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In the past much of the effort expended in the development of Helmet-Mounted Displays (HMD) was directed toward the goal of displaying high resolution video over a wide angular field of view. These systems were not entirely acceptable from an operational standpoint due to excessive weight, size and a number of adverse visual effects related to viewing two competing, high resolution images.

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THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS

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SUMMARY

In the past much of the effort expended in the development of Helmet-Mounted Displays (HMD) was directed toward the goal of displaying high resolution video over a wide angular field of view. These systems were not entirely acceptable from an operational standpoint due to excessive weight, size and a number of adverse visual effects related to viewing two competing, high resolution images.

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1. INTRODUCTION

Over the years a great deal of research time, effort and money have gone into the study and development of Helmet-Mounted Displays without reaching the ultimate objective — an operational system. Many factors have contributed to these results, not the least of which has been the failure of technology to overcome the many diverse human engineering problems involved. This paper discusses a conceptual approach that is successful in avoiding many of the confounding elements of traditional HMD design in favor of a simple, useful, less objectionable system with higher potential for operational acceptance.

The term Helmet-Mounted, Head-Up Display is a rather clumsy, although quite appropriate and descriptive, title for an item of display hardware in that such a device falls under the general category of Helmet-Mounted Displays but takes on some of the attributes and operating characteristics of a Head-Up Display. For those not familiar with these and related display devices a few brief descriptions follow.

1.1 Head-Up Display

The HUD is a large electro-optical instrument that is accurately affixed (boresighted) to the aircraft structure in front of the pilot to provide a sophisticated gunsight capability. Information derived from various aircraft flight instrument and weapon delivery sensors is presented in symbolic form on a very high intensity CRT located within the instrument. This information is projected through an optical system and reflected from a beamsplitter or combining element located in the pilot's forward field of view (see Fig. 1). The symbology is seen focused at optical infinity, superimposed upon the view of the real world scene. This allows the pilot to accommodate the video information and real world information together, and therefore monitor essential flight and weapon delivery data without having to look down into the cockpit as he flies the aircraft, thus the term "head-up" display.

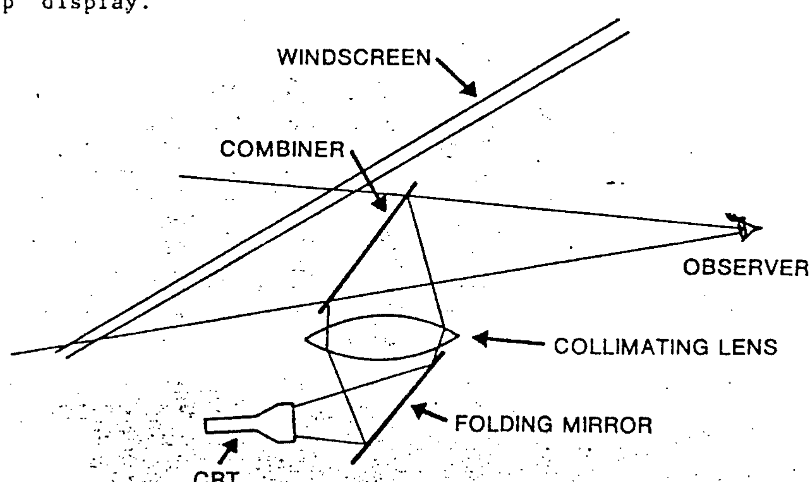

FIG. 1. HEAD-UP DISPLAY (HUD) CONCEPT

1.2 Helmet-Mounted Display

The HMD is a device that makes use of a miniature CRT or other such small, controlled image source mounted on the pilot's helmet to provide an information display. The image source, again, is not viewed directly but through an optical link that presents a virtual image, focused at optical infinity and reflected from a transparent combining element in front of the pilot's eye (see Fig. 2). In some designs the helmet visor is used for this purpose (Kocian and Pratt, 1973). Two visual fields of information are therefore seen simultaneously, the virtual image superimposed upon the real world scene. A wiring bundle must be routed to the helmet from a remote location to supply electrical excitation for the image source. In the case of a CRT approach high voltages (7 to 7.5 Kilovolts) are present and special precautions must be taken to permit separation of the bundle during emergency egress, without introducing potentially dangerous sparks.

