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NASA Conference Publication 2306

Peripheral Vision Horizon Display (PVHD)

Proceedings of a conference
held at NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California
March 15-16, 1983

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National Aeronautics
and Space Administration

**Scientific and Technical
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PREFACE

On March 15 and 16, 1983, the first formal conference devoted exclusively to the Peripheral Vision Horizon Display (PVHD) was held at the Dryden Flight Research Facility of NASA Ames Research Center, Edwards, California. The conference was scheduled because of a need to disseminate information about the extent and diversity of research and applied work done on the PVHD. Organizers of the conference were able to assemble a group of outstanding presenters representing academic, industrial, and military organizations. This fulfilled the need to provide relevant background information pertinent to the development of the PVHD.

The theoretical foundation and applied use of the PVHD were discussed. Results of operational tests were of particular interest to the attendees. Participants agreed that future meetings on the PVHD would be of considerable value to the scientific and engineering communities.

The chairmen would like to thank the participants of the conference and NASA Ames-Dryden.

Dr. Robert S. Kellogg, Program Chairman
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NOMENCLATURE

AB	afterburner
A/C	aircraft
AFFTC	Air Force Flight Test Center
AI	attitude indicators
AL	altitude
AOA	angle of attack
AS	airspeed
CD	course deviation
CRT	cathode ray tube
DAS	data acquisition system
DEP	design eye point
EP	evaluation pilot
FCS	flight control system
FLIR	forward looking infrared
FOV	field of view
GCA	ground control approach
GIB	guy in the back
HE	heading
HUD	head-up display
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological conditions
IP	instructor pilot
ISI	inter-stimulus interval
LANTIRN	low altitude navigation targeting infrared system for night
LCD	liquid crystal diode

MAE	mean absolute error
MFD	multi-function display
MH	Malcolm horizon
MIL	military
MSE	mean squared error
NATC	Naval Air Test Center
ND	nose down
NU	nose up
OKN	optokinetic nystagmus
PA	pitch altitude
PVCAL	Peripheral Visual Cue Assessment Facility
PVHD	peripheral vision horizon display
RA	roll attitude
R/C/P	rear cockpit
RTB	return to base
RWY	runway
SAI	standby attitude indicator
SAT	surface-to-air tactics
SDO	spatial disorientation
SEFE	standardization evaluation flight examiner
SIB	Safety Investigating Board
SSNA	single seat night attack
TACAN	tactical air navigation
TPS	Test Pilot School
TR	turn rate
VASI	visual approach slope indicator
VFR	visual flight rules
VMC	visual meteorological conditions

VSS	variable stability system
VV	vertical velocity
VVI	vertical velocity indicator
WAD	workload assessment device

PERSONAL EXPERIENCE WITH THE PVHD AND OPINION OF SITUATIONS IN WHICH A WIDE FIELD OF VIEW (FOV) PVHD MIGHT BE HELPFUL

by

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My initial introduction to the PVHD occurred in early 1980 accompanying the AFFTC bioenvironmental engineer while he was conducting a laser safety survey of the static cockpit display described in Paper 13. At that time, I was Chief of Aerospace Medicine at Edwards AFB and was more interested in the eye hazard implications. During our evaluation, I sat in the mock cockpit with the laser horizon on and, in turning around to make a seat adjustment, inadvertently glanced momentarily with my right eye directly into its beam. The brightness, of course, startled me. Though after-images persisted for a brief time, I was pleased to find no loss of acuity. (I am myopic and was wearing minus lenses at the time.)

Major Dave Edmondson, then at the USAF Test Pilot School, pointed out the principle of the PVHD and urged me to fly the incandescent light device of Vic Horton and Einar Enevoldson in their T-37 aircraft at NASA Ames Research Center's Dryden Flight Research Facility. One ride was sufficient to convince me that this was indeed a "better mousetrap." Light intensity was low requiring a dark night for adequate use, but the light PVHD worked as advertised. It provided excellent attitude information without the pilot having to look at it, even with the attitude director indicator (ADI) masked. Unusual attitude recoveries were simple, although from steeply banked positions, one might attempt to recover by rolling inverted. Precise attitude control was facilitated during precision approaches, again with the ADI taped over. One could easily monitor attitude with peripheral vision, thus freeing up central vision for tasks requiring acuity, such as monitoring performance instruments. It unquestionably simplified this task.

Having recently been reassigned to the Air Force Inspection and Safety Center as Chief of Life Sciences, I was in a position to analyze USAF aircraft mishaps. The following incidents are characteristic of the type that may have been prevented by a wide field of view attitude indicator such as the PVHD:

- Two-seat fighter aircraft departed single-ship into a low (500 foot) overcast; emerged 15 to 20 seconds later in a 45° dive, 90° of left bank. Wings rolled level and had started pullout just before impact.

- Observation aircraft departed single-ship into a low broken deck conducting a weather check; in and out of clouds on downwind, then

entered a larger darker cloud. Emerged 10 to 15 seconds later in a 45° dive, 90° of right bank. Rolled wings level and had started pullout just before impact.

- Single-seat fighter aircraft on night-weather formation sortie was wingman in left fingertip descending in cloud, breaking out over lightless terrain at about 20,000 feet. The wingman drifted below lead, crossing to the right beneath. He called "lost wingman," continued to roll right, and descended to impact mountains 10,000 feet below.

- Single-seat fighter aircraft on a night-weather formation sortie called "lost wingman" in the clouds and impacted shortly thereafter.

- Single-seat fighter aircraft, number 4 on a daytime departure into weather, entering overcast at about 300 feet AGL. Apparently attempting to track and trail his element mates on his radar scope, he entered a descending right turn to impact.

- Single-seat interceptor aircraft returning single-ship to land, at night, through heavy rainshowers; broke out of a low ceiling left of course; quite likely had one or more warning lights. While angling toward the runway, allowed himself to get too low and struck tall trees less than two miles from the runway. Fatigue also a factor.

- Cargo craft making a circling approach to an unfamiliar airfield in lightless surroundings on a "black-hole" night. During turn to downwind, may have mistaken a lighted tower for conflicting traffic. Entered inadvertent, overbanked descent to impact. Fatigue also a factor.

- Two-seat fighter aircraft on a daytime dogfight mission departed controlled flight while defending against a gun pass and descended into a hazy undercast. Aircraft emerged at about 1,500 feet AGL in a slow spiral. Dual sequenced ejection initiated out of the envelope.

- Two-seat fighter aircraft on a daytime mission departed controlled flight during an intercept and descended into undercast of heavy clouds. Initially thought he had recovered control but then noted the ADI rolling at low altitude and wisely ejected in time.

- Single-seat fighter aircraft flying as wingman on a daytime weather departure into turbulent clouds. Lead became concerned about a collision and called, "Level at 17,000, climbing to 18,000," leaving his wingman in an approximate 30° left bank. Due to radio static, the wingman had misunderstood this call, and by the time he had transitioned back inside the cockpit, his ADI was rolling and showing mostly black. He confirmed the unusual attitude of the ADI on his head up display (HUD), and managed to begin a recovery as he broke through the overcast, pulling over 9g to barely miss the rocks.

- Single-seat fighter aircraft on a night formation radar delivery. Went head-down to the radar scope allowing a 2,000-foot descent to go undetected, impacting short of the target on run-in line. Fatigue also a factor.

- Single-seat fighter aircraft evaluating gunnery techniques on the range, daytime, turned toward downwind, channelized attention on the weapons delivery computer, failed to catch a descent, and flew into the ground.

- Single-seat fighter aircraft, daytime, preparing for a gunnery competition. While on downwind setting up for his third pass, went head-down to his weapons delivery computer, failed to monitor a slow roll descent, and initiated recovery a fraction of a second too late.

- Single-seat fighter aircraft, number 2 on a dark night range mission. Made a radar laydown pass and pulled off into a climbing left turn, during which the flight lead inititated a pre-briefed lead change, passing number 2 on his left. Number 2 indicated he'd entered clouds, then indicated some problem, most likely caution lights. He impacted within 20 to 30 seconds having rolled from a climbing left turn to an inverted right dive, 180° out of phase. Misinterpretation of the ADI or more likely, the HUD, was suspected. (HUDs are not optimized for instrument flying; in the ordnance delivery mode, the pitch ladder, which is mated to the velocity vector (flight path marker), slews all over the face of the combining glass — rendering interpretation difficult.) It is quite easy to misinterpret an upright climb from an inverted dive (Fig. 1).

- Single-seat fighter aircraft leading a number 3 ship to the range between cloud decks announced he had a problem and rolled abruptly into a hard left turn, presumably to return to base, immediately entering clouds. He emerged briefly only to enter lower clouds and impacted cloud-covered mountains at a fairly steep dive. There was a mismatch between the ADI and the standby attitude indicator, which, erroneously, indicated a climb.

- Single-seat fighter aircraft on a single-ship, black-night approach through weather claimed spatial disorientation while in the clouds in icing conditions from 8 to 4 miles out. Shortly after breaking out left of course due to cross-winds, he felt an unfamiliar "thump" (possible ice ingestion), neglected to monitor his vertical velocity indicator (VVI), struck an approach antenna, lost control, and ejected successfully. This pilot was task saturated.

- Bomber aircraft on a night terrain avoidance ordnance; delivery circuit failed to note a slight 1° to 2° descent into slightly rising terrain. Ground impact destroyed aircraft. Fatigue also a factor.

- Helicopter was letting down to a terrain avoidance low level, following a night aerial refueling. Failed to catch mis-set altitude warning and impacted terrain.

- Cargo plane returning from predawn exercise, permitted a 1° descent to go unnoticed for about one minute, impacting the surface. Fatigue also a factor.

- Cargo plane shooting an approach to minimums in low ceilings and blowing fog. Attempted to go visual prematurely, failed to detect an excessive VVI, and hit short, causing major damage.

- Reconnaissance aircraft shooting approach to minimums in blowing snow. Landed short.

- Single-seat fighter aircraft on night intercepts called "Tally-ho" while belly up to his target; had apparently mistaken surface lights for his target. Lost over 11,000 feet and impacted near surface lights. Fatigue also a factor.

- Single-seat fighter aircraft leading a night two-ship to the range. Coming off his initial pass, no spot from the bomb was seen. Turning to downwind, it appeared the pilot was trying to troubleshoot the "no" release. Allowed a descending turn to go undetected and impacted. Chronic fatigue a factor.

- Single-seat aircraft flying as wingman on aerial refueling sortie. Following top-off lead, called he was passing to assume lead, and also told wingman to ensure proper function of navigation equipment. While head-down checking his navigation equipment, the wingman drifted up and into lead and was killed.

- Trainer, solo, attempted to cross a high thunderstorm, flamed out engines, descended into clouds, apparently became disoriented while attempting restart, and crashed before completion of ejection sequence.

- Trainer, solo, flamed out at altitude, descended into clouds, became disoriented attempting restart, and ejected safely.

- Single-seat fighter aircraft lost control above an undercast, became disoriented attempting recovery in the clouds, and ejected safely.

- Single-seat fighter aircraft pilot making a daytime route weather abort became task saturated trying to locate his element mates on radar while changing TACAN channels; inattentive to his altimeter and VVI for nearly one minute during which his aircraft descended nearly 4,000 feet to impact. Fatigue also a factor.

- Single-seat fighter aircraft flying as wingman on a daytime departure into low clouds, entering clouds on the right wing. Within 15 to 20 seconds, both aircraft emerged through the 1,000-foot cloud bases in a steep dive, the wingman now on the left wing. Lead pulled hard; both aircraft struck vegetation.

- Single-seat fighter aircraft at night descended through a 2,000-foot cloud deck breaking out over a lightless black-hole across which a lone interstate highway ran. As he attempted to level off, his "ears" told him he was climbing vertically, yet the highway reflection off the top of his canopy told him he was in a steep dive. He fought hard to make the ADI indicate straight-and-level but admits he came very close to ejecting. After a minute or so, he was able to see city lights on the horizon, and immediately his disorientation vanished.

- Single-seat attack aircraft pilot climbing into weather on a route abort focused all his attention on the ADI to the exclusion of the airspeed indicator, stalled, lost control, and ejected.

Characteristics common to these incidents included night, weather, formation, false horizons, and situations requiring head-down time. These conditions led to either or both of two general types of spatial disorientation (SDO): that which alerts the pilot that something is amiss (such as the leans or pilot's vertigo), and that which does not alert him that anything is wrong. The aircraft is not on rails, and unless one pays attention to his attitude, the aircraft may insidiously and subliminally roll and/or pitch somewhat into unexpected, unanticipated, and unwanted attitudes. Many pilots refer to this latter form of SDO as "mis"orientation. Because the pilot is not alerted that anything has changed, he may postpone his instrument cross-check for too long a time. The insidious nature of "mis"orientation renders it every bit as lethal as the recognized form, if not more so. It would appear that the PVHD would be most helpful in preventing the unrecognized type of disorientation, though hopefully, it would also help him cope with the recognized form as well.

Other situations which would appear to benefit from the PVHD might include:

- Naval operations around the carrier, such as traps and catapult launches.

- Helicopter operations, particularly hovering over loose material such as dust or snow in which the rotor-wash kicks up particle concentrations sufficient to block visibility.

- Operations with special vision restricting devices that compound the difficulty of maintaining attitude.

Needs of the pilot: flying under conditions in which the pilot can visually reference the true surface, or the true horizon, the only instrument needed is an airspeed indicator. In flying under conditions where he cannot use the surface as a height reference, he may also need an altimeter. However, if he is flying in conditions denying valid references to the plane of the surface or to the true horizon, his most important instrument becomes some form of attitude

indicator. Prior to the development of artificial horizons, pilots could maintain relatively level flight by mentally integrating the turn and slip indicator (needle and ball) with airspeed and altimeter. With the advent of the artificial horizon, the pilot now had one instrument that integrated for him all the information required for attitude. This single instrument has become far and away the most important gauge to the pilot and flying in instrument meteorological conditions. Many military aircraft incorporate a type of attitude indicator which also provides heading information and is known as the attitude director indicator ar ADI. In order to maintain awareness of his flying situation (situation awareness (SA)) pilots are trained to employ a cross-check of those instruments providing critical control parameters. This composite instrument cross-check is commonly a scan that refers to the ADI more frequently than to any other instrument. When a pilot feels disoriented, he is commonly instructed to focus the majority of his attention on the ADI and to force it to indicate straight-and-level flight. The larger the ADI, the easier this is to do. Large ADIs should be or should become the rule in the design of instrument aircraft. Whereas it may be permissible to miniaturize some instruments, this does not apply to the ADI. The ADI is one instance where big is definitely better.

In aircraft subject to night/weather formation flying, it would appear ideal to provide an artificial horizon that is wide enough to be monitored out of the corner of the wingman's eye. Preferably, it should also occupy a prominent location at or near the center of the instrument panel. A large, prominent, and commanding ADI is all the more important in the presence of design features that distract and disorient pilots – such as a head position high in a fishbowl canopy prone to glare and reflections. It should also enable him to transition quickly from outside to inside.

Theoretically, the Malcolm Horizon PVHD should serve admirably as a wide FOV attitude indicator, thus reducing spatial "mis"orientation and disorientation, easing and expediting the transition to instruments, and significantly reducing cockpit workload.

Anxious to see the laser PVHD in action, I requested a ride in the USAF/TPS RF-4C aircraft. Major Terry Lutz and Captain Blaine Hammond had been conducting flights with the rear cockpit hooded. I was more interested in noting how the PVHD fared in visually disorienting situations, such as in the weather or in formation. I was also interested in noting how it fared in brighter conditions, such as above cloud, below a cirrus deck, or while head-down as in a range pattern. Hence, we flew unhooded with Blaine Hammond piloting.

The PVHD worked as advertised providing continuous attitude information through 360° rolls and to its stops on loops; however I had several criticisms:

– The quality of the horizon projection needed improvement; bright dots were substituted for the horizon at lower power settings, and when the line appeared to connect the dots, it wavered continuously. I would prefer a nice crisp, sharp, unwavering line as I had seen with Lyle Schofield's model.

– The horizon line was only 18 inches wide; it did not seem that it could be monitored "subliminally" by the peripheral visual fields when head-out as in flying formation, or when head-down. However, it was much easier to "sneak a peek" at it, head-out or head-in.

This brings me to an anecdote regarding the PVHD. The PVHD was installed in the front cockpit of the single-seat night attack (SSNA) A-10 aircraft as described in Paper 9. It was projected onto the instrument panel as shown on page 95 of these proceedings. While conducting tests over a range one pitch-black night, the front-seat pilot initiated pulloff from an ordnance delivery pass. There was some problem with the ordnance, which he began to troubleshoot by looking back and forth from the left multifunction display to the armament control panel on the center pedestal. During the ensuing 10 to 15 seconds, he looked back and forth 4 to 5 times across the position of the PVHD. He had initiated a wings-level climb, but now, with his attention diverted from monitoring his flightpath, the aircraft began a slow roll to the right reaching over 90° of bank. The PVHD worked as advertised, rotating downward and counterclockwise, then moving back toward center as the aircraft began to descend. Though the pilot was looking back and forth across the PVHD, he never caught the unusual attitude. Finally, the safety pilot in the rear cockpit noticed the altimeter begin to unwind and alerted the front-seater to watch his altitude, not his attitude – for he had not caught the unusual attitude either.

Though this is only anecdotal, it indicates to me, at least, that one cannot depend on the PVHD to automatically alert oneself to odd attitudes anymore than the real horizon. One must devote some attention to his attitude. The advantage of the PVHD is that this can be done easily with the peripheral visual fields. There may, however, be some implications for training in its proper use.

Cockpit compatibility cursory evaluation: Following the conference, several participants (Einar Enevoldson, an Ames Dryden test pilot; Art Kennedy of Garrett of Canada, which manufactures the Malcolm Horizon; and I) evaluated the PVHD at night, in three aircraft cockpits at Ames Dryden: F-111, F-15, and F-16.

– F-111. With plenty of instrument panel available, the PVHD appeared quite compatible. Canopy reflections were no problem. Centering roll axis produced the roll-pitch illusion seen in the T-37 aircraft. If used in the F-111 aircraft, it would seem wise to center the roll axis in front of the pilot.

– F-15. There appears to be sufficient panel to display the PVHD, although the pilot's line of sight is somewhat higher. Monitoring is possible during head-out simulating formation flying, as well as going head-down. There were occasional annoying reflections off certain instruments, though none off the HUD or canopy. Interestingly, the PVHD does not show up when projected onto multifunction display (MFD) surfaces, although this could apparently be corrected with a different surface coating.

– F-16. Though F-16 aircraft instrument panels vary somewhat from block to block, they're all similar when it comes to the Malcolm Horizon:

> Surface on the upper portion of the panel is limited and that surface which is available is broken up by the HUD control panel which juts out 5 to 6 inches from the plane of the instrument panel.

The PVHD does appear to be compatible with the F-16 airplane cockpit if it were projected below the HUD control panel over the bottom row of instruments (airspeed indicator, ADI, and (in block 10) the altimeter). Here it would appear to be quite useful to a pilot while he is head-down.

Aimed too low, the PVHD strikes the pilot's knees which jut up above displays on the center pedestal, due to the tilt-back seat.

Canopy reflections might be a problem. PVHD occasionally generated reflections.

Summary: Personal experience with the PVHD indicates that it should have great promise in easing cockpit workload, improving situational awareness, and reducing spatial disorientation.

It should not be assumed that the PVHD will automatically cue the pilot to his attitude without some training or exposure. Some measure of attention needs to be devoted to attitude although this can easily be accomplished by the peripheral visual fields without tying up central vision.

The PVHD would appear useful in any aircraft that flies in spatially disorienting/misorienting conditions, such as night, weather, or formation. It would appear to be particularly useful in aircraft, that by their design, are especially disorienting in such circumstances.

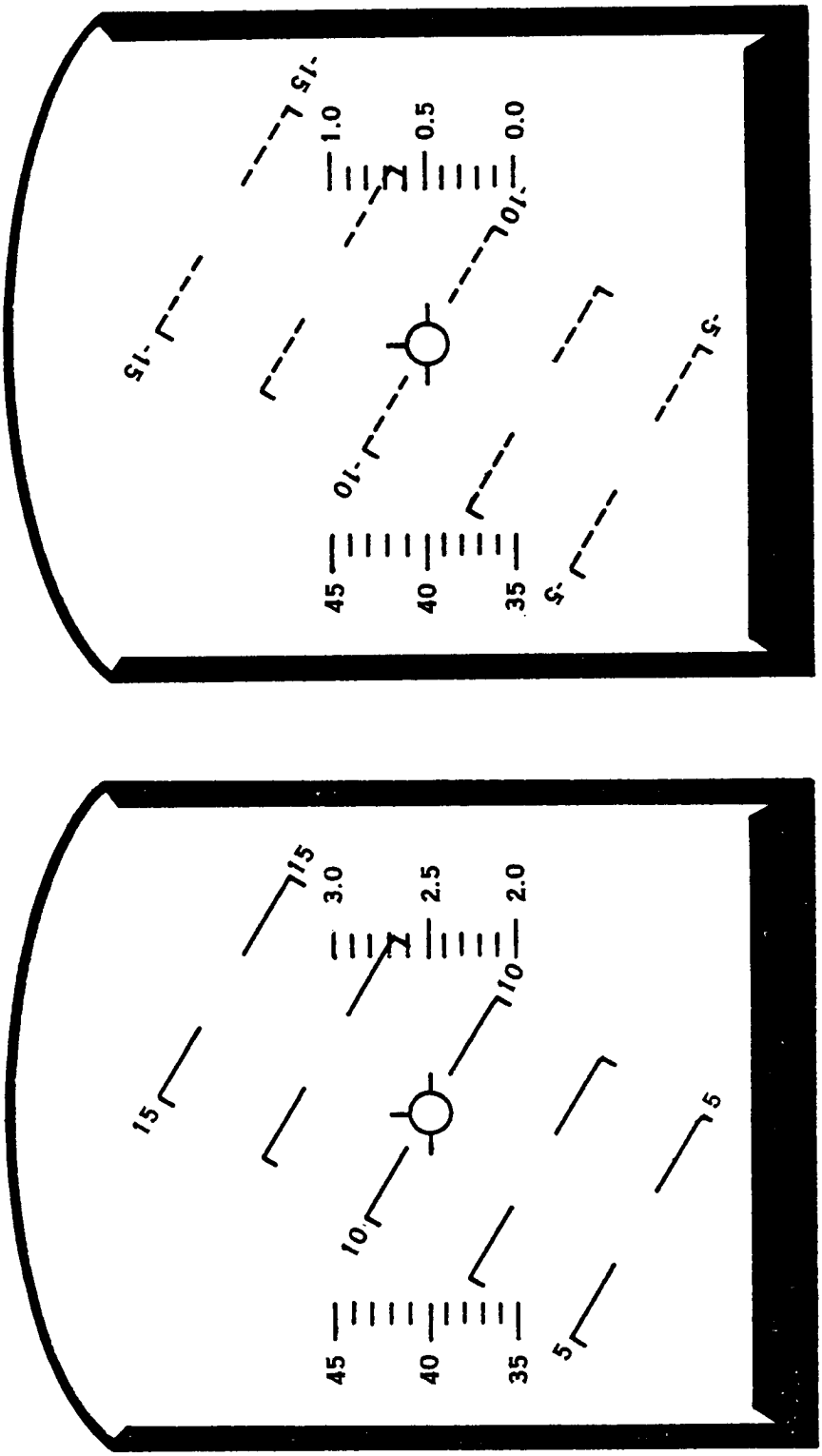

Figure 1.

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THE MALCOLM HORIZON - HISTORY AND FUTURE

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I came to the study of disorientation in aircrew with a background in nuclear physics. While working at the R.C.A.F. Institute of Aviation Medicine, one of my duties was to review aircraft accidents and incidents in the hope that some fresh insight might reduce the toll of planes and men. I was struck by a curious fact that since the Second World War, and the systematic keeping of such records, the number of fatal aircraft accidents in which disorientation is the primary cause has remained relatively constant at 15%. To add to this, the constancy spreads not only over time, but from one country to the next as well. My curiosity in this statistic arose from the obvious fact that across this span of time and nations there have been really significant changes in the training of aircrew to enable them to fly during adverse conditions, and the design and layout of cockpit instrumentation has seen profound changes as well. Could it be that proper orientation in flight is not so much a function of training or instrumentation, but some as yet unnoticed factor?

