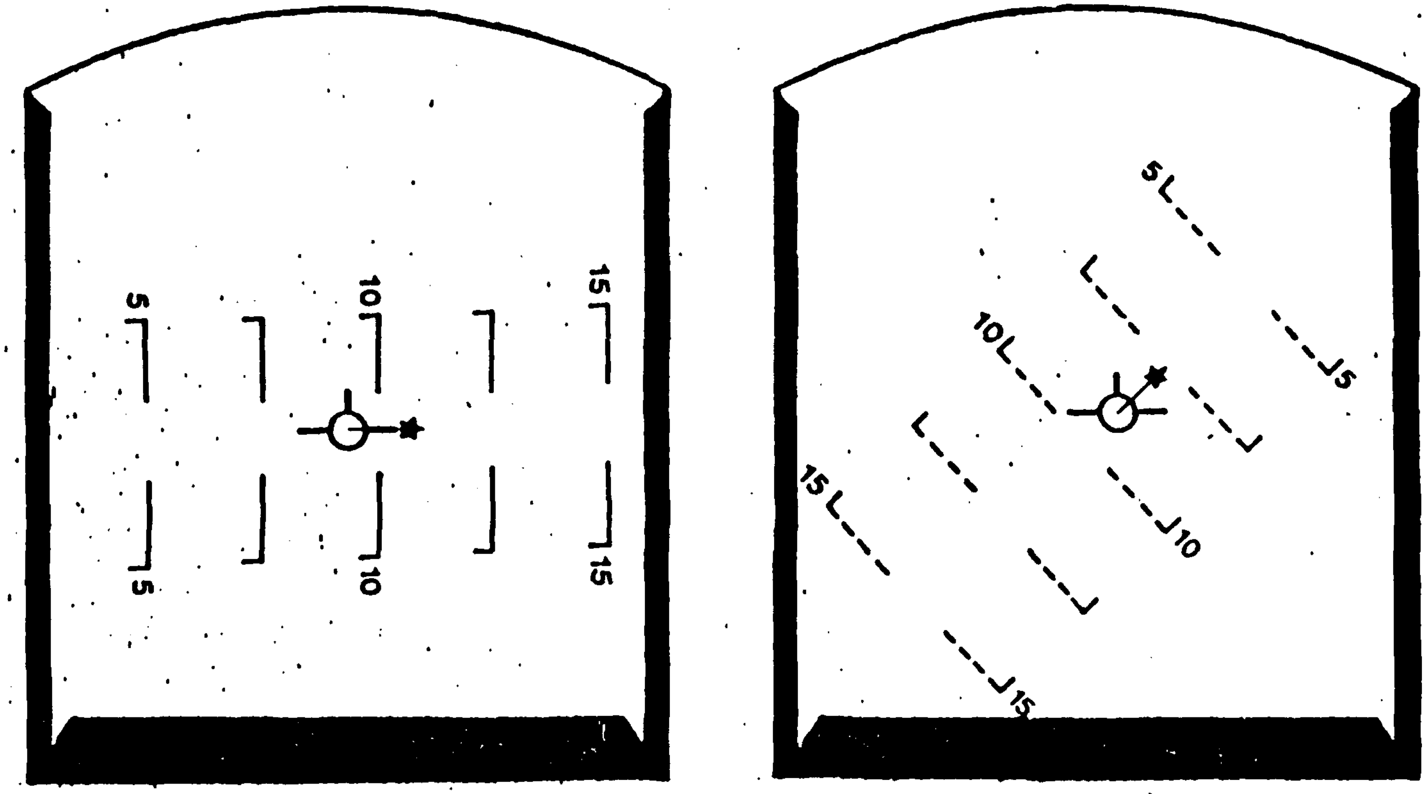


Figure 16C: HUD FPM showing 90° Left Bank at 9° climb; 45° Left Bank at 9° Dive

VERTEX POINTER

ON THE FPM

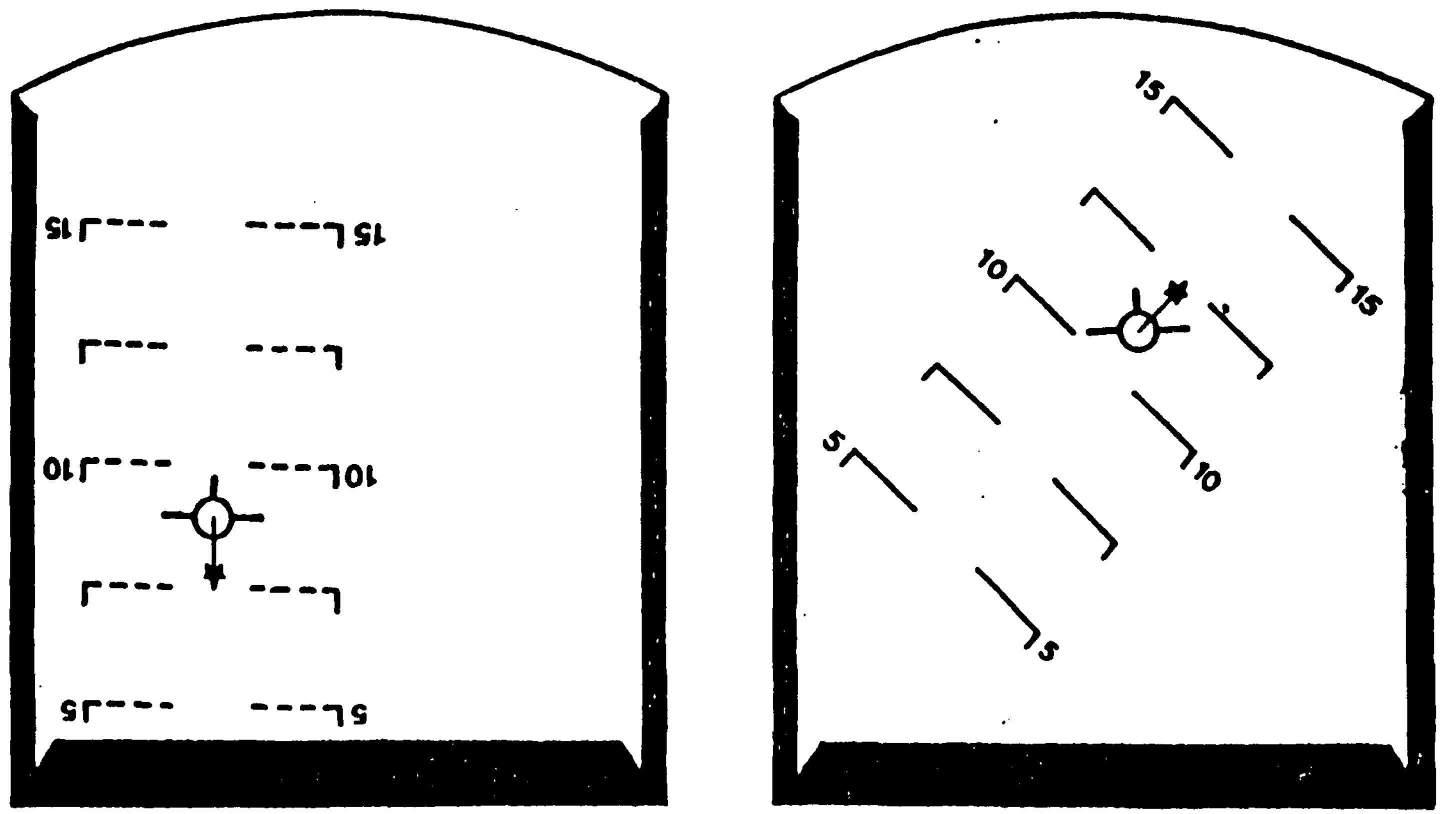


Figure 16D: Vertex Pointer on the FPM

HUD PITCH SCALE SHOWING
RADICAL CHANGES FROM POSITIVE
TO NEGATIVE & WITHIN NEGATIVE

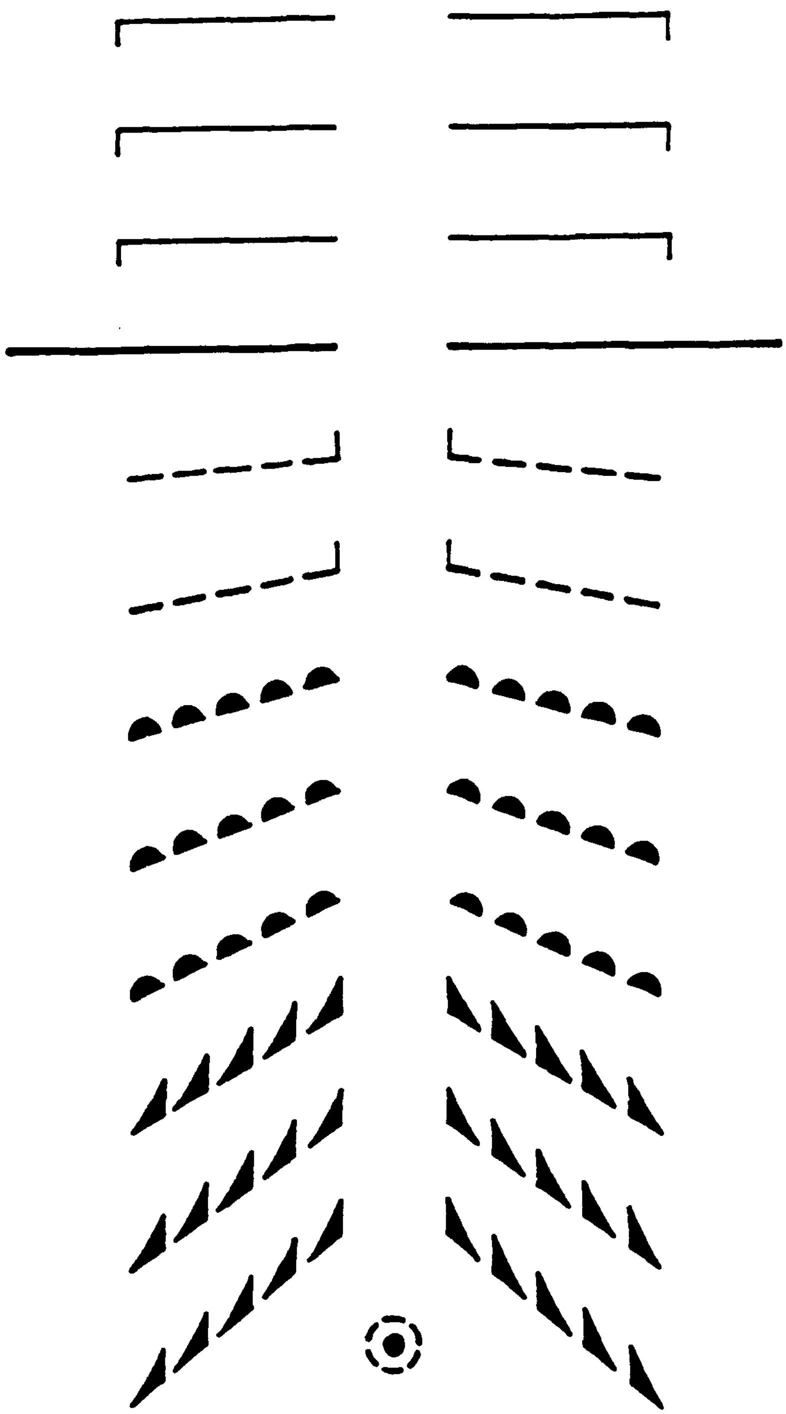


Figure 17

the horizon does provide some cue. But keeping with the premise that humans are basically pattern recognizers, why not alter radically the pattern of positive from that of negative pitch; and since negative pitch is more time critical than positive, why not alter again the pattern of pitch scales from one range of negative to the next, the steeper becoming more urgent, as per the "Shark's Jaws" (Figure 17 A,B)? At least it should cue him to go immediately to the ADI, which is the prime recognition and recovery instrument. Dr. Robert Taylor of the United Kingdom will discuss HUD pitch scales tomorrow.

Arrangement of certain instruments has also been implicated in mishaps, e.g., standby attitude indicator (SAI) and the altimeter. One mishap implicating the SAI involved the lead of a 3-ship to the range. Sandwiched between cloud layers at 7000', shortly after takeoff, lead announced he had a problem and initiated a hard 180° turn, presumably to return to base. In so doing, he entered a cloud, from which he shortly emerged in a dive, entering lower clouds obscuring mountains. There was no further call nor attempt to eject, but positive control movements indicate he was conscious immediately before impact. The Mishap Investigation Board was unable to ascertain the nature of the problem. One of the only things found wrong with the aircraft was a mismatch of over 100° between the primary ADI, which correctly depicted a 67° dive, and the SAI which erroneously indicated a 40° climb. This pilot had a reputation as a strong instrument pilot. Had he been referencing the primary ADI, the Board was certain he would have recovered (or at least attempted). Their conclusion is that he was referencing the erroneous SAI, located closer to the eye line. This raises the question of whether it would improve matters to co-locate the ADI and SAI, either side-by-side or vertically.

As hard as some things are to learn, once learned, they're even harder to forget. This applies to the location of switches, ejection handles and even instruments, in this case, the altimeter. The mishap pilot had just completed his replacement training unit course and had 50 hours in models with the ADI, ASI, ALT, and HSI instruments arranged in a "T" (Figure 9). He then arrived at his new base to fly newer models with those instruments arranged in a "square" (Figure 19). The modification was accomplished by moving the altimeter from the right of the ADI, to the left of the lower horizontal situation indicator (HSI), placing it even deeper into the cockpit.

Having been at his new base about a month, this pilot was assigned to fly a series of surge sorties, in which he awakened at 0200, briefed at 0300, launched at 0400, flew some intercepts, then landed, flew another sortie or two, then headed back to quarters to try to get some rest for the next early morning go. The mishap occurred on a pitch black night over a pitch black range. This was his fourth morning, so first of all, if he wasn't tired, he should have been (although probably no more so than most of the others). Second, he'd been having difficulty acquiring his target, which was his lead