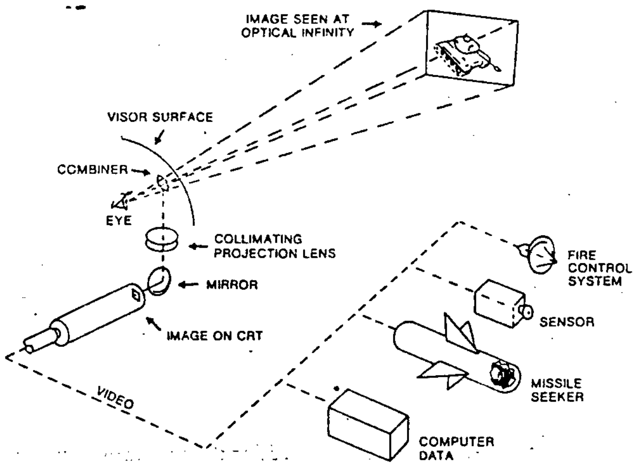

FIG. 2. HELMET-MOUNTED DISPLAY (HMD) CONCEPT

A few important distinctions are worth noting in comparing the HUD and HMD. The HUD requires nothing on the pilot's head. Both eyes view the information presented through the same aperture with restricted head positioning but very stable boresight accuracies can be achieved. In utilizing the HMD the pilot sees the entire video field constantly, regardless of head motion but usually only in one eye. Also, some visual obstructions are usually present due to the proximity of the hardware and boresight does not have significance.

1.3 Helmet-Mounted Sight

A third type of device that is important to this discussion is the Helmet- Mounted Sight (HMS). The HMS measures the pilot's line of sight in relation to the aircraft by sensing helmet orientation. It then provides that information for use in controlling weapon delivery systems and external sensors. A small reticle display reflected from the pilot's visor is used for positioning reference. The pilot overlays the reticle on a target and the system then calculates helmet angle referenced to the airframe, and hence line of sight relative to the target (see Fig. 3). Several techniques have been developed to sense helmet orientation in the cockpit. Such physical phenomena as infra-red radiation, magnetic fields, and ultrasonic waves have been employed for detection. More specific technical detail on this subject can be found in Birt and Task (1973).

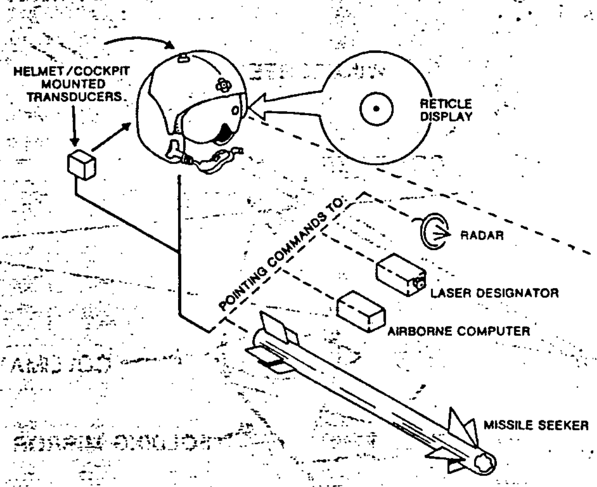

FIG. 3. HELMET-MOUNTED SIGHT (HMS) CONCEPT

1.4 Visually-Coupled Systems

The concurrent use of an HMD with an HMS results in a configuration that has been defined as a Visually-Coupled System (VCS). The HMS determines the operator's line of sight directing video sensors to coincide such that imagery from the observed field of regard is displayed in real time. This powerful technique gives the operator instantaneous visual feedback so that he can introduce corrections and manipulate directional systems (Fig. 4). Additional information on VCS can also be found in Birt and Task (1973).

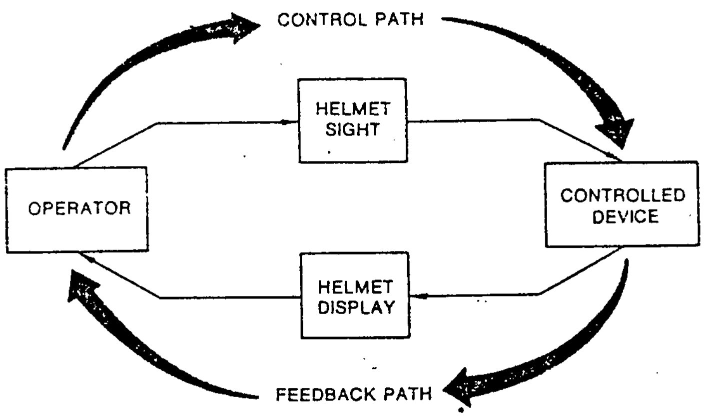

FIG. 4. VISUALLY-COUPLED SYSTEM (VCS) CONCEPT

2. BACKGROUND

Head-Up Displays, although not technically perfected in terms of man-machine interface, have been in operational use in fighter and attack aircraft for the last few decades (Gard, 1978). The Helmet-Mounted Sight, although not so extensively employed, has also undergone production and field service. Helmet-Mounted Displays have languished in the laboratory. The primary reason for this is that every HMD system designed to date has imposed upon the operator more physiological and psychological hardships than could be counterbalanced by the benefits that such systems are capable of providing. This is not to say that HMDs do not offer the potential for significant increases in performance and reductions in pilot workload. It does, however, give some indication of the rather substantial human engineering problems encountered in the design of helmet mounted systems.