I decided to look at the problem of providing orientation information to the brain of a pilot from first principles. To begin with, one has to answer the

question, "How do we normally acquire information about our surroundings when moving about naturally in our accustomed environment?" For more than a century we have known that the tiny organs of balance situated in the inner ear in the skull have played a very important role in the perception of motion and the maintenance of balance. Research has shown that these organs are sensitive to both translation and rotation of the skull and that only very tiny movements are necessary for them to be stimulated. However, these vestibular organs, as they are sometimes called, are not perfect inertial platforms because they only report accurately about translational motion of side-to-side and fore and aft. Work which I did with Geoffry Melville Jones in the late '60's showed that if human subjects were moved up and down even through very large distances they had only a 50/50 chance of guessing the direction of their motion accurately. Fishes and birds, on the other hand, receive very precise information about this motion. The reason, it turns out, is that fishes and birds have a component of the vestibular system called the Lagena specifically designed to detect vertical movement. We humans, on the other hand, spend our time walking around the surface of the earth, and over the millenia have not

required information about vertical movement. In fact, such information might be a liability to a human since, when walking or running, our skulls are subjected to impulses in this direction of several 10's of g's. A number of studies have shown that this type of insufficiency of the human organs of balance can lead to numerous disorienting sensations when we are forced to control a vehicle which is capable of moving very quickly in the vertical plane.

A second problem which has been demonstrated to give rise to disorientation in aircrew derives from the fact that the organs of balance have evolved to the task of sensing motions which are of relatively short duration, that is to say, usually not greater than three or four seconds. Systems capable of detecting motion of longer durations have increasing difficulty maintaining stability and coping with drift. Therefore, nature in its wisdom, has given us a system which is capable of detecting motions whose duration is quite adequate for every day living. An airplane, on the other hand, routinely moves in patterns which are many orders of magnitude longer than what our organs of balance were designed to sense. It is natural then, to experience disorienting sensations from the organs of balance under the usual conditions of flight.

It has been known for many years now, that one of the principal functions of the organs of balance of the inner ear is to stabilize the eyeballs in the skull during movements of the head so that we do not suffer from blurring of the vision as we move about. Visual tracking systems are perforce very complex and to have eyeballs capable of tracking the outside world as our head moves through its full range of motion would require signal processing of much greater complexity than our brains could afford. Evolution has provided us, then, with a very elegant solution to this problem. The vestibular systems generate signals proportional to the instantaneous velocity of the skull and sends these signals directly to the muscles controlling the direction of gaze. In fact, so highly evolved is this linkage, that an anatomist can quickly demonstrate that the plane occupied by each pair of semi-circular canals precisely corresponds to the plane of rotation controlled by the individual pair of muscles hooked to the eyeballs, which pair of muscles is connected directly to the semi-circular canals in question. The result of this arrangement is that for rapid and large excursions of the skull the direction of gaze is automatically maintained by signals emanating from the vestibular organs. In fact, for most normal head

movement, the slippage of the visual scene across the retina is usually less than 40% of the head velocity. This 40% is now within the capability of the visual tracking system to maintain a stable image of the outside world on the retina.

This phenomenon can be easily demonstrated by a very simple experiment. If one holds one's hand in front of one's face and moves it left to right at arm's length, whilst holding the head stationary, as the velocity and frequency of the hand motion increases, there quickly comes a time when it becomes impossible to even count one's fingers. Now motion is an entirely relative affair and so in theory the same visual blurring should occur if the hand was held stationary and the head rotated from side-to-side through the same angle of deflection. Those performing this experiment are very surprised to find, however, that even at much higher frequencies and higher angular displacements, not only are the fingers easily seen, but even the finger prints! Hence, with the head stationary, only visual tracking mechanisms are at work, while when the head moves, the organs of balance do most of the work, leaving the tracking system to correct only the residual errors.

Virtually all of the work done toward the prevention of disorientation in aircrew has centred

around the organs of balance. On the other hand, little attention has been paid to the role of vision in the orienting process, even as it pertains to our moving about in every day life. As it turns out, there are two different functions associated with vision and they play quite different roles. We are most aware of objects we see which are close to our direction of gaze. Since such objects fall on the portion of the retina known as the fovea, the central two degrees or so of vision is often referred to as foveal vision. This is to distinguish it from objects seen in the peripheral vision. Now the function of these two types of vision turns out to be quite different from each other. When we look at an object we naturally use the foveal vision and with it focus on the object of our attention in order to study its detail. We are aware of colours and edges, patterns and shapes, and because of the extra-ordinary fine-point discrimination enjoyed in the foveal vision, are capable of discriminating objects at great distance or reading fine print. In order to accomplish these tasks, we must focus clearly on the object of our attention, and this action has prompted many workers in the field of vision to refer to the process as 'focal' vision. However, everything we view, except under the most unusual circumstances, is seen in some ambient

context or other. That is, the object in our focal vision is seen as big or small, near or far, inside something or outside something else, etc. It has a relationship to ourselves and other things - so called ambiance. The majority of the cues which provide this sense of ambiance to our vision come to us through the peripheral retina and this sensation is referred to as 'ambient' vision.

When we are born and first gaze out into the world around us, we have no idea that the jumble of lines and colours which presents itself in fact represents walls and floors, tables, trees and sky, etc. It is only after we are able to move about in this world, touching and feeling the objects which present themselves to us that we come to attribute these qualities to the images which are formed on our retina and perceived in the brain. So too, we come to relate movement of the visual field around us to the movement of our bodies, because every movement we make is a rehearsal of this process. It is not surprising then that nature has come to use the peripheral vision as a major source of information in the complex task of orienting our bodies as we move about in every-day life. The peripheral retina has become remarkably

well adapted to this job, as was demonstrated by Hubel and Wiesel[1] more than twenty years ago. They showed that there are specific cells in the retina which connect to discrete cells in the visual cortex of the brain which are sensitive to spots of light, a different cell for each different location that the spot of light might occupy. Furthermore, if the spots of light happen to emanate from a line of light in the visual field, this gets integrated to such an extent that it is mapped on the cortex of the brain as stimulation in only another single cell or very small group of cells. And once again, the cell or small group of cells is different for each position and orientation that the line of light might have. The static world, then, is perceived as a matrix of cells in the cortex, all firing according to whether the observer is seeing individual spots of light, such as a starry sky at night, or lines of light, such as we might see looking into the room infront of us.

Now Hubel and Wiesel went on to point out that a third map exists wherein individual cells or small groups of cells are stimulated according to the speed and direction of movement of the line of light in the visual field. Thus, for every different speed and direction of motion of a particular line having a

particular orientation, a discrete pattern of cells in the cortex of the brain is stimulated to fire. It is easy to see then how the map making up these patterns of firing cells could be readily sampled for information indicating that the whole visual scene is moving in a uniform manner relative to us. This would be interpreted by the brain as the observer moving about within the ambiance of the real world outside.

Simple geometry should serve to convince us that if we roll (lean to one side) then the farther off the visual axis we perceive an object, the greater will be the displacement and velocity of that object in our visual field. Thus it is no coincidence that nature has chosen to enrich the peripheral vision with sensors specifically adapted for the purpose of orientation. More recent work by Schwartz and Fredrickson[2] has shown that this information about our moving visual world projects directly onto the so-called vestibular nucleus which is that centre of the brain connected directly to the organs of balance of the inner ear. It has long been known that the vestibular nucleus is a major component of the Central Nervous System's balance and orientation circuitry.

A very simple experiment will serve to convince us how important is the peripheral vision in the

maintenance of orientation. If one performs a balance test by standing with the heel of one foot resting against the toe of the other foot, and then closes one eye, one immediately notices that it is a fairly difficult job to maintain steady balance. If one now takes a tube of paper, rolled up like a toy telescope, and places this in front of the open eye so that all of the peripheral vision is blocked, then one finds that it is very difficult to maintain one's balance. However, if the converse of this experiment is performed, and a clenched fist is brought up to the open eye so as to obscure all the central visual field, leaving only the peripheral vision functioning, then we are surprised to find that maintaining one's balance becomes easy again.

Armed with this information let us consider the plight of a pilot in a modern aircraft flying through cloud so that it is impossible for him to see anything outside the cockpit of his aircraft. When he initiates a turn, the pilot's organs of balance quickly alert him to the fact that his aircraft has banked and is changing its heading. However, the visual field which is made up of the instrument panel, window frames, the pilot's knees, etc. remain fixed in front of the pilot's gaze. Immediately a conflict arises. The pilot must resolve

whether his organs of balance (which are ill-suited for flight) are correct, or whether the visual system is right and he is in fact not turning.

It was not until 1930 that flying instructors came to realize that teaching their students to fly by the seat-of-the-pants under such conditions would soon lead to disastrous results. The pilots had no way of resolving this conflict between the visual and inertial systems and would quickly become disoriented. Thus flying training had to be modified so that the students were taught to ignore their visual perceptions entirely and concentrate solely on the information they were receiving from repeatedly scanning the instruments in the cockpit. By scanning key instruments in succession and interpreting the information thus obtained, the pilot could assemble a picture in his mind of the aircraft's attitude and where it was going. Armed with this, he then could make decisions as to what inputs were necessary to the controls in order to maintain the stability of his aircraft. This is the technique still in use today.

If we look at this situation from the point of view of control theory, we quickly come to the conclusion that this is a rather undesirable set of circumstances. In the first place the information

the pilot receives from his instruments comes in discrete little packages, one after the other as in a train, while the pilot directs his gaze from one instrument to the next. Secondly, each instrument only presents a symbol, be it a number or character, which quantifies a particular motion that his aircraft is capable of making. In order to develop a complete picture of where his aircraft is and where it is going, the pilot must recognize and decode each symbol in turn, then add this updated information to the picture he has formed and is maintaining in his conscious mind. Decoding and assembling all these discrete pieces of information represents a high order mental task of considerable complexity. It is little wonder then that occasionally a serious error can arise, especially if a pilot has been doing this activity uninterruptedly for many hours. Furthermore, should a pilot be distracted from this task by non-routine duties associated with flying or by a sudden emergency, then it is easy to see how the precise control of the aircraft can be lost and the situation quickly get out-of-hand.

In 1965/66 I came to the conclusion that a great deal of the housekeeping duties associated with instrument flying could be accomplished at the subconscious level which we normally use to maintain our orientation

as we walk around in the real world. These so called housekeeping duties of flying represent the lion's share of the pilot's work load, and if they could be relegated to the subconscious in an accurate fashion, then the probability for disorientation should be greatly reduced. Furthermore, it might be possible to significantly reduce pilot workload, especially during unusual situations, and thereby enhance the probability of the successful completion of his mission.

I began to experiment with a small array of tiny lightbulbs which I could illuminate as a line and by means of a control, move the line infront of me in both pitch and roll. The array was constructed in such a fashion that I could vary the amount of peripheral vision occupied by the rows of lights. I quickly discovered that once motion was perceived in the true peripheral vision (20-40 degrees off-axis) that such a display was very compelling in the absence of other visual orientation cues.

In my naiveté, I envisaged a large array of tiny light sources arranged across the entire instrument panel and window frames of an aircraft. This array would be controlled from a switching network so that a line of light composed of dots would appear in front

of the pilot, which line could be made to move in pitch and roll in accordance with signals derived from the aircraft's gyro platform. In order to mock this up in an expeditious manner (read "I couldn't find anyone to sponsor the work.") I found an old walk-in refrigerator which was being used for storage space. This provided an excellent darkroom into which I mounted a hemispherical, plastic skylight, standing on edge and supported there by a crude frame. One could then sit in the concave side of the bubble and look through it much as the pilot did in the early helicopters. Using a paper punch, I cut out a handful of confetti from 'Scotchlite' reflective tape and stuck these in a series of vertical rows down the inside of my plastic bubble. In order to create the line of light I was looking for, I took a small sheet of highly polished metal and bent it into a half cylinder with a light bulb at its centre. By distorting the cylinder so as to give it a parabolic section, I could create a reflector which produced a nice line of light which shone across the rows of dots. The cylinder and light were then mounted on gimbals connected to tiny electric motors and the whole lot was driven by a joy stick. In the blackened room, the array of lights twinkling in a line, and moving in

pitch and roll, was very compelling and quickly proved that this could form the basis for the type of instrument I was contemplating.

I showed what I had found to Dr. Ken Money who is a noted authority on aircrew disorientation, and who is an accomplished military pilot. He immediately saw the potential of this system and agreed to help me with its exploitation. He has proven to be an invaluable ally and collaborator since I have no hands-on flying experience. He was able to bring into focus the true problems and concerns of a pilot flying his aircraft, and was invaluable in the process of rejecting or accepting the constantly changing stream of ideas as this new invention evolved.

It became quickly apparent that the real estate in an aircraft cockpit was much too scarce to be able to support the wiring and the array of lights that I had envisaged. However, it struck me that the bar of light that I was projecting would reflect very nicely off the instrument panel as it was, and that it should be possible to shine a line of light across all of the existing instruments without in any way interfering with the pilot's ability to read those instruments. The difficulty was, however, that no light bulb could be found which was bright enough to be able to project

a line of light sufficiently intense to be seen in broad daylight.

Varian Associates Inc. of Palo Alta, California produced a xenon arc lamp, however, which was five times brighter than the best filament lamp available anywhere. I approached them in order to purchase such a lamp and then engaged the services of a Dr. Walter Mandler, to design an optical system which would convert the spot of light emanating from the arc lamp into the desired bar of light, all in a package small enough to permit testing in a real aircraft. The optical system went well enough, but powering a high pressure arc lamp, which has negative resistance, proved to be an entirely different matter. The Canadian subsidiary of Varian is located near Toronto, and they agreed to accept a contract to design and build a power supply capable of operating in an aircraft up to 10,000 feet. The high pressure xenon arc lamp requires some 35,000 volts to start it, and some very subtle circuitry to control it. Keeping all that energy in its designated place proved to be no mean feat.

The results of these labours were a rather large and cumbersome object which looked as if it should be steam driven. However, it did project a bright line of light some 3/4" thick and subtending an angle of some 50^{o} from the projector. It was capable of

receiving inputs from the aircraft's vertical gyro platform and was provided with suitable gearing so that the resultant bar of light moved in exact accordance with the real horizon outside the cockpit.

The peripheral vision horizon display or as Ken Money dubbed it "The Malcolm Horizon", was first tested in a moving base simulator of the Sea King helicopter belonging to the Canadian Armed Forces. The simulator had no visual display, and the windows were painted white, so with another flourish of naiveté, I projected the line of light across the place where the windscreen should be with the centre of roll exactly coinciding with the centre line of the aircraft. The first flight proved to be quite remarkable since the first time that the simulator was banked, the left side of the bar went up and the right side of the bar went down, correctly following what the real horizon should be doing outside the cockpit. The left hand pilot immediately thought that the aircraft had dived, while the right hand pilot thought that they had pitched up. Both started arguing with each other and the simulator crashed. Nothing spurs one of further insight like acute embarrassment, and it became quickly obvious that when a pilot sees the horizon roll, the centre of roll is directly in front of him and not on

the centre line of the aircraft. Hence the bar of the Malcolm Horizon would have to be positioned so that its centre of roll was directly in front of the pilot who was using it as an instrument. It was during this time that the penny also dropped about the windscreen. In a real aircraft, the light would shine right through the clear windscreen and not be visible to the pilot at all, so I moved the display down onto the instrument panel where it could be clearly seen moving relative to the fixed array of instruments. Once there, it became immediately obvious that as far as the brain is concerned, peripheral vision is peripheral vision, and whether the bar corresponded to the horizon exactly, or whether it appeared to be depressed by a foot or so, didn't seem to make any difference in the pilot's ability to recognize it for what it was intended to represent.

Now the instructors that ran that particular simulator had a routine that could only have been worked out by the Marquis de Sade. Once each pilot had completed his instrument check ride and was simulating the inbound leg of his mission, he was subjected to one emergency after another at intervals of one minute or so until he was so overloaded that

he was unable to fly the aircraft any longer and would lose control and crash it. I was informed by the squadron commander that the average for his forty-odd pilots was three emergencies accumulated over a period of five minutes before disaster. We were delighted to discover that with the Malcolm Horizon operating, these same pilots averaged five emergencies over a period of from eight to ten minutes before they became overloaded. I also observed a curious phenomenon while debriefing these pilots. I would ask them if they subjectively felt that the Malcolm Horizon was of any benefit to them during this emergency phase and they frequently replied that it had failed or was turned off and therefore they could not answer the question. I would then take them back into the simulator and show them that it had been running all the time, and we came to realize that they had been using it in a truly subconscious mode.

We then commenced a series of trials in a various assortment of real aircraft under a wide range of operating conditions. For example, a Sea King crew flying at night under conditions of extreme turbulence over the Atlantic Ocean were able to perform repeated 180° turns to left and right with the Stability Augumentation System off and only the Malcolm Horizon for an orienting

instrument. Another crew on a Twin Huey was directed to fly towards a distant point of light over water at night, and despite repeated trials, were never able to maintain control of the aircraft for longer than two minutes. This was because, as is well known, staring at a point source of light induces an effect known as 'autokinesis' in which the light appears to wander around in the black visual field. Flying towards this constantly shifting target soon causes the pilot to lose control, forcing the safety pilot to take over usually less than two minutes after the start of the experiment. However, with all instrument lights out, and using only the Malcolm Horizon, the pilots were able to maintain pitch and roll to within two degrees, heading to within two degrees and air speed to within five knots for periods always greater than five minutes. The display was also tried out in a 747 simulator with motion base belonging to Air Canada under all manner of different flight conditions and a real DC 8 belonging to the same airline which was undergoing acceptance trials after a major overhaul. The pilots of these last two experiments indicated that the Malcolm Horizon would be particularly useful in conditions of turbulence penetration and landing in 'scud'. Another trial involved a single engine Otter

with special clearances, doing landings and takeoffs under near white-out conditions. Under all of the above experimental conditions, only the subjective responses of the pilot or observer were recorded and all of these were very favourable in their assessment usefulness of the Malcolm Horizon.

While the above-noted trials were taking place, Varian Canada Inc. applied for and was granted a licence to manufacture and sell peripheral vision horizon displays on a world-wide basis. It was obvious from the outset that this "steam driven" model could never form the basis for a commercially realistic product and that a great deal of re-design would be necessary. Varian assembled a team and within one year produced a fully MIL-qualified laser driven display in which the spot of light from the laser was swept across the instrument panel by a pair of optical scanners. Various versions of the laser-fired display were provided to a number of Canadian and U.S. military establishments. These establishments mounted a series of experiments which attempted to yield quantitative as well as qualitative data, and I expect that you shall be hearing reports of some of these throughout this symposium.

Over the past decade and a half, I have come to

a number of important conclusions which I would now like to pass on to you. The first of these is that peripheral vision displays only appear to work in simulators with a moving base. Experience has shown that a moving bar of light is not recognized as representing the outside horizon unless it corresponds to what the organs of balance confirm as the expected motion of that outside horizon. If the motion platform of a simulator is turned off during a demonstation of the Malcolm Horizon, then the bar is no longer instantly, and subconsciously recognized as a horizon, and often becomes annoying or distracting. It is quite possible that for such a display to work at the subconscious level, there must be correspondence in the Vestibular Nucleus between visual and vestibular signals.

The second discovery I have made is that the peripheral vision is remarkably sensitive to any feature which moves as though it were part of inertial space. So much so, that one might conclude that one function within the Central Nervous System is to identify those elements in the ambient vision which appear to be stationary in space so that they may be used for purposes of orientation. In practical terms, this means that when testing Peripheral Vision Displays

in real aircraft, one must be absolutely certain that there are no features of the outside world which are visible, otherwise they will be used for orientation cues instead of the display.

The third conclusion I wish to share with you is that getting to use the Malcolm Horizon in an efficient manner is a rather subtle process. Because it is unusual, pilots initially tend to stare at the line, and use it as though it was merely a large attitude indicator. With proper instruction however, they eventually learn to reduce the brightness of the display, and to drop it from their conscious attention. They are then able to modify their instrument scan pattern so that they only refer to the attitude indicator when they need to know precisely what the attitude of their aircraft is. The remainder of the time, they can tend to other tasks, secure in the knowledge that should the aircraft's attitude change, they will automatically sense it in their ambient vision, and correct it.

Recently, for reasons which shall probably remain known only to Varian Associates' senior personnel, Varian Canada Inc. was ordered to divest itself of this product line. Garrett Manufacturing Ltd. of Canada purchased the technology developed by Varian

and arranged for the transfer of the technical team. It is currently licensed by the Canadian Government to manufacture and sell such displays on a world-wide basis. Garrett is continuing to develop and refine the product and representatives of that corporation will describe their progress to this symposium later.

The foregoing is a brief history of the development of peripheral vision horizon displays up to the present state of the art. The next question I wish to consider is where this is all likely to lead in the foreseeable future. Clearly, a considerable amount of experimental effort is going to have to be undertaken, involving large numbers of aircrew getting considerable numbers of hours using the Malcolm Horizon. They will have to fly not only under specific experimental conditions, but also operational conditions, in order that we can discover the true potential of this type of display. The two important concepts in the above statement are "lots of pilots" and "lots of time". This is because we have to be certain that whatever is the nature of the display put up on the aircraft instrument panel, it must be universally understood for what it is meant to convey. Secondly, there appear to be two learning curves, superimposed one on top of

the other. There is a short learning curve in which the pilot comes to realize that the bar is providing him the same information he would get were he flying over an open body of water on a clear day. Pilots have always noted that it is easier to fly on instrument flying rules under such conditions because their peripheral awareness of the outside horizon allows for much easier control of the aircraft. The longer time constant is associated with the pilot's realization that he is not required to look at the artificial horizon every few seconds or so in order to maintain control of his aircraft's attitude. Rather, he sets the attitude of his aircraft while looking at the artificial horizon and then need not refer to that instrument again until such time as he wishes to change the attitude. This is because he is subconsciously aware of any attitude changes and can correct for them without having to look at the artificial horizon itself. The time that he has thus freed up in his normal instrument scan pattern can then be used to good effect for other tasks which would normally compete for his attention. As yet, we do not have any idea what these time constants are, or how they can be efficiently reduced.

The other important road which we must travel down concerns the addition of extra symbology on the line as it is presently constituted. The line which is in the Malcolm Horizon at present is capable only of pitching and rolling in accordance with the true horizon outside the aircraft. However, some reflection should serve to convince you that the sensation in the peripheral vision of other types of motion might also be represented. I have given considerable thought and done a number of experiments to demonstrate the feasibility of providing similar subconscious information relevant to heading, air speed, vertical speed and side-slip. From this work, I am convinced that all of these degrees of freedom can be represented in the peripheral vision and used in the same way that the current horizon bar is being used at present. However, I make this statement with a very important caveat. Namely, we have no knowledge at present as to whether the symbols I have chosen to use will be universally recognized for the information they are intended to convey. Garrett Manufacturing Ltd. is undertaking to explore this important area in the expectation of optimizing the symbology which they will present to the pilot. It is clear that this is

no mean task and will require some time for its completion. And, so for the present, we must satisfy ourselves with only the representation of pitch and roll.

Depending upon the point of view of the pilots using the Malcolm Horizon, we find it variously held out to be a workload reduction device or an orientation device. I think we have to maintain a clear perspective on this issue, which is that peripheral vision displays are capable of doing both these jobs depending on how they are used and under what conditions they are used. I am confident that, as more and more aircrew gain experience with devices of this nature, ways which we have never dreamt of for its use will become obvious. One small example comes to mind at the moment, involving the use of non-dedicated CRT's. There is a great thrust in modern military and commercial transport aircraft to replacing large numbers of dedicated instruments with displays shown on cathode ray tubes which are not dedicated to any specific function, but capable of being directed by the pilot to display all manner of information from check lists to primary flight instruments. It is easy to see how such a situation could demand a great deal of work from the pilot since he

now must remember how to call up the information he is looking for and then how to interpret it. This is far different from simply directing one's gaze towards an instrument whose position the pilot knows beforehand and which instrument is dedicated to one specific piece of information. There is no question that non-dedicated CRTs will increase the versatility of the pilot's cockpit instrumentation by a whole order of magnitude. However, this will be at the cost of a greatly increased potential workload, especially during times of emergency or combat. They also bring with them the potential for disorientation, since the tendency appears to be to put a great number of symbols up on the screen at any one time. It is my belief that peripheral displays, such as the Malcolm Horizon, when used in conjunction with non-dedicated CRT's, might prove to be the salvation of the latter by enabling the pilot to do the house-keeping part of flying at a subconscious level and thereby freeing his conscious thought to attending to the information he calls up on the CRT's.