COMBINATION OF VERTEX
POINTER ON FPM PLUS
RADICAL CHANGE IN FLIGHT PATH
SCALES FROM POSITIVE TO NEGATIVE

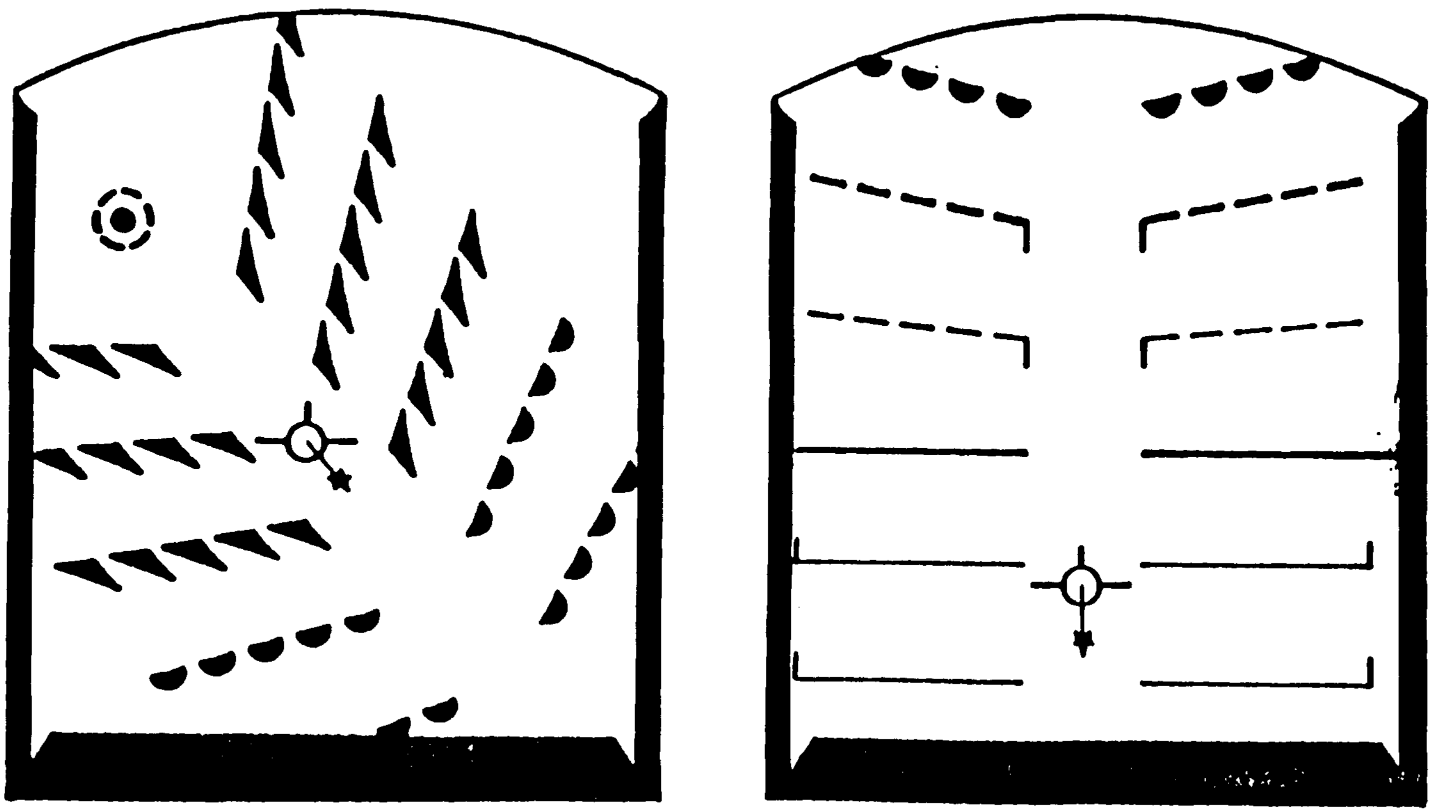
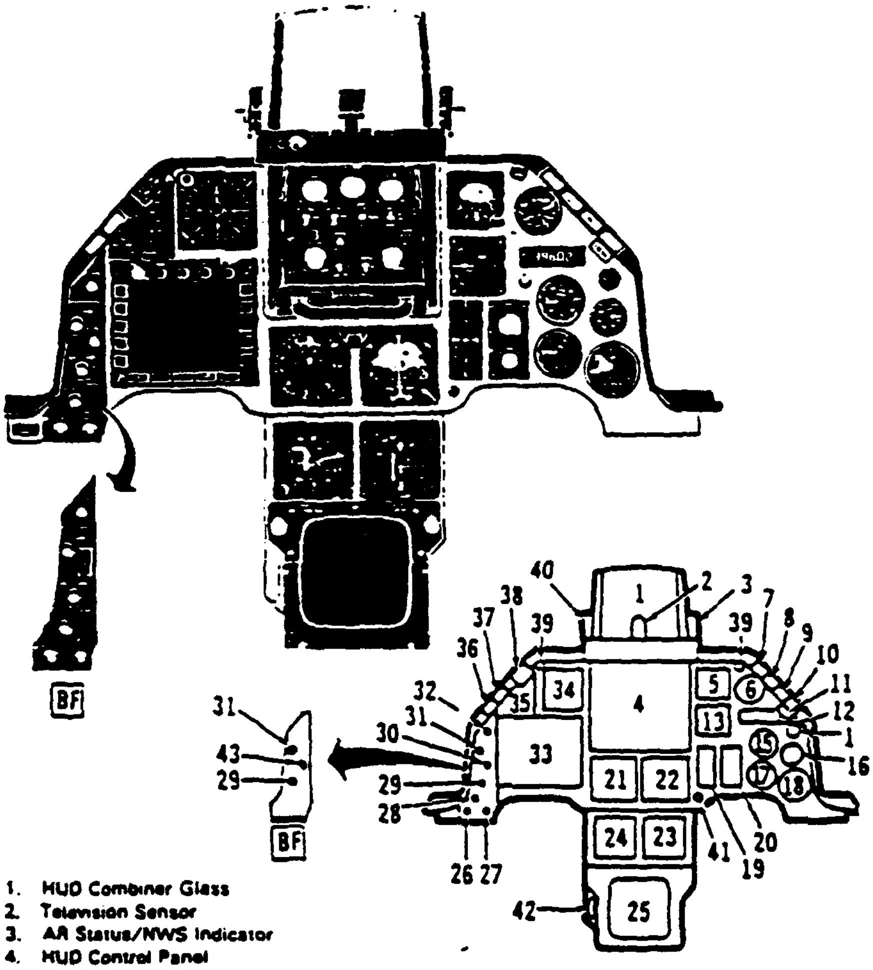


Figure 18

INSTRUMENT PANEL [A] [BF]



1. HUD Combiner Glass
2. Television Sensor
3. AR Status/NWS Indicator
4. HUD Control Panel
5. Standby Attitude Indicator
6. Fuel Flow Indicator
7. DUAL FC FAIL Warning Light (Red)
8. HYD/OIL PRESS Warning Light (Red)
9. CANOPY Warning Light (Red)
0. RDR ALT LOW Warning Light (Red)
1. ENGINE Warning Light (Red)
2. Radio Channel/Frequency Indicator
3. Vertical Velocity Indicator
4. Oil Pressure Indicator
5. RPM Indicator
6. Nozzle Position Indicator
7. FTIT Indicator
8. Fuel Quantity Indicator
9. AOA Indicator
0. Instrument Mode Select Panel
1. Airspeed Mach Indicator
2. Attitude Director Indicator
3. Horizontal Situation Indicator
4. Altimeter

25. Radar/EO Display
26. Autopilot PITCH Switch
27. Autopilot ROLL Switch
28. AUTOPILOT Switch
29. MASTER ARM Switch
30. ALT REL Button
31. LASER ARM Switch
32. IFF IDENT Button
33. Stores Control Panel
34. Threat Warning Azimuth Indicator
35. THREAT WARNING Controls and Indicators
36. ENG FIRE Warning Light (Red)
37. T.O./LAND CONFIG Warning Light (Red)
38. MASTER CAUTION Light (Amber)
39. Spotlight
40. AOA Indexer
41. MRK BCN Light
42. Rudder PEDAL ADJ Knob
43. [BF] OVRD Light

Figure 19: F-16 Instrument Panel, Block 15 Aircraft

aircraft, so was under some self-imposed pressure to get the talley. When it was his turn to be the interceptor, he thought he saw his target, called "Talley", lost talley, then called "Talley" again from a position where he was belly up to his target aircraft--no way could he have seen it. Over the ensuing 1-1/2 to 2 minutes, he proceeded to lose 11,000 feet, impacting near a lighted train siding. It so happened that a train had passed within several minutes. It's possible that his Doppler locked up the train and that he mistook its light for that of his target. Again, we'll never know. But just suppose that he had decided to check his altitude during that pitch black night (altimeter constitutes a fairly critical instrument on a pitch black night over terrain devoid of height references), and not seen it in the old location, could he have simply deleted it from his cross-check? After all, nothing was alerting him that he was going downhill and he certainly did not want to lose sight of that target again.

Or take another tack and ask, suppose the altimeter (or any of the other critical control parameter instruments) were formatted for instant, unequivocal recognition in such a way that they could be monitored by the ambient mode or via a focal mode snap glance; might pilots be prompted to cross-check them oftener and thus maintain their aircraft attitude/altitude awareness with less effort?

That raises the question: In the Pilot Vehicle Interface, what does the pilot really need to maintain attitude awareness? Attitude cues, airspeed and altitude cues without requiring focal mode to dwell on instruments.

Have we considered adequately how the human perceptual system works or what man needs by providing him a proper mixture of inputs to sensory channels other than the focal visual mode? For example, analog, pattern, pictorial, color, orientation; focal/ambient auditory displays; and tactile/proprioceptive cues. Have we asked whether the aircraft "talks" to the pilot by providing him a proper mix of auditory and kinesthetic cues?

The advantages of providing inputs to sensory routes other than the focal visual mode are that it frees the focal mode for tasks requiring focal mode attention, promotes situational awareness, reduces the propensity for SDO and, if formatted correctly, should reduce workload. Regarding workload, we should recall that, most of the time, when a pilot looks at a display, he wants only to know whether the parameter it represents has changed, and, if so, in which direction, how fast and how much.

Now in keeping with man's pattern recognition abilities, why not design instruments taking advantage of that innate capability and also utilize the moving tape format so popular in the past? The moving tape lends itself well to airspeed and altitude. Note Figure 20, in which the pattern of airspeed changes radically from one range to the next to enable recognition out the corner of the eye, once one learns the pattern. In Figure 21, the altitude is a zig-zag pattern to create a side-to-side motion that might help catch the

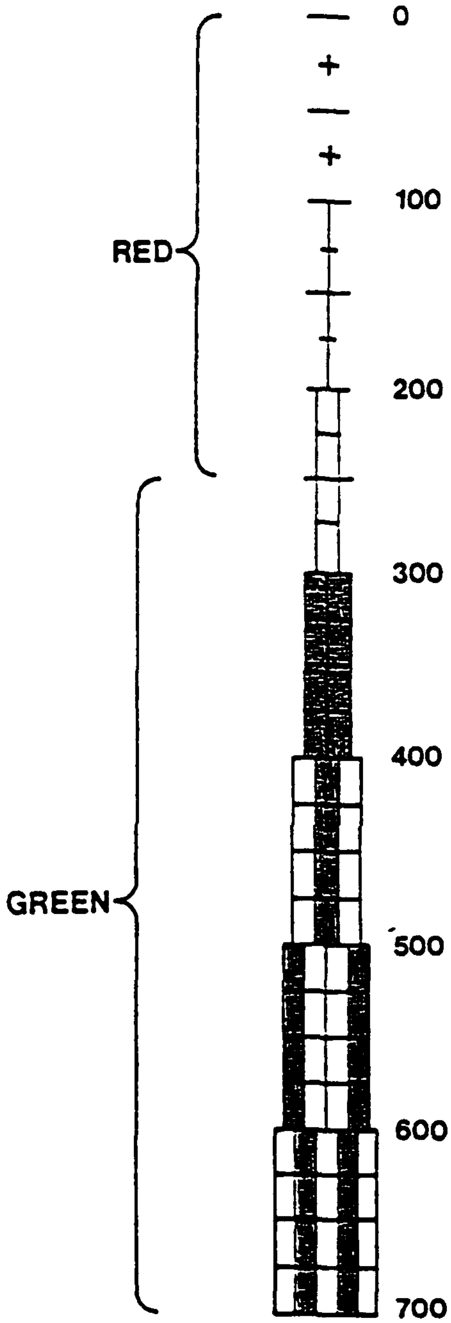


Figure 20: Moving Tape Format Proposed for Airspeed Indication

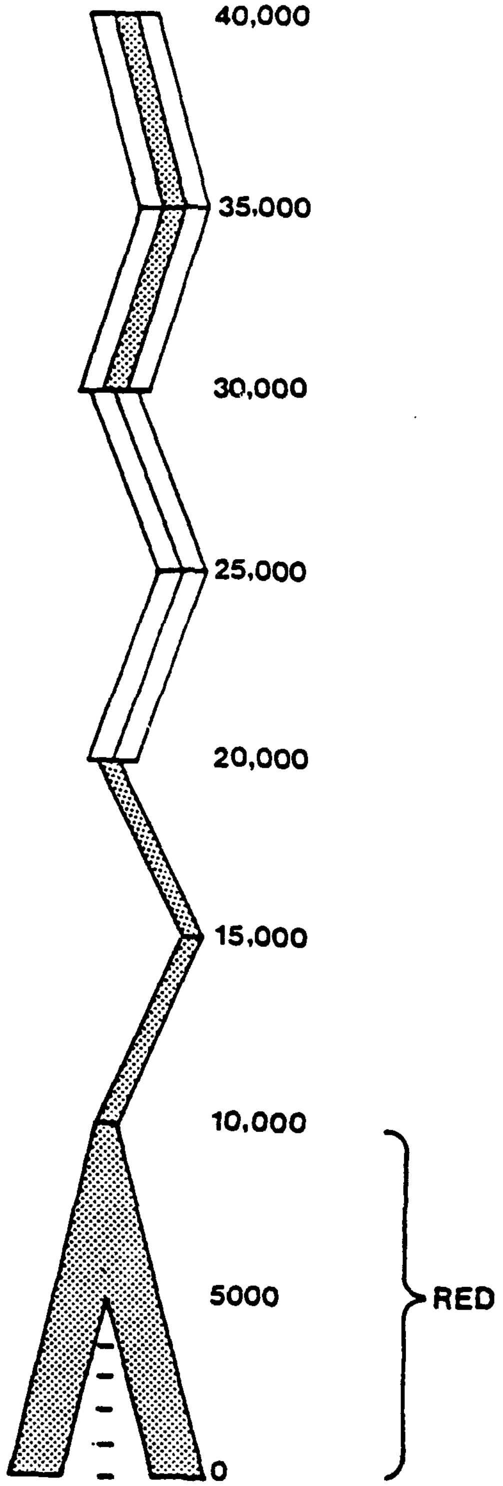


Figure 21: Moving Tape Format Proposed for Altimeter

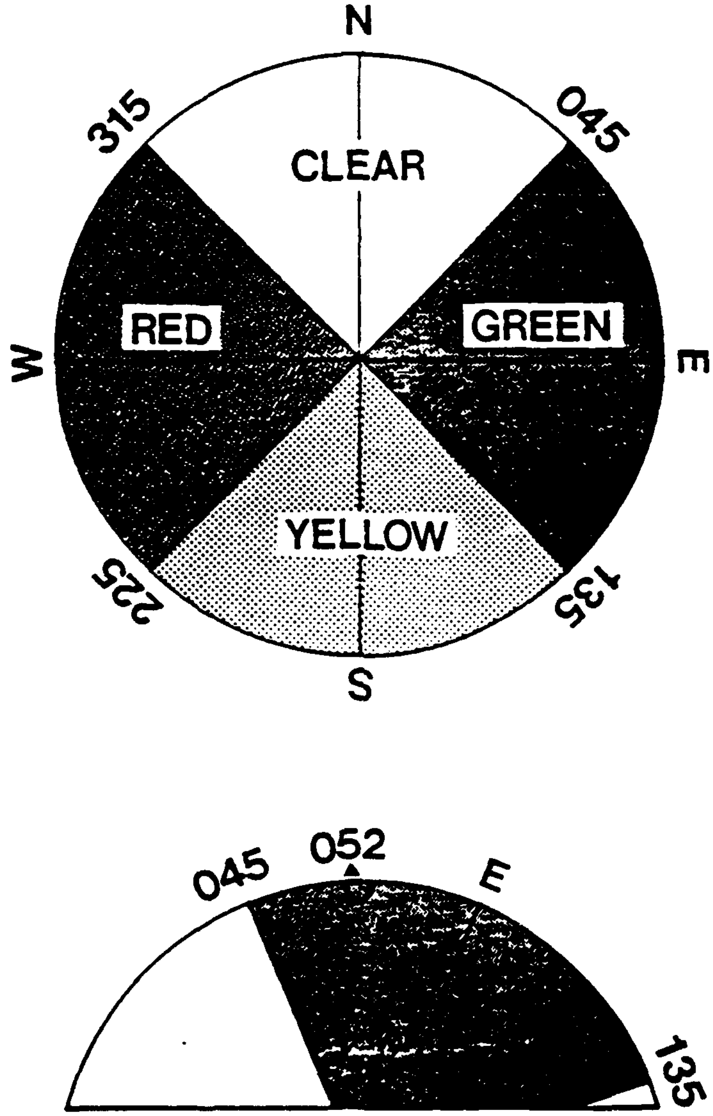


Figure 22: Proposed Heading Indicator

pilot's eye should he enter an unplanned descent with his attention directed elsewhere. The pattern would again change radically below 10,000 feet. The reason for this is that certain out-of-control maneuvers, such as roll rates over 100°/second, can exceed the fixating capacity of the eye, making everything a blur. It would take a big, bold, instantly recognizable pattern change in the altimeter at this point to alert the victim that the time has come to recover the aircraft now or else eject without further delay.

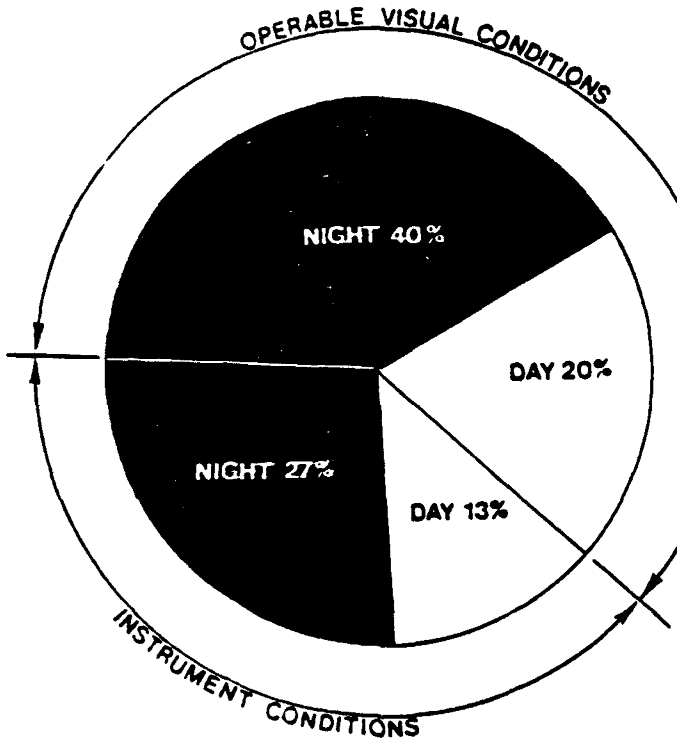
While on the subject of display improvement aimed at reducing processing time and workload, why not use the color pattern recognition capabilities of the ambient mode for heading? As per Figure 22, the entire compass might not need to be shown; perhaps the top one-fourth or one-third would be sufficient.

The night-weather role needs mention again. Regardless of the original intention in procuring the aircraft, if it has AF markings, it will sooner or later be flown at night and in weather. To answer the question of why train in night/weather, one has to look no further than a chart showing the average weather conditions for any typical 24-hour period during the winter in central Europe (Figure 23). This pie-graph shows that about 40% can be expected to be IMC. The reason we train night/weather is that we may very well have to fight there.

The night role requires some special considerations. For the pilot, fatigue is a given; reactions are slowed; perceptions impaired--especially height and distance judgments; and he is more subject to illusions, disorientation, distraction and channelized attention.