There are many complex and interacting parameters involved in the design of a given HMD (Task, Kocian and Brindle, 1980) making trade-offs very difficult. Typically, improving field of view, exit pupil or eye relief results in a larger optical system and unwanted extra weight. The potential solutions are geometrically limited. More detailed discussion on the subject of optical constraints can be found in Larkin (1980). Adverse visual effects are also difficult to avoid. These include such phenomena as distortions, occlusions, brightness inadequacies and binocular rivalry to name only a few. Binocular rivalry has been examined in some depth and documented in Hershberger and Guerin, (1975).

Finally, the physical properties of weight, size and balance (center-of-gravity) complicate the design task even further. Ultimately, the most objectionable feature of an HMD system is added helmet weight. Generally speaking the problems discussed herein increase with system sophistication.

Historically much of the significant HMD development transpired in the late 1960's and early 1970's (Birt and Task, 1973). A large portion of this work included optimization of miniature CRTs in terms of size, brightness and resolution and in the manipulation of various helmet and optical design configurations to reduce weight, improve center-of-gravity and provide for satisfactory viewing characteristics. As one might expect with a fresh technology, design goals were quite high and not knowing the true design limits, researchers emphasized systems with large fields of view, high resolution imagery, binocular viewing capability, color, etc. As discussed earlier the complexity of the systems led to their unacceptability.

3. HELMET-MOUNTED HEAD-UP DISPLAY

A much simpler HMD configuration has been suggested that has fewer physiological disadvantages and the potential for operational usefulness. A Flexible Fiber Optics Bundle can be used to relay the image from a CRT located off the helmet to the helmet optics. Several advantages can be seen with this approach (see Fig. 5). Removing the CRT not only gives a significant weight reduction but does away with high voltage on the helmet. This permits a simple optical decoupling mechanism that the pilot can easily separate in an emergency. Increased flexibility in CRT choice permits the use of larger devices exhibiting higher brightness, ruggedness and even the option of color. Tailoring the design for a symbology-only capability has additional advantages. The lower resolution required to generate recognizable symbols permits a fairly flexible and lightweight bundle, since fewer fiber elements are required. The durability of such a bundle would be quite good. Excellent viewing characteristics result from being able to display a singular, high level of brightness as opposed to several levels of brightness as would be required for imagery. A monocular display presenting symbology only would not be susceptible to binocular rivalry as studies have indicated (Jacobs, Triggs and Aldrich, 1970). In addition, symbolic information is readily interpreted and understood.

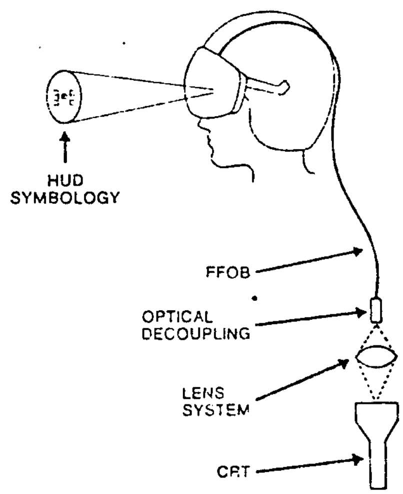

FIG. 5. HELMET-MOUNTED, HEAD-UP DISPLAY (HMHUD) CONCEPT

The overall capability would be similar to that of a HUD although boresight would be lacking. Use of a HMHUD with an HMS would provide the advantages of off-boresight target designation, weapon lock-on and navigation update. Warning and caution information would always be within the view of the operator. The display would be very convenient for input/output interaction with on board computers. Retrofit of course would be relatively simple, giving HUD capability to aircraft that were not originally so equipped.

4. HMHUD PROTOTYPE

With this concept in mind, an in-house effort was undertaken to demonstrate the HMHUD. A Honeywell Mod 7A HMD was chosen to be modified (see Fig. 6). This particular HMD design originally made use of a short non-flexible fiber optics bundle to relay the image from a miniature CRT located on the back of the helmet to the optical system used to project the image onto the helmet visor. The unit shown in Fig. 6 includes Helmet-Mounted Sight sensors and cabling. It was a simple task to replace the CRT and original FFOB with a one meter long, off-the-shelf FFOB. The completed prototype unit is pictured in Fig. 7.