As you know, the primary reason for this symposium is to compare notes amongst those of us who have used the device and those of us who are working in areas associated with perception and orientation. We have

seen how the pilot's subjective impressions of an instrument intended for subconscious use can be quite at odds with the measured facts. Because of this type of experience, we shall have to be very clever about how we design the experiments in the future and, more importantly, how we attempt as scientists to relate the findings of the controlled experimental situation to the real time operational world of the modern pilot.

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THE TWO MODES OF VISUAL PROCESSING: IMPLICATIONS FOR SPATIAL ORIENTATION

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The concept of two visual systems or two modes of processing visual information (1, 2), although in some respects an oversimplification, is nevertheless helpful in evaluating the role of vision in spatial orientation. The two modes are:

A FOCAL mode which in general answers the question of "what," i.e., what is the nature of the object being examined? What is its form? What patterns does it contain? Most studies of vision, particularly in relation to performance evaluation, have been concerned exclusively with focal vision. The familiar capital letter optotype is the most widely used test of focal vision.

An AMBIENT mode which is concerned with the question of "where," i.e., where is the observer in space? Is the observer or the environment moving?

Focal and ambient vision differ along a number of dimensions. Specifically:

1. The focal mode is almost, if not exclusively, visual while the ambient mode acts in concert with the vestibular, somatosensory, and auditory senses to subserve spatial orientation, posture, and gaze stability. In effect, we have a focal visual mode which is predominantly visual and an ambient system to which vision contributes along with vestibular and somatosensory inputs.

2. Object recognition by the focal mode is subserved by the full range of spatial frequencies, whereas the ambient mode is adequately activated by low spatial frequencies typically stimulating large areas of the visual field.

3. Adequate luminance and lack of refractive error are critical for some aspects of focal vision (for example, foveal acuity), but play a much less important role in ambient vision. The low spatial frequencies subserving ambient vision are less sensitive to degradation of retinal image quality by refractive error or by reduction of illumination.

4. As would be expected in terms of spatial frequency, focal vision is less efficient in the peripheral visual field. Although ambient functions are less efficient if restricted to a small area of the periphery as compared with central vision, unlike focal vision, ambient functions are typically optimized the larger the area of the visual field stimulated.

5. Focal vision typically involves attention while ambient visual functions are more reflexive in nature. Reading while walking illustrates the fact that although attention is dominated by the focal-mediated reading task, spatial orientation is adequately maintained by the ambient mode with little or no conscious effort.

When analyzing the contribution of vision to spatial orientation, it is important to consider the characteristics of ambient vision and its interaction with the vestibular and somatosensory inputs. Some examples include:

SPATIAL DISORIENTATION/MOTION SICKNESS. In recent years, the importance of sensory mismatch within the ambient system in the etiology of spatial disorientation and motion sickness has been demonstrated. Whenever the multiloop sensory inputs differ from the habitual pattern of previous stimulation, the conflicting and incompatible signals to the gaze stability and spatial orientation systems result in disorientation and/or gastric symptoms (3).

VEHICLE GUIDANCE/NIGHT DRIVING. The two modes can be functionally dissociated. For example, spatial orientation is adequate in the absence of the ability to recognise objects due to refractive error or reduction of luminance level. We have suggested that this selective degradation is a factor in nighttime driving accidents. Vehicle guidance is a dual task: steering relies on ambient vision while recognition of signs and hazards is mediated by the focal mode. At night, ambient vision functions as well as in daylight. However, since the drivers' self-confidence derives from the ability to steer the vehicle, and they are not aware of reduction in the ability to recognise hazards with the degraded focal system, nighttime driving speeds are often too fast to permit a timely response to infrequent and unexpected hazards on the roadway (4).

VISUAL NARROWING UNDER STRESS/CORTICAL BRAIN DAMAGE. The two modes can be dissociated in other situations as well. Under various kinds of stressors, reaction time to objects imaged in the peripheral visual field may be increased or the objects may not be detected. This phenomenon is referred to as "tunnel" vision or narrowing of the visual field (5). Even more dramatically, studies of patients with cortical brain damage have demonstrated that spatial orientation can be carried out completely without awareness when the stimuli are imaged on areas of the visual field which are scotomatous as tested by conventional perimetry; i.e., "blindsight" (6). Thus, focal and ambient vision can be dissociated either by brain damage or by the nature of the attentive demands in certain tasks such as occur when driving a vehicle. A possible implication of functional dissociation in normals is that the phenomenon of visual narrowing could result from the concentration of focal vision due to shifts of attention. On the other hand, ambient vision which does not require attention, is probably unaffected by attentional narrowing. A critical factor is that traditional static perimetry makes use of a focal task requiring attention which can be redirected by the observer. Ambient vision, in contrast, is reflexive and therefore not susceptible to modification by attention shifts. Whether selective degradation of focal vision, while ambient function remains intact, is also characteristic of visual narrowing resulting from stressors such as hypoxia or excessive gravitational forces has not yet been determined.

Because both focal and ambient vision are critical in human performance, it is important that visual tests be employed which are sensitive to <u>both</u> functions. Most tests of vision in current use evaluate only focal vision and are therefore of limited usefulness in predicting performance in many situations, particularly those involving spatial orientation.

AIRCRAFT INSTRUMENTATION. Because ambient visual functions are reflexive, they present potential advantages in displaying orientation information in aircraft as compared with symbolic displays which involve learning and interpretation (7). As pointed out by Head (8), processes which require higher levels of information processing are more vulnerable to loss during stress than reflexive functions. This concept is incorporated in the Malcolm Peripheral Vision Horizon Display which provides a wide angle artificial horizon in order to more adequately stimulate the ambient system (9).

INTERACTION BETWEEN FOCAL VISION AND THE AMBIENT SYSTEM

Although the ambient system can function adequately in the absence of focal vision, focal vision is not independent of disturbances of the ambient system. Disruption of gaze stability mechanisms, either vestibular or optokinetic when the head is in motion, results in retinal image motion. Such inappropriate image movement lowers contrast and reduces spatial resolution (dynamic visual acuity). Another consequence of ambient dysfunction is disorientation and/or motion sickness. Gastric symptoms associated with intersensory mismatch within the ambient system are attention-demanding and interfere with object recognition and visually mediated judgments. Illusory object or self-motion frequently occurs when, in order to compensate for ambient dysfunction, the pursuit system is activated to preserve gaze stability (10). Such illusory motion is difficult if not impossible to distinguish from true object or self motion.

IMPLICATIONS FOR FUTURE RESEARCH

In order to evaluate and predict performance in demanding situations, tests of both focal and ambient function are necessary. Because focal vision has been emphasized historically, a number of reliable techniques are available to assess spatial resolution, visual fields, color vision, depth perception, etc. Significant improvements in some of these have recently been developed, in particular the contrast sensitivity function (11). Some tests of ambient function are available but they are not as comprehensive. Although we have excellent techniques for assessing vestibular sensitivity, the integrated function of the components of the ambient system has not been extensively investigated. Quantitative evaluation of body sway has shown considerable promise in clinical diagnosis and represents a potentially powerful methodology in the performance context (12). Individual differences in illusory self-motion (vection) and induced tilt are marked, but their origin and significance are unknown. Sensitive measures of optokinetic nystagmus are in extensive clinical use but, with few exceptions, the visual parameters have not been studied in detail. Questions such as the relative contribution of various areas of the visual field (particularly central vs. peripheral), and the role of spatial frequency, contour extent, and contrast remain to be resolved.

In many respects, the ambient system and in particular, its visual component represents an uncharted frontier with important implications for psychophysics, medicine, and human engineering. It is perhaps appropriate that this meeting has been scheduled in the middle of a vast desert. Let us hope that this gathering represents an oasis which will inspire further study of this hitherto neglected system.

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THEORY UNDERLYING THE PERIPHERAL VISION HORIZON DEVICE

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INTRODUCTION

A simple statement of the Peripheral Vision Horizon Device (PVHD) theory is that the likelihood of pilot disorientation in flight can be much reduced by providing a new kind of artificial horizon that will provide orientation information to peripheral vision. In considering the validity of this theory, three questions are crucial:

1. Why was the artificial horizon chosen, instead of some other flight instrument?
2. Why is peripheral vision used instead of foveal vision?
3. Is there convincing evidence that peripheral vision is particularly well suited to the processing of orientation information?

THREE CRUCIAL QUESTIONS

1. Why the artificial horizon?

Disorientation is an error in the perception of orientation (motion, position, or attitude), usually an error in the

perception of attitude of the aircraft (1). The artificial horizon (part of the more modern "attitude director indicator") is the primary attitude instrument, the only one that gives both roll and pitch information, and the only one that gives the critical pitch information correctly under all conditions of flight. Normally, pitch information is derived also from the air speed indicator, the altimeter, the vertical speed indicator, and the G meter, but all of these four instruments give incorrect pitch information in some conditions of turbulence. Barring instrument unservicability, the artificial horizon always gives correct pitch information (14).

2. Why peripheral vision?

There are four benefits, four obvious advantages to providing orientation information to peripheral vision:

1) Peripheral vision is the kind of vision normally used for orientation and posture (9) and it is therefore well suited to the effortless and correct processing of orientation information. The intellectual effort of reading and interpreting the standard artificial horizon is also saved, a small saving under most circumstances of flight, but a major advantage in some disorientation situations in which severe psycho-

logical stress (9,12) or an increase in workload (6) can dramatically increase the viewing time required for perception. Also, the perceptual reversal of roll information from the standard artificial horizon, that occurs occasionally even in experienced pilots, is less likely to occur with a peripheral vision device.

2) Peripheral vision (ambient mode vision) still works well when the retinal image is blurred, as it often is by severe turbulence or vibration. Foveal vision (focal vision), on the other hand, fails rapidly as the clarity of the retinal image is degraded (9). Since disorientation is often provoked by severe turbulence with resulting vibration (10,14,15,16),it is better to provide anti-disorientation information to the visual mode that functions better when clarity of the retinal image is degraded. During some conditions of flight, in which certain kinds of vestibular stimulation occur, a reflex pseudo-myopia occurs, and this adverse optical effect (in some pilots) would also make the standard flight instruments difficult to read, with resulting predisposition to disorientation (11).

An ambient vision device is also easier to see in

turbulence and vibration simply because it is big.

3) Having provided attitude to ambient vision, focal vision then needs to be used for checking the standard artificial horizon much less frequently. This means that foveal vision can be used more for other things, and other things should then be done better.

4) With attitude information provided to ambient vision, the pilot is continuously receiving "artificial horizon information" no matter what else he is looking at. The constant provision of orientation information will, in all likelihood, reduce the frequency of the kinds of disorientation that are precipitated by unperceived changes in the attitude of the aircraft.

In instrument flying, the pilot uses his focal vision for many things, one at a time. With the standard artificial horizons, he receives "artificial horizon information" only during the fraction of his time that he is actually looking directly at the artificial horizon.

3. What is the nature of the evidence that peripheral vision is particularly well suited to processing orientation information?

There are five different kinds of evidence indicating that ambient vision (peripheral vision) is, normally, much more involved in orientation functions than is focal vision:

1) Studies of humans with discrete brain lesions have shown that people without focal vision can retain good ambient vision and good visual orientation and bodily equilibrium. These observations in humans have been confirmed by experiments with animals (9,13).

2) Postural tests have shown that ambient vision makes a much greater contribution to bodily equilibrium than does focal vision. Artificially imposed movement of the peripheral visual field can cause people to experience self-motion and to fall down, whereas movement of central visual fields has no such effects (7).

3) Ambient vision has been found to be much more important than focal vision in a variety of orientation/equilibrium phenomena, including circularvection, linearvection, and optokinetic nystagmus (2,3,4,5,7).

In some experiments, opposite information inputs have been provided to the ambient and focal systems, and the ambient system has always determined the orientational responses.

4) There are single neurons in visual areas of the brain that are responsive only to lines or edges that are oriented at particular angles and located to stimulate certain discrete parts of the retina. For some such single neurons (although possibly not most) the effective lines must stimulate a specific peripheral area of the retina in order to provoke a response from the neuron (8).

5) Rotation of the peripheral visual field can actually cause systematic alteration of activity in certain "semicircular canal units" (neurons) in the vestibular nuclei in the brain stem. The vestibular nuclei are areas of the brain known to be largely concerned with orientation and self-motion; the fact that peripheral retinal areas are physically connected to these particular nuclei is good evidence that ambient vision is involved in orientation and self-motion (7).

THE BASIC DIFFERENCES BETWEEN FOCAL AND AMBIENT VISION

These differences have been summarized by Liebowitz and Dichgans (9).

FOCAL VISION	AMBIENT VISION
Answers the question "what".	Answers the question "where".
Small stimulus patterns, fine detail.	Large stimulus patterns.
Optical image quality and light intensity are important.	Optical image quality and light intensity are relatively unimportant.
Central retinal areas only.	Peripheral (and central) retinal areas.
Well represented in consciousness.	Not well represented in consciousness.
Serves object recognition and identification.	Serves spatial localization and orientation.

CONCLUSION

Because of the abundance of evidence, the dominant role of ambient vision (as opposed to focal vision) in orientation is now generally accepted by scientists working in this area. It is reasonable therefore to expect that an instrument for providing information about orientation will be more effective if it presents the information to peripheral retinal areas.

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STIMULUS FACTORS IN MOTION PERCEPTION AND SPATIAL ORIENTATION

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INTRODUCTION

The Malcolm horizon (Malcolm, et. al., 1975) utilizes a large projected light stimulus (PVHD) as an attitude indicator in order to achieve a more compelling sense of roll than is obtained with smaller devices. The basic principle is that the larger stimulus is more similar to visibility of a real horizon during roll, and does not require fixation and attention to the degree that smaller displays do. Succesful implementation of such a device requires adjustment of the parameters of the visual stimulus so that its effects on motion perception and spatial orientation are optimized. With this purpose in mind, the present paper reviews the effects of relevant image variables on the perception of object motion, self motion and spatial orientation.

Stimulus size:

The PVHD differs from other attitude indicators primarily in that it subtends a substantially greater extent of the visual field. For this reason it might be anticipated that the variable of stimulus size exerts significant influences on motion perception and spatial orientation responses.

The influence of size on motion sensitivity was examined by Johnson and Scobey (1980), who varied the length of moving line stimuli both at the fovea and 18 degrees in the periphery. Increases in line length improved motion sensitivity for peripheral, but not foveal viewing. The improvement, however, was obtained only with increases of line length up to a degree in subtense. Further increases did not alter sensitivity for object motion perception.

A different response measure commonly used to investigate the influence of visual scenes on spatial orientation is vection, or the apparent self-motion which results when a sufficiently large stimulus moves relative to an observer. In general, increases in the size of the moving surround produce consistantly larger influences on perceived orientation in both roll vection (about the line of sight; Held, et. al., 1975) and circular vection (about the vertical axis; Brandt, et. al., 1973). It is this finding that perhaps forms the basis for the more automatic sensation of roll when the PVHD is employed. Results obtained with other

measures of spatial orientation are consistant with those for vection. Postural stability is enhanced by the visibility of large, rather than small stimuli and reflexive eye movements termed optokinetic nystagmus (OKN) are elicited primarily by the motion of large stimuli. In general, the importance of stimulus size for these orientation measures is consistant with reports concerning the PVHD.

Retinal eccentricity:

As the size of the roll stimulus is increased by use of the PVHD, the retinal eccentricities which are stimulated are neccesarily altered at the same time. It is therefore important to determine the contributions of different retinal eccentricities to motion perception and spatial orientation.

Although it is sometimes asserted that peripheral vision is specialized for the detection of motion, sensitivity to movement actually decreases with increasing retinal eccentricity. If acuity and motion sensitivity measures are obtained at various retinal eccentricities in the same observers (see e.g., Johnson, et. al., 1976), the ratio of motion sensitivity to acuity values is roughly constant throughout the visual field. That is, motion sensitivity decreases with increasing retinal eccentricity about the same amount as acuity does. A perceptual effect which is perhaps related to the decreased sensitivity for threshold motion in the periphery is that the perceived velocity of peripheral moving targets is also decreased (Tynan and Sekuler, 1982).

With regard to spatial orientation responses, the contribution of different retinal regions is somewhat unclear. Although there are some reports that vection is elicited more easily from the periphery (Brandt, et. al., 1973), the differences are small and may be reversed depending on the manner in which stimulation is restricted to a region of the field (Held, et. al., 1975). Unlike vection, optokinetic nystagmus is clearly dependent on eccentricity of stimulation. Both the frequency and gain of these movements are greatest with perifoveal stimulation and decrease systematically as eccentricity is increased (Post, et. al., 1983). Similarly, preliminary postural stability measures indicate that for this orientation response the central visual field contributes to a greater degree than stimulation of an equally large portion of the periphery.

Stimulus luminance:

Luminance is another stimulus feature to be considered in the implementation of a PVHD, as it would be desirable for

the device to be intense enough to be effective, yet not so bright as to degrade the visibility of other detail in the cockpit. The influence of luminance on motion sensitivity was examined by Johnson and Scobey (1980) in both central and peripheral vision. The results revealed an apparently greater influence of luminance on peripheral motion sensitivity than on foveal motion sensitivity. The effect is restricted, however, to a relatively small range of luminances, about one log unit above the threshold for detection of moving detail. That is, for most of the range of luminances tested, there was no benefit to motion detection from increasing the luminance of the moving stimulus.

Studies of the effects of luminance on orientation responses are similar in that there are either small effects or no effects of decreased luminance on these behaviors. Leibowitz, Rodemer and Dichgans (1979) report that vection is undisturbed with reductions of luminance to near-threshold values. Similarly, the localization of visual detail and optokinetic nystagmus are not influenced by changes in luminance (Leibowitz, et. al., 1955; Grüttner, 1939).

Image quality:

Image quality is a fundamental and limiting variable for foveal visual resolution. There are also typically large and variable refractive errors in peripheral vision. It is therefore of interest in the present context to determine the influence of these peripheral refractive errors on motion sensitivity. Correction of these errors has been found to improve peripheral motion sensitivity (Johnson and Leibowitz, 1974), although the effects are small and limited to threshold motion sensitivity, or the finest possible movement that can be detected (Post and Leibowitz, 1981).

Image quality is apparently not a significant determinant of the adequacy of orientation responses, either. The addition of refractive errors does not alter the magnitude of vection responses (Leibowitz et. al., 1979) the radial localization of seen detail (Post and Leibowitz, 1980) or the gain of optokinetic nystagmus responses. Apparently the loss of fine detail does not alter the performance of orientation systems, and exerts little influence on the detection of motion.

Summary:

The literature concerning the effects of stimulus variables on motion perception and spatial orientation responses has been reviewed in order to determine the potential relevance of selected stimulus variables on the

Malcolm horizon. The following tentative conclusions are possible:

1.) Increases of stimulus size serve to increase the contribution of stimuli to spatial orientation sensations and responses. For this reason, a horizon display might be expected to be more effective the greater its angular subtense.

2.) The existing literature does not permit a conclusion as to the contributions of different retinal eccentricities to orientation responses, although motion detection is systematically degraded at greater eccentricities.

3.) The luminance and optical clarity of stimuli, except near threshold values, exert very little influence on either the ability to detect motion or the influence of stimuli on spatial orientation. For this reason, the luminance of the horizon display might still be effective although adjusted to a perceptually dim intensity.

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The Peripheral Visual Cue Assessment Facility at Ames Research Center

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Introduction:

A great deal of time and effort have been expended over the years to gain a better understanding of what extra-cockpit visual information pilots use to initiate manual control inputs. This effort has been expended in flight simulators as well as in flight and has provided some valuable insights into various subject areas discussed in detail elsewhere (AGARD, 1981). In both simulators outfitted with advanced, computer-generated scenes and actual aircraft there is usually a rich array of constantly moving optical information from which the observer must extract relevant information in order to carry out his various tasks. Because of the amount and complexity of this array of information it is extremely difficult to know precisely which cue or set of cues led to which response. Similarly, because flight vectors may be considered in terms of their various linear, orthogonal components (e.g., glide slope is a resultant of forward velocity and descent

rate) there is a natural confounding interaction that takes place. Warren and Owen (1982) and Owen et al. (1981) have commented on this matter at some length. The Peripheral Visual Cue Assessment Facility (PVCAL) was established to study various responses to controlled dynamic stimuli that could be considered as visual analogs of some real-world counterpart such as the horizon. Careful stimulus control permits specific responses to be traced to specific stimulus dynamics.

Another basic objective for establishing this facility was to be able to quantify the ability of the visual system to assess various kinds of stimulus motion. A major emphasis is upon the peripheral visual field, however, since the author believes that this area has been sorely neglected yet very probably plays an important role in a pilot's assessment of where he is in space, where he is going, how fast he is travelling, and what angular and linear rates of movement are taking place. The facility was designed to be able to carry out carefully controlled psychophysical vision research over a wide angular range.

The Peripheral Visual Cue Assessment Facility:

This facility comprises three separate collimated optical display units driven by an Evans and Sutherland picture system II. A PDP 11/60 digital computer is used to derive the specific motion

dynamics of interest for the picture system. Figure 1 presents a block diagram of the major systems. Data from the response panel is output via a disc to a printer and plotter. The response panel permits each observer to initiate each trial.

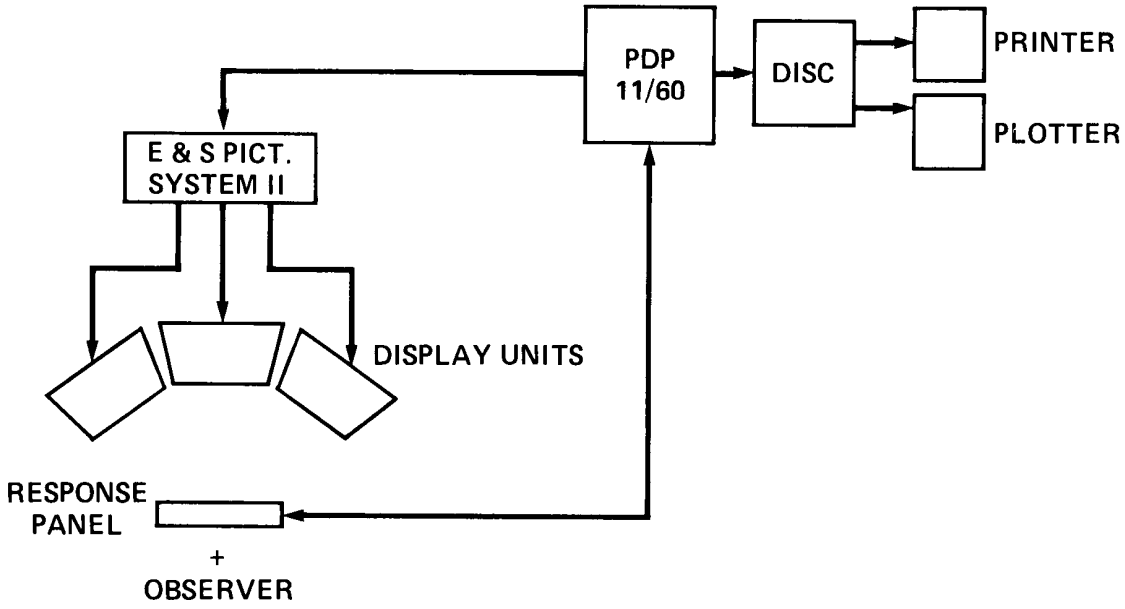

Figure 1. Block diagram of major systems.

Figure 2 illustrates the spatial relationships existing among the three 25-inch focal length mirror-beam splitter optical display units in plan view. Each unit incorporates a 25-inch (diagonal) Zytron stroke monitor.