The aircraft needs special considerations, too. No longer is it permissible to say, "It's a day VFR air superiority dog fighter," and wash our hands of it. That type of attitude constitutes negligence. For the night role, aircraft need, as a minimum:

- Better attitude references to include a large, primary dedicated attitude display (PDAD) high in the center of the instrument panel.
- Critical control parameters formatted for instant, unequivocal recognition.
- Better cockpit/instrument lighting with minimal, if any, canopy glare and reflections.
- Better formation lighting.
- No false horizons from external lighting.



FLYING CONDITIONS - CENTRAL EUROPE
WINTER - TYPICAL 24 HR. PERIOD

Figure 23: Pie graph showing the average weather conditions during a typical 24 hour period in Central Europe during the winter

Well, with all that, just where are we headed in the design of the modern cockpit? Note the F-15E and F-18 (Figures 24 and 25). No dedicated primary ADI (it's on call on any of the multi-function displays but it is not there all the time--which means that it is not there to alert the pilot that he needs it). Each has an SAI, low in the instrument panel and effectively out of view. On the F-16C/D, Figure 26, note that the primary ADI has been moved even deeper than in the A/B, to a sort of "Y" cross-check pattern. Note, also, all that prime real estate occupied by the HUD control panel. As an improvement, why not use that area for a primary attitude display, as per Figure 27, so that it displays attitude practically within the same field of view as the HUD?

If we do not set our priorities properly in the design of future aircraft, we're going to lose many of these ultra-expensive machines, and their pilots, in training mishaps. The first priority is aircraft control--and the ingredients of good aircraft control are an awareness of attitude, airspeed and altitude. Attitude control is basically a visual task. To improve attitude control requires improved visual displays, as we have attempted to illustrate. But that's not the whole problem.

Just as important is altitude awareness--loss of altitude awareness results in collisions with the ground, the controlled flight-into-terrain (CFIT) mishap. Currently, CFITs outnumber SDO mishaps 2 or 3 to 1 (Figure 28). CFITs account for the largest proportion of operator error mishaps and fatalities. To attack this problem, we cannot rely on vision. This is basically a problem of alerting the pilot, whose attention is invariably directed elsewhere, to check his flight path and pull up. What he needs are audio warnings and alerts; effective, unequivocal inputs to his hearing system. You'll hear more about this in the days ahead.

Finally, if all else fails, if the pilot is incapacitated, either physically, as in G-induced loss of consciousness or hypoxia, psychologically, as in severe disorientation/vertigo, or visually, as in laser/nuclear flashblindness, the aircraft should resist crashing and recover itself. The state-of-the-art is rapidly approaching the point of being able to do this, and we are approaching the point of building aircraft that are simply irreplaceable, dollar-wise, not to mention their occupants. You'll hear more about aircraft that resist crashing and auto-recovery on Thursday.

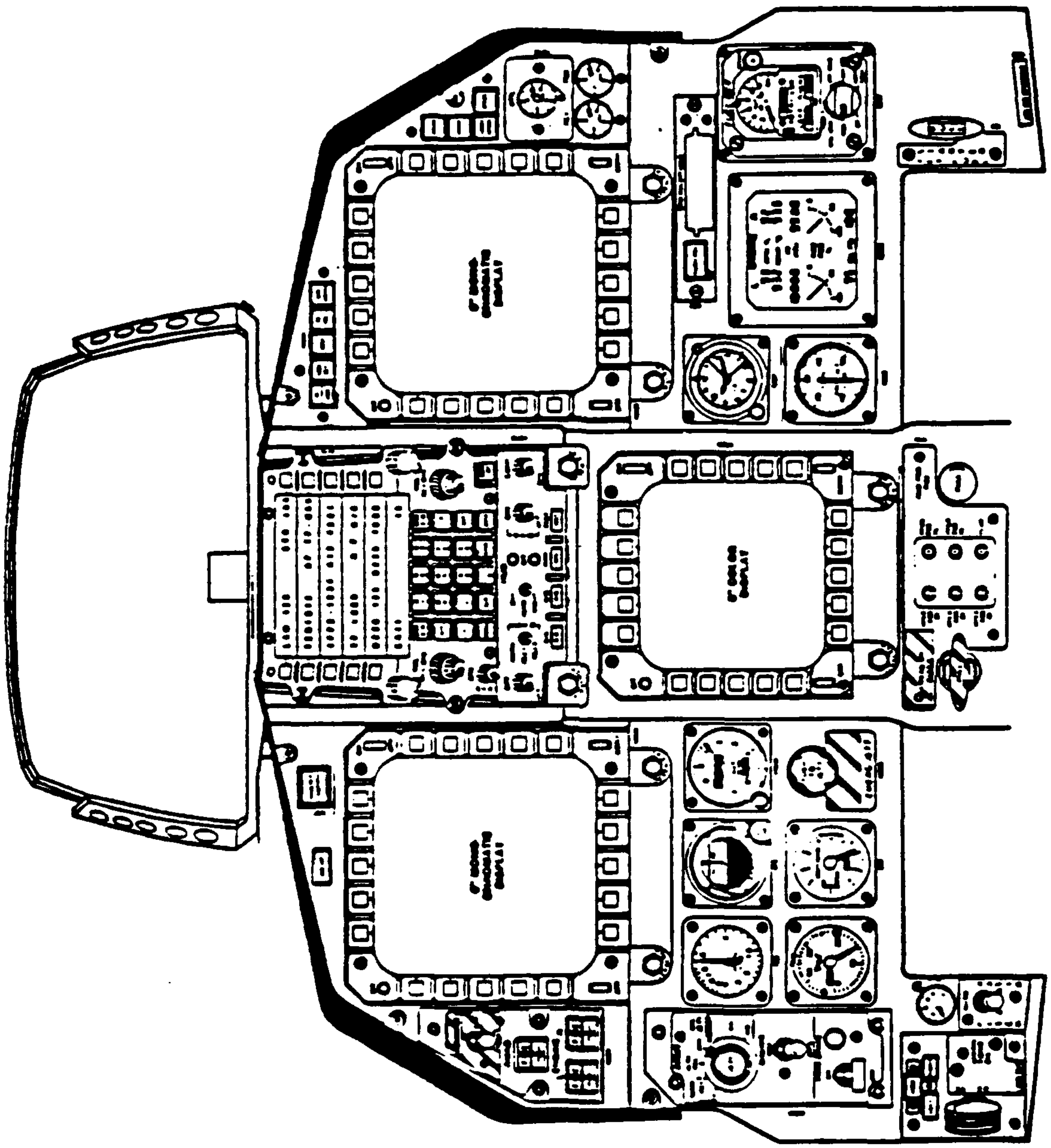


Figure 24

F/A-18 HORNET COCKPIT

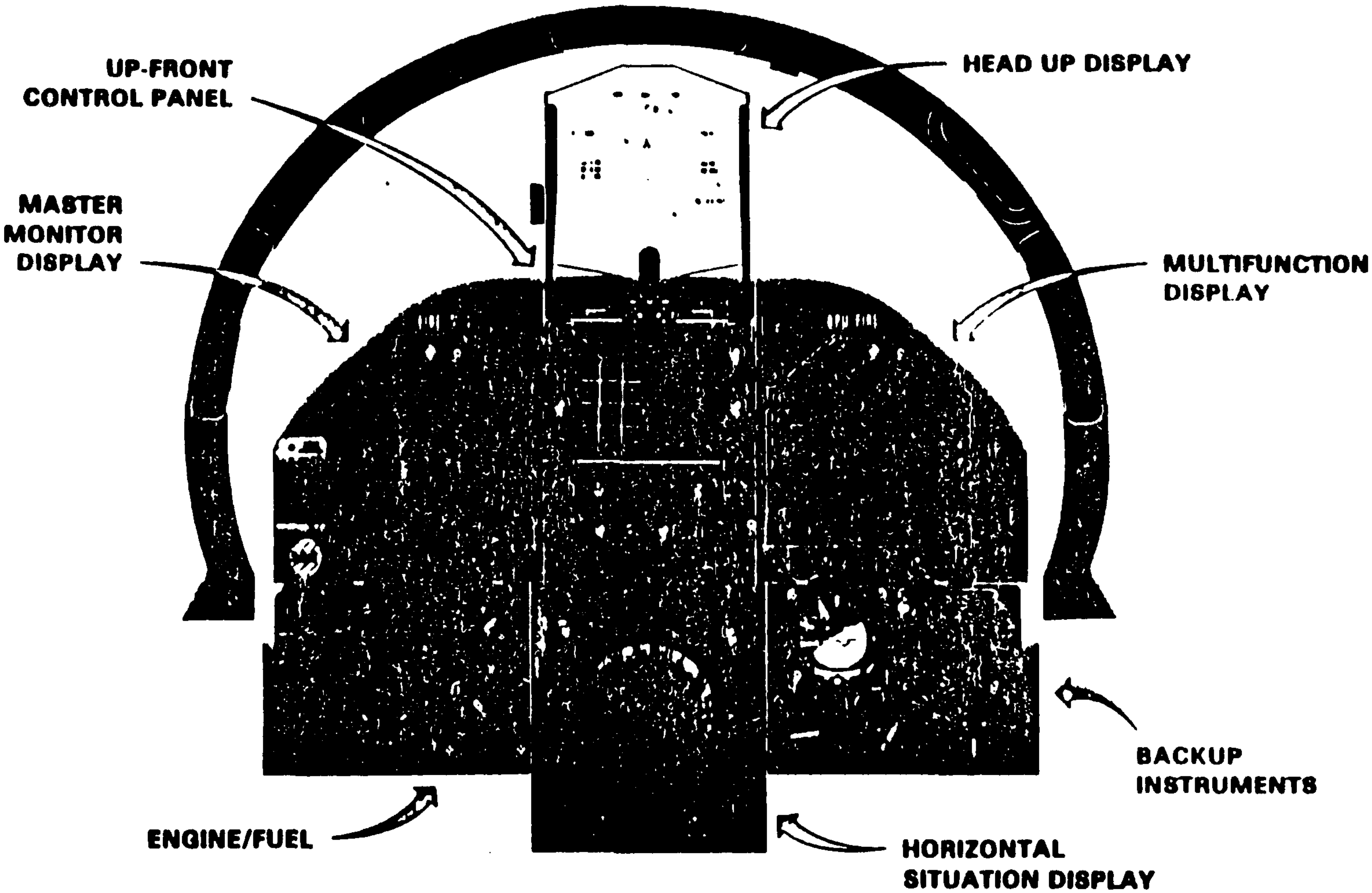
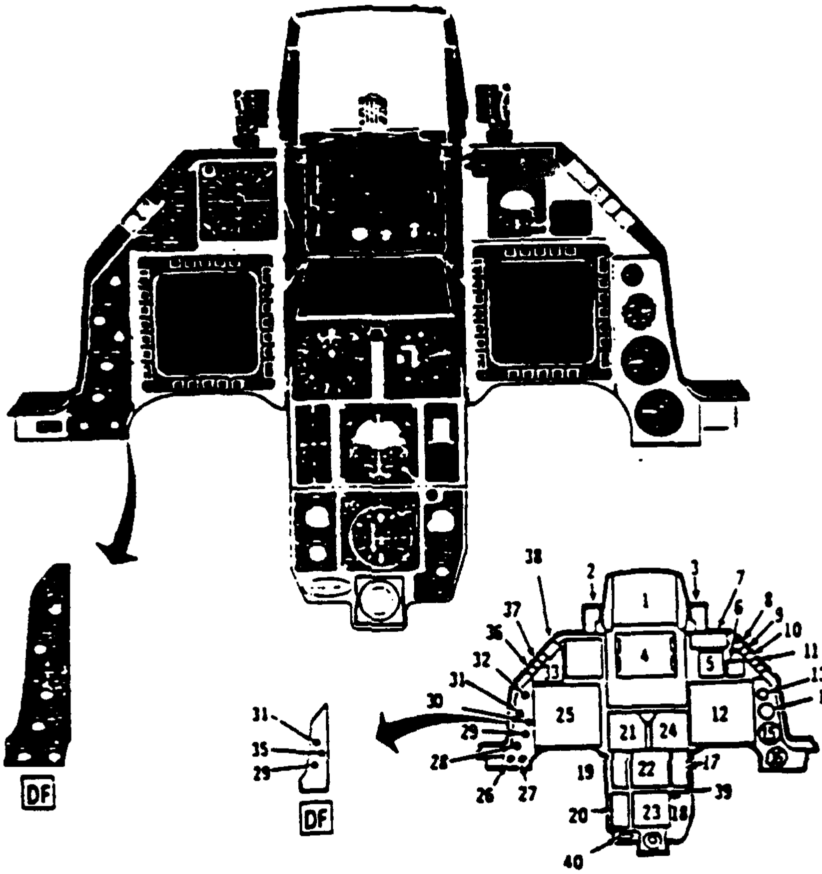


Figure 25

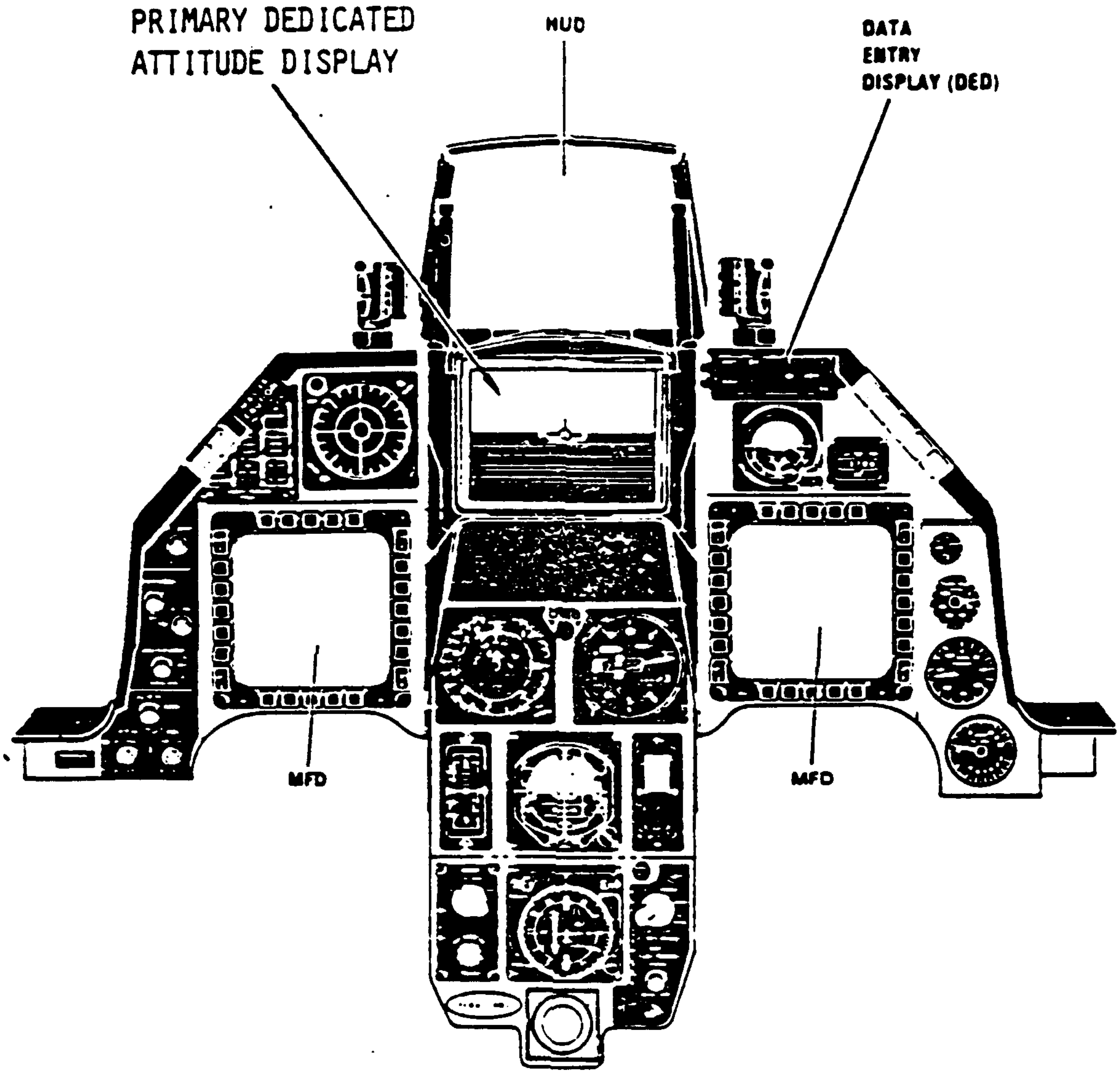
INSTRUMENT PANEL [C] [DF]