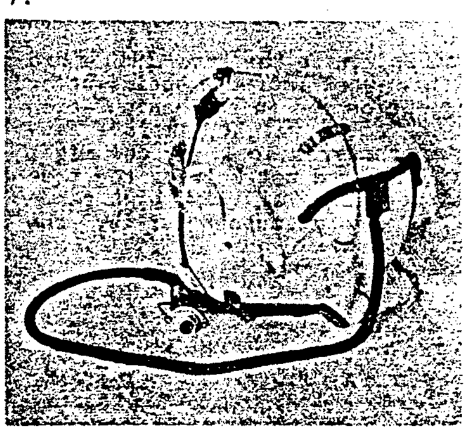

FIG. 6. HONEYWELL MOD 7A HMD

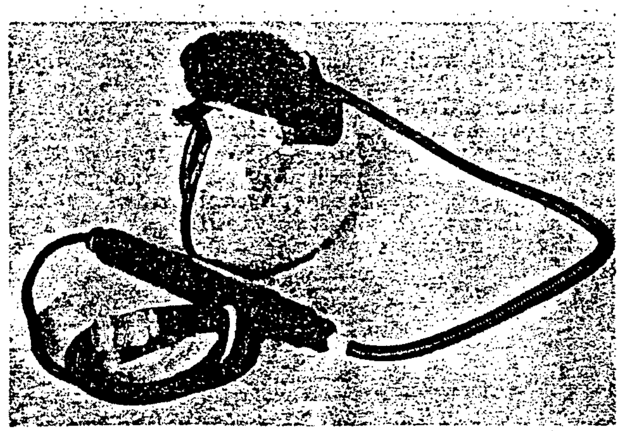

FIG. 7. HMHUD PROTOTYPE

A lens was used to optically couple the image from a miniature CRT to the end of the bundle. Work is presently in progress to couple the miniature CRT to a micro-computer for generating appropriate symbology. The entire system will be used as a research tool to develop a symbology set best suited for HMHUD use.

To determine whether or not a flexible fiber optics bundle of reasonable size could support the image quality required for HUD symbology some test situations were set up and photographed. Figure 8 shows a photograph of a 35 mm slide with a sample of HUD symbology. This slide was then imaged through a 50,000 element, hexagonally formatted FFOB composed of 50 micron fibers. Fig. 9 shows the resulting image at the other end of the FFOB. The FFOB selected for the research prototype is a 350,000 element bundle in a rectangular format composed of 10 micron fibers in 6x6 element subbundles. This FFOB should provide slightly better resolution, depending on the misregistration and fiber breakage of the particular bundle acquired.

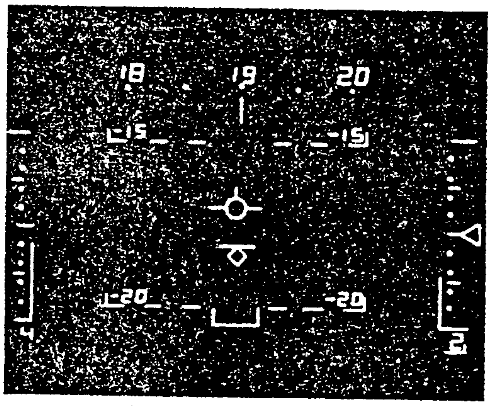

FIG. 8. HUD SYMBOLOGY (35mm SLIDE)

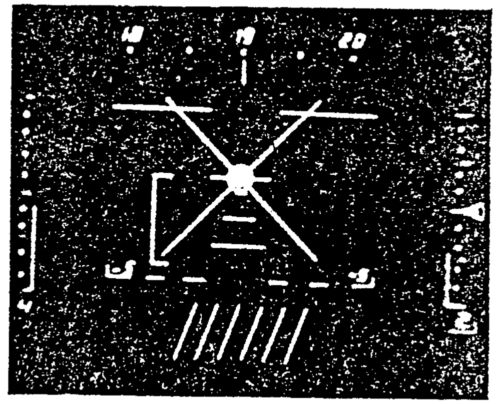

FIG. 9. HUD SYMBOLOGY ON FFOB IMAGE PLANE

5. FFOB STUDIES

Since resolution is directly related to the number of fibers and since weight and flexibility are improved with fewer fibers, it becomes desirable to know how many fibers across a given symbol are required for easy recognition. Studies are being conducted at AFAMRL to define limits such as these. One study, already completed, varied both the number of fibers across alphanumeric characters and the angular subtense of the characters themselves. Subjects were scored on response time and number of correct responses. Two different bundles were used, one having a rectangular format (Fig. 10) and one having a hexagonal format (Fig. 11). Major findings of the study indicated that performance with the hexagonal bundle was superior to that with the rectangular bundle and optimal performance occurred at approximately 8.7 elements or more per character height and with character angular subtenses greater than 18 minutes of arc. This data will serve to define the lower limit of symbol sizes for a Helmet-Mounted Head-Up Display.