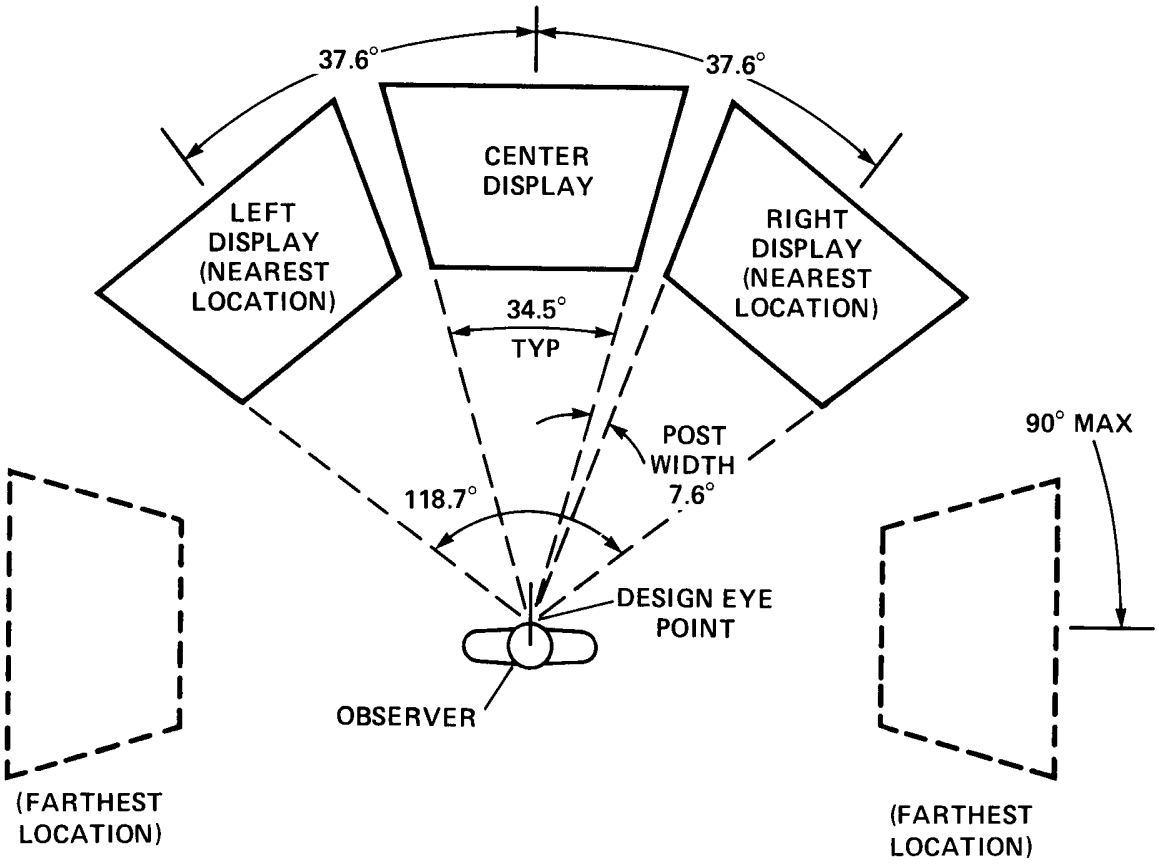

Figure 2. Illustration of display layout/angles.

Referring to Figure 2, each display unit subtends a total (binocular) field of view (FOV) of 34.5 deg (0.602 rad) in width with a minimum post width between displays of 7.6 deg (0.132 rad). With the three displays located next to each other a total horizontal angle of 118.7 deg (2.072 rad) is subtended. The measured instantaneous FOV width of each display is 31.7 deg (0.553 rad). The vertical angle subtended by each unit is 21.9 deg (0.382 rad). The right-hand display can be repositioned as far as 90 deg (1.570 rad) to the right (left-hand unit similarly to the left) through the

use of rigid pivotal "radius bars" attaching the two side displays to the observer's seat. This pivot point lies directly beneath the design eye point (DEP) of the three displays. The optical focal distance of the stimulus line(s) was found to be at apparent optical infinity (-0.01 diopter) within the central 80 percent of each display's FOV as measured with a precision dioptometer located at the DEP. A Hilger-Watts No. 2 Microptic theodolite was used to measure all angles. A single, stroke-drawn line subtends an angle of 0.033 deg (0.58 mrad) width at the DEP.

Concerning stimulus luminance and contrasts within the FOV, the stroke-written line(s) has an eight bit intensity resolution with an independent contrast adjustment. Initial calibrations have shown that stimulus intensities ranging from about 0.1 to 3.7 $\log_{10}$ units neutral density above the eye's absolute, central visual field light threshold are attainable. In order to provide an illuminance upon the front of the three displays that is approximately equivalent to twilight, two 20 watt tungsten incandescent lamps are mounted in front of and to each side of the observer. Light shields prevent illumination from falling on the observer; it is necessary to maintain the observer in darkness in order to prevent reflections from being seen in the spherical mirrors of the displays. The contrast of black diffuse metal surrounding frames and the dynamic display area can be adjusted

between zero and 0.66 where contrast is defined as surround (metal frame) luminance minus display area luminance divided by display area luminance.

Use of an optical display system using mirror-beam splitter collimation requires strict control of ambient illuminance to prevent unwanted static and dynamic reflections. This is no small task; the observer's region should be kept in relative darkness during testing.

Figure 3 is a photograph of the three display units. It was taken just behind and to the right of the DEP (defined by the plumb bob). An aircraft seat that may be adjusted both fore and aft as well as vertically is used to place the eyes at the DEP.

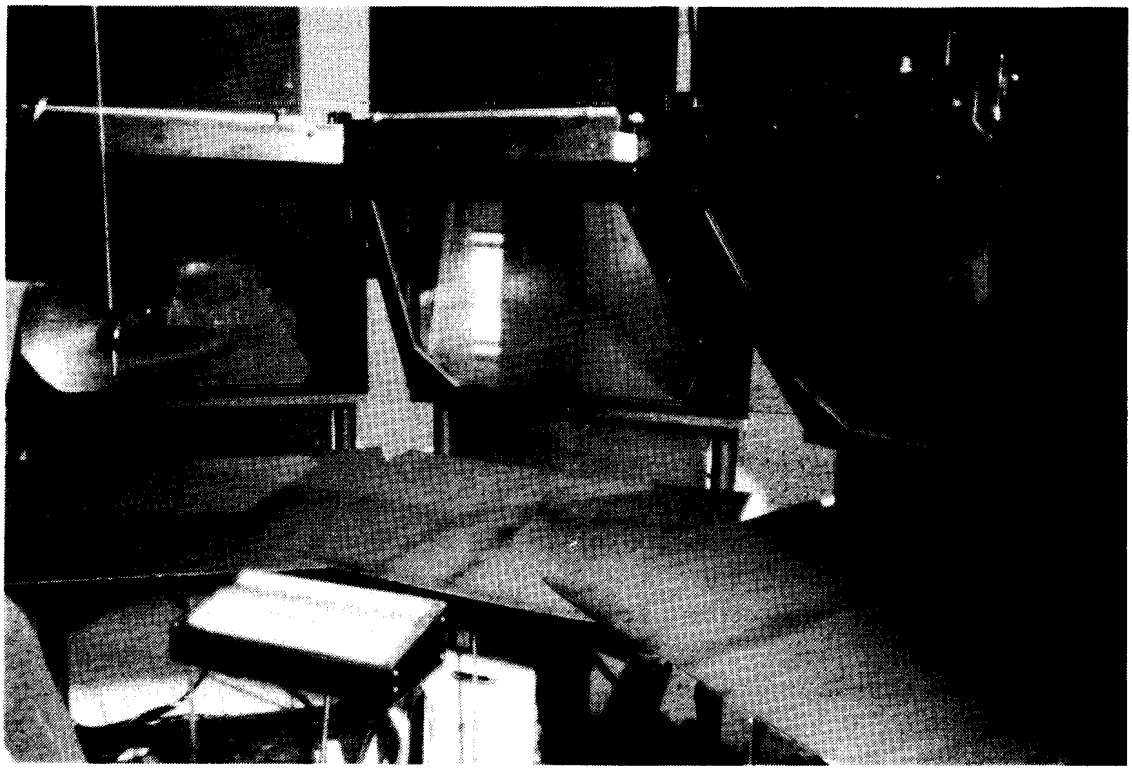

Figure 3. Photograph of three collimating display units.

Painted panels (diffuse black) are located beneath each beam splitter glass to prevent nearby objects from becoming visible. The observer's response panel is seen below and to the right of the plumb bob (white rectangular panel). All areas between and around the three display units are masked with black cloth.

Located beneath the center beam splitter is a low light level TV camera aimed at the observer's face. This device makes it possible to monitor head and eye location during testing. A padded head rest is used to maintain a stable head position. A preliminary investigation has found that the eyes may be as much as 2.5 cm above or 2.5 cm below the DEP without significantly influencing angular judgments of pitch displacement of a simulated earth horizon.

Several initial studies have been conducted to date and the equipment and computer programs have been found to afford highly flexible control of the dynamic stimuli in the spatial and temporal domains.

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EVALUATION OF THE MALCOLM HORIZON IN A MOVING-BASE FLIGHT SIMULATOR

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The Malcolm horizon (MH) provides a pilot with pitch and bank orientation information by projecting an artificial horizon across the instrument panel of his aircraft (1) (Fig. 1). This mode of presentation theoretically allows orientation information to be processed by peripheral (ambient) vision in the natural fashion, thus reducing the likelihood of spatial disorientation and sparing foveal (focal) vision for other tasks, thereby reducing workload and improving performance (2). It was our objective to demonstrate the efficacy of the MH in a controlled, simulated, instrument flight environment.

METHOD A Garrett/Varian Model B laser MH was installed in a Singer/Link GAT-3 (USAF T-40) flight simulator, with the MH projector located in the ceiling directly above the pilot's head (Fig. 2). The GAT-3 simulates the North American Sabreliner (USAF T-39) business jet, and has a two degree-of-freedom (pitch and roll) motion system that employs washout, washback, and scaling to create a fairly realistic feeling of instrument flight. Fourteen pilots, 7 USAF and 7 civilian with instrument rating, served as subjects. Although the pilots in this group could generally be classified as inactive or flying infrequently, they had a mean of 1700 hr of pilot time with 330 hr of instrument flying and 130 hr of simulator time. The subjects were allowed to practice ad lib the TACAN RWY 33 approach to Kelly AFB; after about two hours of practice in each mode they felt they were "ready for the check ride" and were tested on the VOR RWY 33 approach, which was similar to the TACAN approach.

To balance the potential order effect, 7 subjects were tested first using the MH plus the conventional instruments (experimental condition) and then tested with conventional instruments only (control condition); the other 7 were tested in the reverse order. Mean squared error (MSE) and mean absolute error (MAE) measurements of deviation from desired values for each of 8 flight parameters were used to compare performance during the experimental condition with that during the control condition. These parameters were: pitch attitude (PA), roll attitude (RA), turn rate (TR), airspeed (AS), vertical velocity (VV), heading (HE), altitude (AL), and course deviation (CD). One-tailed paired t-tests were employed in the preliminary statistical analysis, reported here. When each subject had completed testing under both the experimental and control conditions, his solicited comments on the positive and negative aspects of the MH were recorded.

In addition to the 14 subjects described, a NASA test pilot was subjected to the test protocol, first in the experimental and then in the control condition. As his flying was frequent and regular, and his level of sophistication was presumably greater than that of the other subjects, we felt it appropriate and instructive to present his results separately.

RESULTS Data from two portions of the instrument approach have been analyzed. The first portion is the approximately 6-min segment from completion of the procedure turn to the missed-approach point. The second is a 1-min segment between final approach fix and missed-approach point during which task loading was increased markedly by having the subject change communications transceiver frequency and transponder code. These tasks required the subject to abandon his instrument scan temporarily, as the transceiver was to the right of the flight instruments and the transponder was on a pedestal below his right thigh. During the 6-min segment of the approach (Table I) the

subjects exerted much better control over vertical velocity when using the MH than when using conventional instruments only, and pitch attitude deviations were significantly less at the $p<0.10$ level. (Airspeed deviation comparisons are not presented in Table I because subjects reduced airspeed at their discretion during the middle portion of the 6-min segment. Moreover, the altitude deviation measurements are to be read with caution, as digitization errors account for a substantial portion of these data and have necessitated additional analysis.) The subjects' performance on the 1-min segment with high task loading (Table II) was again characterized by better control over pitch attitude when the MH was used, but vertical velocity control was not significantly better with the MH on this segment. In addition, control of course deviation was worse, although heading was significantly more stable at the $p<0.10$ level.

The test pilot's performance on the 6-min and 1-min segments are presented in Tables III and IV, respectively. His control of pitch attitude and vertical velocity was consistently better with the MH than without (Fig. 3). On the other hand, his heading deviations were greater with the MH, and his airspeed control on the 1-min segment was worse with the MH.

All of the subjects praised the MH for its ability to provide rapid indication of pitch deviations; its ability to provide rapid bank information was mentioned less frequently. A number of subjects felt a heading reference on the projected horizon would make the MH considerably more useful. Negative comments were to the effect that the horizon is too narrow; a sky pointer is needed; the flicker and specular reflections are irritating; and that pitch sensitivity is too great, even though the MH used in this study was set at the lowest of three pitch sensitivity levels. All subjects felt that the MH functions as a large, sensitive, attitude indicator, rather than as a provider of

primary orientation cues through peripheral vision. Some thought that making the projected horizon longer and adding heading reference lines might promote the latter function, however.

DISCUSSION The subjects felt the MH gave them better control over pitch attitude, and their performance bore this out. The highly significant improvement in vertical velocity control associated with use of the MH in the 6-min approach segment is a manifestation of their better control of pitch attitude. Why the improved pitch attitude control did not result in improved vertical velocity control in the 1-min segment is perhaps explicable: the forced disruption of the instrument crosscheck during this segment prevented the subjects from using pitch control inputs to effect vertical velocity control responses, and they merely stabilized pitch attitude with the MH. The reasons for the inconsistent results relating to heading and course deviation are not readily apparent.

The MH concept is sound. Testing of a commercial realization of this concept in a flight simulator has revealed certain strengths and weaknesses of the currently available MH hardware. Further statistical analyses of the data acquired in the present study, as well as additional studies in different flight environments, are required to ensure a complete understanding of the potential utility of the MH as an aid to flying.

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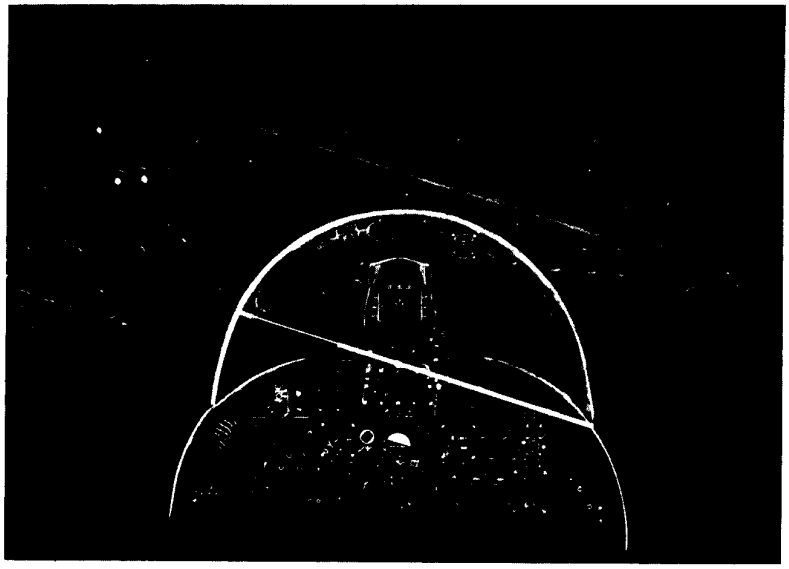

Figure 1. The Malcolm horizon, projected on the instrument panel, indicating a nose-down left bank.

Figure 2. The MH projector in the simulator (above the subject's head).

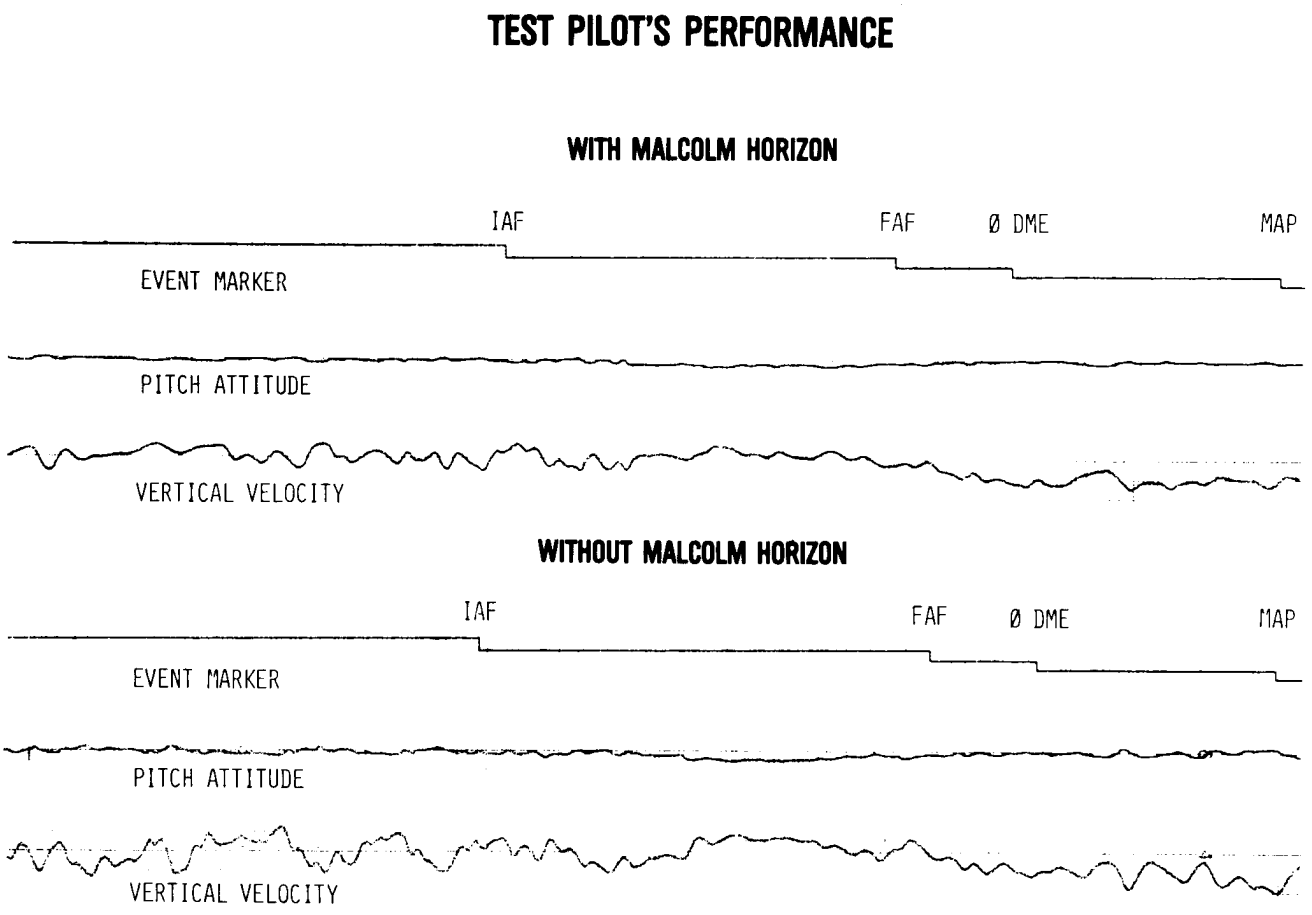

Figure 3. Test pilot's pitch-attitude and vertical-velocity performance, using the Malcolm horizon plus conventional instruments (above) and using conventional instruments only (below).

TABLE I. PERFORMANCE OF 14 SUBJECTS ON 6-MINUTE SEGMENT OF INSTRUMENT APPROACH

Flight Parameter	MSE			MAE		
	MH + Conventional $\bar{X}$ ± SEM	Conventional $\bar{X}$ ± SEM	p	MH + Conventional $\bar{X}$ ± SEM	Conventional X ± SEM	p
PA	2.22 ± 0.21	4.27 ± 1.34	<0.10	1.17 ± 0.07	1.55 ± 0.24	<0.10
RA	153 ± 8	146 ± 19	NS	10.7 ± 0.3	10.0 ± 0.9	NS
TR	1.79 ± 0.05	1.85 ± 0.12	NS	1.21 ± 0.01	1.23 ± 0.02	NS
AS	---	---	--	---	---	--
VV	53,800 ± 6,300	78,200 ± 10,100	<0.005	176 ± 8	209 ± 10	<0.0025
HE	49.9 ± 9.2	56.5 ± 9.0	NS	5.5 ± 0.5	5.9 ± 0.4	NS
AL	(79,600 ± 16,100)	(93,800 ± 31,500)	(NS)	(243 ± 28)	(262 ± 39)	(NS)
CD	147 ± 9	132 ± 13	NS	11.9 ± 0.4	11.2 ± 0.6	NS

TABLE II. PERFORMANCE OF 14 SUBJECTS ON 1-MINUTE SEGMENT WITH HIGH TASK LOADING

Flight Parameter	MSE			MAE		
	MH + Conventional $\bar{X}$ ± SEM	Conventional $\bar{X}$ ± SEM	p	MH + Conventional $\bar{X}$ ± SEM	Conventional $\bar{X}$ ± SEM	p
PA	1.93 ± 0.48	5.11 ± 1.76	<0.05	1.05 ± 0.15	1.65 ± 0.31	<0.05
RA	141 ± 9	138 ± 20	NS	10.5 ± 0.3	9.8 ± 0.9	NS
TR	1.75 ± 0.10	1.90 ± 0.16	NS	1.20 ± 0.03	1.24 ± 0.04	NS
AS	890 ± 92	898 ± 84	NS	28.8 ± 1.6	29.3 ± 1.3	NS
VV	68,500 ± 11,500	71,000 ± 10,100	NS	209 ± 72	222 ± 71	NS
HE	46.8 ± 13.6	97.3 ± 31.7	<0.10	5.3 ± 0.8	7.6 ± 1.3	<0.10
AL	(110,200 ± 39,100)	(113,000 ± 48,200)	(NS)	(287 ± 45)	(269 ± 55)	(NS)
CD	156 ± 9	131 ± 15	<-0.05	12.4 ± 0.4	11.2 ± 0.7	<-0.05

TABLE III. PERFORMANCE OF TEST PILOT ON 6-MINUTE SEGMENT OF INSTRUMENT APROACH

Flight Parameter	MSE			MAE		
	MH + Conventional	Conventional	% Diff	MH + Conventional	Conventional	% Diff
PA	1.62	3.55	-54	1.10	1.45	-24
RA	177	177	0	11.4	11.8	-3
TR	1.72	1.87	-8	1.19	1.20	-1
AS	---	---	---	----	----	---
VV	37,300	79,100	-53	158	237	-33
HE	349	183	91	15.0	10.5	43
AL	(123,000)	(180,700)	(-32)	(342)	(413)	(-17)
CD	133	178	-25	10.5	12.3	-15

TABLE IV. PERFORMANCE OF TEST PILOT ON 1-MINUTE SEGMENT WITH HIGH TASK LOADING

Flight Parameter	MSE			MAE		
	MH + Conventional	Conventional	% Diff	MH + Conventional	Conventional	% Diff
PA	1.46	2.26	-35	1.07	1.15	-7
RA	150	264	-43	11.2	12.7	-12
TR	1.61	2.70	-40	1.16	1.35	-14
AS	1194	785	52	34.4	27.9	23
VV	26,600	40,300	-34	143	162	-12
HE	146	56	161	10.8	7.1	52
AL	(126,900)	(132,600)	(-4)	(354)	(363)	(-2)
CD	227	218	4	14.9	14.7	1

EFFECTS OF FOVEAL INFORMATION PROCESSING

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INTRODUCTION

The art of oculometry has progressed a long way from the days of Jones, et.al., 1946, when they determined a pilot's lookpoint by subjectively judging motion pictures of a pilot's face frame by frame. Today, we have the ability to record a pilot's lookpoint with an accuracy of a dime's diameter on the instrument panel. These data are computer generated and recorded at a rate of 30 times a second. The technique (fig. 1) which allows this is to shine an infrared beam of light into the pilot's eye. Two reflections are returned to a video camera. The first is a broad (4 to 8 mm) reflection of the pupil, much like a cat's eye reflection from car headlights. The second is an intense pinpoint reflection from the surface of the cornea. From the video picture the computer determines the centers of each reflection and, based upon their relative positions, calculates the pilot's foveal lookpoint on the instrument panel. These lookpoint coordinates and pupil diameter are recorded for subsequent analysis. This paper will summarize the results of seven years of collecting and analyzing pilot scanning data.