1 HUD Combiner Glass
2 AOA Indexer
3 AR Status/NWS Indicator
4 Integrated Control Panel
5 Standby Attitude Indicator
6 Fuel Flow Indicator
7 Data Entry Display
8 ENG FIRE and ENGINE Warning Light (Red)
9 HYD/OIL PRESS Warning Light (Red)
10 DUAL FC and CANOPY Warning Light (Red)
11 T.O./LAND CONFIG Warning Light (Red)
12 Right MFD
13 Oil Pressure Indicator
14 Nozzle Position Indicator
15 RPM Indicator
16 FTIT Indicator
17 Vertical Velocity Indicator
18 FUEL QTY SEL Panel
19 AOA Indicator
20 Instrument Mode Select Panel
21 Airspeed Mach Indicator
22 Attitude Director Indicator
23 Horizontal Situation Indicator
24 Altimeter
25 Left MFD
26 Autopilot PITCH Switch
27 Autopilot ROLL Switch
28 TF Switch
29 MASTER ARM Switch
30 ALT REL Button
31 LASER ARM Switch
32 IFF IDENT Button
33 THREAT WARNING Controls and Indicators
34 Threat Warning Azimuth Indicator
35 [DF] OVRD Light
36 TF FAIL and OBS WRN Warning Light (Red)
37 ALT LOW Warning Light (Red)
38 MASTER CAUTION Light (Amber)
39 MRK BCN Light
40 Rudder PEDAL ADJ Knob

Figure 26: C/D Instrument Panel

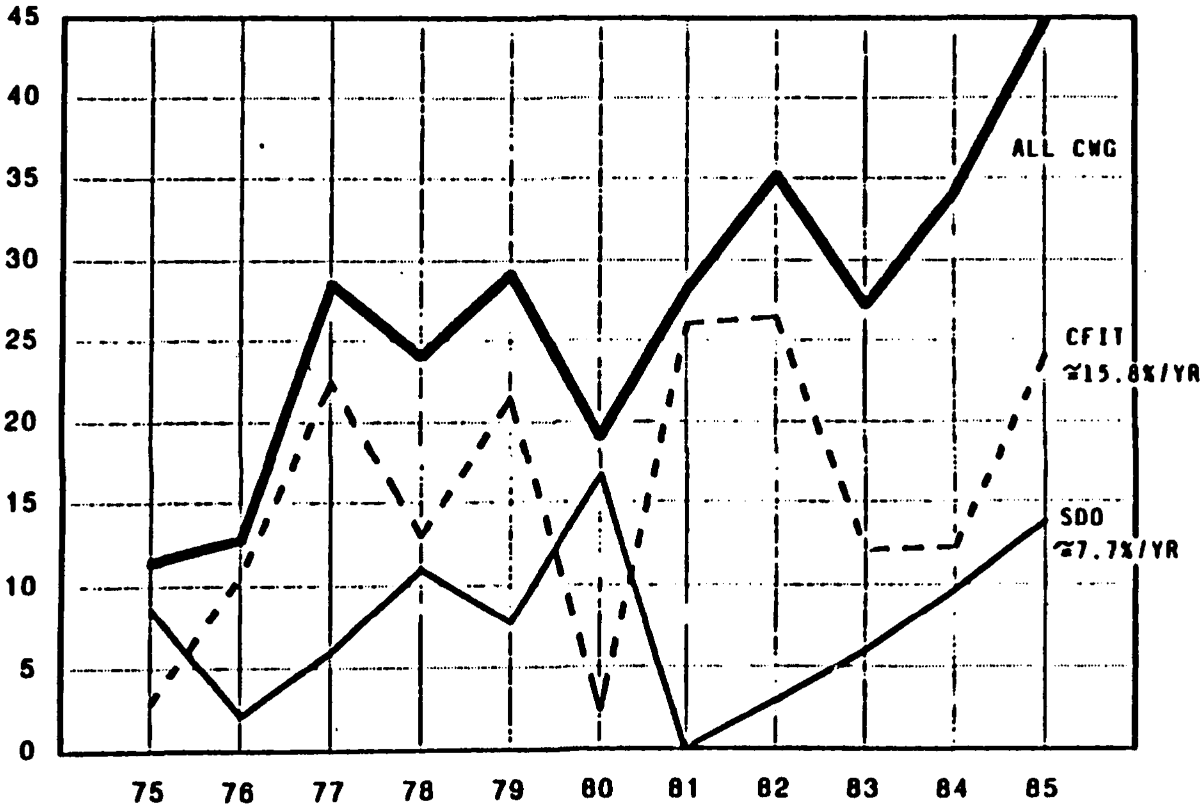
F-16C



C DF

Figure 27

COLLISIONS WITH GROUND - % OF OPS CLASS A MISHAPS
1 JAN '75 - 4 OCT '85 (AFISC)



%	75	76	77	78	79	80	81	82	83	84	85
CWG	11.4	12.8	28.6	24.1	29.2	19.1	28.3	35.3	27.3	34.2	44.9
CFIT	2.9	10.6	22.5	13.0	21.5	2.4	.26.1	26.3	12.1	12.2	24.1
SDO	8.6	2.1	6.1	11.1	7.7	16.7	0	2.9	6.1	9.8	13.8

Figure 28: CFIT vs SDO Mishap Chart

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APPENDIX B

EXCERPTS FROM PROCEEDINGS OF AIRCRAFT ATTITUDE AWARENESS WORKSHOP, OPEN FORUM SESSION[B-1]

[B-1] "Thursday Afternoon Open Forum Session, 10 October 1985," in G. B. McNaughton, ed., *Proc. Aircraft Attitude Awareness Workshop*, held at Flight Dynamics Laboratory, Bldg. 146, Rm. 203, Wright-Patterson Air Force Base, 8-10 October 1985, Life Support SPO, Deputy for Aeronautical Equipment, Aeronautical Systems Division, and Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 8 April 1987, pp. 3-8-1 to 3-8-49.

APPENDIX B

EXCERPTS FROM PROCEEDINGS OF AIRCRAFT ATTITUDE AWARENESS WORKSHOP, OPEN FORUM SESSION

Col McNaughton: I'd like to focus on a couple of aspects; namely, what can we do to improve the immediate problem. To kick this session off, I'd like Maj Gary Morphew, HQ AFISC/SEFF, an F-4 pilot with 4000 hours plus strong interest in human factors, to provide a safety perspective.

Maj Morphew: I called AFISC over the noon hour for data since 1980, Class A mishaps, which involved spatial disorientation (SDO), (meaning there was some attempt to fly the aircraft out of the situation by looking at instruments and trying to recover, but hit the ground anyway), versus controlled Flight Into Terrain (CFIT) where the guy isn't looking forward; he's just not monitoring his flight path at all and he hits the ground. Just so we know where the problem is, SDO we've had 19, CFIT 54. I'm allowing 10 percent for coding errors because I haven't had a chance to look at the raw data myself. There's a significant difference as to where the problem lies. That means we can form better opinions where our problems are. No one will disagree with a lack of training and getting better displays, but if the pilot is unaware of the situation, he can't very well use the best information we can provide him on the HUD, ADI or whatever.

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Dr William Richardson: Let's sort out the facts on SDO: We probably can't sort out what happened very easily to those who died unless witnessed by a wingman or he made a call. But if they hit the ground under full power, I think we can assume they were unaware. Milt Miller's training manual talks about maneuvering over rising terrain, unaware it's rising; you may misperceive that your attitude is okay--you may fail to realize the terrain is gradually rising. That's one class of spatial misorientation. Probably combining that with the illusions case where an individual is doing a night aerial refueling and breaks off the tanker into a dead man's spiral, that's a different kind of a situation. If we talk about them as the same thing, we probably are not going to get anywhere. They require different solutions.

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Col McNaughton: We're addressing the rising terrain - CFIT problem with GPWS but I think the Big ADI is important to help keep a pilot oriented in an unobstrusive manner so that he doesn't have to stare at it. You don't want the pilot to stare at anything, for any display, procedure or control that traps his attention can kill him. The idea of the Big, High ADI is to provide him that all-important aircraft attitude awareness subliminally, to his peripheral vision, so he can free up his central focal vision for the crucial tasks of clearing his flight path and maintaining altitude awareness. The Big, High ADI (or Primary Dedicated Attitude Display, PDAD, if you will) is important to help him regain orientation and to keep him aware. In these aircraft with the bubble canopies, the glare and reflections bombard the ambient mode with conflicting, confusing, distracting and disorienting stimuli. The pilot needs a Big, High ADI/PDAD to successfully cope despite all that confusion. What we don't know and what would seem to be an important study is what minimum size of ADI is needed to successfully compete with all that conflict, including false horizons or situations of wrap-around star fields (star and ground lights blending) and no horizon, or with frank vertigo, or with frank oculovestibular disorganization (type III SDO from rapid rolls). All I know is it's gotta be big--bigger than it is now.

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Maj Harold Gonzales, Hill AFB: I'm Chief of Flying Safety at Hill. The USN and Canadian Forces have gone to HUDs as the primary attitude instrument. I would like to see a statistical comparison between their SDO incidents and ours, the training issues, and also how they certify their HUDs for instruments--to see how we might improve ours for instruments. I'm not sure we can put a big round ball ADI in the F-16A/B where we think we need one, nor from what I've heard in the past few days am I convinced that that's the thing we need. Now if the USN/CF-18 experience is good, maybe we could modify our own HUDs, through software changes, to provide a lot better attitude references using the same visual equipment that we've got right now.

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Dr Richardson: I'd like to ask the gentleman from Hill what percentage of accidents have occurred from impact with the ground when the pilot was flying low level, versus disorientation coming off refueling or going lost wingman.

Maj Gonzales: The only one that comes to mind in high altitude is the kid that did the intercept on the train (in which he lost 11000 feet over a 1-1/2-2 minute period). It required a software change to put a break-X in the radar scope and we haven't lost anyone else from attention-trapping on the radar scope.

Col William Runkle, AFISC/SEL, Norton AFB, CA: There were nine F-16's classified as SDO-type accidents. The remainder were all pretty close to the ground and involved low level situations: Two occurred on radar-trail departures, one of which was totally unrecognized by the individual--a sort of type I SDO. And one of which was recognized but corrective maneuvers at the last second were too late. The only real type II that I know of where the pilot was disoriented and survived was an ANG accident--day departure into IMC.

Col McNaughton: There was the case where lead was referencing an erroneous SAI, not the same case of the erroneous flight plan. There were the two radar trail departures. There was the student at RTU who was coping with a lighting problem plus a warning light, while rolling over onto his back: The ADI was just too small and far out of plane to be sufficiently commanding for him. Another problem brought up by Maj Gonzales is that at night under certain conditions of cockpit lighting, glare and reflections, the entire top half of the ADI can appear to be gray, misleading the pilot into thinking he's level or climbing, when he could be otherwise.

Dr Richardson: Of the accidents we're discussing, could we also divide them not only between those that occurred at higher altitude to represent pilot workload type of accidents causing disorientation that was recognized by the pilot, but could we also consider the case where he experiences disorientation but doesn't know it and flies into the ground? This is a strong case where we could have the vehicle inform the pilot he's lost orientation, or alternatively, have the vehicle recover automatically. Think about whether there's that difference in types of accidents.

Lt Col Dick Krobusek: Regarding CFIT vs SDO, the one key factor was, which way was up? The cues are hard to read or hard to find--especially if momentarily distracted or disoriented. To discern his real attitude is a real problem. The symbology can probably be changed quickly. You can put anything you want up there. The HUD is still a primary instrument.

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Col McNaughton: Let me run by you a couple ideas on improving the HUD as an alert to unusual attitudes. Note I said alert--not to function as an attitude instrument by itself. I hope we've made the point that by the HUD you can't tell, at a snap glance, upright from inverted, or climb vs dive, or to about what degree. Also, the dynamics of the HUD are such that you can't read the numbers on the flight path scale during rapid rolls or pitching maneuvers. To tell where you are, you must first slow or stop the roll or pitch. Allow me to take a moment to introduce a couple ideas to improve the HUD as an attitude alert.

First, the HUD provides lousy roll cues since roll angle requires interpolation between the tail of the FPM and an imaginary line extending from the center of the FPB toward the vertex running between the Flight Path Scales (FPS). Also, the quickest route to upright is not always apparent. Though the horizon pointing tails on the FPS's may help you find the horizon, they don't necessarily help get you upright. Despite the fact the FPM does not roll relative to your aircraft (being an inside-out display), it is the most commanding symbol on the HUD. So to improve it for attitude alert in roll, why not add a vertex pointer to it? (Fig 13). A line coming out of the FPM with a star (for sky) might serve well--would provide a distinct pattern for various roll angles, especially upright vs inverted, and would tell the pilot which way to roll to get upright quickest (simply roll the tail of your FPM towards the vertex pointer). The star is Dick Malcolm's suggestion and may be better than using an arrowhead, because it's more intuitive. Dick Newman is going to test this.

Second, to provide a better alert to pitch attitude, radically change the pattern of the FPS from climbs to dives, and since the dive is the more critical, again radically change the pattern within degrees of dive, say every 30 degrees (Figs 14 and 15). Again, the idea is not to make the HUD a primary attitude instrument, but to make it an attitude alerting display which tells the pilot to go to the ADI--which really is the primary attitude display. (Note the pitch scales become increasingly commanding the steeper the dive, resembling "Jaws".)

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Don Gwynne, GD: Reviewing F-16 CFIT mishaps, I count 12, amounting to 23 percent of USAF F-16 mishaps. Of those 12, I personally investigated 5. If we accept type I SDO as misoriented, i.e., he's not well oriented but he's not afraid, is that the proper definition? Of these 12 CFIT mishaps, only 2 didn't fit this pattern of misorientation without being cognizant of it. One of them I believe was consciously disoriented and afraid. The other knew full well how he got where he was, and how to get out, but just didn't have the room. Of these, I asked how many were looking at the HUD. In 8 of 12, the pilot almost certainly was not looking through the HUD, or at the ADI. Of those remaining, you've got at least one where probably he was looking through the HUD, two where maybe he was looking through the HUD. Bumping into the ground when you're not afraid is really the leader here. All of these point to some sort of Ground Proximity Warning as the place to invest your money, rather than updating displays.

Col McNaughton: The argument with this position is that the GPWS doesn't help keep you oriented whereas a well-designed visual display would help keep you oriented, ease the job of operational flying, and thus tend to free up time to maintain terrain clearance; i.e., a good attitude display might reduce the need for a GPWS while improving effectiveness.

Don Gwynne: If people have trouble imagining how you can fly controlled into terrain, let me remind them of:

- Descending slowly into ground while focused on radar scope (at night).
- Running into the side of a mountain while typing the FCNP.
- Slowly descending into the Great Salt Lake while you think your auto-pilot's keeping you level, while looking for your buddies on the TACAN Radar.
- Looking at a train at night mistaking it for your target.

The great majority of these would not be affected by either the HUD or the ADI.

Col McNaughton: What do you think of Dick Reynold's idea of a variometer, like on a glider? What do these cost?

Lt Col Dick Reynolds: We need an audio warning of some sort, not continuous, but perhaps a ground proximity beep in the ear sort of thing, till he responds.

Col Bill Runkle: I'd like to clarify something: Spatial disorientation and controlled flight into terrain. I feel that 7 of the 9 F-16 mishaps were CFIT because they didn't know they were disoriented and there's no evidence any of those seven were looking at any sort of instruments. In many instances, something else was going on in the cockpit--a warning light, looking at a checklist, radar to the proper range, or other distractions. Had they been looking at their instruments, a lot of those guys might be here right now.

What we're talking about here is that the F-16 aircraft has some characteristics that make it particularly tricky when you're distracted, low level, or in the weather. It's smooth and you can get into a sub-threshold roll or pitch change without being aware of it. The instrument flying equipment provided in the F-16 is rather small, and it does not command a lot of visual response, especially from the ambient part of your vision, if you are distracted. What we're lobbying for is something more prominent, something a guy could catch out the corner of his eye if he were distracted, and something to help him like a ground proximity warning system. Now the GPWS, I think, is great. It may be the only thing you can do. You cannot move hardware around in the limited space and provide the guy a two-foot ADI. Since you can't fix the ADI, why not improve the HUD to make it better suited an easier for instrument flying?

Ed Hartman, GD: We have a number of things being considered for the F-16: A line-in-the-sky barometric altimeter, probably ready to go close to a year ago. We recognized a visual only system was insufficient, and we'd want an aural warning system as well, either via a tone or via the voice message unit. We recognized that was insufficient and stated they needed an aural warning system to say, "Warning, Warning." The multinational cockpit review team said we don't want "warning, warning"; we want a tone. Well, what kind of tone? We went back and forth. What were the words used for: Everything. We also had a capability for a Voice Message Unit that would say, "Altitude Altitude," or "Pull up." Political issues--I don't like this or that and that's it. So we've got a line-in-the-sky barometrically based warning system that's visual and aural. The CARA (Combined Altimeter-Radar Altimeter) system coming on. Also have the ground clobber system (a visual system only that provides flashing X in a HUD using an algorithm based on gross weight, TAS, AOA, VVI and radar range to compute a ground impact point; the flashing X commands a 4 G pull within 2 seconds to miss the ground) in all air-to-ground modes, not air-to-air. We have a study proposal to get air-ground range information and put in air-to-air modes to give you a pull up command so it's a no delay, immediate response system. We'll bring in radar altimeter with the other sensors to provide a predictive GPWS. We're going to get a widespread GPWS for the F-16A/B. For the C/D we'll integrate these into the ground clobber mode. We've a lot of proposals in and it's a matter of getting the budget approved. We'll get the VMU. With the coming of ECT 1085, the three altitude/ground collision warning systems (line-in-the-sky, CARA, and ground clobber) will be integrated and operable in all modes (air-air, air-ground, and navigation) in the Block 15 F-16A/B aircraft. There's a plan to eventually integrate this into all Block 10 F-16's too.

