The LANTIRN Head – Up Display

by G. R. Sleight

(LANTIRN is a USAF acronym for LOW ALTITUDE NAVIGATION and TARGETTING by INFRA RED at NIGHT).

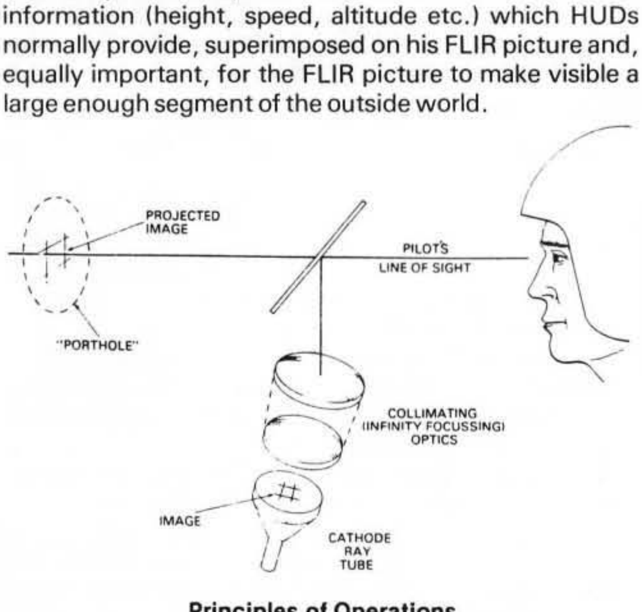
Extending current technology

To put into their proper perspective the advances which we have made in holographic Head-Up Displays (HUD), for this programme, I would like to spend a few moments describing current technology HUD systems.

A HUD is, of course, an equipment which projects images into a pilot's line of sight. The forerunner of today's equipment, in which high brightness cathode ray tubes are used to generate the image, was the HUD developed by the Company and the UK Ministry of Defence for the Buccaneer aircraft, in 1960. Aircraft and HUD are both still doing yeoman service.

Using a CRT to generate the images makes it possible to provide the pilot with a comprehensive set of information regarding height, speed, heading, altitude and so on. Additionally, as the HUD image is collimated (focussed at infinity), information cues on it can be space stabilized. In other words the HUD, alone, of all an aircraft's instruments, can provide the pilot with cues (such as an artificial horizon, for example) which overlay and relate directly to his view of the real world. This can make low-level flying safer, by showing the pilot at all times an indication of his actual flight path vector. With this he can immediately appreciate exactly where the aircraft is going and whether it will clear the terrain ahead. The extension of this technique for weapon aiming purposes is obvious.

To extend the capability of existing NATO aircraft, to enable them to operate more effectively beyond the hours of daylight, various programmes have been sponsored by the United States and United Kingdom governments. They have also been the subject of significant private venture invesment by our own Company. They have explored the use of various forward-looking sensors such as low-light TV (LLTV) and forward-looking infra-red (FLIR). It has been found that by providing the FLIR or LLTV image on the HUD at a scaling of 1:1 with the real world (synthesized information co-incident with the real world) the pilot can have restored to him much of his normal daylight freedom to 'see to fly'. There is, however, still the need to have all information (height, speed, altitude etc.) which HUDs normally provide, superimposed on his FLIR picture and, equally important, for the FLIR picture to make visible a large enough segment of the outside world.

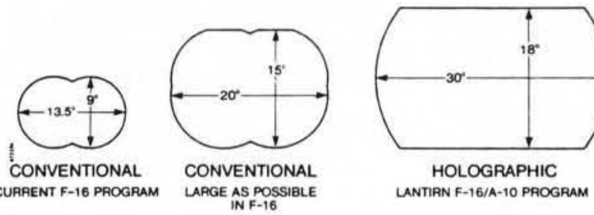


Principles of Operations Head Up Display

How much of the outside world the pilot sees depends on the 'field of view' of the HUD. All HUD systems have a field of view which is limited, the so-called 'porthole' effect, by the final lens element in the collimating optical system. The angular field of view (FOV) is very simply a geometric function of the size of this lens and the distance of the lens from the pilots eye – the bigger the lens and shorter the distance (two incompatible parameters with normal HUDs) the bigger the FOV. To get a feel for the effect of FOV I do not believe any of us would feel free (or indeed safe) to drive around Hyde Park Corner with our normal panache if we had blanked off side windows, a shattered windscreen and only a small area ahead of us as the clear vision panel. Yet this is exactly the kind of feat we would be expecting fighter pilots to achieve with a restricted field of view.