SCANNING BEHAVIOR

Scanning is Subconscious

First of all, scanning by a pilot is a subconscious conditioned activity. Scanning becomes automatic for a pilot and this is the way it should be. If a pilot had to consciously think "I need altitude information, eyes look at the altimeter," the pilot would not function well in an aircraft cockpit. Since scanning is automatic for pilots, pilots are unreliable information sources concerning how they scan. Many myths have arisen as to how pilots gather information. One pilot has said, "I look between the attitude and directional gyro, defocus, and take everything in peripherally." Another has said, "I look at the instruments in a circular pattern." And some will say, "I never look at the altimeter. I get that information in my periphery." However, the data (Spady, 1978) indicates that in scanning, pilots have a home base (spending as much as 75% of their time there) – the attitude indicator. Looks at other instruments are made aperiodically as they have time to look at them for cross checks, then back to home base. There is no simple pattern to the sequence of looks at these other instruments. These looks may be dictated by several conditions such as uncertainty, need for more precise control, need to make an input to change aircraft state soon, etc.

Scanning Can Be Disrupted

If pilots are forced to "think" about something – that is, make a conscious decision – their scanning is disrupted. This causes the pilots to "stare" (Tole, 1982) at the instrument panel (generally the home base). This "staring" phenomena is worse with less experienced pilots (some "stare" as long as 10 to 15 seconds). Figure 2 shows the breakdown of the dwell histogram as cognitive tasks are forced upon the pilot. In this context a dwell is the continuous time spent looking at a particular instrument. The left figure shows a typical dwell histogram with a peak at about 0.5 seconds with a long tail out to about 2.5 seconds. The right figure no longer shows the peak at 0.5 seconds and many dwells longer than 5 seconds are plotted at the 5 seconds position at the right of the pilot. Not only do the less experienced pilots "stare" but their sequence of looking at the various instruments changes. Figure 3 shows what happens to the 10 most frequent scan sequences (a sequence in this case is the consecutive sequence of four instrument dwells) as a cognitive task is increased. Pilots 4 & 11 are the more experienced and pilot 9 is the least experienced. This disruption in scanning sequences lends credence to the hypothesis of being able to develop the ability to time share, which the more experienced pilots apparently have done. This is much like the situation of piano playing. If a person is very experienced he can play and carry on a conversation at the same time (pilots 4 and 11 have the same percentages for all mental loading conditions), but if he is a novice, he can do one or the other but not both (pilots 5, 9, and 10 decrease the percentage of the 10 most used under the no mental loading condition).

Scanning is Situation Dependent

The conditioned activity of scanning is different for each pilot. That is, the dwell percentages (percent of scanning time looking at an instrument), average dwell times (total time looking at an instrument divided by total number of looks at that instrument), and the sequences of scanning each instrument are different for each pilot. There is also a slight variation between test runs of the same conditions for each pilot. This indicates that scanning is situation-dependent. We do know, for instance, that if a pilot changes from an active controller to a system monitor his scanning behavior is different (Spady, 1978). As a controller, his percent and average dwell time on home base is increased with fewer looks at peripheral instruments. This is because his role has changed his information requirements. More information is needed to make control inputs than to monitor the position of needles (this is reflected in longer dwells). When dwells are classified (Harris, 1980) as monitoring or controlling dwells (no movement of controls or movement of controls, respectively), the longer dwell times associated with monitoring becomes evident even when the pilot is making control inputs as needed.

The dwell histograms for monitoring and controlling are shown in figure 4. Controlling dwells can even be further classified by the number of control inputs being made during a dwell. The more the number of inputs, the longer the dwell. Figure 4 shows the histograms for 1 and 2 control inputs. The monitoring dwells are the shortest in duration and generally tend to be double peaked. This indicates that at least two processes are active in monitoring. Estimates of these two monitoring distributions are shown in figure 4 (Harris, 1980). It is believed that the shorter dwell, called glances, are what pilots are talking about when they say they are looking at instruments peripherally. They actually make a saccade to the instrument but they only want to know the orientation (o'clock position) of the needle. The longer dwells, called reads, are those dwells which are used to obtain more detailed information such as the actual position of the needle and perhaps information about rate

of needle movement. As can be seen, these two curves overlap each other. This overlap prohibits us from knowing whether a dwell in the overlap region is a glance or a read. Therefore, we are forced to plot only one curve of all monitoring dwells.

Rate of Information Transfer

The relative amplitude of the glance peak (Harris, 1982 and Harris, 1981) has been found to be sensitive to the ability of the display to transfer information rapidly. For instance, figure 5 shows two monitoring dwell histograms. The solid one is the histogram for a conventional type of directional gyro. This type of display is a fixed pointer, generally the nose of an airplane outline, with a moving scale. However, the dotted line is the histogram for the same type of display with the addition of a movable index which can be placed on the movable scale at the desired aircraft heading. This gives an immediate indication of heading error and displacement of the index from the airplane's nose to the pilot. Consequently there are a lot more short dwells and fewer long dwells. Also notice that the read peak is shortened with the index present 0.4 versus 0.5 seconds.

Advanced Techniques

Finally, we have been trying to develop testing techniques and scanning analysis techniques that are sensitive to workload. One of the more promising testing and analysis techniques is one in which a side task is introduced, not to measure spare time, but to occupy or rob time from the pilot. The side task chosen is a number pattern recognition task (Tole, 1982). A series of three digits are presented aurally (0.75 seconds between digits). The pilot's task is to classify the triplet as positive or negative. A positive set would be a triplet whose first digit was lowest and last digit highest (e.g., 3-4-8) or whose first digit was highest and middle digit was lowest (e.g., 7-2-5). All other patterns are negative. The difficulty can be adjusted by varying the time interval between triplets. The reciprocal of the time interval is called the rate of presentation. The analysis of the eye scanning data is an offshoot from information theory. The entropy or randomness of the scanning is calculated. The entropy is then used with the dwell times to calculate an entropy rate.

These techniques were used to evaluate differences between two types of vertical speed indicators (Harris, 1982). One was the conventional round dial and the second was a vertical bar graph type. Pilot opinion was mixed as to which display was better. Figure 6 is a plot of the entropy rate of scanning for each display configuration plotted against the rate of presentation of the number triplet side task. As can be seen, there is only a very slight difference between the curves. This small difference corresponds to the mixed subjective evaluations. In both cases, as the rate of presentation is increased the entropy rate decreased. An exponential curve was fit to the data. As shown on the figure, the difference between the curves is a bias constant in the exponential term. This constant shifts the curve along the abscissa. The bias term was zero for the vertical vertical-speed indicator and 0.045 for the conventional vertical-speed indicator. This indicates that if the scanning workload of the two situations were to be made equal, then when flying with the vertical vertical-speed indicator the pilot would also have to be answering triplets at a rate of once every 22 seconds. This is not a very heavy workload difference and explains the reason that subjectively it was hard to discriminate. But it does show that the vertical vertical-speed indicator would be preferable in cases where workload was going to be high.

CONCLUDING REMARKS

A lot of progress has been made in the past several years in understanding the scanning behavior of pilots. However, there are still a lot of unknowns about scanning and the next several years should unravel some of these unknowns. A whole new era of display formats are forthcoming that will challenge us to unravel these unknowns so that cockpit displays can be assembled which will provide the most information accurately and quickly to the pilot so that he may perform safely all the tasks assigned to him.

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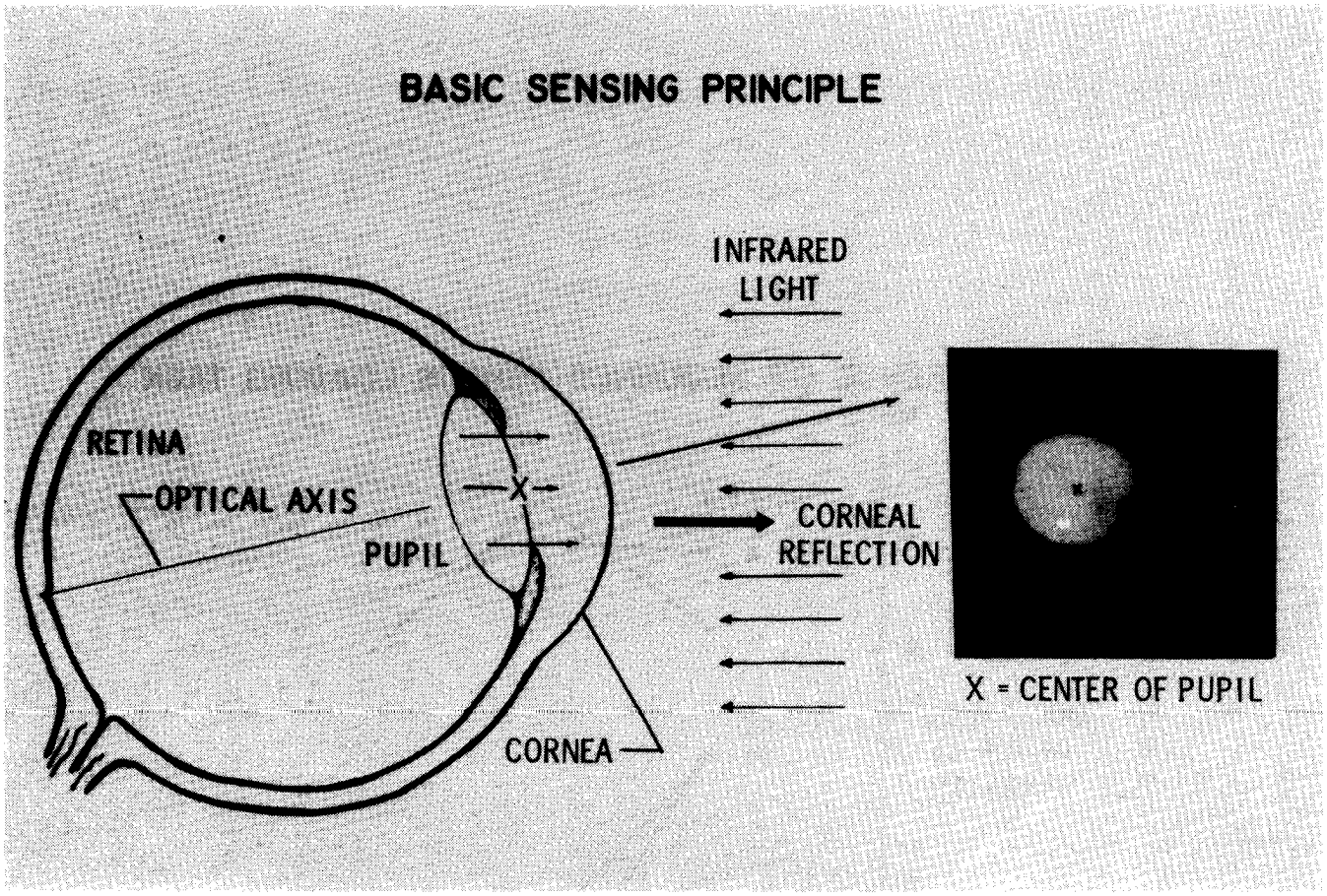

Figure 1

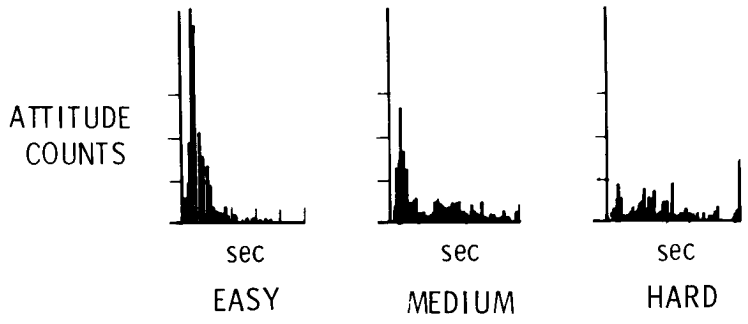

Figure 2

PERCENT OCCURRENCE OF SEQUENCE VERSUS LOADING TASK

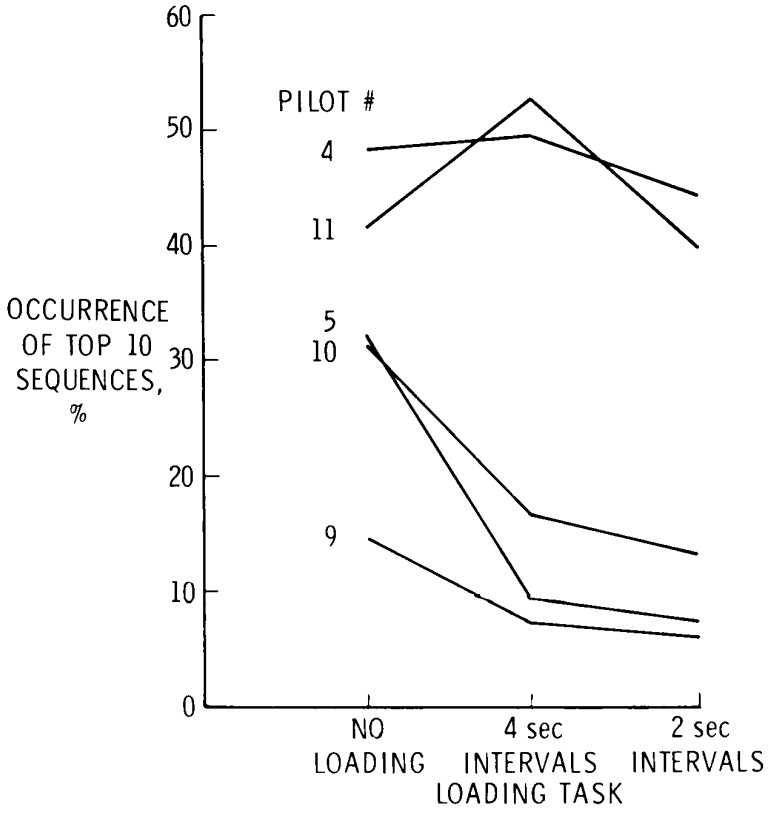

Figure 3

DWELL DISTRIBUTIONS

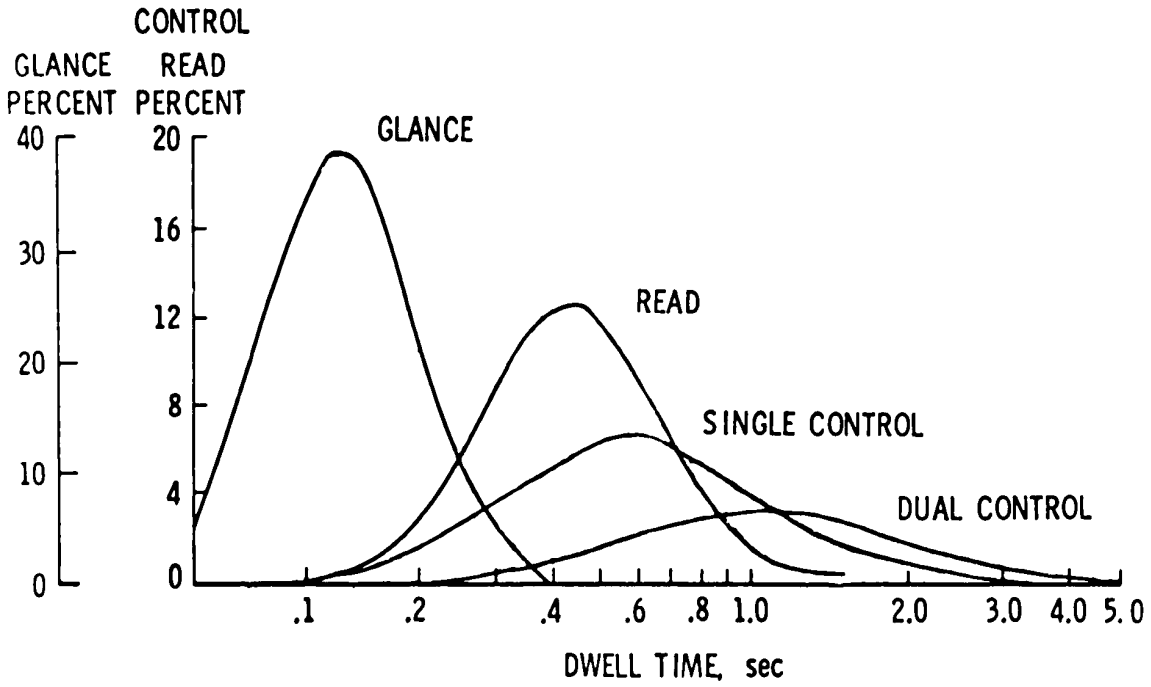

Figure 4

DIRECTIONAL GYRO MONITORING DWELL HISTOGRAM

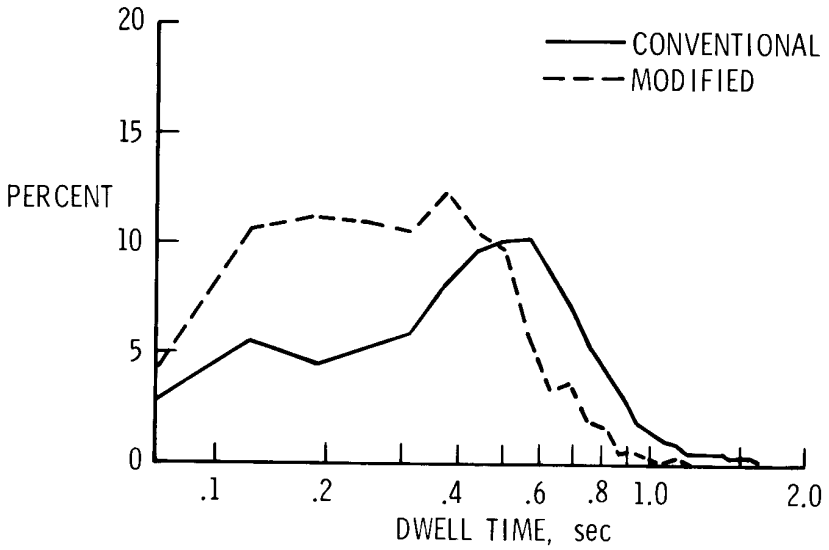

Figure 5

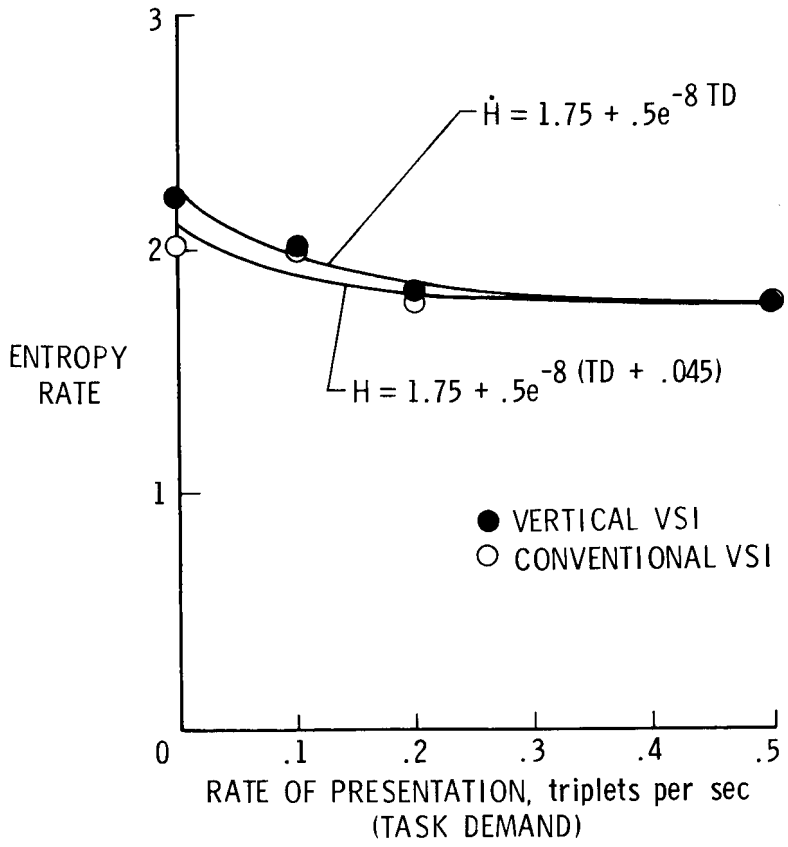
3
2
1
0
ENTROPY RATE
$\dot{H} = 1.75 + .5e^{-8\,TD}$
$H = 1.75 + .5e^{-8\,(TD + .045)}$
VERTICAL VSI
CONVENTIONAL VSI
.1
.2
.3
.4
.5
RATE OF PRESENTATION, triplets per sec
(TASK DEMAND)

Figure 6

Paper 9

PERIPHERAL VISION HORIZON DISPLAY ON THE SINGLE SEAT NIGHT ATTACK A-10

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INTRODUCTION

The concept of the peripheral vision horizon display (PVHD) held promise for significant reduction in workload for the single seat night attack pilot. For this reason it was incorporated in the single seat night attack (SSNA) A-10. This paper presents a discussion of the implementation and results of the PVHD on the SSNA A-10. The paper will briefly discuss the SSNA program, then give a description of the part the PVHD played in the test and the results and conclusions of that effort.

SSNA A-10 PROGRAM

The SSNA A-10 program was an outgrowth of previous night attack testing on the A-10. In the late 70's Fairchild Republic Company conducted a company funded effort to create a night attack variant of the A-10 close air support aircraft. In this original concept an A-10A was modified to allow a second crewmember, and a night attack systems suite was developed for two-man operation. This aircraft underwent extensive company and Air Force testing and it was found that the aircraft had significant capability. However, the Air Force expressed interest in determining the capability of a single seat variant of the same night attack system. In 1982 the aircraft was modified to provide a highly integrated front cockpit with complete control of all aircraft systems. The rear cockpit was retained as a safety observer's station and for control of the aircraft instrumentation systems. The night attack systems aboard the aircraft included a FLIR with snap-look and narrow field-of-view which could be presented on the head-up display (HUD). A terrain following/terrain avoidance multi-mode radar included could also simultaneously provide a ground map or ground moving target indicator display. Navigation was aided by an inertial navigation system and progress could be monitored on an electronic moving map display. The system included a laser ranger and a radar altimeter. The AGM-65D imaging infrared Maverick missile was used as ordnance. A PVHD was installed on the right canopy rail of the front cockpit.

The SSNA test was primarily a workload study of the job of single seat, low level, night attack. The test was broken up into several phases. An avionics test phase was used to conduct a limited test of the aircraft systems. A training phase allowed the project pilots to get familiar with the SSNA systems. The heart of the project, the workload testing, was conducted in three phases. First, the workload associated with the basic tasks of night attack was investigated. In the second workload phase the basic tasks were combined to form realistic workload levels for the SSNA job. Lastly, simulated typical night attack profiles such as interdiction and close air support were flown. In all, over 30 sorties were flown under very dynamic conditions, low altitude, at night.

THE PVHD IN THE SSNA TEST

The PVHD system was introduced as part of the SSNA suite in response to two areas. First, the job of maintaining attitude awareness at low altitude at night is one of the major workload drivers of the SSNA mission. Stress, another facet of workload, was generated by concern over attitude awareness. It was hoped that the PVHD would alleviate some of the workload associated with maintaining attitude, and provide the pilot with a stress reducing confidence in his attitude awareness.