Maj Art Fowler: We already said we don't see anything if we're not looking there for it. I need something better and I need it now.

Lt Col Mike Lichty, TAC/SE: I'd like to go back to what Don Gwynne said: We're not looking at the ADI or HUD when we fly into the ground--so one is a training issue--we must train to do the right thing at the right time; the other thing is we've got an airplane design with a pilot-aircraft interface in which we're gonna be subjected to SDO in the F-16. So now we have two tasks at hand.

(1) To provide him a cue to return him to attitude awareness or to an attitude instrument.

(2) The other task is to evaluate the cockpit he's flying to determine whether his attitude information is readily available and easily interpreted so that he can recover.

We have a law that says he's gotta pull 4 G's in 2 seconds; if it takes 6 seconds to locate, read and decode the attitude display, I'm dead anyway.

Lt Col Dick Reynolds: Get the guy's attention to the attitude indicator's information. Put it up so he can find it easily and train him so he knows he's got to use it. To reiterate:

(1) Do something to tell him he's in trouble and he's got to use whatever's available to reestablish what his attitude is-- to regain attitude awareness.

(2) Clean up the HUD or the vertical situation display (VSD), or do whatever you can to relocate the ADI within capability so that he has got useable information. And I think some of your suggestions regarding improving the HUD as an attitude alert are great. Might as well standardize 'em while you're cleaning the HUD up.

(3) To reiterate Bill Ercoline's plea: Standardize USAF training by whatever documentation is available; and through MAJCOM training shops, you educate the pilot population to the problems and how they can fight it.

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David Pannkuk, Perceptual Dynamics Research, Milford, OH: I'm David Pannkuk and I have zero hours of flying (laughter). I don't think you can teach a monkey to fly; perhaps a gorilla (laughter). All I know about flying is I don't like it. It bothers the hell out of me. We've talked about training and we've talked about vision. We haven't talked about training vision. You've been told there are limitations to what we can do. You've been told we have a focal system that's truly keen, that the focal vision is conscious, and the ambient system is subconscious. The problem is that we're not working with trained levels of vision. If you were to measure perceptual activity as a skill in any performance you want to prescribe, it would come out as spastic, disjointed and disjunctive. Flying is a perceptual, working activity. It's hard work, primarily because you're overloaded with stuff you cannot see. In WW II, early on, it was a fact that of every 3 planes shot down by American servicemen, one was a friend. Now their skill in gunnery was uncanny--but their problem was distinguishing friend from foe. As an 18 year old kid on board ship, I can tell you we didn't give a damn who he was--he was flying and I was shooting. How long did it take the USN and the AAC to realize that the red ball in the center of the American star was identical to the red Japanese ball? How long did it take for them to get that out of there and put a bar across so you could identify? In the British raid on Dieppe, 91 planes were lost; 62 were shot down by British guns. USN pilots were scared to fly past a destroyer after an action, for damn good reason. On Kodiak Island, they were using 55mm shells to shoot any plane down that came over. There was a warning out for Kodiak--don't fly over Kodiak.

The United States Navy (USN) was confronted with a training program they called WEFT (wings, engine, fuselage, tail) for aircraft identification.

The USN went to Dr Samuel Renshaw at Ohio State who'd been doing some basic research on how to train people to see. This has always been a problem. It goes way back to the early days of World War II, to train pilots to know how to see. The training was instituted; there was a complete reverse. The kill ratio was 99 enemies to only one friendly. What you've got to know is my perspective on things. What you've got now is a situation where you've made an aircraft highly capable of climbing rapidly to intercept like a pergrine falcon, and you've insured that the major component in that system is a pilot with the visual attributes of a myopic penquin.

Not that they don't have the capacity. Let me ask you a very simple question. You're looking at that display. Which would you prefer to do when you're recognizing words? Have a visual skill that would take you approximately 1 second to cover or visual skills that would take you 1/10th of a second? Which is going to make you more comfortable with the information coming into your eye? You've got a hell of a lot of confusion. You've got a tacky visual display. What do you do when you hit break distance at 3000 feet and you've got 1.2 seconds to make up your mind? What are you going to do with the visual skill, a level of vision, that works at .25 seconds to 4 or 5 characters per look. You can speed yourself up against the wall. You can put in training tasks till you're blue in the face. You've done training backwards, forwards, upwards and down, but you haven't done enough. If you put in training for task performance, you will have overloaded the basic underlying skill to make that happen. You'll be no better off tomorrow than you are today. Is that where you want to be? You haven't got any parameter described except attitude. I'm not even sure you have a good vision check as far as quality, but nowhere do I see anything in the Air Force or in the Armed Services that tells me that you know how people work with their vision. Do studies. Find out what the difference is between somebody that can handle the situation and somebody that seems to grind himself into the ground. And I apologize for being so long.

Col McNaughton: I'd like to say one thing in defense of the way we do select. We are doing some work looking at the contrast sensitivity function. I might add that one of the services that's known well for their skills in pilot selection is the Israelis. They don't do anything special about vision selection. They have the same thing we do; they just use Snellen charts and require, I think, 20/20 or perhaps 20/17. What they do is select candidates on their ability to switch their attention quickly, and they do a very simple test which we have not yet instituted in our Air Force. But we're evaluating it at USAFSAM now. It's called the Dichotic Listening Test, which is the ability to switch your attention quickly without losing track. Some of these things probably need to be looked at. Unfortunately, we haven't broken the code on a lot of this yet.

Mr Pannkuk: We can give you an assessment of how it would work. We can give you a technology that will allow that to be taken in. But we say, well things are like this. Then we establish norms, great norms. The person who performs visually versus the nonperformer is the difference between night and day; there's no comparison. We're talking about a virtuoso versus a beginner.

Unidentified: I have a question. I don't understand what you're talking about. Are you saying we ought to be screening pilots?

Mr Pannkuk: No! Training pilots.

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Maj Harold Gonzales: If we could publish today a syllabus on training that would increase my perception several times, I think we ought to recommend that somebody look at it because I haven't gotten training one in the Air Force in 14 years that has increased my perception of anything. If this exists, I think we ought to take a look at it. For example, going over intelligence photos of airplanes fairly often should improve your ability to detect things, but only once every six months is probably not enough.

Maj Steve Detro, Ohio ANG: Maj Milt Miller's low altitude awareness program does that. It teaches you what to look for on the horizon at 100 feet, what to look for out the side window, how to get that speed rush and what to do about it, mentally and visually, and you're gonna see more of it and hear more about it. It's in physiological training now and also shown on VTR.

Question: Does it improve your ability to take in more at a snap glance, in a very short period of time?

Maj Steve Detro: Yes, because it trains you to look selectively to see the velocity vector in relation to the pitch line. And you can tell just by that much whether you're going to hit the ground in the next 3 seconds. It trains you to get what's important in minimal time. It's a very good program.

Lt Col Gary Matthes: I know this sort of stops this discussion, but I'm afraid there are some things we're not going to get in the executive summary. What we said before is good, and that takes care of getting things done in a hurry, but something has bothered me for the last 13 years of flight testing. I've seen many airplanes come into the inventory and with different airplanes, we go about things differently. In cargo aircraft, one of the biggest requirements in its Request for Proposal (RFP), and because of the way they flight test, is instrument qualification of the system. I talked to Major Rounds to see if he runs his tests the same way and he wasn't sure, but I bet they have some way to check the instrumentation. I bet if you look at the F-16 RFP, you won't find a damn thing. I'll bet you won't find a thing in the Advanced Tactical Fighter RFP that was just let. We don't even concern ourselves with it, and one recommendation ought to be that when ASD lets out an RFP for a new fighter, they ought to force people to at least think about it. These considerations should be part of an RFP. In addition to be able to turn 9 G's at 50,000 feet and go 1.2 on the deck, by the way, he has to have a Ground Proximity Warning System, and it has to have some type of attitude warning system. You have to have attitude systems that allow it to be flown easily in IMC. Fighter pilots just don't worry about that and they forget. Although you may go out and shoot a bogey once a month and you may go air-to-ground once a week, you come back and land everyday. And if you're in Europe, you come back and bust the ceiling everyday, and we don't address those. I'd like to see this group put forward that we need to address the way we ask for things in fighter work, in our RFPs or in whatever form it takes to request the things we need in fighters to optimize them for the night-weather role. The bomber and Navy ys should make sure it's part of their RFPs too.

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Dr Emily Howard: The impression I'm getting from the discussion on training and designing better displays is that all of you are suggesting issues that are true, but what we need is a model that lays out exactly what is true about a pilot's perception in the cockpit. I mean there are certain immutable hard-wired facts about the visual system that cannot be changed by physiological or any type of training. Areas we might improve with training include attention--to switch attention, to train attention to peripheral stimulation, and also the interpretation of information; by just exposing hours and hours to the ADI, we can improve the facility for interpretation till it becomes second nature to 'em. Talking about training, we should look at both of those issues. One the issue of attention, switching attention, being able to select information appropriately and also to interpret information as it's offered, so interpretation of it becomes second nature. But on the other side, we have these hard-wired features of visual perception that should be considered in the design process.

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Dr Kent Gillingham: I've seen more cases of G-induced loss of consciousness than probably anybody here. I've been working with the centrifuge for approximately 8 years now. There is a bell shaped curve. There are some people who've had the exposure who cannot do it. They have G-tolerances that are at the bottom 5 percent, the bottom 1 percent. I think it's idiotic to try to select that type of person to fly your 20 million dollar aircraft. Where do you want to draw that cutoff line? Do you want to draw it at 50 percent of G-tolerance or 95 percent? That's up to the Air Force. There are people who are physiologically deficient; they just can't tolerate G's as well as other people and it seems there are other options for people like this. We're talking about people who can tolerate 9 G's for 45 seconds consistently; I'm not talking about day to day variation. On the other hand, there are people who cannot tolerate 4 G's for any length of time at all. There are a number of factors that relate to G-tolerance and all add up. But there are certain biological capabilities that you start out with. Take an individual and give him weight training and frequent exposure to G's. Give him a good straining maneuver and the proper equipment. He'll have a super-G-tolerance. Take another guy and give him the same things, and he's not going to be a super-G puller. I think that we have to make sure we start out with the best protoplasm that you can get and go from there. There's no sense taking a deficient condition right at the very beginning, and I'm not talking about anything extreme here. I think that almost everybody that has completed undergraduate pilot training is okay. I take that back. Most of the people you know probably would have made the 8 G's in 15 seconds' tolerance standard: a reasonable standard that almost everybody passes. I think it would be inappropriate to take someone who you know is going to give you problems, especially when we're operating on the ragged edge of human capability under some circumstances in high performance type of aircraft. For them, the situation is going to get worse, not better. Their selection is going to harbor some real potential mishaps in the future Air Force.

Dr Sheldon Ebenholtz, Univ of Wisconsin: There's an aspect of ocular motion that may relate to acceleration. There are a number of responses like smooth pursuit, vergence systems, etc. It seems to me these should be considered in pilot selection. Several of these systems are adaptive: For example, the vestibulo-ocular-response, which compensates for rapid head movements, enabling your eye to stay on target. These are highly adaptive systems. It may be that pilots who exhibit compensation are better adapters. We know that one segment of our college population will not adapt and another percent will. There are people whose systems will not adapt. There are others whose systems are highly adaptive, then there's a group in between. It strikes me that intelligent screening might be able to sort these out.

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Unidentified: One of the problems we have is that the HUD is a fighting instrument, and looking through it, pilots hate to see anything flashing or moving. We don't want the clutter, either. The HUD's a distraction while fighting though it helps while flying, and we spend much of our time fighting. We commonly punch de-clutter.

Col McNaughton: I'd like to ask Jerry Gard if you could put a texture change on the HUD to represent the surface, to increase sky-surface contrast?

Dr Jerry Gard: You can do anything you want, but pilots won't stand for all the clutter.

Maj Art Fowler: They declutter all that stuff now, including the FPM and pitch scales.

Mr Paul Metz: Somebody tell me what percentage of the 73 accidents flew into the ground due to lack of cues versus flying into the ground due to fixation, or due to spatial disorientation or GLC.

Brig Gen DeHart: SDO is number one in the TAF; it leads GLC.

Col McNaughton: The F-16 is running over 2:1; SDO/SMO mishaps are at 9-12 depending on how you look at it. GLC is at 4, so ratio-wise, it's 2 or 3 to one, SDO vs GLC.

Mr Paul Metz: We've got so many reasons for hitting the ground, how do we know what's the most important - SDO vs the high speed low level (HSLL) collision with ground mishap?

Col McNaughton: Percentage-wise, in the F-16, SDO's the bigger problem compared to GLC. GLC's a big problem but not as big as the SDO problem. SDO constitutes a segment of the overall distraction, misorientation-disorientation problem producing collisions with the ground. We've had 12 SDO mishaps and 19 CWG. To my way of thinking, both are part of the overall loss of aircraft attitude awareness problem. The attentional problem is basically a ground-proximity warning problem: My idea is that if we provide displays and cues that can free the focal mode up to attend to the flight path and cue him when to look ahead, perhaps we could solve most of the CWG and misorientation problems.

♦♦♦♦♦

Col McNaughton: Major Fowler mentioned the night-role needs. Does that vugraph include most of them?

- To improve attitude references, to include a large Primary Dedicated Attitude Display (PDAD).

- To format critical control parameters such as airspeed and altimeter for instant unequivocal recognition; design the displays, alpha-numerics, symbols and numbers to take advantage of our ability to see objects in degraded lighting at the peak of the human cantrast sensitivity curve, IAW Art Guisburg's recommendations; i.e. design them to subtend 3 to 5 cycles per degree, or about 1/3 to 1/5 the width of your thumbnail held at arm's length.

- To improve cockpit and instrument lighting.

- To initiate efforts to minimize/eliminate canopy glare and reflections.

- To eliminate false horizons.

- To consider establishing a "night-weather role" committee to evaluate proposed aircraft designs and write a design guide.

Maj Art Fowler: Designers need to consider all the night-adverse weather situations; e.g., night-wx formation penetrations, etc. Need to look at the HUD too. Night brightness prevents seeing through it. Haloes and double images prevent reading the symbols.

◆◆◆◆◆

Maj Gonzales: We're talking about the future now. What we saw this morning where they're going to project the world on this virtual cockpit which you're going to be wearing. It's stupid to build a projection system if I can't fly everything. I need to go head-up. We're talking third generation now; we're talking 15 years from now, probably.

Col McNaughton: Well, I don't know if VCASS will be ready for ATF, so we're talking ATF and possibly some other interim aircraft before we start getting virtual cockpits. But technologies like MAGIC with its 5 CRTs or PCCADS - the big flat instrument panel, may be. What I'm saying is, we need a vertical situation display or attitude display close to the eye, right below the HUD. The HUD calibrates the outside world--it's a vernier scale which is referenced to the earth: it provides the precision for ordnance delivery, close terrain clearance or spot landings--the micropicture if you will. The attitude display is aircraft referenced--gives the instant Big Picture of attitude; by its very nature, it's not a precision instrument but it's not supposed to be; it's supposed to provide the macropicture, to tell him whether he's upright, inverted, climbing or diving and how much at a glance without him having to think about it. It's becoming apparent that you really need them both and need them both in the same general field of regard.

Dr William Richardson: Correct. It's important you get your research going in the Aeromed Lab or wherever, to support the ATF for these specific kinds of conclusions and presentations. You know, we're going to multipurpose displays and to HUDs so you could identify those specific new technologies that look most promising for improving crew station design and the Aeromed Lab people are going on it right now to demonstrate their practicality for this type of an operation. We have a flight simulator here at the base and could bring in pilots, both experienced and nuggets, to get an evaluation based on reality. I think it would be a most useful outcome of this meeting to get that.

♦♦♦♦♦

Unidentified: Why not make a goal to make the HUD an ADI?

Col McNaughton: I don't think that's a goal. I don't think you want to make the HUD an ADI because you want the HUD for killing bad guys and you don't kill bad guys with an ADI. You keep your attitude awareness via the ADI but the HUD's basically a gunsight.

Unidentified: A future HUD may be able to do it all.

Maj Gonzales: Let's not forget, the F-15 can kill other aircraft at night, in the weather, where your tactical symbology in the HUD gives you guidance, while your instruments in the HUD, because of the dynamics of the situation, doesn't give you the time to move your eyes. That's why I'd like to see the HUD give me the same feeling of security I get off of the big round ADI. I'm sure the F-15 driver wants the HUD where he has it. We all have got to be flying the damn HUD at night.

Unidentified: What are you trying to say, Grant?

Col McNaughton: What I'm trying to say is that I think we need 'em both. I think we need the HUD that's a gunsight, that provides the micropicture, and I think we need a dedicated attitude display right below it, right at eyeball level, practically within the same field of view.

Dr Richardson: What's wrong with that? Why don't we do that? Why isn't that a good idea?

Unidentified: We haven't been able to do that because of size of the CRT.

R. J. Stroup, HQ PACAF/SEF: If you put up a flat-panel display and put a touch panel on the front of it, you can have both worlds: a control panel and a display depending on what you want. The technology to do it exists today.

Unidentified: That's a great idea!

Unidentified: Is it dedicated?