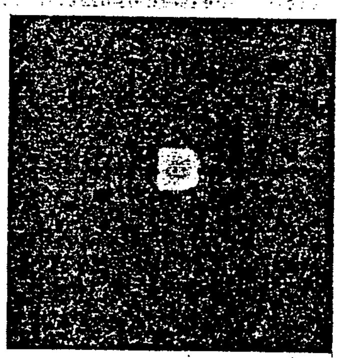

FIG. 10. RECTANGULAR FORMAT FFOB

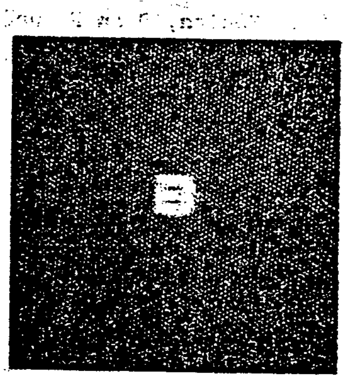

FIG. 11. HEXAGONAL FORMAT FFOB

There are a few FFOB disadvantages worth discussing. Imperfections are present in every bundle to some degree. Fibers are not always registered perfectly from end to end although this is not a severe problem. Misregistration displaces a pixel of information slightly from its original physical location. Broken fibers and sub-bundles result in small, dark inactive areas (see Fig. 10). This problem becomes worse with time and use as more fibers break. Light transmission is attenuated by approximately ten percent per foot in a typical FFOB. A sufficiently bright source would compensate for this effect. Since each end surface of the bundle is an image plane, debris and scratches on these surfaces can interfere with any image being projected. Extra care must be taken to insure that the imaging surfaces are kept isolated from foreign material and abuse. The bundle structure itself results in a fixed pattern that is superimposed on the image plane. This can be a mild distraction. There are two techniques that can be employed to limit fixed pattern effects, if this is desirable. A small specially designed prism set properly at each end of the bundle breaks up and recombines the transmitted light according to wavelength eliminating the image of the pattern. This technique is called "wavelength multiplexing". Wavelength multiplexing results in additional complexity, size and added weight. Another method to effectively eliminate the pattern image utilizes synchronized vibration at each end of the bundle. It is not a simple task to control vibration with the accuracy necessary to eliminate the fixed pattern noise without blurring the image due to unsynchronized vibration. None of the problems discussed above appear to be insurmountable.

6. CONCLUSIONS

The authors believe that a Helmet-Mounted, Head-Up Display as described in this paper offers the pilot a unique and useful information source without many of the more prominent disadvantages usually associated with Helmet-Mounted Displays. Very important weight reductions are possible with this configuration, adverse visual effects are minimized, high voltage separation is unnecessary and retrofit is simple and inexpensive.

Tactically, the device can be used with a Helmet-Mounted Sight to provide off-boresight, head-up interaction with weapon delivery and navigation systems.

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Task, H. Lee, Kocian, Dean F. and Brindle, James H., 1980, "Helmet-Mounted Displays: Design Considerations," in Advancement on Visualization Techniques, Hollister, W.M. (Ed.), AGARDograph No. 255, Harford House, London.

AFAMRL-TR-82-4

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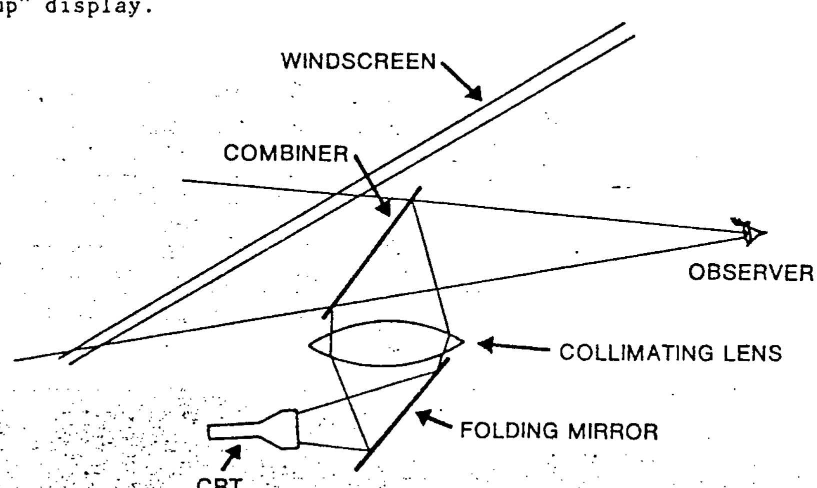

FIG. 1. HEAD-UP DISPLAY (HUD) CONCEPT

1.2 Helmet-Mounted Display

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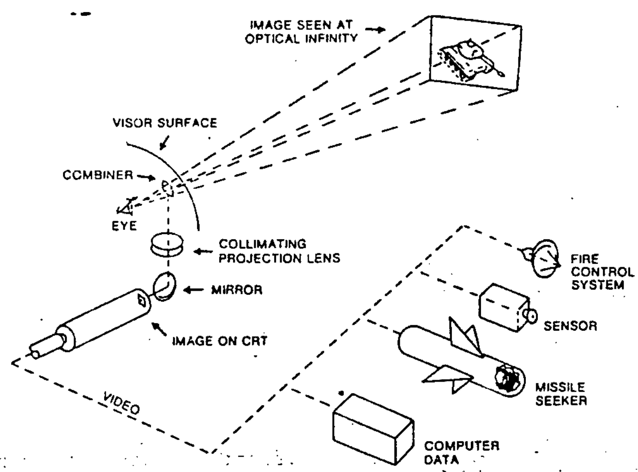

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A few important distinctions are worth noting in comparing the HUD and HMD. The HUD requires nothing on the pilot's head. Both eyes view the information presented through the same aperture with restricted head positioning but very stable boresight accuracies can be achieved. In utilizing the HMD the pilot sees the entire video field constantly, regardless of head motion but usually only in one eye. Also, some visual obstructions are usually present due to the proximity of the hardware and boresight does not have significance.