The SSNA test did not include a direct effort to determine the value of the PVHD system. Specific testing with the PVHD did include a system operation checkout and familiarization flight for each of the SSNA project pilots. In general the PVHD was treated as one of a number of systems upon which the pilot could rely to do his job. The PVHD was used at the pilot's discretion on the remaining SSNA workload missions.

RESULTS

The tests found that the PVHD did function as designed. There was adequate control of brightness to suit the night mission. The pitching and rolling response of the system was in agreement with the aircraft motion. The alerting feature at maximum travel activated properly. The 1 to 1 pitch scale factor was found to be suitable for the night attack mission.

Though the PVHD functioned properly, a number of problems were associated with the installation of the system. The design display area was located low on the main instrument panel. This area was selected because the upper area of the panel was occupied by two CRT multifunction displays (MFDs). The first problem was caused by the fact that the main instrument panel was built in two sections with the lower section slightly recessed from the upper. In addition, the PVHD was mounted about shoulder height on the canopy rail. As a result of this geometry, it was possible for the horizon line to be displayed just below the upper portion of the instrument panel in an area at the top of the lower section of the panel which was not directly in the pilot's line of sight. Unfortunately, although only a very small area was not visible to the pilot, this was the location where the horizon line would be displayed with the system initialized in the normal manner and the aircraft at nominal operating speeds. The next problem with this low display area was that substantial portions of the area were blocked from the pilot's vision by the stick and the pilot's arm. The pilot's peripheral vision of this area was also reduced by his oxygen mask. In effect, much of the display area was not in the pilot's peripheral vision. In an effort to overcome these problems associated with the low display area, the nominal position of the horizon line was moved to a position much higher in the pilot's peripheral vision in the middle of the upper instrument panel. There were problems associated with this location as well. The actual range of the PVHD motion could not be changed to accommodate this location. The problem was that although the nominal position could be displayed, the horizon line could only move a very limited distance up (pitch down direction) before it reached the limits of its travel. The actual display area in this upper location was limited in width because the beam could only be seen on a narrow HUD control panel located between the two MFDs in the upper instrument panel. The beam could not be seen on the surface of the MFDs. The geometry of the PVHD installation and the location of the right MFD put it in perfect position to cause a major reflection into the pilot's eyes of the laser beam when the upper display area was used. This bright red light was very distracting to the pilot. In summary, no suitable location could be found to present the PVHD horizon line in the SSNA cockpit.

The effect of these problems, associated with the installation of the PVHD, was that the desired benefits of the system were not accrued. Most pilots gave the system one or two flights, then deemed the problems to outweigh the value and turned the system off. This amount of exposure to the system was not felt to be adequate to arrive at any meaningful conclusions about the operational utility of the system.

The last result that will be discussed is not directly associated with the PVHD system. Though the majority of SSNA operations were conducted at night, frequently with overcast or no moon conditions, the pilots did not have a major problem with attitude orientation. This result is primarily attributed to the use of the FLIR presentation on the HUD. The HUD display was 16 degrees wide. Though not as wide as the desired use of the PVHD, this does extend significantly into the pilot's peripheral vision. (Future HUD displays will be even wider; e.g., the LANTIRN HUD, 30 degrees.) The FLIR provides a natural horizon which the HUD reinforces with the horizon line symbol. The FLIR picture also provides surface texture from which the pilot can gain peripheral cues of altitude, attitude, and translation. Testing is warranted to determine the necessity of a PVHD system given the availability of a HUD/FLIR combination.

CONCLUSIONS

The most obvious conclusion that can be drawn from the SSNA experience with the PVHD system is the difficulty in achieving a suitable installation in a fighter type cockpit. Innumerable major and minor problems seem to crop up to defeat the efforts of the design engineers to successfully install the PVHD.

As a result of compromises for the sake of installation, a less than desirable display area might seem necessary in order to use the PVHD. Though only common sense, it bears stating that a peripheral vision horizon display that is not in the pilot's peripheral vision does not have much utility.

The SSNA project pilots did not have significant problems with attitude awareness. This was attributed to the constant use by the pilots of the FLIR presentation on the HUD. The value of this FLIR/HUD combination in satisfying the needs for a PVHD should be investigated.

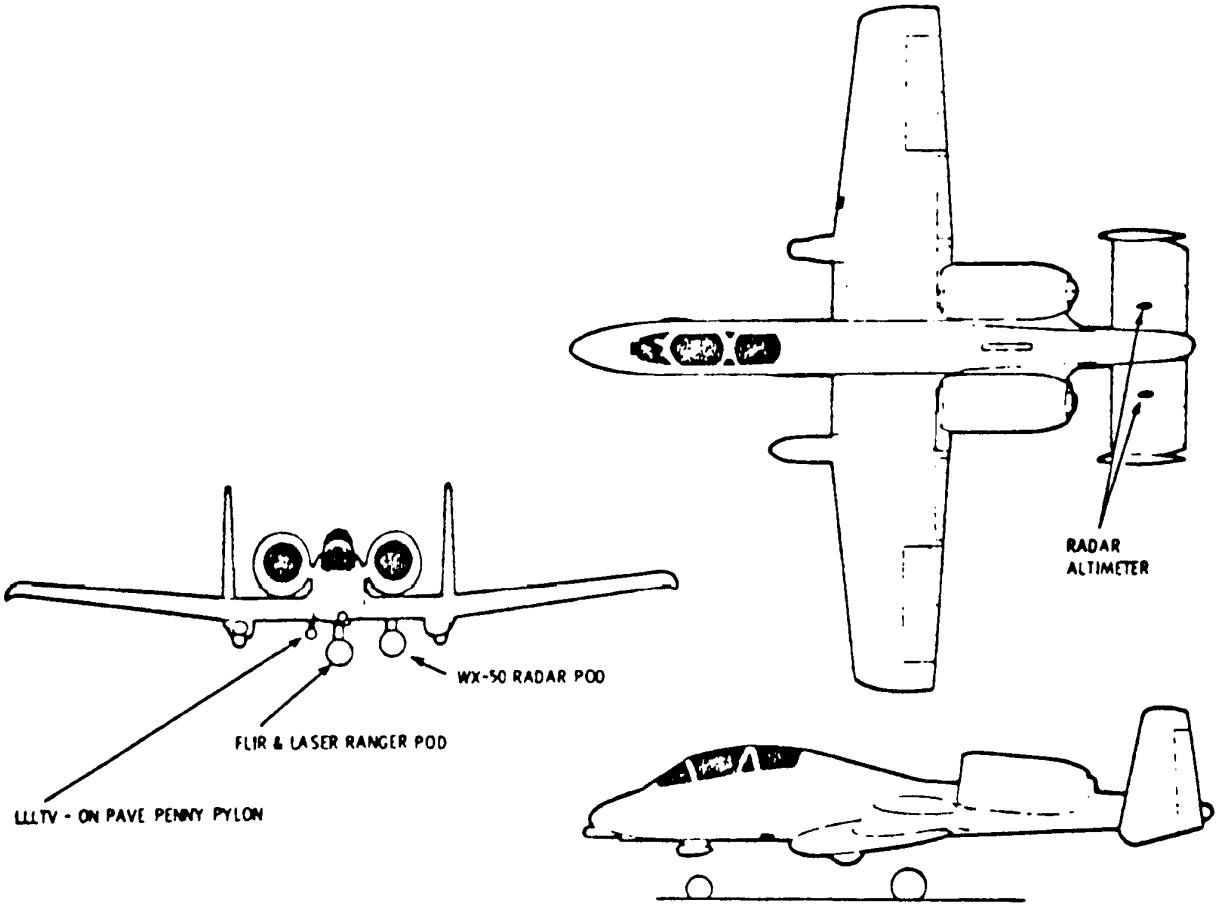

Figure 1
SSNA YA-10B EXTERNAL CONFIGURATION

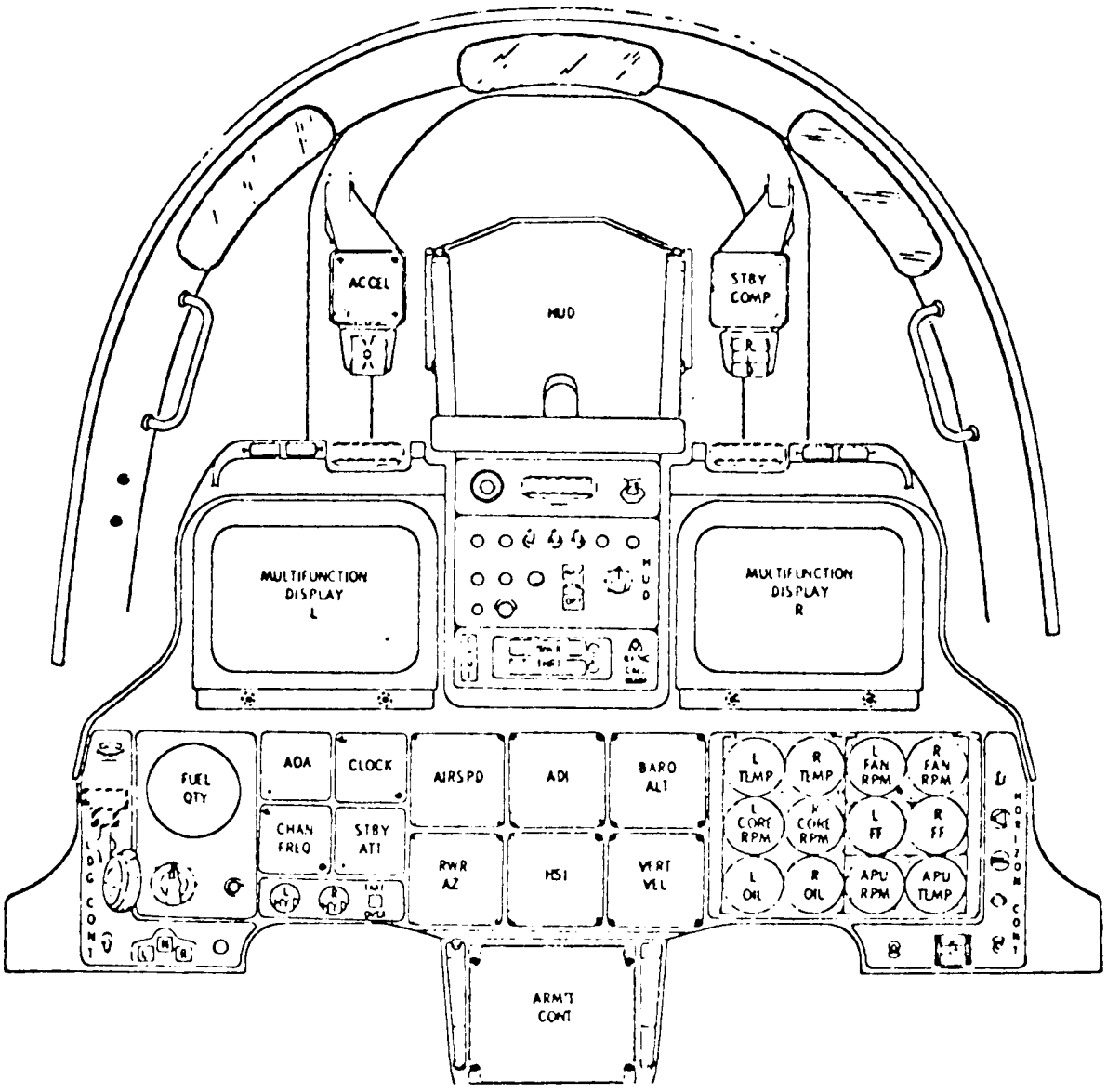

Figure 2
FRONT COCKPIT INSTRUMENT PANEL

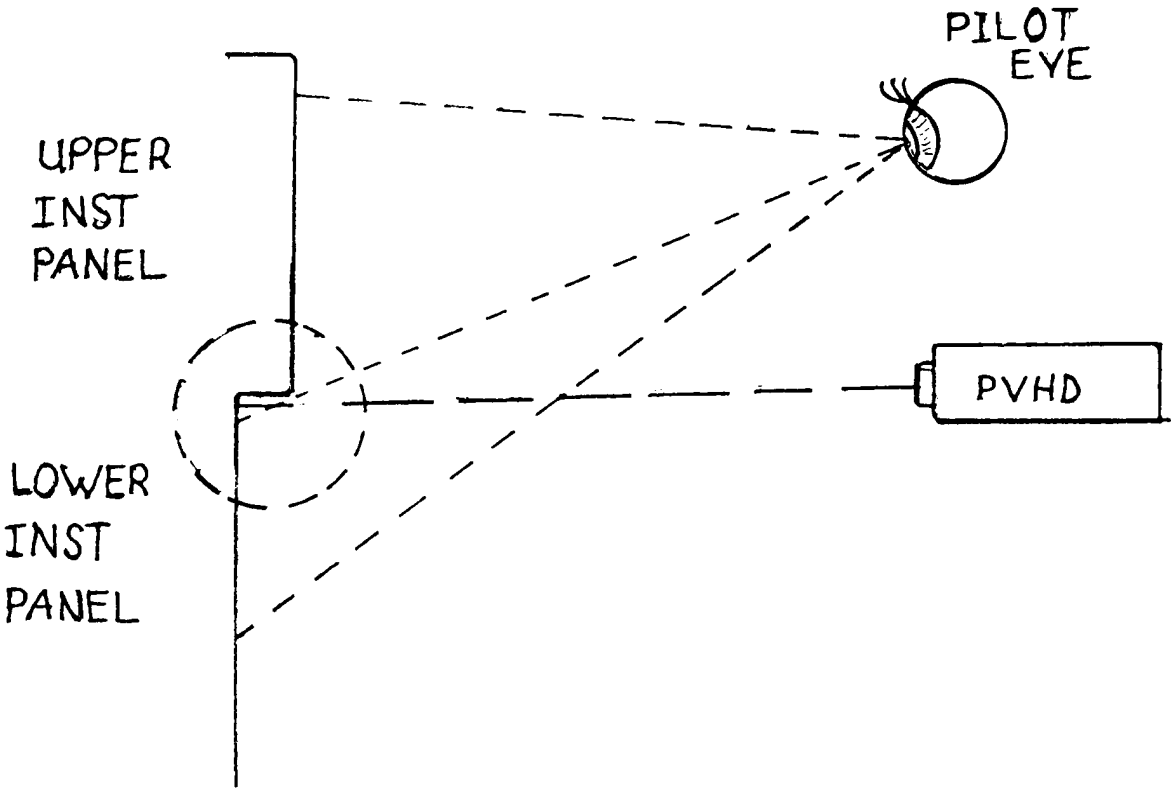

Figure 3
SHELF EFFECT

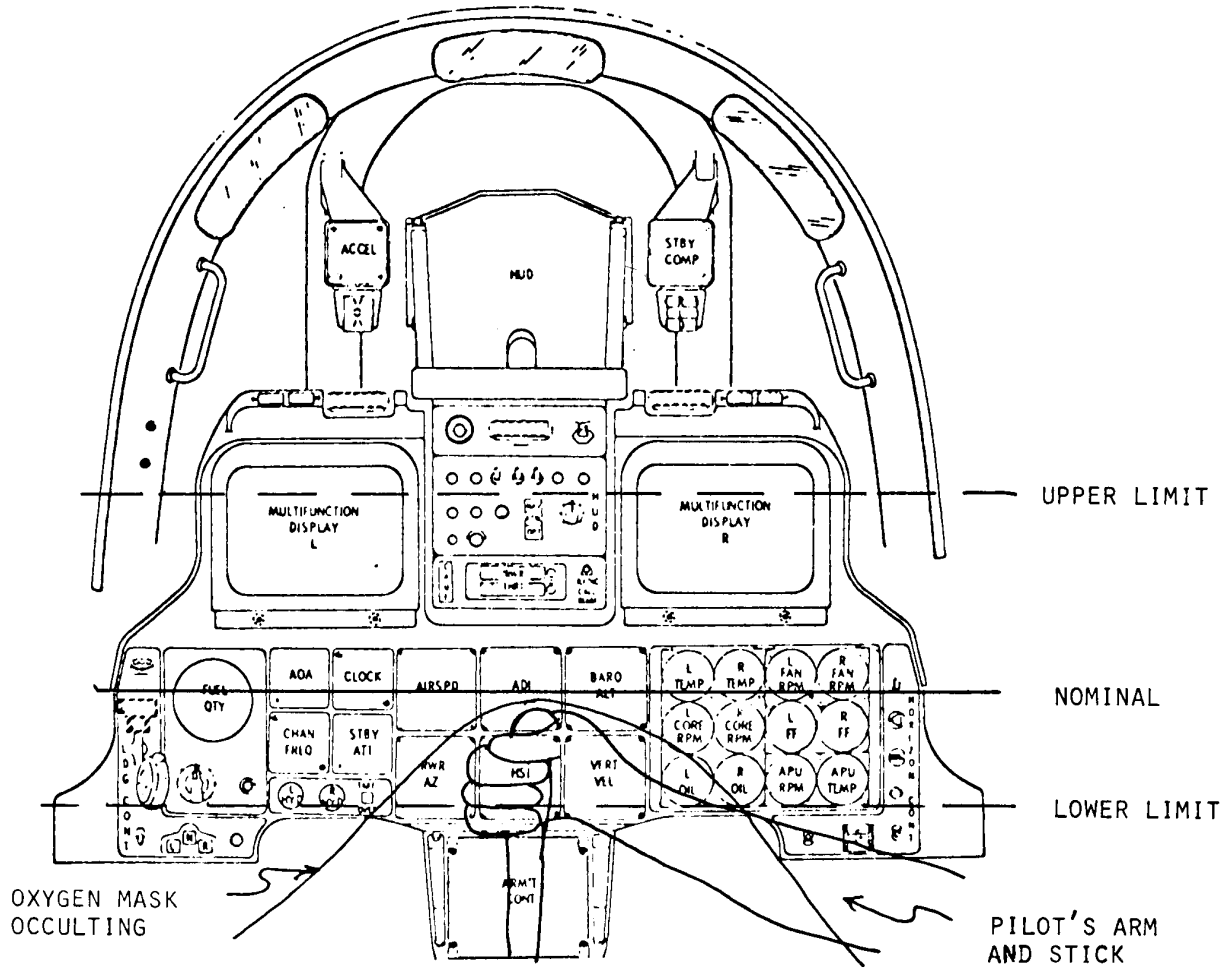

Figure 4
LOW PRESENTATION

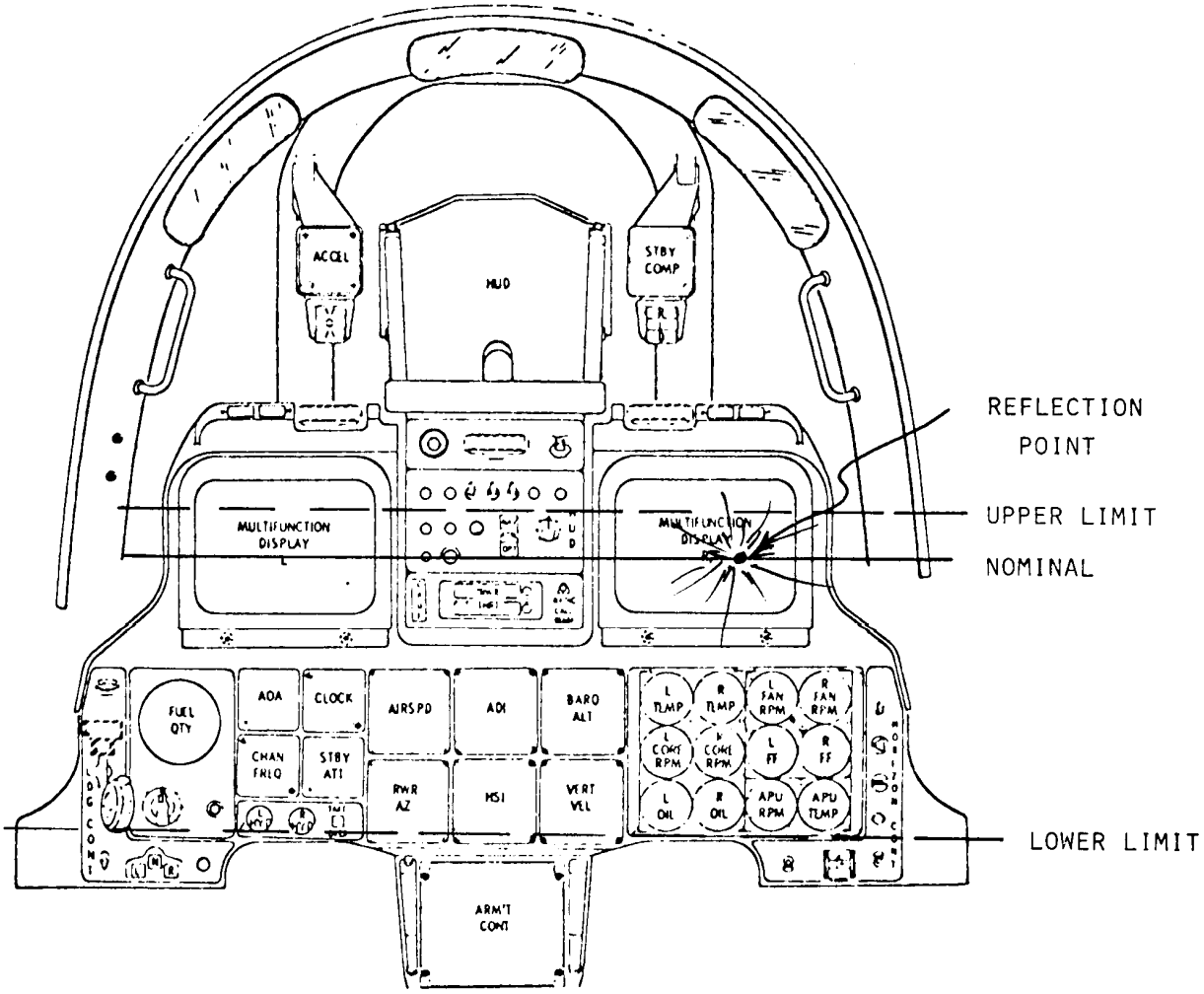

Figure 5
HIGH PRESENTATION

Peripheral Vision Horizon Display Testing in RF-4C Aircraft

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1. The USAF Test Pilot School (TPS) is currently responsible for testing the Peripheral Vision Horizon Display (PVHD) installed in an RF-4C aircraft (SN 68-7744). The primary objective of this program is to assess the capability of the PVHD (sometimes called the Laser Horizon) to provide peripheral attitude cues to the pilot. These peripheral cues are expected to reduce the likelihood/severity of spatial disorientation episodes and to improve performance during precise attitude tasks in Instrument Meterological Conditions (IMC).

2. The PVHD being tested by the TPS is an evolution of a previous design by Dr Richard Malcolm which was tested by TPS Classes 80A and 80B. The previous system used a Xerox arc lamp installed in a UV-18 aircraft. Although the results from those tests were generally inconclusive, the basic design concept was considered to have merit if the displayed horizon line could be made thinner, brighter and overall more distinct. A laser-generated horizon line was the logical choice for improving the quality of the display. This new system was subsequently installed in the RF-4C as well as in other aircraft (e.g., NASA T-37, Calspan NT-33 and Single Seat Night Attack (SSNA) A-10).

3. The basic concept of the PVHD is that it should provide an unconscious attitude cue to the pilot through his peripheral vision sensing system.

Ideally, once the pilot has become acclimated to the PVHD as a valid cue, he should be less susceptible to spatial disorientation. Additionally, this subconscious attitude cue should reduce the amount of concentration required on the aircraft Attitide Indicator (AI), thus freeing him to concentrate more on other performance instruments. The end result should be improved performance during unusual attitude recoveries and precision instrument tasks (i.e., instrument approaches). It must be emphasized, however, that the PVHD is not designed as an alternate/substitute attitude indicator, but merely as an aid to attitude reference.