Capt William Burgin, USAARL: It's time-sharing, time-limited. He can use it for whatever he wants for a limited amount of time. If he wants his map, he punches his map. After 30 seconds or so, it goes back to ADI.

Unidentified: The French do that on their Mirage follow-on (Rafale); have an MFD immediately below the HUD.

APPENDIX C

IMAGE INTENSIFIER THEORY AND FABRICATION FOR PROXIMITY FOCUSED IMAGE INTENSIFIER GOGGLES (NIGHT VISION GOGGLES)

APPENDIX C

IMAGE INTENSIFIER THEORY AND FABRICATION FOR PROXIMITY FOCUSED IMAGE INTENSIFIER GOGGLES (NIGHT VISION GOGGLES)

Modern night vision goggles consist of four component assemblies:

1. A mounting frame or case to hold the components
2. An objective lens with focusing adjustments to image the scene on the photocathode of the proximity focused image intensifier
3. A channel plate proximity focused image intensifier
4. A magnifying eyepiece with focusing adjustments to allow the viewer to see the intensified image.

The design and use of the objective lens is conventional and needs little explanation except perhaps to say that in its function it is similar to the objective (front) lens in a pair of binoculars. The eyepiece is similar to the eyepiece in a good pair of binoculars. The heart of the device is the channel plate proximity focused image intensifier.

Let us therefore discuss image intensification using channel plates. The following brief description is reproduced in slightly modified form from an article by C. E. Catchpole:[C-1]

> The channel image intensifier consists of: a surface for converting photons to electrons; electrostatic or electromagnetic focusing means to direct the emitted photoelectrons into the multiplying channels in accordance with the geometric distribution of the initial photon image; the channel multiplier array to multiply the incident photoelectron flux and thus provide the principle gain mechanism of the device; electrostatic or electromagnetic focusing means again; and finally a phosphor behind a thin, opaque aluminum shield.
>
> The conversion surface produces the photoelectrons; the focusing maintains electron flux distribution corresponding to the light flux on the cathode; the multiplier usually produces some 10^2-10^8 secondary electrons

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[C-1] C. E. Catchpole, "The Channel Image Intensifier," Chapter 8 in L. M. Biberman and S. Nudelman, eds., *Photoelectronic Imaging Devices*, Vol. 2, Plenum Press, New York, 1971, pp. 167-190.

for every photoelectron entering the system; and the phosphor reconverts the secondary electrons to output photons. A single-stage device can yield a brightness gain of 10^4-10^7.

First, an introduction to channel multipliers. The channel multiplier is a device which amplifies a stream of electrons and at the same time confines this electron stream geometrically within the walls of the channel-multiplier device. The channel multiplier is a vacuum-tube device for the same reasons as other electron tubes are vacuum tubes, i.e., to prevent scattering by gaseous molecules or ions. The initial design concept of the device resembling a channel multiplier was made by Farnsworth[C-2] in the 1930s. However, the present design of channel multipliers using modern technology, and much improved over the initial concept, was developed at the Bendix Research Laboratories in the late 1950s (Fig. C-1). This latest

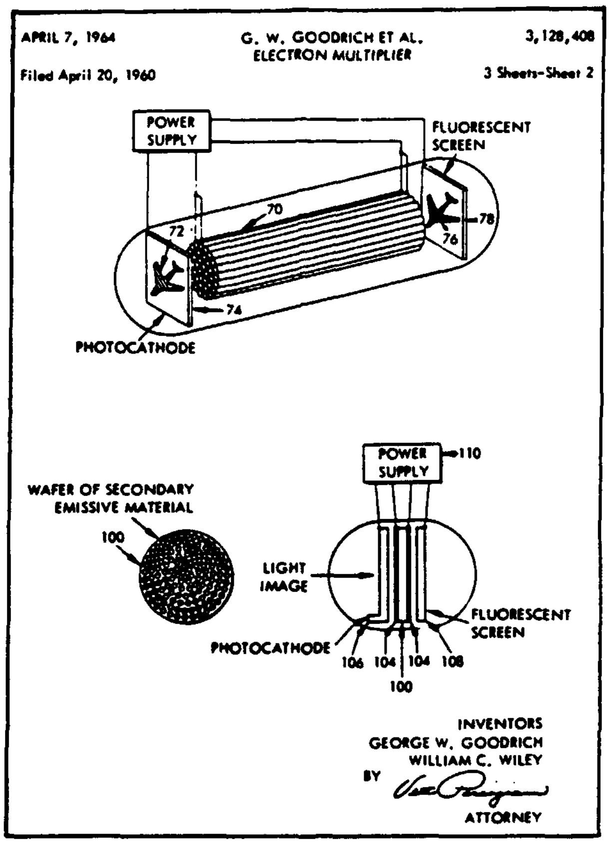


Figure C-1. Channel Multiplier Design. (Source: Goodrich *et al.*[C-3])

development enables a channel multiplier to provide a very high electron gain and at the same time maintain extreme simplicity, enabling such devices to be made in a wide variety of shapes and sizes. This wide variety of shapes and sizes enables the channel multiplier to fill many electron-image-

C-2 P. T. Farnsworth, U.S. Patent 1,969,399, 1930.

C-3 G. W. Goodrich *et al.*, U.S. Patent 3,128,408, 1960.

multiplication requirements. The flexibility of size and shape is a consequence of the construction techniques initially developed at the Bendix Research Laboratories, relying to a large extent on glass drawing, pulling, and shaping operations.

A single multiplier in its most common form consists of a hollow glass tube which has a resistive coating on the inside surface. A typical multiplier is illustrated diagrammatically in Fig. C-2, together with typical electron trajectories. In operation, a voltage of about 1000 V is applied between electrodes on the ends of the tube, and this potential sets up a quasi-uniform voltage gradient along the multiplying tube. If an electron is emitted from the wall of the channel near the negative-potential end of the tube, it will travel down the channel toward the positive end because of the electrostatic field and, also because of the emission energy of the electron, will cross the tube and hit the wall on the opposite side. When it impinges upon the opposite side, it has gained some energy, typically 100 or 200 V, because it has been accelerated down the channel. This energy at impact is sufficient to cause emission of secondary electrons. These secondary electrons will, in turn, travel down the channel to liberate more secondary electrons where they hit, and thus create an avalanche of electrons down the tube.

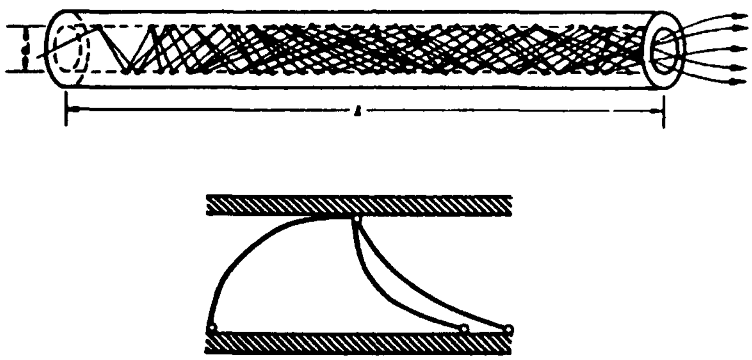


Figure C-2. Typical Multiplier and Typical Electron Trajectories. (Source: C. E. Catchpole, *op. cit.*)

It is important to note that in the channel multiplier the accelerating forces are electrostatic, and it is the total applied field rather than the gradient that determines the total acceleration. A careful study of this fact and the geometry of Fig. C-2 leads quickly to the realization that, for a given total potential applied across a channel, the gain is independent of the scale of the geometry and thus depends only upon the total applied potential, the secondary-emission ratio of the tube walls, and the length-to-diameter ratio of the interior of the channel. Because of possible saturation effects which may or may not be of importance, the resistivity of the walls, and thus the current flowing down the channel walls, is also important.

The shape of the interior cross section of the channel is only of minor importance and can vary rather broadly without much effect on channel function. Obvious points of importance to the multiplication and electrical characteristics are: (a) the secondary-emission ratio of the tube walls, (b) the amount of current which is conducted by the tube walls--this in turn depends upon the resistance of the wall material, (c) the geometry of the device, or, in practice, the length-to-diameter ratio of the channel, and (d) the applied voltage.

One can in practice alter within rather wide limits the actual shape of the channel. In fact, the channel-multiplier cross section need not be perfectly round and its axis need not be straight. Indeed, in some applications it is advantageous to have curved channels, in others tapered channels where the diameter changes along the length. One can also see that by manufacturing techniques of glass drawing and stacking and fusing similar to those employed in the manufacture of fiber optics, one can construct a device which consists of a multitude of small, straight channels arranged in a parallel fashion.

The process of amplification needs some further explanation. The process depends upon the property of the surface to emit more than one electron for each electron impinging on that surface with an energy sufficient to cause secondary electron emission. Further, some sort of electric field is required to draw those secondary electrons down the tube where further impacts will occur, generating still more secondary electrons. The length-to-diameter ratio of the tube is sufficient that a single electron entering the channel or tube will produce 10,000 to 1 million electrons emerging from the far end of the tube, depending on the length, the material, and the applied electric field.

Ordinary glass usually is completely unsatisfactory from a consideration of secondary-emission ratios. Nor is it easy to achieve a proper electric field to satisfy the need to draw the electrons down the tube. The success of the channel amplifier depends upon achieving a material that allows both to happen easily.

This is presently accomplished by using glass tubing that has a high lead oxide content. The tubing is then passed through a flame and pulled strongly and wound upon a drum in quite long sections. The sections are then formed into bundles, and the process is repeated. In this sequence two things happen: (1) the tubes are reduced in diameter quite dramatically, and (2) they fuse together into a more or less solid bundle, with many hollow cores at the center of each original tube. The fused bundles are again passed through the flame and pulled until the interior of the original tube is reduced to perhaps one-thousandth of its original diameter (Fig. C-3). The larger bundles are then cut into wafers, with the axes of the original tubes more or less perpendicular to the wafer surfaces.

The next step places the wafers into a hydrogen furnace. In this process the hot glass and the hot hydrogen react to reduce the lead oxide on the surface of each hollow channel to a microscopically thin coating of metallic lead.

Figure C-3. Drawdown of Hexagonal Array, Reducing Diameter While Retaining Cross-Sectional Geometry. (Source: C. E. Catchpole, *op. cit.*)

A coating is applied to both surfaces of the wafer, usually by evaporation of a metal, so that electrical contacts can be made to each and every channel through wafer surface metallization.

Figure C-4 shows the tubing in various states of drawing, Fig. C-5 shows slices from a fused bundle, and Fig. C-6 shows a magnified view of such a slice.

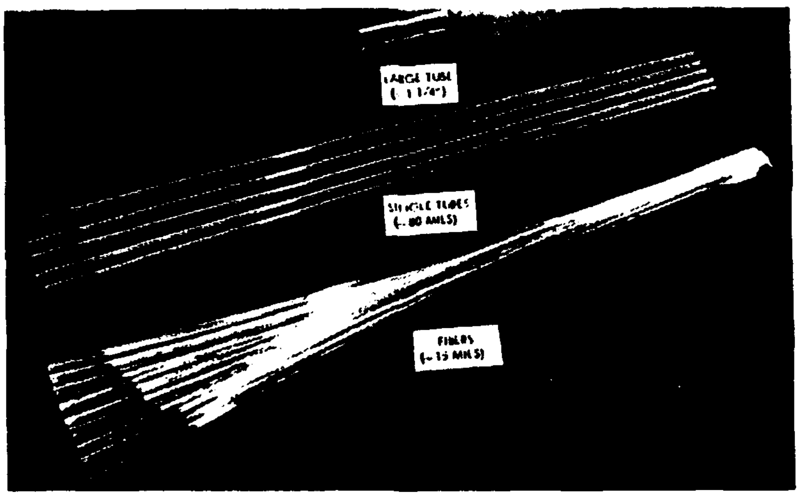


Figure C-4. Drawn Tubing. (Source: C. E. Catchpole, *op. cit.*)

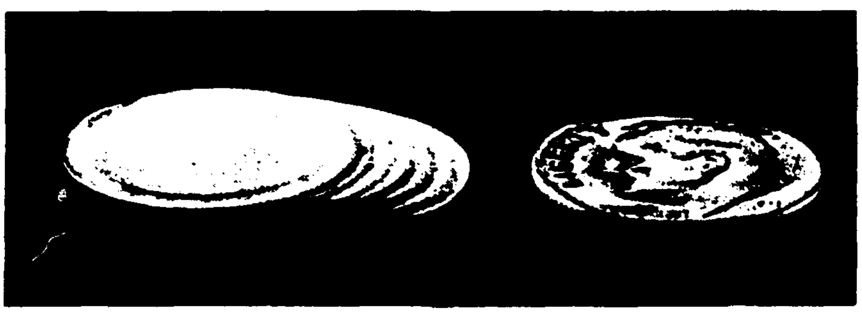


Figure C-5. Slices From Fused Bundle of Small-Diameter Parallel Channels. (Source: C. E. Catchpole, *op. cit.*)

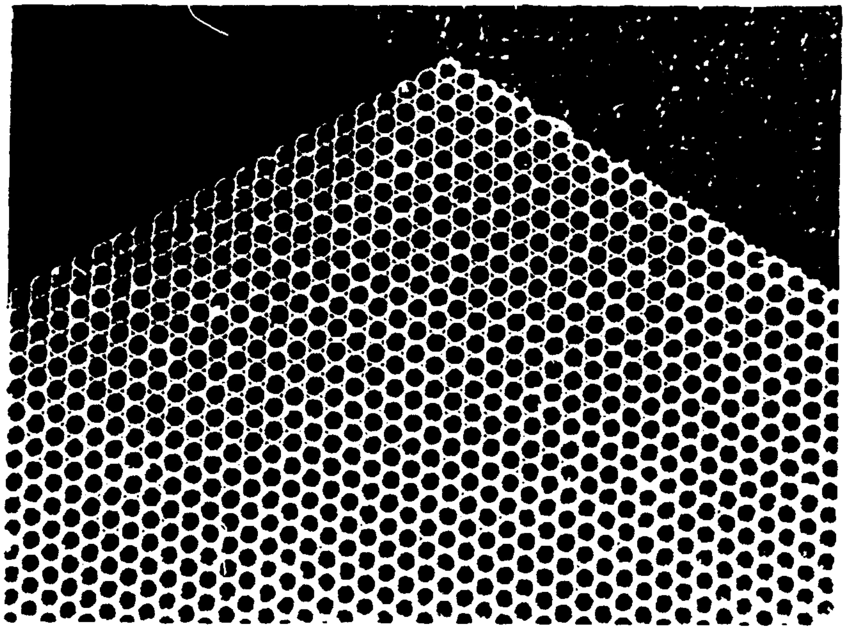


Figure C-6. Part of One Side of Microchannel Plate.
(Source: C. E. Catchpole, *op. cit.*)

The term "proximity focused" refers to the fact that this channel plate image intensifier is very compact, has no focusing lens, and has its photocathode and channel plate amplifier so closely spaced that the normal angular dispersion of electrons does not reach a sufficient blur-circle diameter to seriously limit overall resolution. The channel plate output and the phosphor or picture screen are similarly close. The smaller the distance between the exit point of a channel and the phosphor, the smaller the beamspread and thus the smaller the blur circle (Fig. C-2). Analogous geometry applies to the paths of electrons leaving the photocathode (which converts the light flux of the image into an electron flux) and traveling to the front surface of the intensifier channels.

Figure C-7 shows a proximity focused direct-view image intensifier, which accepts an optical image on one side, amplifies it, and emits the amplified optical image on the other side. The device consists of a photocathode, a channel plate or Channeltron array, and a phosphor screen. The electron image from the photocathode is proximity focused onto the channel plate, amplified, and the amplified image is focused onto the phosphor screen. This very compact device has relatively low operating voltages and great size and power advantages over conventional image intensifiers.