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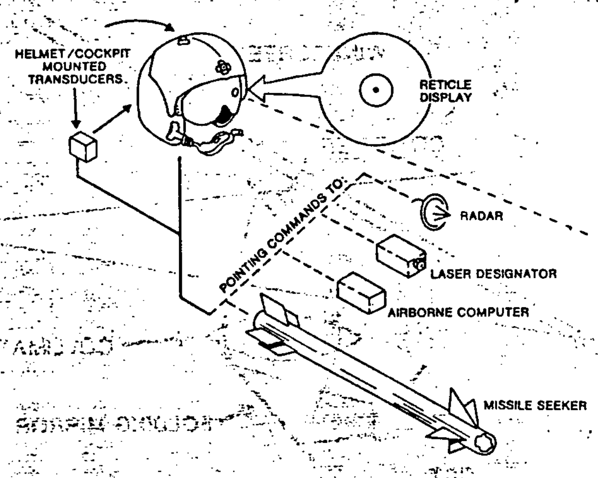

FIG. 3. HELMET-MOUNTED SIGHT (HMS) CONCEPT

1.4 Visually-Coupled Systems

The concurrent use of an HMD with an HMS results in a configuration that has been defined as a Visually-Coupled System (VCS). The HMS determines the operator's line of sight directing video sensors to coincide such that imagery from the observed field of regard is displayed in real time. This powerful technique gives the operator instantaneous visual feedback so that he can introduce corrections and manipulate directional systems (Fig. 4). Additional information on VCS can also be found in Birt and Task (1973).

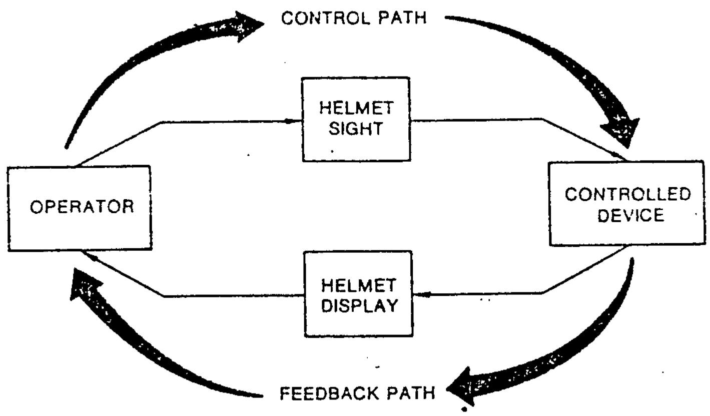

FIG. 4. VISUALLY-COUPLED SYSTEM (VCS) CONCEPT

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Finally, the physical properties of weight, size and balance (center-of-gravity) complicate the design task even further. Ultimately, the most objectionable feature of an HMD system is added helmet weight. Generally speaking the problems discussed herein increase with system sophistication.

Historically much of the significant HMD development transpired in the late 1960's and early 1970's (Birt and Task, 1973). A large portion of this work included optimization of miniature CRTs in terms of size, brightness and resolution and in the manipulation of various helmet and optical design configurations to reduce weight, improve center-of-gravity and provide for satisfactory viewing characteristics. As one might expect with a fresh technology, design goals were quite high and not knowing the true design limits, researchers emphasized systems with large fields of view, high resolution imagery, binocular viewing capability, color, etc. As discussed earlier the complexity of the systems led to their unacceptability.

3. HELMET-MOUNTED HEAD-UP DISPLAY

A much simpler HMD configuration has been suggested that has fewer physiological disadvantages and the potential for operational usefulness. A Flexible Fiber Optics Bundle can be used to relay the image from a CRT located off the helmet to the helmet optics. Several advantages can be seen with this approach (see Fig. 5). Removing the CRT not only gives a significant weight reduction but does away with high voltage on the helmet. This permits a simple optical decoupling mechanism that the pilot can easily separate in an emergency. Increased flexibility in CRT choice permits the use of larger devices exhibiting higher brightness, ruggedness and even the option of color. Tailoring the design for a symbology-only capability has additional advantages. The lower resolution required to generate recognizable symbols permits a fairly flexible and lightweight bundle, since fewer fiber elements are required. The durability of such a bundle would be quite good. Excellent viewing characteristics result from being able to display a singular, high level of brightness as opposed to several levels of brightness as would be required for imagery. A monocular display presenting symbology only would not be susceptible to binocular rivalry as studies have indicated (Jacobs, Triggs and Aldrich, 1970). In addition, symbolic information is readily interpreted and understood.