4. To help determine the validity of the PVHD concept, the TPS was tasked to install the system in the rear cockpit (R/C/P) of an RF-4C aircraft. The laser projector is mounted on the lower edge of the canopy, aft of the pilot's right shoulder. The control box is located low on the center console, directly in front of the control stick. This particular aircraft is modified with an onboard Aydin Vector Data Acquisition System (DAS) as well as with data telemetry capability. The R/C/P of the RF-4C was chosen for two reasons. First, the R/C/P can be totally blacked out by use of an instrument hood and specially designed blackout panels. Second, the instrument crosscheck in the R/C/P is extremely poor in terms of human factors criteria, especially when performing an Instrument Landing System (ILS) approach. The ID-249 ILS glide slope and localizer indicator is located remotely on the instrument panel which forces the pilot's attention away from the AI in order to monitor localizer and glide scope deviations. This makes the RF-4C R/C/P an ideal natural test bed for assessing the ability of the PVHD to improve attitude awareness and thus ILS approach performance.

5. The PVHD test plan for the RF-4C was designed to assess three primary areas: (1) ability of the system to reduce spatial disorientation, (2) ability of the system to aid the pilot in recovering from unusual attitudes, and (3) improvement in pilot performance during ILS approaches. To reduce some of the "learning curve" effects, only F-4 instructor pilots will be utilized as project pilots because of their experience in flying instrument approaches from the R/C/P. So far, only two data and two orientation flights have been flown. The test plan calls for approximately 15 sorties (18 flying hours) to be divided among three to five pilots. No attempt has been made however to ascertain at just what point the PVHD becomes accepted as a valid input to the pilot's peripheral senses. The test plan calls for measurement of the pilot's performance from the very outset, both during unusual attitude recoveries and ILS approaches. Consideration is now being given to revising the test plan to allow for an adaptation period. Only the last one or two flights would be data flights. The emphasis would then be on showing degraded performance without the PVHD, rather than trying to assess arbitrary improved performance with the PVHD (arbitrary in that adaptation may not have occurred, especially during the first flight or two).

6. Initially, specific maneuvers were designed to help create distinct types of spatial disorientation: Somatogravic, somatogyral and combinations of the two. The first four flights of the PVHD revealed that although valid in theory, the maneuvers were not very successful in flight in generating the desired spatial disorientation. Somatogravic effects (false perception of climbing/diving during accelerations/decelerations) were the most difficult to create. Somatogyral effects (or the "Leans") seemed to be the

easiest to create. Since the "Leans" are one of the most commonly occurring forms of spatial disorientation, further test missions will concentrate on creating these effects repeatedly in order to assess the functionality of the PVHD. Hopefully, as testing progresses, it will become increasingly difficult to generate the "Leans" in the project pilot as the influence of the PVHD becomes more accepted by his subconscious. Additionally, the project pilot should display quicker reaction to and recovery from the unusual attitude resulting from this particular maneuver.

7. To assess the ability of the PVHD to improve pilot performance during instrument approaches, a self-setup ILS pattern has been devised. From a fixed starting point, the project pilot will fly a standard pattern to intercept the localizer and glide slope and fly the approach through the missed approach. The aircraft's DAS has been specially modified to include glide slope and localizer deviation as recorded parameters along with airspeed, altitude, heading, pitch and bank angles, and other standard parameters. Deviations from localizer and glide slope will be totalled and a mean deviation per unit time will be determined for comparative purposes. It is expected that improved performance will be experienced by using the PVHD and will be indicated by lower mean values of localizer and glide slope deviation. Originally, an optional, increased workload task was conceived, to be used if a normal ILS was not providing a sufficient workload for the project pilot. However, in the few sorties already completed, it was a unanimous opinion that the ILS, by itself, is more than a sufficient workload and does not require any additional tasks to saturate the pilot.

8. Although only two data flights have been flown so far, a number of

problem areas have surfaced. The most predominant problem is that of the display itself. The line is extremely wavy, not sharp and distinct as desired and expected. Although it has ten discrete brightness levels, the display is too dim for effective use in any form of daylight. Additionally, the sky pointer is not distinct at lower brightness levels. Geometric considerations prevent the line from being projected across the entire instrument panel and it can be partially obscured by only a slight movement to the right by the pilot. The system's controls are difficult to reach and the brightness control has no discrete setting corresponding to each level of brightness. Other problems include the lack of complete darkness in the R/C/P due to the absence of a blackout panel directly behind the front pilot's seat. Although the project pilot cannot see any horizon or outside references, there is enough stray light transmitted through this area so as to reduce the effect of complete darkness/IMC. Additionally, sunlight changes due to aircraft motion provide limited motion/orientation cues and thus reduce the effectiveness of any maneuvers to create spatial disorientation. All project pilots so far agree that the most easily recognized motion on the PVHD was roll, and that pitch motion was barely discernible at all, regardless of the scale selected (the pilot can select a 1:1, 2:1, or 3:1 scale factor for pitch sensitivity - 3:1 implies that one degree of PVHD movement in pitch equals three degrees of actual aircraft pitch attitude change). Also, there tended to be a "pendulum effect" in roll if the display was repositioned in pitch at other than its center; i.e., the display rolled about a point other than the intersection of the horizon line and the sky pointer.

9. Currently, the major effort at the TPS is to eliminate the non-aesthetic

horizon display. It appears to be due, in part, to noise from the aircraft electrical bus. Nonetheless, it is felt that unless the display is corrected to appear sharp and distinct as expected of a laser, subconscious adaptation to the PVHD system may be prolonged or, in fact, may never occur. Although other tests have shown that the quality of the image does not necessarily affect the mind's ability to perceive motion, image quality may affect the mind's acceptance of the validity of the input, thus inhibiting adaptation to the PVHD. An additional blackout panel will be made in order to create the desired environment and eliminate distractions from stray light. It must be remembered that the present configuration in the RF-4C is by no means necessarily the final configuration. This test is merely one means of attempting to verify or refute the validity of the PVHD concept and provide some degree of quantitative (and qualitative) evidence to support the conclusions. Also, it must be borne in mind when assessing the PVHD system that its only intended use is as an aid to attitude orientation, not as a substitute attitude indicator. Any attempt to refine the PVHD to the level of an attitude indicator necessarily disregards the basic design premise. That is, the PVHD is to be sensed by the pilot's peripheral sensing system thereby providing him a subconscious awareness of his attitude. This, in turn, relieves the pilot's workload and allows him more time for concentration on other cockpit instruments. The R/C/P of the RF-4C is an excellent natural environment in which to obtain quantitative and qualitative data for assessing the validity of the PVHD concept.

EXTRACTS FROM THE TEST PLAN FOR IN-FLIGHT EVALUATION OF THE NT-33A PERIPHERAL VISION DISPLAY

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INTRODUCTION

The Peripheral Vision Display (PVD) presents the pilot with a gyro stabilized artificial horizon projected onto his instrument panel by means of a laser light source. During instrument flight conditions, such a display allows the pilot to gain attitude awareness by sensing the horizon line through his peripheral vision. The pilot can therefore detect changes to aircraft attitude without continuously referring back to his flight instruments.

A second generation PVD unit was installed in the USAF/Calspan NT-33A during late 1982. An NT-33A flight evaluation of the display provides a unique opportunity to utilize a Workload Assessment Device (WAD) to obtain quantitative data regarding the utility of the PVD in reducing pilot workload.

This test plan describes the experimental design and procedures for a two phase NT-33 PVD flight evaluation program. Six NT-33 flights will be flown at Buffalo, N.Y. during February 1983. These flights will consist of a calibration flight, a familiarization flight, and four data flights. The second phase of the PVD evaluation program will be flown at Edwards AFB during April 1983. Approximately two familiarization flights and six data flights will be flown at this time.

The general nature of the experiment covered by this test plan is as follows. The evaluation pilot (EP) flies the NT-33 in simulated instrument conditions created by means of a hood covering the front cockpit. He is tasked with performing a series of mild instrument maneuvers which emphasize angle of bank control. The NT-33 variable stability system (VSS) is used to provide the aircraft with a lightly damped Dutch roll with a high roll-to-yaw ratio. A mild random disturbance is introduced into the three aircraft axes by means of the VSS. The Workload Assessment Device (WAD) generates a random sequence of letters which are displayed on a readout located below the pilot's instrument panel. The evaluation pilot must respond to these letters with a 'yes' or 'no' as quickly as possible by pressing the appropriate cockpit button. His answers and reaction times are recorded by the WAD and are processed to determine pilot workload. The above tasks are performed with the PVD alternately on and then off. Differences in WAD data are used to quantify changes in pilot workload due to the Peripheral Vision Display.

OBJECTIVES

The objectives of the PVD flight evaluation program in the NT-33 are as follows:

- To obtain quantitative data regarding the utility of the PVD in reducing pilot workload during a high workload instrument flight environment; and
- To determine if the PVD improves pilot performance in eliminating large excursions from the desired aircraft attitude.

SCHEDULE

The following table shows the approximate dates, location, and purpose of all PVD evaluation program flights. Each flight will be of 1.5 hours duration. Chase aircraft flights are also included on the schedule.

Table 1

PVD Flight Evaluation Program Schedule

DATE	LOCATION	MISSION	FLT. HRS.
2-9 Feb 83	Buffalo	1 calibration flight	1.5 hr
7-18 Feb 83	Buffalo	1 familiarization flight	1.5 hr
		4 data flights	6.0 hr
		5 chase flights	7.5 hr
29 Mar-8 Apr 83	Edwards AFB	2 familiarization flights	3.0 hr
		6 data flights	9.0 hr
		8 chase flights	12.0 hr

NT-33 FLT. HRS.		CHASE FLT. HRS.	
Buffalo:	9.0	Buffalo:	7.5
Edwards:	12.0	Edwards:	12.0
Total:	21.0	Total:	19.5

PROJECT PILOTS

The number of PVD project evaluation pilots will be kept small in order to allow each pilot to fly several data flights. This will enable each pilot to gain sufficient experience with the PVD to learn to use the display to its best advantage.

The evaluation pilot who will take part in the PVD flights at Buffalo is Captain A. Lamoureaux, Canadian Forces.

During the flights at Edwards AFB, two Air Force Test Pilot School staff pilots, Major Lawrence Davis and Major Wayne Staley, will serve as evaluation pilots.

The NT-33 safety pilot will be from the Calspan engineering pilot staff.

TEST SYSTEM

NT-33A AIRCRAFT:

The test aircraft is the USAF/Calspan NT-33A in-flight simulator (Reference 1) operated by Calspan under contract to the USAF Flight Dynamics Laboratory. The NT-33A variable stability system (VSS) uses a response feedback technique to generate the dynamic response of the simulated aircraft. In this program the VSS will be set to provide Level 1 flying qualities in the longitudinal axis. The lateral/directional axes will be programmed to create a lightly damped Dutch roll ($\zeta = 0.1$) with a high roll-to-yaw ratio ($\phi/\beta = 3.5$). The variable stability system gains are scheduled with aircraft fuel quantity so that the dynamics remain constant throughout the flight.

A special circuit is available on the NT-33 which creates random disturbance inputs that can be entered into any of the VSS control axes. In this way a low level disturbance can be created and added to the aircraft's three axes to further complicate the evaluation pilot's flying task. The level of this turbulence is scaled to the NT-33's changing moments of inertia as fuel is consumed.

To simulate instrument flight conditions, and at the same time to darken the cockpit sufficiently to enable the evaluation pilot to see the PVD laser line under bright ambient light conditions, a hood will be manufactured for the front cockpit of the NT-33. Since this hood will severely limit the forward visibility of the rear seat safety pilot, the hood will be used only during in-flight evaluation of the PVD and taken down for take-off and landing.

The programmable Head-Up-Display will be removed from the NT-33 front cockpit during the PVD evaluation program. In the center front instrument panel a 5" attitude indicator will be installed. This will provide a conventional head down instrument scan pattern for the evaluation pilot.

WORKLOAD ASSESSMENT DEVICE:

The Workload Assessment Device (WAD) was developed by Systems Research Laboratories, Inc. (SRL) for the Systems Engineering Test Directorate of the Naval Air Test Center (NATC). The device consists of a processor and recording system located in the nose of the aircraft, a display system in the front cockpit, and a control terminal in the rear cockpit. The processor generates a random sequence of letters which are presented to the evaluation pilot either visually on the HUD or aurally over the pilot's intercom. During this program the visual presentation mode will be utilized; however, the WAD letters will be displayed on a small Liquid Crystal Diode (LCD) display below the front instrument panel instead of on the HUD. To control the WAD system, a handheld keyboard terminal is mounted to the rear cockpit left instrument panel. The WAD recording system uses a small cassette to record workload measurement data as well as up to 16 channels of other flight parameters.

During the workload test, the WAD presents one letter at a time to the evaluation pilot at a random interval of from 2 to 15 seconds. The mean inter-stimulus interval (ISI) will be set to 5 seconds, so that during a four minute evaluation approximately 50 letters will be presented to the evaluation pilot. While the pilot performs his primary flying tasks, he must also note each WAD letter and determine whether it is a

member of his "positive" set of letters (called MSETS) which he memorized prior to flight. He must perform this secondary task of responding to the WAD letters as quickly and accurately as possible; however, he must not let his response to the WAD degrade his primary piloting tasks. The evaluation pilot responds to each letter by pulling the control stick trigger when a letter is "positive" (that is, a member of his set) or depressing the upper stick button when the letter is "negative" (that is, not a member of his memorized set). As soon as the pilot responds, either correctly or incorrectly, the letter disappears. If a response is not received within a set period of time, a time-out error response is logged. Four different sizes of "positive" letter sets, containing zero, one, two, and four letters (MSET0 through MSET4, respectively) are used to obtain a complete workload evaluation. The zero letter set is a baseline in that no mental "sorting" is required for the evaluation pilot to respond – every letter is "negative." As the positive letter set size increases from one to four, more processing time is required by the evaluation pilot to determine if a letter is "positive" or "negative." Further information concerning use of the Workload Assessment Device can be found in Reference 2.

PERIPHERAL VISION DISPLAY:

The Peripheral Vision Display (PVD) or Malcolm Horizon was manufactured by Garrett Manufacturing, Ltd. for the Canadian Forces. The display provides a large horizon line which allows the pilot to maintain aircraft attitude without looking directly at his gyro reference. The PVD horizon line is produced by a Helium-Neon laser which rapidly sweeps across the instrument panel. This line remains parallel with the outside horizon through 360 degrees of aircraft roll. The line also moves in pitch to reflect aircraft pitch attitude changes. A switch is available to the evaluation pilot which allows him to select 1:1, 1:2, or 1:3 pitch scaling of the PVD line with respect to true pitch attitude. During this workload study, the 1:3 pitch scale will be used.

Other controls available to the evaluation pilot include a roll trim and pitch trim adjustment, a brightness control, and an on/off switch. The evaluation pilot switches are located on a remote control unit attached to the front cockpit left canopy rail. Other system components include a processor unit located above the safety pilot's instrument panel, and a laser projector located above and behind the evaluation pilot's right shoulder. Details of the PVD installation in the NT-33A can be found in References 3 and 4.

INSTRUMENTATION:

The 28-channel NT-33A digital tape recorder can record pilot control forces and displacements, aircraft response variables such as angles, angular rates, accelerations, and altitude.

A voice tape recorder is available for use during the PVD workload program. The voice recorder will be left on throughout each PVD evaluation to record pilot comments, WAD letters, and external distractions.

The Workload Assessment Device will record the evaluation pilot's responses to the visual letters as well as his reaction times. In addition, aircraft angle of

bank information will be recorded at a rate of 4 samples per second using one of the 16 available analog-to-digital recording channels.

FLIGHT TEST PROCEDURES

FAMILIARIZATION FLIGHTS:

The first flight that each evaluation pilot receives during this program will be a familiarization flight. The purposes of the familiarization flights are to:

- expose the evaluation pilot to routine NT-33 procedures;
- practice PVD, WAD, and VSS procedures;
- practice performing the instrument maneuvers;
- gain familiarity with use of the PVD; and
- collect preliminary PVD workload data.

Inflight procedures for the familiarization flights will be very similar to the evaluation flight procedures. Fewer WAD data runs will be performed on the familiarization flights than on subsequent data flights so that the evaluation pilot can devote more time to instrument maneuvering using the PVD.

EVALUATION FLIGHTS:

Each PVD data flight will consist of ten workload measurement evaluations. Each evaluation will consist of a four minute instrument maneuvering primary task concurrent with a WAD secondary task. The primary task requires the evaluation pilot to maintain a constant airspeed and altitude while accomplishing a sequence of constant angles of bank. As these maneuvers are performed the evaluation pilot must alter his instrument scan to allow him to observe the WAD letter display as much as possible without degrading his maneuvering task.

Four runs of the primary task are performed with the PVD turned off and another four runs are performed with the PVD turned on. During these runs the WAD 0, 1, 2, and 4 member letter sets are each used once.

Detailed flight cards will be generated for each flight, however, the following steps will help clarify the procedures for a typical evaluation flight.

- Cruise flight is established above 10,000' MSL at 250 KIAS.
- Front cockpit hood installed.
- PVD turned off.
- VSS engaged, evaluation pilot (EP) flies NT-33 with unstable spiral.

- Artificial lateral turbulence turned on (if required).
- Safety pilot (SP) turns on digital recorder, voice recorder, starts WAD.
- EP starts clock for 4 minute task.
- EP performs maneuvering primary task and responds to WAD secondary task.
- At end of 4 minutes, SP takes control of aircraft, stops WAD, turns off digital recorder, maneuvers to remain in designated airspace.
- EP makes comments concerning run, resets clock.
- Procedures are repeated until 4 runs are made using WAD MSETS 0, 1, 2, and 4.
- EP turns on PVD.
- Procedures are repeated for 4 more runs using WAD MSETS 0, 1, 2, and 4.
- Front cockpit hood removed.
- Return to base.

EVALUATION TASK:

The instrument maneuvering task which will be used during the PVD evaluation program will emphasize holding a set aircraft attitude for fairly long periods of time. The task will be coordinated with the clock so that the pilot's instrument scan will concentrate on aircraft attitude, airspeed, altitude, and time, with as much scan to the WAD visual letter display as is possible. With the PVD turned on, the pilot can set his precise attitude using the attitude indicator, and then rely on peripheral cues from the PVD horizon bar to warn him of changes to the set aircraft attitude. This may allow the pilot to devote more attention to the WAD visual display.

The sequence of specified angles of bank for the primary instrument task will be simple to avoid the necessity of having the evaluation pilot refer to an in-flight instruction card during the task. The following instrument task, or variations thereof, will be used for the PVD evaluation.

- Maintain 250 KIAS and constant altitude throughout the maneuver.
- First minute: hold wings level.
- Second minute: hold 30° bank to the left.
- Third minute: hold 30° bank to the right.
- Fourth minute: hold wings level.

TEST DATA

The most significant data collected during the PVD evaluation flights will be the workload information recorded on the WAD cassette recorder and the aircraft response data collected on the NT-33 digital recorder.

The Workload Assessment Device recorder provides information concerning the letters presented to the pilot as a secondary task, the responses made by the pilot, and the time it took the pilot to respond. Discrete angle of bank information will also be recorded by the WAD, but this information is intended primarily as a backup to the NT-33 digital recorder. Statistical reduction and print out of the WAD data can be accomplished using the WAD portable ground support unit. Interpretation and analysis of the workload data will be accomplished under the direction of Dr. Samuel Schiflett of the Naval Air Test Center.

Data concerning pilot performance in maintaining the desired aircraft flight condition will be collected by the NT-33 digital recorder. Angle of bank, pitch attitude, and altitude excursions are of primary interest in determining pilot performance during the instrument flight maneuvers. Time histories of appropriate parameters can be made using the "Quicklook" digital playback system located at the USAF Test Pilot School and at Calspan.

The voice recordings made during PVD evaluations will be reviewed to obtain pilot comments concerning workload, utility of the PVD, operation of the Workload Assessment Device, and whether external distractions interfered with any of the data runs.

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NASA AMES-DRYDEN T-37 DEMONSTRATION COMMENTS

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At NASA Ames Research Center's Dryden Flight Research Facility we had a homemade PVHD in our T-37 for several years. We did not make an evaluation of the instrument or the concept, but used it to demonstrate the idea to anyone interested. This paper is a summary of my observations, based on riding with a large number of pilots using the system and making several flights myself.

The peripheral vision horizon device (PVHD) we used was made from an eight-ball attitude indicator, with a slit cut at the equator of the eight ball, and a light source at its center. The instrument produced a sharp white line about one-fourth of an inch that extended completely across the cockpit from about the left to the right quarterpanels. The line remained parallel to the real horizon during all maneuvers. Its brightness and vertical distance from the horizon were adjustable in flight, as was the lateral center-of-rotation in later flights.

Flight demonstrations were done on visual flight rules (VFR) moonless nights and over terrain with few lights. Pilot responses were mostly favorable to enthusiastic, with no negative reactions. Problem areas noted were the upright-inverted ambiguity; one pilot recovered inverted following an unusual attitude exercise and a general deterioration in the naturalness of cuing at bank angles greater than 60° or pitch attitudes greater than 30°.

During one demonstration we inadvertently flew into a cloud. Surprisingly, the center-of-rotation in bank suddenly was found to be quite unacceptable at its location in the center of the instrument panel between the two pilots. It caused bank changes to be seen as pitch motions. It was very distracting, and the PVHD was immediately turned off. It was apparent that the few ground lights that had been in the visual field during the previous evaluations were indeed significant. We added a provision for adjusting the roll center-of-rotation in flight, and made another flight at low altitude off the coast of San Diego. No surface lights and very few stars were in view. The importance of matching the roll center-of-rotation with the center of the conventional artificial horizon was confirmed on this flight. Any other location was distracting and unpleasant. Even with the roll center-of-rotation correctly positioned, there remained some anxiety and reluctance to abandon the traditional instruments.

Clearly, the flights we had done did not constitute a system evaluation. They did dramatically illustrate how easily that premature and wrong conclusions could be drawn from an inadequate test. In addition to the usual experimental design considerations, the test environment must provide that no external reference is available and, most important, that the subject must have complete responsibility for the safety and control of his airplane.

In the papers I have heard here I have been concerned that no test has been proposed that addresses the main purpose of the PVHD – to reduce the likelihood of disorientation. I can see three possible approaches to such a test.

(1) A direct approach in which one attempts to document a reduction in the incidence of a rare event – disorientation. This seems out of the question because of the length and size of the sample required.

(2) A direct approach in which one examines the state of the mental process of orientation to find out the effect of a PVHD on that process. This may be beyond the art as we presently know it.

(3) An indirect approach in which the effect of a PVHD on various pilot responses is measured to learn if pilot behavior is made more nearly like that in visual flight by the addition of a PVHD. This does seem feasible to me. It would require that differences in pilot response between instrument and visual flight be known. Responses such as control strategies, control aggressiveness, error "signature" for instrument landing system (ILS) task, postural response, eye scan pattern, and response to additional workload would be candidates for measurements.

I think a measuring tool should be developed so that the PVHD can be evaluated and improved in a rational way. The present process of subjective assessments in a poorly controlled or inappropriate environment will not converge on an effective system, or prove that the system is worth its cost.

EARLY AIR FORCE FLIGHT TEST CENTER (AFFTC) EXPERIENCE WITH PERIPHERAL VISION HORIZON DISPLAYS (PVHD)

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Three separate AFFTC tests were conducted in 1980 and 1981 on two models of the PVHD (Malcolm Horizon). A fixed base simulator test was conducted with twenty test pilot subjects using the Flight Simulator Demonstration Model which incorporated a Helium Neon laser as the light bar medium. Two separate flight tests were conducted by the Test Pilot School classes 80A and 80B in a Twin Otter commuter aircraft using the Stage A Model PVHD. The Xenon lighted A Model was tested in its original configuration by class 80A. Class 80B used a modified configuration which incorporated an AFFTC designed and manufactured hood. With the hood the PVHD projected a thinner, distinct light bar. All of these tests are reported in detail in the reference. Only a few general remarks concerning the tests and unrestricted, overall conclusions reached by the author will be presented here.

The test conducted in the fixed base simulator was a pre-prototype of the present Garrett Model B Malcolm Horizon. All of the computations for combining the pitch and roll signals were done in the simulator system and were then transmitted to the projector for projection onto the instrument panel. Ground loop problems and inertial effects on the projector x-y mirrors resulted in a display which had some flicker and waviness and often broke up into two lines slightly separated on the sweep and return. Despite these problems, the display was reasonably sharp and distinct.