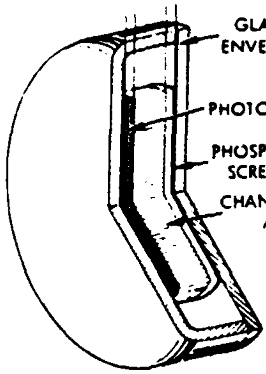


Figure C-7. Proximity Focused Image Intensifier.
(Source: C. E. Catchpole, *op. cit.*)

APPENDIX D

NIGHT VISION DEVICE PREFLIGHT ADJUSTMENT AND FOCUSING PROCEDURES

APPENDIX D

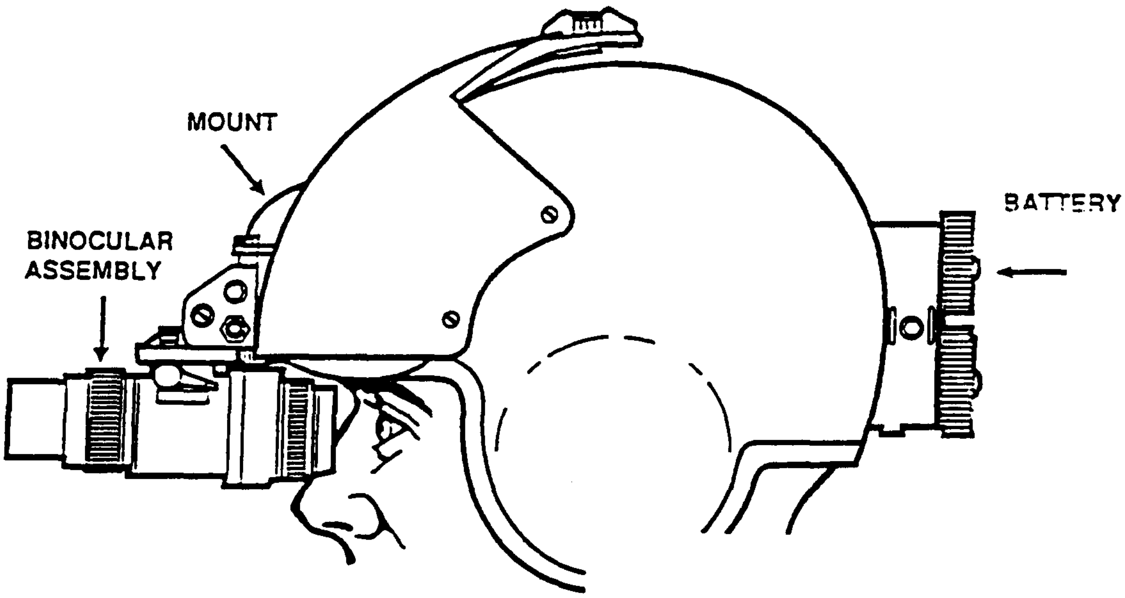
NIGHT VISION DEVICE PREFLIGHT ADJUSTMENT AND FOCUSING PROCEDURES

Introduction

Night vision device (NVD) use can be a double-edged sword. Properly fit and adjusted they dramatically enhance night vision. But the adjustment process is critical to obtaining optimal visual capability, and poor or improper adjustment can severely degrade NVD performance. NVDs are not hard to use, but their design characteristics and features require that you completely understand how to get the most out of them. This chapter presents the basics of NVD preflight alignment and focusing procedures for the ANVIS 6 system. Additionally, these procedures can also be applied to other NVD systems.

NVD components

ANVIS NVDs consist of three components:
(1) the mount, (2) the battery pack, (3) and the binocular assembly.

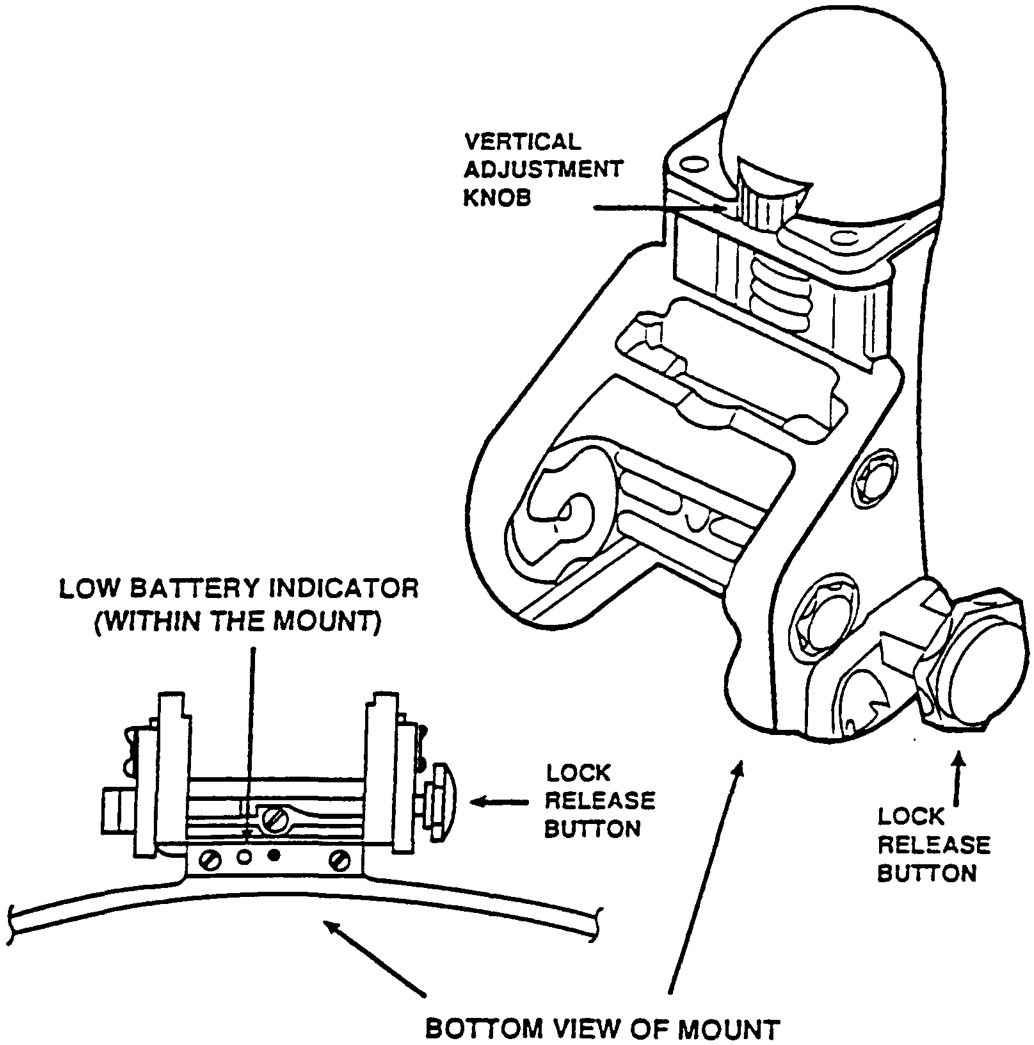


1. The mount is secured to the helmet and holds the binocular assembly in front of the eyes. It has three important features:

   a. **Vertical adjustment knob** – moves the binocular assembly and the optical plane up and down.

   b. **Lock release button** – which aids in rotating the goggles from the stowed position to the operating position, and helps in removing the binocular assembly from the mount.

   c. **Low battery indicator** – provides warning of impending battery failure.

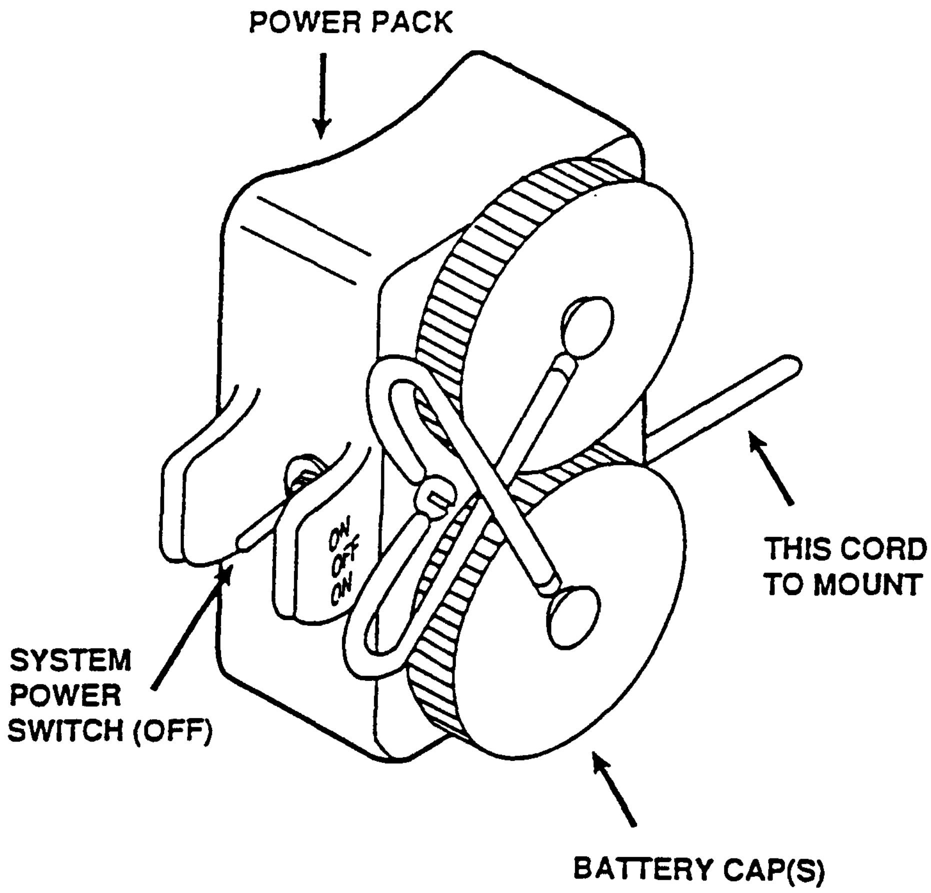


2. The battery pack powers the device and can be used with either AA penlight batteries or lithium batteries. Remember the following facts about the battery pack:

   a. **Loading batteries** – The type of battery dictates how to load. Lithium batteries are inserted with the positive side up, while AA batteries go in positive side down.

   b. **Switching battery power** – The battery pack has a three position switch with the off position being in the middle and separate positions for each of the two battery compartments. ANVIS goggles operate on the individual battery which corresponds to the switch position, thus providing an internal spare in the system.

   c. **Handling batteries** – Lithium batteries contain toxic substances and can vent or explode if handled improperly.. Never carry spare batteries in pockets with other potential conductors, particularly keys or spare change..



3. The binocular assembly contains all the optical elements of the system. This component has several adjustment features, and learning to operate them is essential for proper alignment of the device. The following is a list of adjustment features on the binocular assembly:

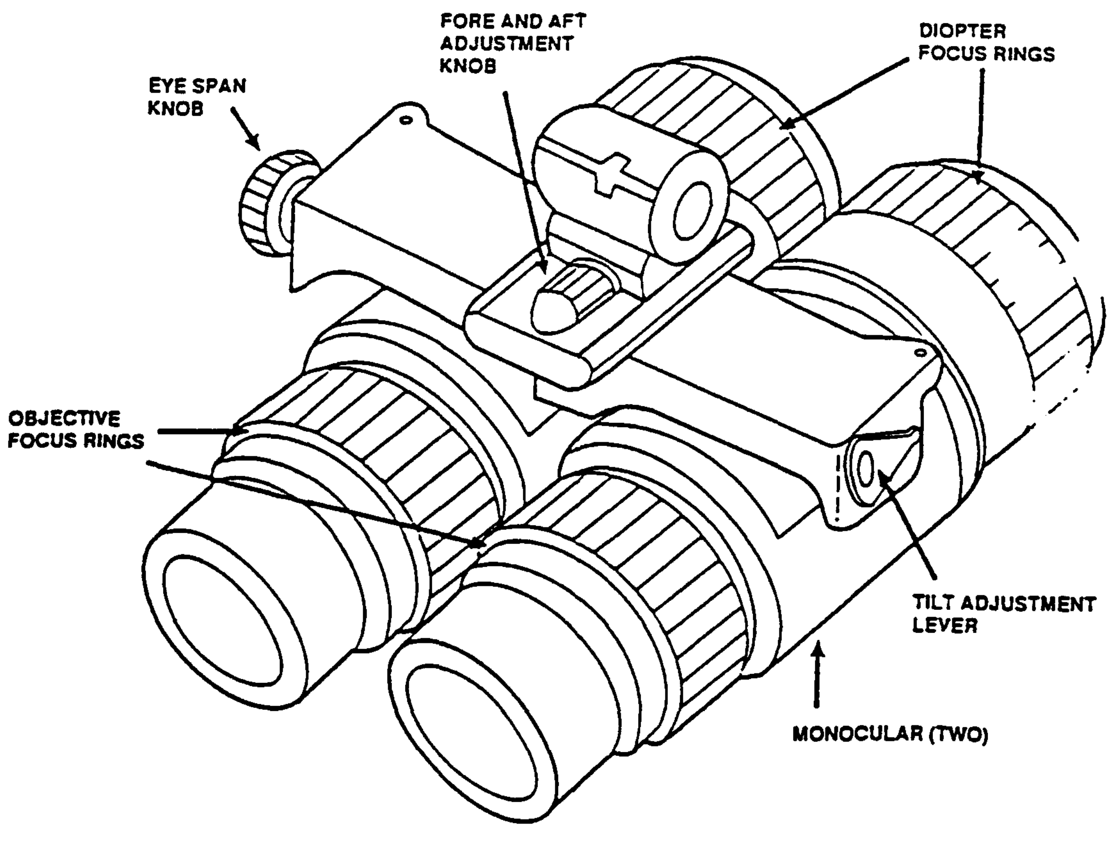
a. **Fore and aft adjustment knob** – moves the entire binocular assembly toward or away from the eyes.

b. **Tilt adjustment knob** – allows wearer to rotate the optical plane of the assembly

c. **Interpupillary distance (eyespan) adjustment knob** – allows wearer to adjust for the distance between the eyes.

d. **Objective focus ring** – focuses the goggles for distance (adjustment range is from 10 inches to infinity.

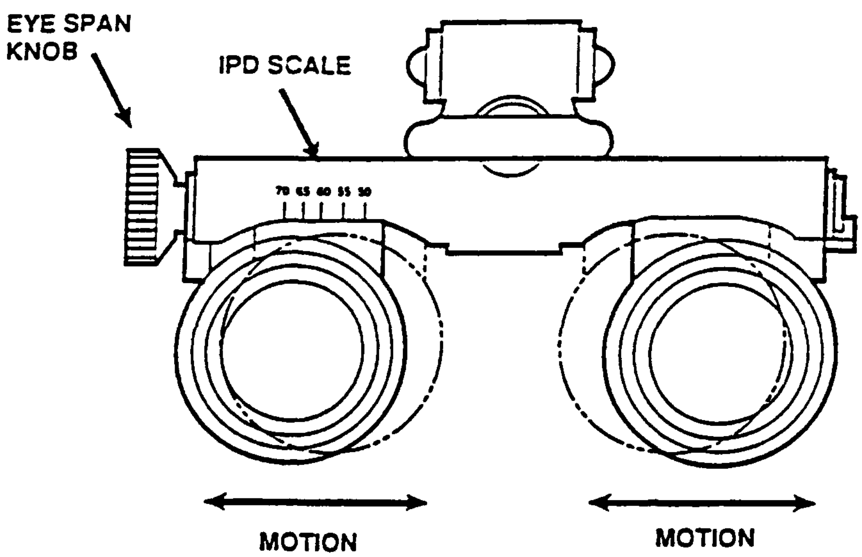
e. **Diopter focus ring** – permits focus of the NVD to compensate for individual refractive error and allows wearing of the device without spectacles.



Operating procedures

Before flying with NVDs a series of alignment and focusing procedures must be performed to verify proper fit and function of the device. Remember that proper alignment of the optics is critical to achieving the best available optical acuity from the equipment. Perform the following procedures prior to donning the NVDs at the test lane:

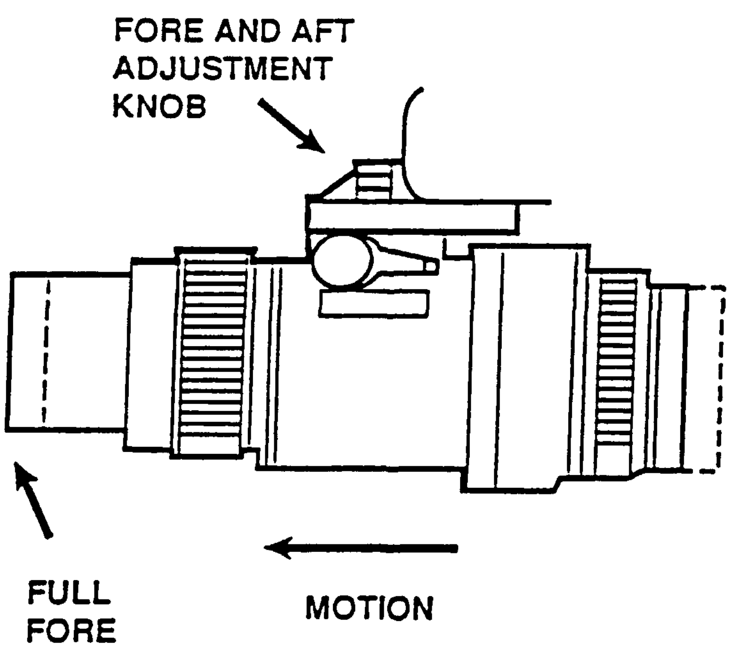
1. Check the overall condition and security of the goggles NVD.
   a. Make sure all the knobs work properly.
   b. Check for loose parts.
   c. Check for frayed wiring.
2. Inspect and clean the lenses if needed. Make sure only lens paper is used to prevent scratching the lens surfaces. Dirty optics can degrade performance by up to 30%.
3. Set your interpupillary distance (IPD) using the scale on the front of the goggle frame. The flight surgeon should be able to measure your IPD if you don't know it.