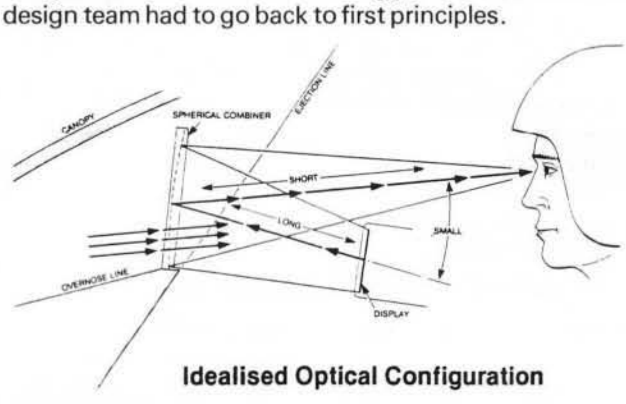
Quest for field of view

One of the key aspects of the LANTIRN HUD programme has been the achievement of a large field of view. The target we were set was 30 degrees in azimuth and 20 degrees in elevation. The HUD system has to achieve its required functions whilst still conforming to a very specific set of constraints. It must not infringe the pilot's view over the nose of the aircraft, nor protrude aft of the safety line required for pilot ejection. It must fill up only a very modest area of the total instrument panel (which as you will see, for an aircraft like the F-16, is very small anyhow) and last, and most obvious of all, every part of the optical system including combiner elements must stay within the confines set by the windscreen.



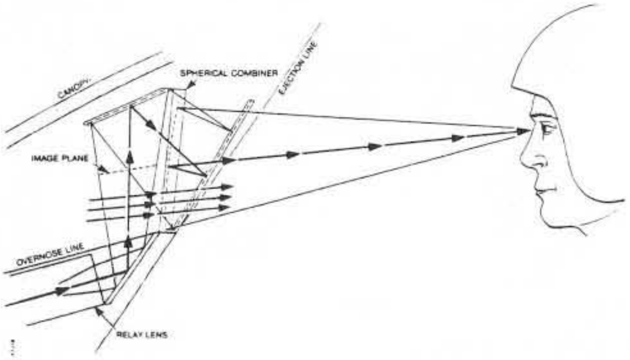
Fields of View achievable for F-16 using Refractive and Diffractive Optics

To enlarge the field of view of the standard F-16 HUD Marconi Avionics had, in advance of the LANTIRN Programme, designed a special HUD for the 'Advanced Fighter Technology Integrator' (AFTI) version of the F-16. This uses a relatively conventional optical system, about 30% larger than the standard production unit and coupled with some other improvements, provided a field of view of about 20 by 15 degrees. This was still short of the USAF requirements, but was the largest which could possibly be achieved with a conventional HUD optical design. To achieve an even bigger field of view our design team had to go back to first principles.



Idealised Optical Configuration

If the collimating element is placed on the corner of the glareshield at the intersection with the ejection safety line, one can achieve the biggest field of view with the smallest possible size of collimating element. This optical system, however, requires the CRT image to enter from the pilot's side. This is not readily achieved as we have already moved next to the ejection line. Our team evolved therefore a method of folding the light around, using a variety of flat mirror-type surfaces, to achieve a condition where the CRT would fit back into the location available for it.