The simulated aircraft was a modern fighter with overall handling qualities of Level 2 (desired performance requires moderate pilot compensation). The intent was to provide the pilot with an aircraft that was moderately unstable and would require pilot attention to maintain attitude control and thus be able to evaluate the utility of the PVHD in assisting the pilot to control the aircraft.

Because of the limited availability of the evaluation pilots for training with the new display concept, and because of the short evaluation time available, it was decided that the evaluation would be qualitative only. A questionnaire was developed which covered the areas of horizon line characteristics, assistance of the PVHD in performing the evaluation maneuvers, pitch scale sensitivity and a judgment of the applicability of the PVHD concept to flight. The questionnaire was reviewed by the pilot prior to the evaluation and was then filled out by him immediately following the evaluation.

The evaluation task was developed around a ground control approach (GCA) task which included a holding pattern. The timed turns, descents, and speed changes were provided to the pilot on a pilot card and knee board. The evaluation pilot had to refer to the knee board to keep track of both the maneuver sequence and timing. This resulted in some distraction from the instrument panel. Additionally, at random times during the GCA maneuvers, the pilot was asked to copy flight clearance information. This also caused distraction from the instrument panel. Other tasks of switch selection on side console panels were added to provide distraction from the instrument panel.

The evaluation task was performed first with the PVHD on and then was repeated with just the conventional instruments. This order was to reduce any bias for the PVHD. The display was also used at ambient light settings of 2.1- and 15.1-foot candles to evaluate lighting contrasts for the 0.9 milliwatt laser beam.

The results of the evaluation did not show that the PVHD was compelling in terms of providing a replacement for the natural horizon. The laser light bar was determined to be generally adequate in providing help in recognizing and controlling aircraft attitude, particularly when the pilot was distracted from the instrument panel by tasks other than aircraft flight path control such as copying flight clearances. This result was not unanimous but 40-50 percent of the pilots indicated an improvement with the PVHD on and the rest of the pilots said it was the same with or without the PVHD. Sixty percent of the pilots responded that the PVHD would be applicable to flight.

Inflight evaluations of the A Model PVHD were conducted by two successive Air Force Test Pilot School classes (classes 80A and 80B) as class projects. Class 80A evaluated the A Model in its original configuration. The light bar for the original configuration was about three inches wide, was fuzzy, and extended over most of the evaluation pilot's panel. The roll axis of the light bar, although not marked, was directly in front of the pilot. All of the evaluations were conducted in simulated instrument meteorological conditions (IMC). This was accomplished by placing amber colored plexiglass panels over all of the cockpit windshields and then having the evaluation pilot use a matching blue visor which completely blocked external vision. The unhooded safety pilot had unrestricted external visibility. This was an excellent simulation of IMC except for some small shafts of light which got around a few edges of the windshield amber plexiglass and poor instrument panel lighting for the blue-visored evaluation pilot. The problems of the wide unmodified A Model light bar and poor visibility of the instrument panel for the evaluation pilot made the results of this evaluation suspect. Consequently, they will not be reported here. (Refer to the reference for full details.)

As previously stated, the hooded A Model Malcolm Horizon provided a much thinner (less than one inch width), distinct light bar. Also, a small section of the light bar was blanked out to indicate the roll axis. This modified display was used by class 80B. Other changes made by Class 80B were to exchange the evaluation pilot's visor with blue ski goggles, provide better instrument panel lighting, and block out the small shafts of external light with electrical tape. The whole evaluation setup was much improved over those for Class 80A. Most of the changes were recommended by Class 80A based on their experience.

The evaluation tasks used by Class 80B were timed "vertical S" maneuvers. The following conditions were maintained for the four climbs and descents which constituted a vertical S set. The required accuracies are in parenthesis.

Airspeed – 100 KIAS (±5 knots)
Altitude – 6000 feet MSL ±40 feet (±25 feet)
Time for one climb or descent – 30 sec (±5 sec)
Bank angle – 0 deg and 30 deg (±2.5 deg)

The required accuracies had to be maintained during a vertical S set for satisfactory performance. Vertical S maneuvers were flown both with and without the PVHD on.

Four sets of vertical S maneuvers were conducted, each set increasing in difficulty. The four sets were as follows:

A — 0 deg Bank Angle
B — 30 deg Bank Angle
C — 30 deg bank reversal at the top of each vertical S
D — 30 deg bank reversal at the top and bottom of each vertical S

A workload task was devised based on lights at each top corner of the evaluation pilot's front windshield, well out of the pilot's normal field of view. These lights were randomly lighted throughout the vertical S maneuvers and then as soon as he recognized they had been lighted he turned the light off with a button on his control column. The time required to recognize that a light had been turned on and then to turn it off with the button on the control column was measured and evaluated as a measure of pilot workload.

The six non-project evaluation pilots were given one sortie which constituted a series of A through D vertical S maneuvers with the PVHD on and then a repeat of the same maneuvers with the PVHD off. The two project pilots had five sorties each so they were higher on the learning curve.

The results of the measured workload showed that the project pilots did slightly better with the PVHD on and the non-project pilots slightly better with the PVHD off. However, the improvements for both the project and non-project pilots could not be considered significant.

The performance results (maintaining maneuver accuracy) showed a moderate improvement by the project pilots with the PVHD on and no difference for the non-project pilots with the PVHD on or off. Again the differences were not considered to be significant.

All of the pilots were asked to make a subjective pilot rating of the utility of the PVHD. The non-project pilots rated the PVHD on and off as providing no difference. The project pilot's ratings were weighed in favor of the PVHD on, but again the results could not be considered to be significant.

The conclusions of all three AFFTC evaluations of the PVHD concept were that it has not yet been adequately evaluated. There seems to be a significant learning curve associated with the PVHD and the project pilots for Test Pilot School Class 80B only got a good start on the learning curve. After all, a lengthy learning curve for the PVHD should be anticipated in view of the training period required for the attitude display indicator (ADI). This does seem to point out that the PVHD, in its present form, is simply not as compelling as the natural horizon. It can also be concluded that any attempt at a valid evaluation of the PVHD concept can be done only under IMC or validly simulated IMC conditions. The knee in the learning curve, how-ever, may be reached without full IMC although it may take much longer to reach.

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Schofield, B. L.; Coombs, D. F., Capt USAF; Tudor, D. I., Capt CAF; et al. Interim Report of Air Standardization Coordinating Committee, Test Project Agreement 769-10 (CF/USAF) Peripheral Vision Horizon Display (PVHD) Stage A Model, D STDZN C3, National Defence Headquarters, Ottawa, Ontario K1A OK2, Canada.

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PERIPHERAL VISION DISPLAYS - THE FUTURE

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GML has been active in research studies on future developments for the PVD, and I would like to outline several areas which have progressed to the developmental stage.

1. Fibre Optics

We believe the fibre optics problem of recollimating the light as it leaves the fibre has now been solved. Development engineering has begun on an alternate configuration to the present baseline system.

The availability of a means of placing the laser and power supply in a remote location opens up many new possibilities:

(a) The projector will be considerably smaller and more compatible with small or high density cockpits.

(b) The extra degrees of freedom in laser size opens up the possibility of using a source other than the HeNe red line.

Which brings us to the second item:

2. Change of Display Colour

It has been known for some time that the red HeNe display is not the optimum colour for PVD, but it does have the advantages of being inexpensive, reliable and available.

The disadvantages of red, to mention just two at this stage, are:

(a) Red signifies danger.

(b) Red light striking a red enunciator light will give a momentary red flash to the pilot, which adds stress to his flying.

In order to choose the optimum colour for display, we undertook a research program to measure retinal sensitivity against varying ambient conditions for three different colours:

Red	-	HeNe laser	-	632 nm
Green	-	Argon Ion laser	-	514 nm
Blue	-	HeCd laser	-	442 nm

The reasons why these colours were chosen, were fairly straightforward. They gave (theoretically) wavelengths which represented either highs or lows of retinal sensitivity for both Foveal and Peripheral Vision, and they were readily available. (See Figure 1).

The experiments used 8 subjects, and each were seated 1 metre from a screen on which was displayed a gently undulating line. Ambient lighting was varied from maximum (600 lux using a bank of photoflood lamps) to minimum (dark and scotopic with 10 - 15 minutes dark adaptation time). For each measurement, the light was attenuated (using Wratten neutral density filters) until the subject declared that the line was just visible as a PVD, and also when the line was just perceptible.

The results are shown in Figure 2.

Figure 3 illustrates the theoretical predictions along with the measured values. The prime conclusion is that a Green laser gives about 3 times improvement in retinal sensitivity for photopic vision. Or put another way, the existing 3 mW HeNe red line could be replaced by a 1 mW green line and compete with the same ambient conditions.

Unfortunately, the large increase in retinal sensitivity under scotopic conditions cannot be used, as we are already well-dimmed for dark adaptation.

The next stage was to find a suitable green source which satisfied the requirements of size, weight, power consumption, cost, etc.

Analysis of the Lagrange Invariant for optical systems, which briefly, states that in any closed optical system, the product of image size x angle of field x refractive index of medium, is invariant whenever a ray path crosses the optical axis, suggests that only a laser can supply the small image, narrow angle display we require.

A survey of all possible green (or yellow) laser sources, gave many possibilities, most of which can be disregarded due to size, weight, power consumption and cost.

The "short list" of options which we are pursuing is shown in Figure 4.

One conclusion which becomes very clear on looking at our options, is that the HeNe red line stands in a class of its own, at least with regard to power consumption and cost. With regard to weight and size, we have received encouraging news from our suppliers with respect to future requirements, but the HeNe laser is by far the most efficient laser ever produced.

The next question which arises, is how bright we can make the display, in order to compete with the Mil. Spec. requirement of 10,000 ft. candles (107,000 lux).

Extrapolation of the curves of Figure 2 gives approximate power requirements for threshold detection for each colour. I stress "approximate", as we are extrapolating over nearly 3 orders of magnitude to reach 10,000 ft. candles.

HeNe red line	70 mW
Argon green line	20 mW
HeCd blue line	150 mW

A few words about the HeCd laser. The laser used was a "positive column" laser, where photons could not be excited to energetic levels beyond the blue line. We are also negotiating with two possible suppliers to acquire a "hollow cathode" HeCd laser, where we may excite our photons to produce blue, green and red lines. In fact, we may soon be in a position to offer a "white" light laser.

The continued use of lasers leads us into our next topic.

3. Holography

We are already experiencing some problems related to projecting our bar of light on the changing contours of modern-day instrument panels. In addition, small instrument panels preclude the possibility of using a true peripheral display. We cannot display the line on the windscreen, as this could present an easily recognisable signature to the enemy.

Holography offers the possibility of giving the pilot a horizon bar in space, either inside or outside the cockpit. It enables us to wind the horizon around him, so giving true peripheral vision. It also allows us to forget the concept of a horizon "line", and present to the pilot a view similar, if not identical to the true horizon; i.e. an interface between two areas, sky or ground, blue or brown, or even to present the complete 3 D picture of an airport runway, regardless of whether the airport is in fact visible.

We are still in the very early stages of the holographic PVD, but the potential of this technique is extremely impressive and stimulating even at this early stage.

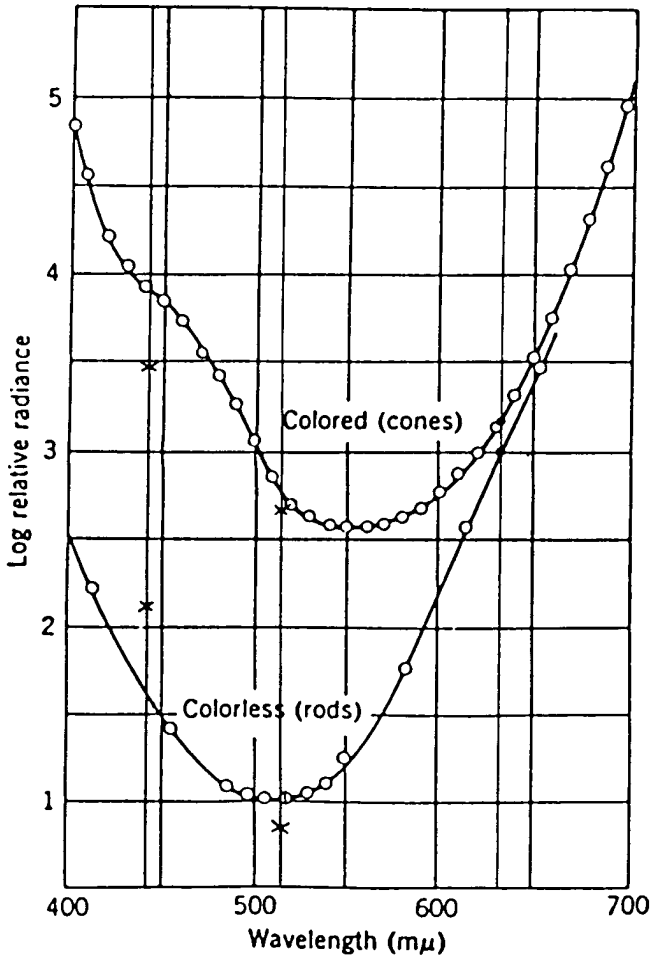

FIG. 1. Relative radiance required for rod and cone vision at different wavelengths. Positioning of the two curves is based on the fact that the thresholds for rods and cones are most similar in the red beyond about 625 mμ. The precise form of the curve and the values of radiance required for the rods will depend upon the duration of exposure, the area of stimulus, and its retinal position. The same considerations apply to the curve for the cones. In consequence, the precise relationship of one curve to another will depend upon the values of these parameters. The curves shown here may be considered to apply to conditions that give minimum thresholds for each type of receptor. (From Hecht and Hsia, 1945.)

•	Reference	632 nm
×	Measured	514 nm
×	Measured	442 nm

Figure 1

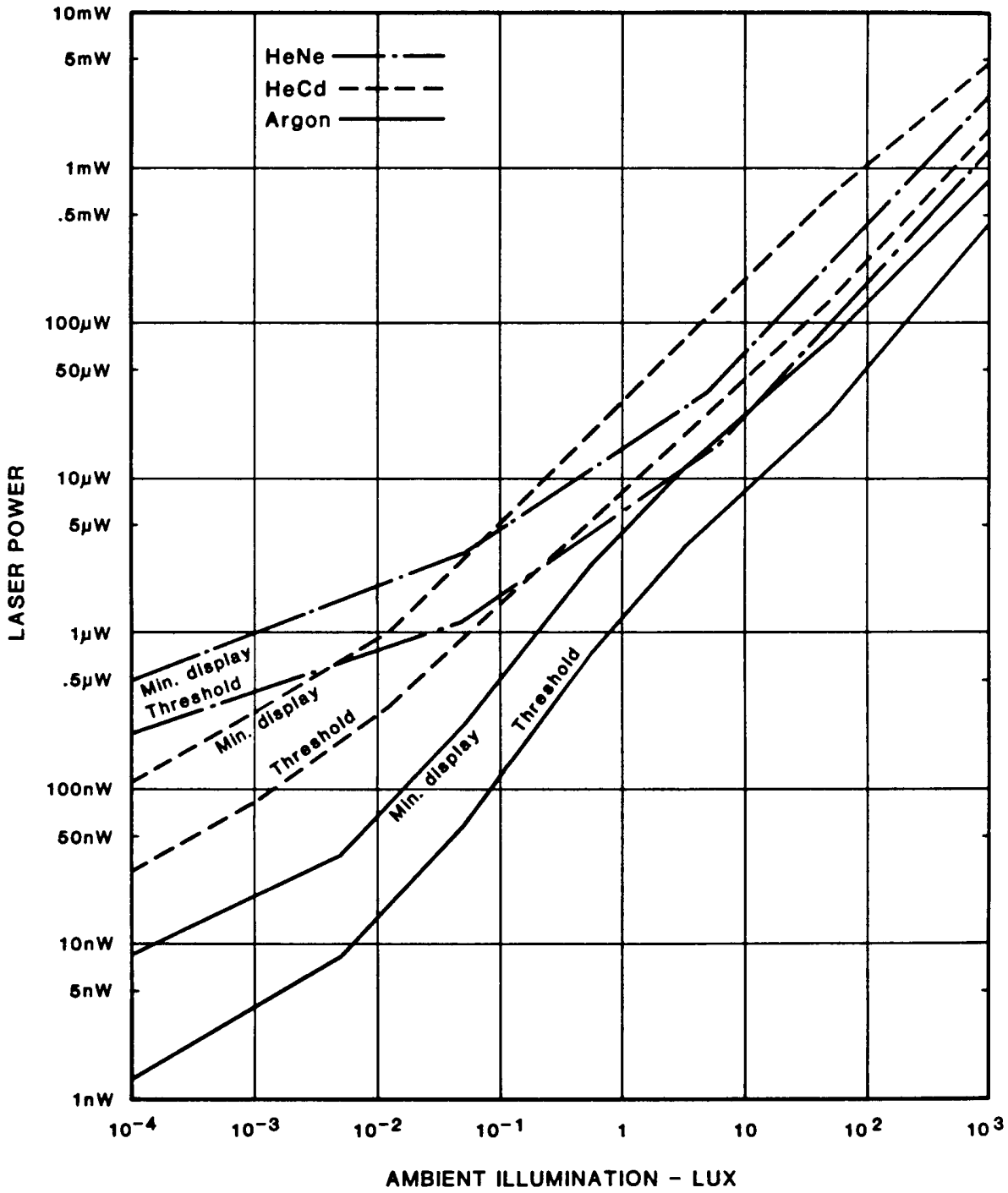

Figure 2 RETINAL SENSITIVITY

Relative Retinal Sensitivity

			Calculated		Measured	
			Foveal	Peripheral	Foveal	Peripheral
HeNe	Red	632 nm	1	1	1	1
Argon	Green	514 nm	2.5	100	3.1	160
HeCd	Blue	442 nm	0.2	22	0.48	7.4

Figure 3

Laser Source for Green Light (530 nm)

	Gas Lasers			Solid State Lasers	
	He Cd		Argon ion	Nd YAG + SHG	
	Pos. Column	Hollow Cath.		Tungsten Halogen Pump	High Density LED Pump
Output power mW	20	20	25	10	50
Wavelength nm	442 but fluor-escent screen possible	530	514	532	532
Input power W	300	200	350	200 ?	200
Size (inc. P.S.)	6" x 6" x 12"	6" x 6" x 12"	6" x 6" x 12" could be developed	8" x 6" x 5"	6½" x 2½" x 1¼"
Weight (inc. P.S.)	10 - 15 lbs.	8 - 12 lbs.	20 lbs.	7 lbs.	5 lbs.
Cost (inc. P.S.)	$5,000	$5,000	$6,000	$5,000	< $5,000
Cooling	Air convection	Air convection	Air convection	liquid & air	air convection
Mil. Spec.	Yes ?	Yes ?	Yes ?	Yes	Yes
Risk ≒ Development	Low	High	High	Low	High
Comments	Available in near future if fluorescent screen acceptable	Not yet avail-able to these sizes and weights	Not yet available	Available within 6 months	Not yet available. Involves some R&D investment

Figure 4

A PRODUCTION PERIPHERAL VISION DISPLAY SYSTEM

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Abstract - A small number of Peripheral Vision Display Systems in three significantly different configurations have been evaluated in various aircraft and simulator situations. The use of these development systems has enabled the gathering of much subjective and quantitative data regarding this concept of flight deck instrumentation. However, much has also been learned about the limitations of this equipment which need to be addressed prior to wide-spread use. This paper briefly discusses a program at Garrett Manufacturing Limited in which the Peripheral Vision Display System is being redesigned and transformed into a viable production avionics system.

Introduction -

In preparing the development system for the various evaluation applications, and in assessing the feedback resulting from their use and their servicing, it became obvious very quickly that none of the three evaluation system configurations was suited from hardware and software standpoints to introduction and use in the field in large numbers. Further, it was felt that the required system and hardware characteristics could not be achieved satisfactorily by further development of any of the development configurations. Also, it was realized that the first applications of production systems will be by way of retrofit to existing aircraft making a 12 to 18-month design and development cycle unacceptable.

Consequently in June 1982, Garrett Manufacturing Limited (GML) embarked on a program to design a new PVD system, incorporating some significant new design features and drawing heavily on GML's experience as a supplier of quality avionic equipment. It was decided that to achieve a satisfactory result in the shortest time the new design would use technology which was then currently available at GML from the previous PVD equipment or from other sources. The design would be modular in concept which would permit maximum upward compatibility with advanced new systems which will incorporate the technology expected to emerge from the various concurrent and ongoing R&D programs. Some of the salient features of the new design are discussed below:

The Production PVD System -

(a) Modular Implementation

The production design is being implemented in a modular arrangement which will minimize the impact and lead-time for later incorporation of added functions or features which may be unique to particular applications.

The electronic circuitry in the Processor is functionally grouped into plug-in modules and the detachable power supply can be produced in versions which utilize 115V 400 Hz, 28VDC or 270VDC aircraft power sources.

The microcomputer program is also organized in approximately 50 software modules permitting easier documentation and configuration management and also facilitating the preparation of unique-application programs or features with a minimum of software redesign.

(b) Interchangeable, Line Replaceable Units

Unlike the existing evaluation PVD systems, the production system comprises units which are individually interchangeable and line-replaceable. Large unit-to-unit performance characteristic variations in the laser beam scanning devices require five calibration adjustments for each scanner in the drive and feedback electronics. Utilizing multilayer thick-film hybrid microcircuits, the scanner drive and feedback electronics and the calibration adjustments have been located with the scanners in the projector head enabling precise and constant interface definition between the Processor and Projector.

(c) Extended Dimming Range

The production system incorporates a new electronically-controlled optical attenuator in series with the light beam which provides selectable attenuation of the solid line from 0 to 30 db without interfering with the line scan. This means that a sky pointer or any other symbology on the line is simultaneously attenuated, but otherwise unaltered. Also, a mask in the projector is now unnecessary which means a longer display line can be projected. Existing evaluation systems provide only about 10 db dimming of the solid line by means of an altered scanning rate and periodic "parking" of the beam in the projector mask.

(d) Fail Safety and Built-In-Test-Equipment

Because of the compelling influence of the PVD display on the pilot, it is imperative that the PVD be prevented from displaying erroneous attitude information. The production system has a comprehensive monitoring and fault detection scheme to ensure that the laser light source is turned off if any system malfunction occurs. As a design objective, the display of erroneous attitude information can be caused only by two or more simultaneous unrelated failures with a mean time between occurrences of at least 10^9 operating hours.

The monitoring scheme continuously checks the onboard microcomputer, internal power supplies, analog to digital and digital to analog conversion circuits, optical scanner operation and the laser with its power supply and dimming system.

Having incorporated the capability of fault monitoring and detection for fail safety, a very small further increase in complexity provides fault isolation to the discrepant line replaceable unit, greatly simplifying the first line maintenance of the system.

(e) Improved Reliability

The present evaluation systems being essentially hand-built prototypes have not exhibited the reliability necessary for day-to-day in-service use. Reliability on the production system will be achieved by stringent electronic parts selection and derating criteria and an end-unit burn-in. The design will be supported by a thorough Failure Modes and Effects Analysis and Reliability Analysis per MIL-HDBK-217. A preliminary parts-count reliability analysis indicates that a system Mean Time Between Failures exceeding 2000 operating hours should be achievable.

(f) Environmental Integrity

The production PVD system is designed to meet the requirements of MIL-E-5400 Class 2 (-54°C to 71°C and altitudes to 70,000 feet). It is felt that these and other environmental parameters defined for the new system will accommodate the known potential applications for the PVD system.

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16. Abstract

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Vertigo or disorientation is a recognized problem to pilots flying under instrument conditions. A Canadian invention, the peripheral vision horizon display (PVHD), shows promise in alleviating this problem and easing the piloting task when flying in weather or other conditions requiring close attention to aircraft attitude instruments.

A diversity of research and applied work was being done to investigate and validate the benefits of the PVHD during the years immediately preceding this conference. Organizers of the conference were able to assemble a group of outstanding presenters representing academic, industrial, and military organizations. The theoretical foundation and applied use of the PVHD were discussed, and results from operational tests were presented.

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