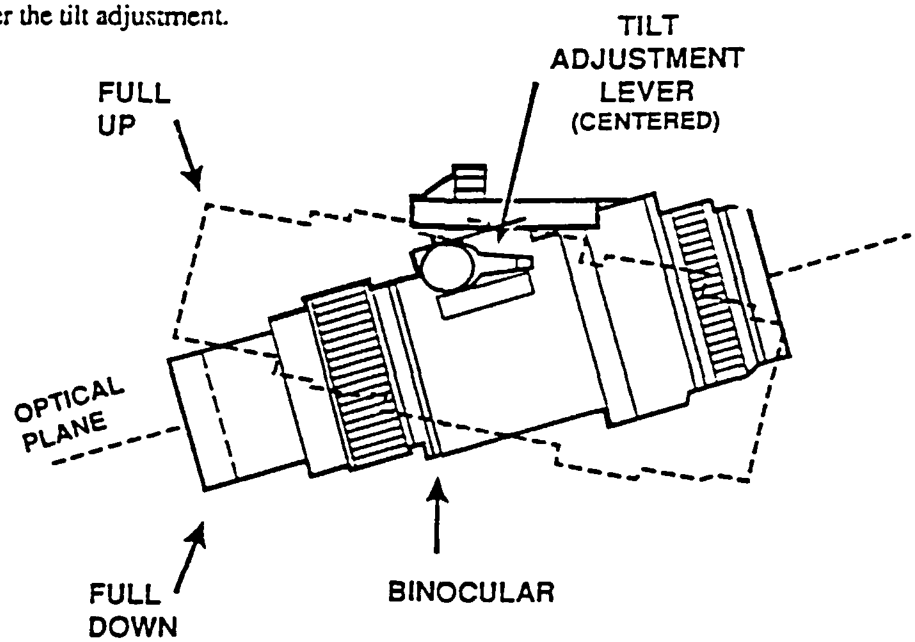
4. Set the diopter adjustment to your individual setting if known. If you do not know your diopter setting then rotate the ring fully counter clockwise to its most positive setting.

(rear view)

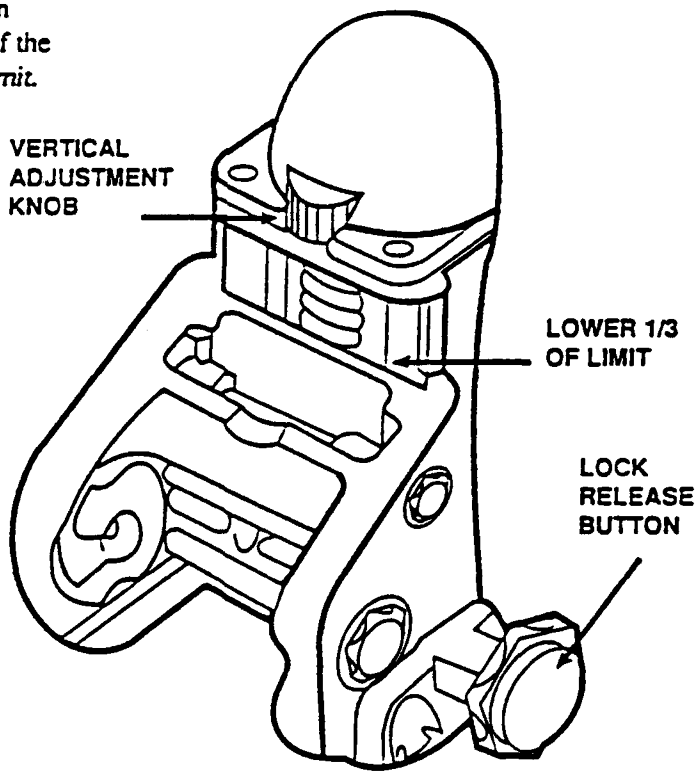
5. Move the binocular assembly as far forward (away from the eyes) as possible.



6. Center the tilt adjustment.



7. Set the mount to a position approximately one-third of the distance from its lowest limit.



8. Attach the mount at the appropriate location. Life support personnel can help you determine what kind, and where the mount should be placed..

9. Load the battery pack (with batteries) and connect it to the mount. The pack should be attached to the velcro on the back of the helmet. Confirm that the switch is in the off position.

10. Attach the binocular assembly and place it in the stowed position.

This may seem like a long list of procedures, but with experience, they will only take a few moments.

NVD test lane procedures.

The purpose of using the NVD test lane is two-fold. First, it provides a place to align and focus your NVDs and second, it checks the resolution capability of the device. Test lane procedures are divided into two groups: (1) alignment procedures, and (2) focusing procedures. Alignment procedures are necessary because NVDs are designed to achieve best performance when the viewer is looking straight down center of the optics at a perpendicular angle with the eyes.

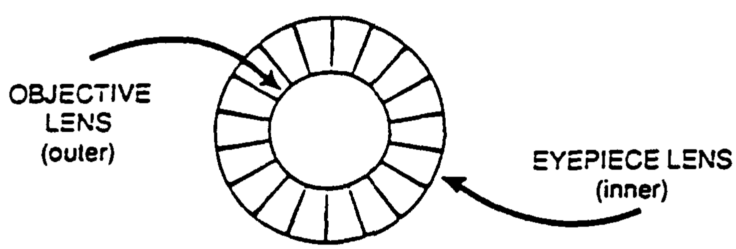
1. Alignment procedures – Alignment procedures should be performed before focusing procedures to insure that any performance degradation is not caused by alignment error.

   a. In the test lane when ready the helmet should be donned, the lights turned off, and the NVDs turned on. The room must be dark before turning on NVDs to avoid damaging the intensification tubes.

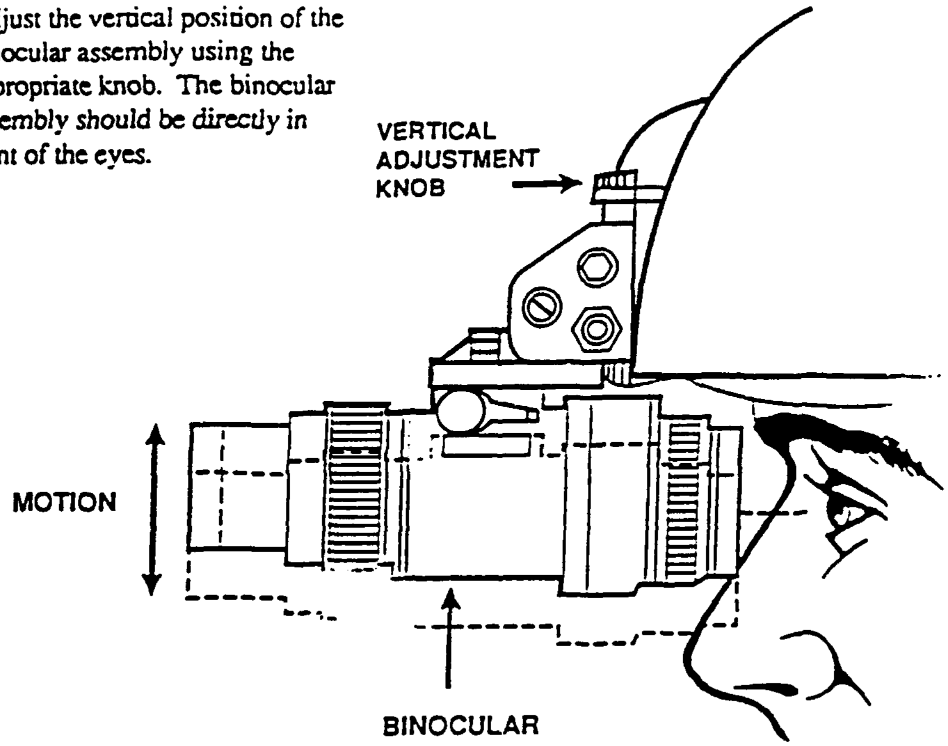
CAUTION

DO NOT TURN NVDS ON IN LIGHTED AREAS. DAMAGE TO IMAGE INTENSIFICATION TUBES WILL RESULT.

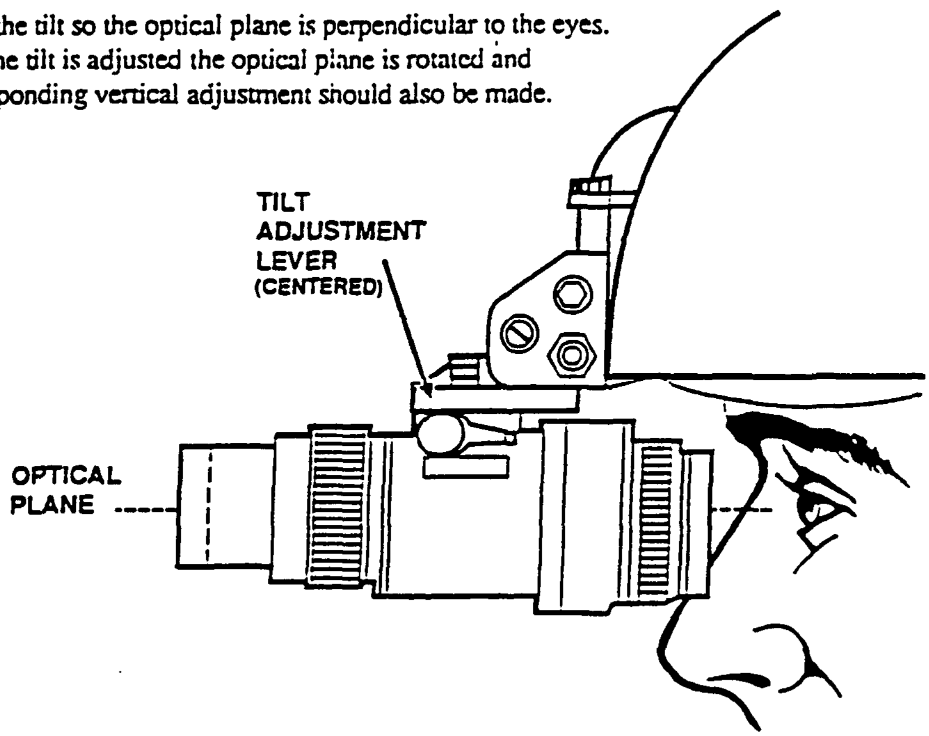
While performing the alignment procedures it may be helpful to evaluate each tube indivic well as together. Perfect alignment for each tube occurs when the objective lens circle is direc center of the eyepiece lens circle.



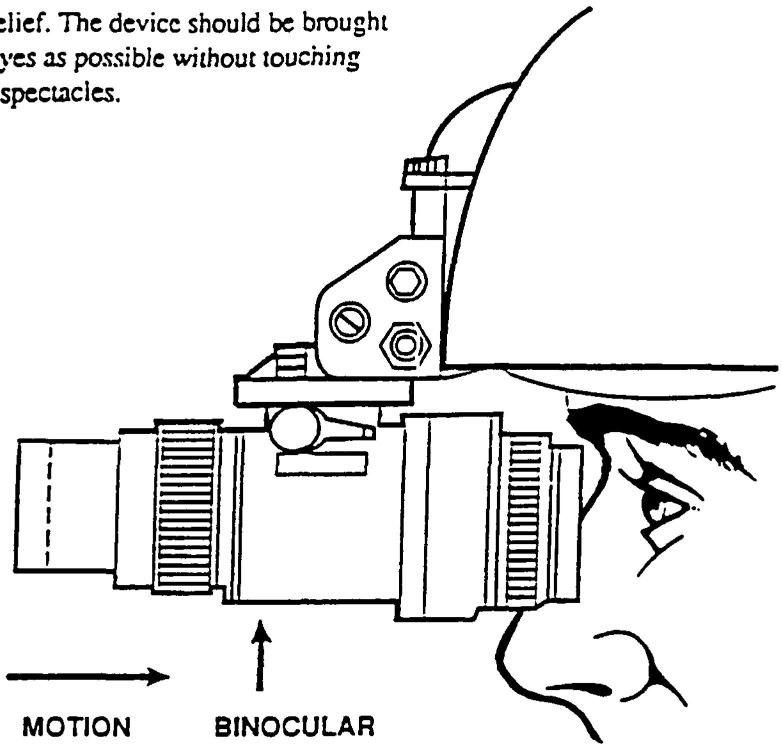
b. Adjust the vertical position of the binocular assembly using the appropriate knob. The binocular assembly should be directly in front of the eyes.



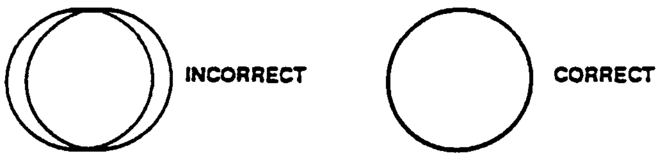
c. Adjust the tilt so the optical plane is perpendicular to the eyes. When the tilt is adjusted the optical plane is rotated and a corresponding vertical adjustment should also be made.



d. Adjust the eye relief. The device should be brought as close to the eyes as possible without touching the eyelashes or spectacles.



e. Fine tune the interpupillary distance (IPD). Adjust the IPD so that the two images of the tubes overlap as one and each image is directly in front of the corresponding eye. It is important to note that improper adjustment of the interpupillary distance can cause eye strain loss of depth perception, and loss of visual acuity in flight.

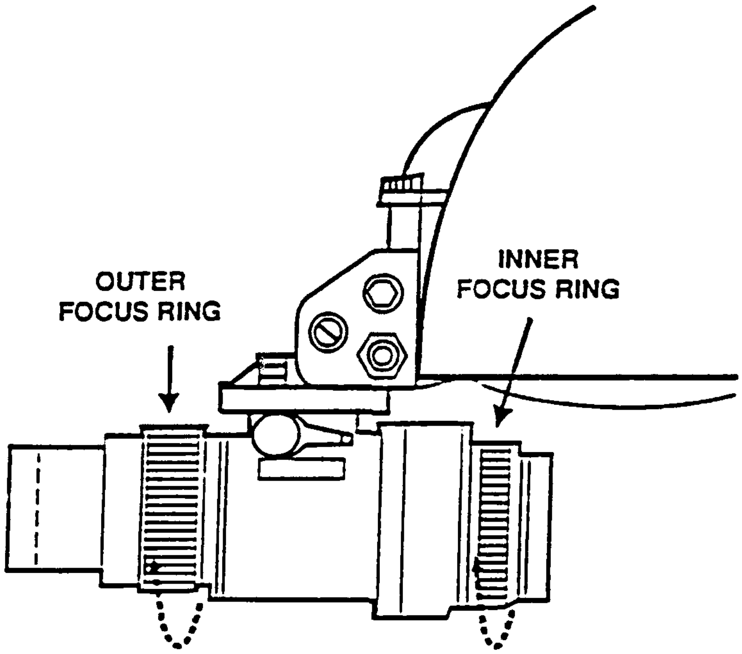


f. Evaluate the picture. The NVDs should be aligned now. There should be no shading in any part of the field of view. If there is then recheck mount positioning and angle.

2. Focusing procedures are as follows:

a. Move to the twenty foot line in the testlane and observe the acuity chart. Close one eye, or cover one of the tubes with a free hand (be careful not to touch the lens or you will leave oil on it).

b. With your open eye, focus the vertical and horizontal lines on the chart using the objective (outer) focus ring.



c. Fine tune the picture using the diopter (inner) focus ring. Be careful not to rotate the knob beyond just sharpening the picture. If the diopter is turned too far the eye muscles will accommodate for the overcorrection and over time this can cause eye strain and/or loss of visual acuity.

d. Focus the other tube using the same procedures. Do not be alarmed if one tube performs better than the other. Evaluate acuity with both eyes open. Acuity should be no worse with both eyes open than the acuity was with the best tube.

e. Before leaving the test lane note IPD and diopter settings so they can be reset at the aircraft before donning.

Aircraft operating procedures

Before donning NVDs in flight set the IPD and diopter to those settings which were used in the test lane. Since the device was focused at twenty feet in the test lane you will have to re-focus at the aircraft. Use only the objective focus knob for this. While re-focusing try to pick a distant object that has some horizontal or vertical lines in it. Avoid focusing on noncompatable lights because the halos they create are hard to focus on. During flight you may need to make minor adjustments to vertical, tilt, and horizontal alignments due to helmet setting and pilot comfort. DO NOT CHANGE IPD OR DIOPTER SETTINGS DURING FLIGHT!

NVD malfunctions

Several types of NVD malfunctions exist which the operator needs to be aware of. The most common malfunctions are as follows:

1. Shading – will appear as a dark area along the edge of the image. If shading is present a fully circular image will not be seen. If it is present write up the malfunction and turn the device in for maintenance.
2. Edge glow – will appear as a bright area along the outer edge of the viewing area. If it appears, block out all light entering the objective lenses and see if it is still present. If so, write the device up and turn it in for maintenance.
3. Bright spots – will appear as constant or flickering spots anywhere in the image. They are caused by tiny holes in the phosphor screen. Block out all light entering the tubes and check to see if they are still present. If so, write the device up and turn it in for maintenance.
4. Flashes/flickering – if more than one flash or flicker occurs write the device up and turn it back in for maintenance.

There are some apparent problems that can occur with NVDs which are not grounding items but may be noticed by the user. Honeycombing, distortion, veiling glare, and dark spots are the most common items. If NVDs with these types of problems are encountered evaluate them in the following way:

a. Honeycombing is most often seen in high light levels. If it occurs in a very dark environment a problem exists.

b. Distortion is optical bending of a viewed object. If it is present and excessive don't fly with them.

c. Veiling glare is caused by dirty, chipped, or scratched lenses which scatter light that strikes them at an angle. If it interferes with vision leave them behind.

d. Dark spots should be evaluated for size and interference with vision. If the problem is severe don't fly with them.

Any time NVD operational capabilities are in question have them checked by the local life support technicians.