

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 extraordinary 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 everyday life. The peripheral retina has become remarkably

well adapted to this job, as was demonstrated by Hubel and Wiesel¹ 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 in front 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 Fredrickson² 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 in front 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 Alto, 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° 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 Augmentation 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 demonstration 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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