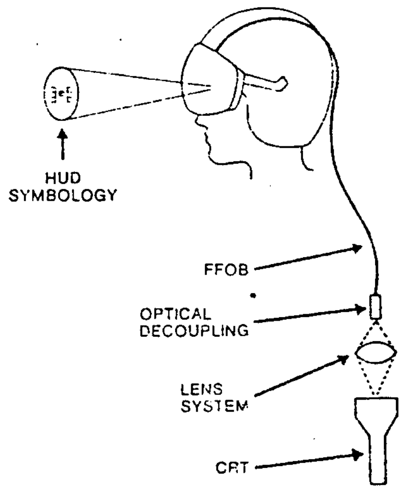

FIG. 5. HELMET-MOUNTED, HEAD-UP DISPLAY (HMHUD) CONCEPT

The overall capability would be similar to that of a HUD although boresight would be lacking. Use of a HMHUD with an HMS would provide the advantages of off-boresight target designation, weapon lock-on and navigation update. Warning and caution information would always be within the view of the operator. The display would be very convenient for input/output interaction with on board computers. Retrofit of course would be relatively simple, giving HUD capability to aircraft that were not originally so equipped.

4. HMHUD PROTOTYPE

With this concept in mind, an in-house effort was undertaken to demonstrate the HMHUD. A Honeywell Mod 7A HMD was chosen to be modified (see Fig. 6). This particular HMD design originally made use of a short non-flexible fiber optics bundle to relay the image from a miniature CRT located on the back of the helmet to the optical system used to project the image onto the helmet visor. The unit shown in Fig. 6 includes Helmet-Mounted Sight sensors and cabling. It was a simple task to replace the CRT and original FFOB with a one meter long, off-the-shelf FFOB. The completed prototype unit is pictured in Fig. 7.

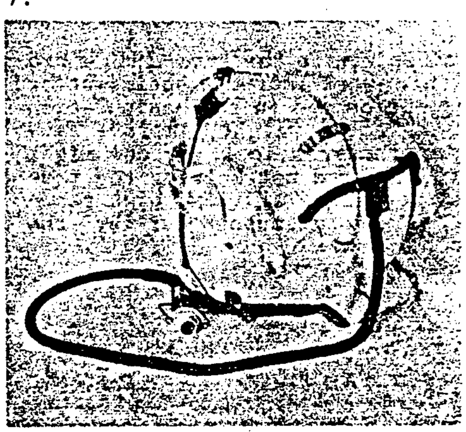

FIG. 6. HONEYWELL MOD 7A HMD

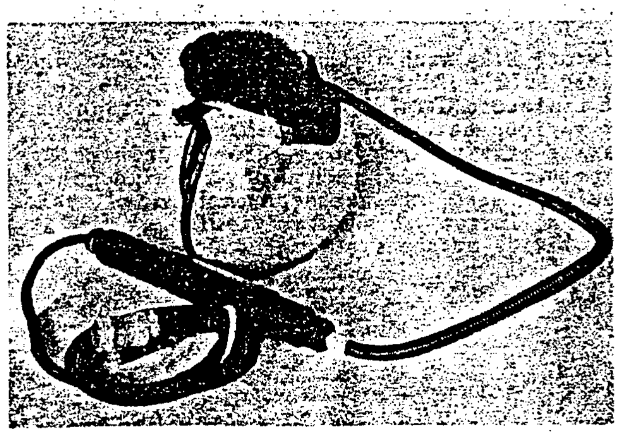

FIG. 7. HMHUD PROTOTYPE

A lens was used to optically couple the image from a miniature CRT to the end of the bundle. Work is presently in progress to couple the miniature CRT to a micro-computer for generating appropriate symbology. The entire system will be used as a research tool to develop a symbology set best suited for HMHUD use.

To determine whether or not a flexible fiber optics bundle of reasonable size could support the image quality required for HUD symbology some test situations were set up and photographed. Figure 8 shows a photograph of a 35 mm slide with a sample of HUD symbology. This slide was then imaged through a 50,000 element, hexagonally formatted FFOB composed of 50 micron fibers. Fig. 9 shows the resulting image at the other end of the FFOB. The FFOB selected for the research prototype is a 350,000 element bundle in a rectangular format composed of 10 micron fibers in 6x6 element subbundles. This FFOB should provide slightly better resolution, depending on the misregistration and fiber breakage of the particular bundle acquired.