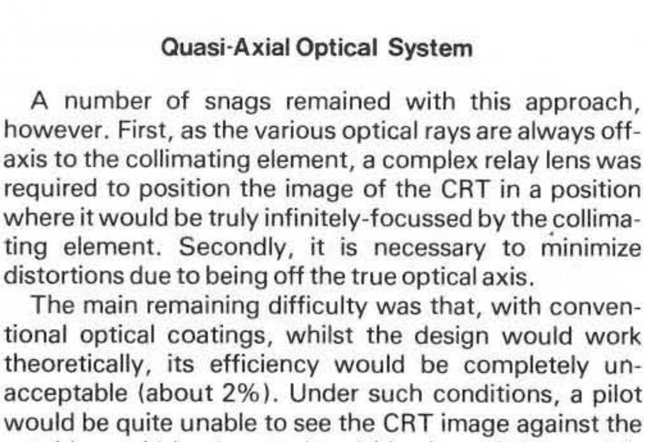
Quasi-Axial Optical System

A number of snags remained with this approach, however. First, as the various optical rays are always off-axis to the collimating element, a complex relay lens was required to position the image of the CRT in a position where it would be truly infinitely-focussed by the collimating element. Secondly, it is necessary to minimize distortions due to being off the true optical axis.

The main remaining difficulty was that, with conventional optical coatings, whilst the design would work theoretically, its efficiency would be completely unacceptable (about 2%). Under such conditions, a pilot would be quite unable to see the CRT image against the outside world background and his view of the outside world would also be attenuated.

Holograms the answer

The ability to use holgrams (or, to be more technically precise, diffraction gratings), instead of conventional reflective coatings, transforms the situation and makes the whole optical layout feasible.



Reflectance/Transmission Properties of Holograms

I should explain that the holograms used in the LANTIRN HUD are essentially holograms of mirror surfaces, produced by exposing a photo-sensitive material to an interfering pattern of light produced by that mirror surface. They can be thought of as semi-silvered mirrors, such as are produced by conventional optical coatings but with unique properties. First, they will reflect light only of a certain bandwidth (i.e. colour). We choose the colour produced by a narrow bandwidth green phosphor on the CRT. They do, however, reflect this light very efficiently (typically about 90%), while still allowing all other light to pass straight through. Because of the narrow bandwidth in which they operate, white light is effectively transmitted at about 90%. In other words we have found one of the rare conditions in life where we are getting something for nothing: a surface which transmits 90% of the light hitting it and yet apparently also reflects to similar value!

In addition to this useful phenomenon such holograms can, over a fairly limited range of angles, go from reflecting nearly all light of this phosphor bandwidth to transmitting (with some change in the angle of incidence), nearly all of the same light. Thus for some angles, a green ray will reflect from the hologram, whilst at other angles it will pass through unimpeded. These features allow us to raise the efficiency of the optical arrangement used from the miserable figure of some 2% to something more like 40% – a figure which makes the display even brighter than achieved with a normal HUD optic.

No aberration

It is also possible to make rays reflect from holograms at angles which are not the direct reflection of their incidence angle. Indeed, the effect of such altered reflection angles can be controlled across the area of a hologram. Such optical shaping or power characteristics would create an aberrated hologram. Because such aberrated holograms are much more difficult to manufacture, and produce other side scatter effects, we do not use them in the LANTIRN system.

Design for manufacture and service use

Great attention has been paid to the manufacture and maintenance of the HUD system with acceptable long term life cycle costs.

In particular, maximum use has been made of the important design standards evolved by the United States Air Force. The three MIL standards making up the so called 'TRIAD' have been successfully brought together, for the first time, in this equipment. These are –

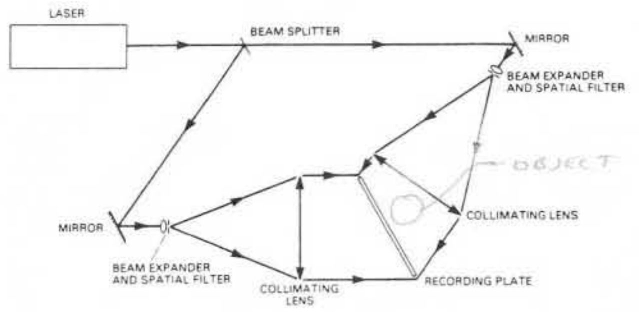
MIL-STD-1553B – Standardised Electronic Data Highway. This reduces aircraft wiring and would enable additional equipments to be installed in an aircraft more flexibly.

