

Head Up Display Performance Improvements and Cost Reductions through the Application of Non-conventional Engineering Solutions

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ABSTRACT

This paper describes displays realized by the use of radically new optical and image source design techniques that have facilitated very significant performance improvements beyond those previously achieved.

These improvements are not only in respect of size, weight, volume and cost for a given optical performance, but also in the characteristics that currently limit, or in some cases prohibit, the use of such displays in many cockpit applications. Displays that have been realized and tested through the implementation of these new techniques are described and their performance in laboratory and flight trials discussed, together with a discussion of the way ahead for further progress in their development.

INTRODUCTION

Since their early military roots in reflector, or Gyro, gun sights in the middle of the last century, head up displays have undergone continuous and intensive development in aerospace applications.

The designs have to date been implemented optically through geometric design techniques and whereas recently solid state image sources have begun to replace the Cathode Ray Tubes traditionally used [1],[2], the impact of that particular change has not been that great in respect of cost or performance, the main benefit being in reliability.

The HUD has probably progressed, in its current form, to the point where very little further improvement in these areas is possible.

Recently, novel methods have been developed in the techniques both of image generation and optical design [3] that have enabled significant improvements to be realized. Before these techniques are discussed in

detail, it is perhaps appropriate to briefly summarize the conventional designs produced to date such that the significance of this new work may be more readily appreciated.

HUD DESIGN TECHNIQUES

CONVENTIONAL APPROACH - HUD optical designs may be either *refractive* or *reflective* the principal difference between the two being in where the final lens element of the system is placed.

Whereas both present a collimated¹ image in the pilot's forward field of regard, the position of the final element has a fairly significant impact on the optical performance of the display.

The two types are illustrated in figure one where the most immediate difference is evident in that *refractive* designs employ flat Combiners whereas *reflective* designs incorporate curved.

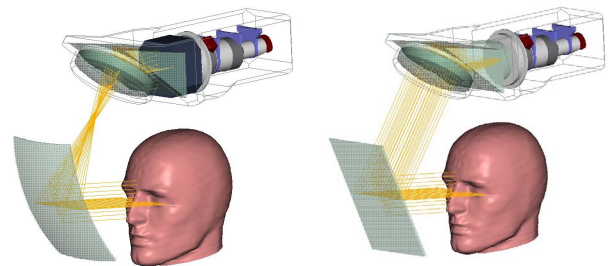


Figure 1; Reflective cf. Refractive configurations
Refractive designs- In the *refractive* design, the final focus or collimation is performed, (as it's name implies), by refraction at the exit lens of the projector, this image

¹ A collimated display is one that is effectively focussed at or near infinity.

being finally reflected from a flat Combiner that has no optical power.

In this case, the instantaneous field of view² is limited by the size of the exit lens on the projector and the pilot's eye relief³, such that usually only part of the total field of view⁴ is visible from a given point in the eye motion box⁵.

Reflective designs- In the reflective design, the final image focus, or collimation, is performed by the reflection of an intermediate aerial image formed by the projection optics in the focal plane of a semi-silvered mirror that also performs the function of the Combiner. In this type of design, the total and instantaneous fields of view can be made equal from the centre of the eye motion box, which is desirable since it precludes information being hidden from the pilots view, however it does have the disadvantage of having an eye motion box that will be smaller than that of a refractive design with an equivalent sized final lens element and Combiner. This is illustrated in figure (2).

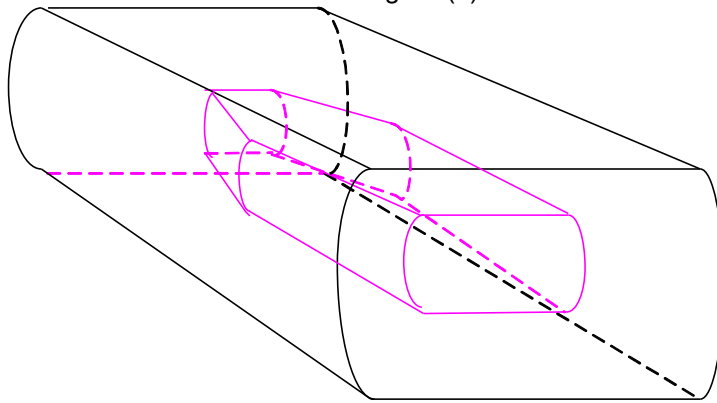


Figure 2; Eye motion box dimensions for similar reflective and refractive HUD designs.

The reflective HUD EMB is the smaller box contained within the larger EMB of the refractive HUD

In a given application, the fields of view and eye motion box are constrained by the maximum volume that is available for the overhead projector in the cockpit, hence

the choice between which to adopt will depend on the particular application.

All HUDs currently in service will be based on one or the other of these design approaches.

HUD designs based on both these geometric optical design techniques have been in production by BAE Systems since 1962, and though the development of the optical design has been continuous since that time, it has reached a practical limit in achievable total fields of view of slightly over forty degrees for an acceptable projector optic size, since field of view is bought at the expense of lens size.

² The Instantaneous Field of View is the proportion of the total field of view of the system that may be seen from a particular point in the eye motion box

³ Distance from the pilot's eye to the Combiner

⁴ The Total Field of View is the angular image that represents the total extent of the image source

⁵ The eye motion box is that volume in space from which the centre of the field of view is visible.

Image sources- Until very recently, cathode ray tubes have been universally employed as the image source for all conventional HUDs, however these are now being replaced by liquid crystal or MEMS based designs illuminated by LED or Laser light [1], [2]. The improvements from this approach are basically in the area of reliability.

UNCONVENTIONAL APPROACHES-

System designs with a useful field of view have to date required a rather bulky projector and whereas this may be buried in the overhead structure of the cockpit to some extent, there has nevertheless always some intrusion into the space above the pilot's head which though undesirable has had to be accepted as unavoidable.

Waveguide technology- Recently, a new optical design approach, called *waveguide technology*, has been applied to HUD designs resulting in the realization of systems with performance equal to or better than existing systems but in a far more compact form factor that does not need to compromise the head space above the pilot.

As its name implies, this technology is in essence a revolutionary way of manipulating and controlling light using parallel sided sheets of glass (or polycarbonate) that act as waveguides to light contained within their structures.

Application of this technology results in significant reductions in complexity providing benefits in mass, cost, volume, and optical performance

Principles of operation- It is a well known property of light that under certain conditions it may be trapped within a parallel sheet of glass by a mechanism referred to as *total internal reflection* (TIR). This is illustrated in figure three.

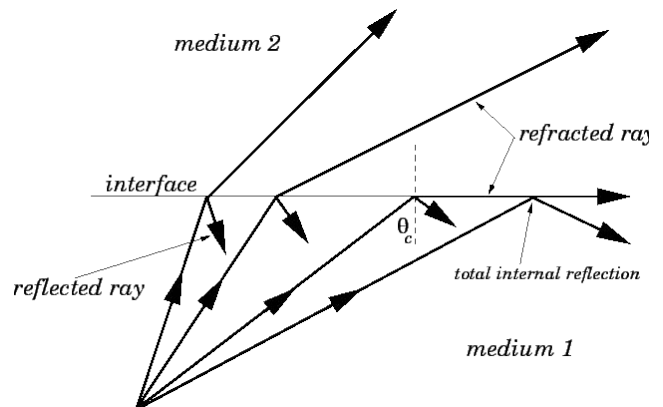


Figure 3 Total Internal Reflection; beyond a critical value of the angle θ_c , the light is totally internally reflected and cannot escape the glass

This phenomenon has been exploited in the HUD design as illustrated in figure four and explained in the theory of operation.