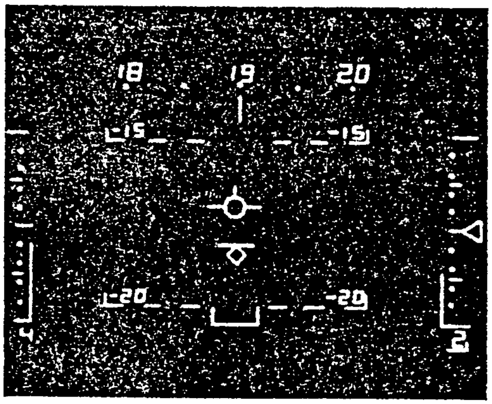

FIG. 8. HUD SYMBOLOGY (35mm SLIDE)

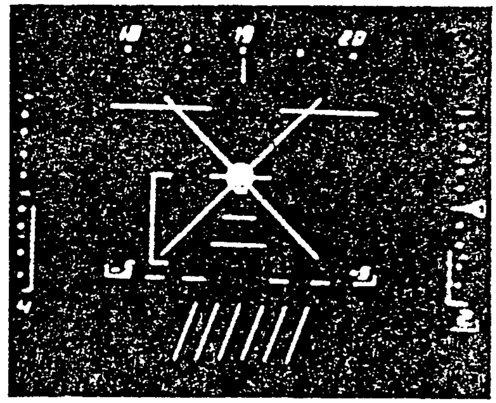

FIG. 9. HUD SYMBOLOGY ON FFOB IMAGE PLANE

5. FFOB STUDIES

Since resolution is directly related to the number of fibers and since weight and flexibility are improved with fewer fibers, it becomes desirable to know how many fibers across a given symbol are required for easy recognition. Studies are being conducted at AFAMRL to define limits such as these. One study, already completed, varied both the number of fibers across alphanumeric characters and the angular subtense of the characters themselves. Subjects were scored on response time and number of correct responses. Two different bundles were used, one having a rectangular format (Fig. 10) and one having a hexagonal format (Fig. 11). Major findings of the study indicated that performance with the hexagonal bundle was superior to that with the rectangular bundle and optimal performance occurred at approximately 8.7 elements or more per character height and with character angular subtenses greater than 18 minutes of arc. This data will serve to define the lower limit of symbol sizes for a Helmet-Mounted Head-Up Display.

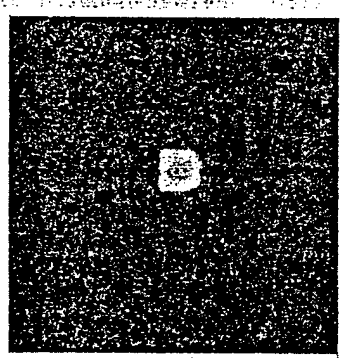

FIG. 10. RECTANGULAR FORMAT FFOB

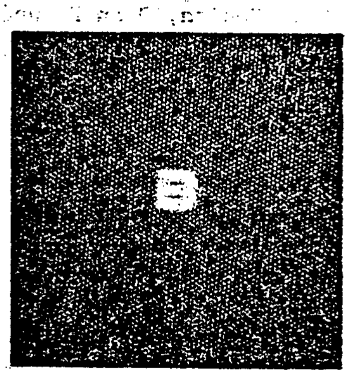

FIG. 11. HEXAGONAL FORMAT FFOB

There are a few FFOB disadvantages worth discussing. Imperfections are present in every bundle to some degree. Fibers are not always registered perfectly from end to end although this is not a severe problem. Misregistration displaces a pixel of information slightly from its original physical location. Broken fibers and sub-bundles result in small, dark inactive areas (see Fig. 10). This problem becomes worse with time and use as more fibers break. Light transmission is attenuated by approximately ten percent per foot in a typical FFOB. A sufficiently bright source would compensate for this effect. Since each end surface of the bundle is an image plane, debris and scratches on these surfaces can interfere with any image being projected. Extra care must be taken to insure that the imaging surfaces are kept isolated from foreign material and abuse. The bundle structure itself results in a fixed pattern that is superimposed on the image plane. This can be a mild distraction. There are two techniques that can be employed to limit fixed pattern effects, if this is desirable. A small specially designed prism set properly at each end of the bundle breaks up and recombines the transmitted light according to wavelength eliminating the image of the pattern. This technique is called "wavelength multiplexing". Wavelength multiplexing results in additional complexity, size and added weight. Another method to effectively eliminate the pattern image utilizes synchronized vibration at each end of the bundle. It is not a simple task to control vibration with the accuracy necessary to eliminate the fixed pattern noise without blurring the image due to unsynchronized vibration. None of the problems discussed above appear to be insurmountable.

6. CONCLUSIONS

The authors believe that a Helmet-Mounted, Head-Up Display as described in this paper offers the pilot a unique and useful information source without many of the more prominent disadvantages usually associated with Helmet-Mounted Displays. Very important weight reductions are possible with this configuration, adverse visual effects are minimized, high voltage separation is unnecessary and retrofit is simple and inexpensive.

Tactically, the device can be used with a Helmet-Mounted Sight to provide off-boresight, head-up interaction with weapon delivery and navigation systems.

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