MIL-STD-1750A – Standardized Computer architecture, ensuring compatibility with international high level language development such as ADA.

MIL-STD-1589A – Standardized Jovial J73 Computer language, to allow ready support or modification by the USAF during the life of the system. Pending the long term availability of ADA, Jovial J73 will be the standard USAF language.

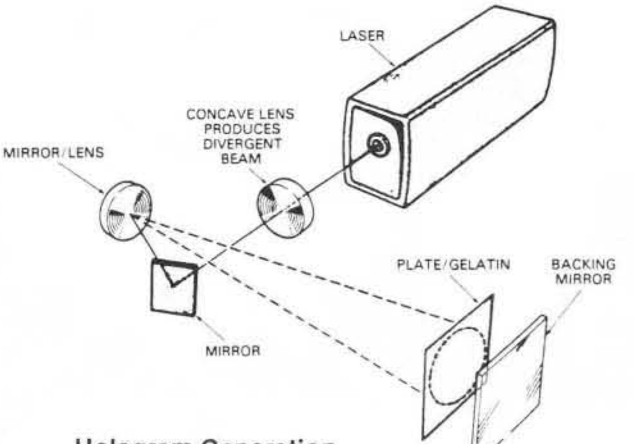
The equipment makes use of a wide variety of 'state-of-the art' electronic devices – large scale memory, programmable array logic and microprocessors and includes many custom designed hybrid micro circuits. In common with all other Marconi Avionics HUDs, it comprises convenient replaceable modules, for ease of manufacture and maintenance.

I have already stated our avoidance of aberrated holograms in the optical system. To produce them would require the laser beam we use for hologram exposure to be split into two and brought together again to intefere on the element under exposure. With a sizeable difference



Production of Reflection Holograms Using Separated Beams

in the two path lengths, a controlled wavelength difference can exist in the two beams. The total energy which can be put into the element being exposed however, would be low and the exposure time, therefore, fairly long (of the order of 20 minutes). The problem of holding two beams stable to fractions of a wavelength over such a time would be considerable.



Hologram Generation Using Back Reflection

With unaberrated holograms it has been found possible to achieve the necessary interference pattern by a single beam of light, back-reflecting from a mirror in close contact with the element being exposed. This technique also allows an order more laser energy to be focussed into the element, drastically reducing exposure time. With only this single beam to control and a short exposure time, the stability problem is eliminated so the holograms are easier to make.

The LANTIRN programme

The USAF programme involved the placing of two independent contracts, with Martin Marietta for the LANTIRN navigation and targetting pods, and with Marconi Avionics for the HUD. Both contracts have required ambitious technical developments. The equipment from each contract is for fitment to the F-16 and A-10 aircraft but must be capable of fitting other types. Thus the programme has required extensive technical co-ordination between the various contractors involved. The large number of sub-contractors, whose expertise in their respective fields has also been important, has created a complex international programme management task for both the USAF and their prime contractors. Today's event testifies to the success and effectiveness of this programme management.

Notwithstanding our handover of this initial system, we have a busy time ahead of us. There are a total of 11 development HUD systems to produce for the F-16 and 5 for the A-10, all within the next eight months. Flight trials start on the F-16 this summer, with a corresponding programme for the A-10 a little later. The various equipments are scheduled for qualification tests, reliability tests, maintainability test and bench integration tests, as well as spares and back up for flight trials. This depth of testing will ensure that, when production aircraft receive this system in 1984, it will meet or exceed the standard set by our present F-16 HUD. The capability of this aircraft with the Marconi Avionics 'conventional' HUD was convincingly demonstrated recently by clear superiority in the RAF tactical bombing competition. With the LANTIRN system the USAF intends to achieve a comarable capability at night for both the F-16 and A-10, so enhancing the effectiveness of the NATO defences. We are pleased to play our part in the successful development of equipment for this programme, in the way we are demonstrating today.