MARCONI
AVIONICS

MONOHUD

A Head Up Display System for Civil Transport Aircraft

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AIRBORNE DISPLAY DIVISION

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1 INTRODUCTION

The positive interest shown over the last decade in HUDs by Airline Management, pilot associations, the FAA and the CAA has begun to solidify and a number of applications for the use of HUDs in civil aviation are being actively evaluated. The impetus of this increased interest has caused the FAA to assume an active role in the debate by devising a joint programme with NASA to determine how significantly a HUD could contribute in particular to the safety of operation of civil jet transport aircraft.

The factors which affect the fitment of a HUD to a civil aircraft include:

- role definition
- certification
- installation problems
- cost effectiveness
- equipment development timescale
- pilot acceptance

and a detailed assessment of the implication of each of the factors is essential before an airline can make a decision as to which HUD system, if any, to adopt.

Marconi Avionics have to-date produced more than 25 HUD systems variants for military aircraft (as well as several experimental civil HUD systems), delivered more than 2500 in total, and are fully conversant with the problems involved in the installation, evaluation and certification of HUD systems in a civil cockpit. System and operational arguments aside, the most difficult technical problem has been to achieve an installation with an acceptable field of view in the very confined areas of the glareshield, or the space overhead which can be applied to a variety of existing or new flight decks.

A satisfactory solution for a civil HUD calls for a mounting position which does not inhibit crew movement, does not give visual cut off to instruments or degrade downward vision. Equipment should be developed which permits a common standard of installation on both sides of the flight deck with minimal effort in re-alignment following an equipment replacement. Specific customer requirements should not involve changes to the display unit but only the associated avionic equipment.

Working towards this ideal Marconi Avionics have now established a probable solution known as Monohud which because of its low cost and straightforward retrofit capability could significantly hasten the introduction of HUDs into civil aviation and provide the commercial benefits which market leadership in civil HUDs would bring.

Monohud is an overhead mounted display unit using conventional optics which give a large instantaneous field of view and as such is suitable for the whole range of current civil transport aircraft. Models have been produced which demonstrate the potential of the simple optical concept together with the feasibility of using small CRTs for HUD application. The Monohud concept now has to be developed to the stage where a suitable system can be assembled for evaluation under flight operational conditions, in both simulated and actual flight.

In addition to the move to introduce HUDs onto the civil flight deck there is also a world wide interest in evolving simpler overall systems to achieve Category 3 operations without jeopardising safety. The Cat. 3 requirements were specified nearly a decade ago and considerable advances have since been made on aspects such as fog characteristics and measurement, avionic system design and reliability, airfield visual aids and airline experience of all weather operations. This trend toward an Economic Category 3 (EC3) would allow existing suitably equipped aircraft to operate down to lower weather minima, thus increasing regularity and revenue.

2. APPLICATION AREAS

The primary applications foreseen in civil aviation in which the use of a HUD can be made more cost-effective are:

- As a system element in economic Category 2 and 3 automatic landing systems
- As a means of visual approach guidance to runways lacking a precision approach – especially short runways and/or night 'black hole' approaches.
- As a means for detecting and coping with low level windshear.

Additionally, once fitted the HUD can provide the following secondary facilities.

- In conjunction with curved path approaches (either for control or as a monitor using microwave landing system curved paths).
- As an aid to energy management and fuel conservation
- In conjunction with a ground proximity warning logic for terrain avoidance
- As a take off and go-around director
- For runway guidance

3. INSTALLATION PROBLEMS

There is a fundamental similarity in all civil aircraft cockpits, arising from the fact that the pilot has a number of control activities to perform related to the aircraft and its systems and that these activities are limited by his workload capacity and by his physical reach. Despite the advent of wide body jets this installation problem remains the same today because pilots are still as close as an arms length to each other, to the instrument panel and to the centre console and overhead glare shield panels as they were in the smaller jets. In consequence the recognised display installation sites, overhead and glare shield, are equally limited in old and new aircraft types and it can be seen from figure 1 that the amount of room available to install a Head-Up Display system is limited by factors other than the size of the aircraft. There are of course differences in the layout, disposition and geometry of different cockpits but none of them have a very large amount of space in which to install a Head-Up Display system.

The problem of providing adequate optical fields of view fundamentally is dependent on the size and distance of the optic from the pilot's eye, and is therefore directly affected by installation constraints.

Thus the essential conclusion from our experience and our various discussions with the aircraft industry is that the projection unit must be reduced in size and volume to the minimum possible consistent with a reasonable viewing aperature and installation flexibility.

For the aircraft manufacturers, the multiple type fleet operator and the certification authorities significant standardisation advantages of installation, use the certification are obtained if a HUD system concept can be devised which is small enough to fit universally in all aircraft types and yet give a large field of view. In this event not only the equipment bay electronics but also the flight deck display and electronics equipment can be controlled by a single ARINC specification and a single ARINC form factor.

An entirely new design approach has therefore been pursued resulting in an overhead mounted display of small dimensions and large instantaneous field of view that is applicable across the range of existing civil transport aircraft.

This philosophy has resulted in the remaining system hardware assemblies consisting of a small drive unit located in a suitable position adjacent to the projection unit, an electronics unit suitable for radio rack amounting, and a pilot's control unit conforming to normal ARINC box standards.

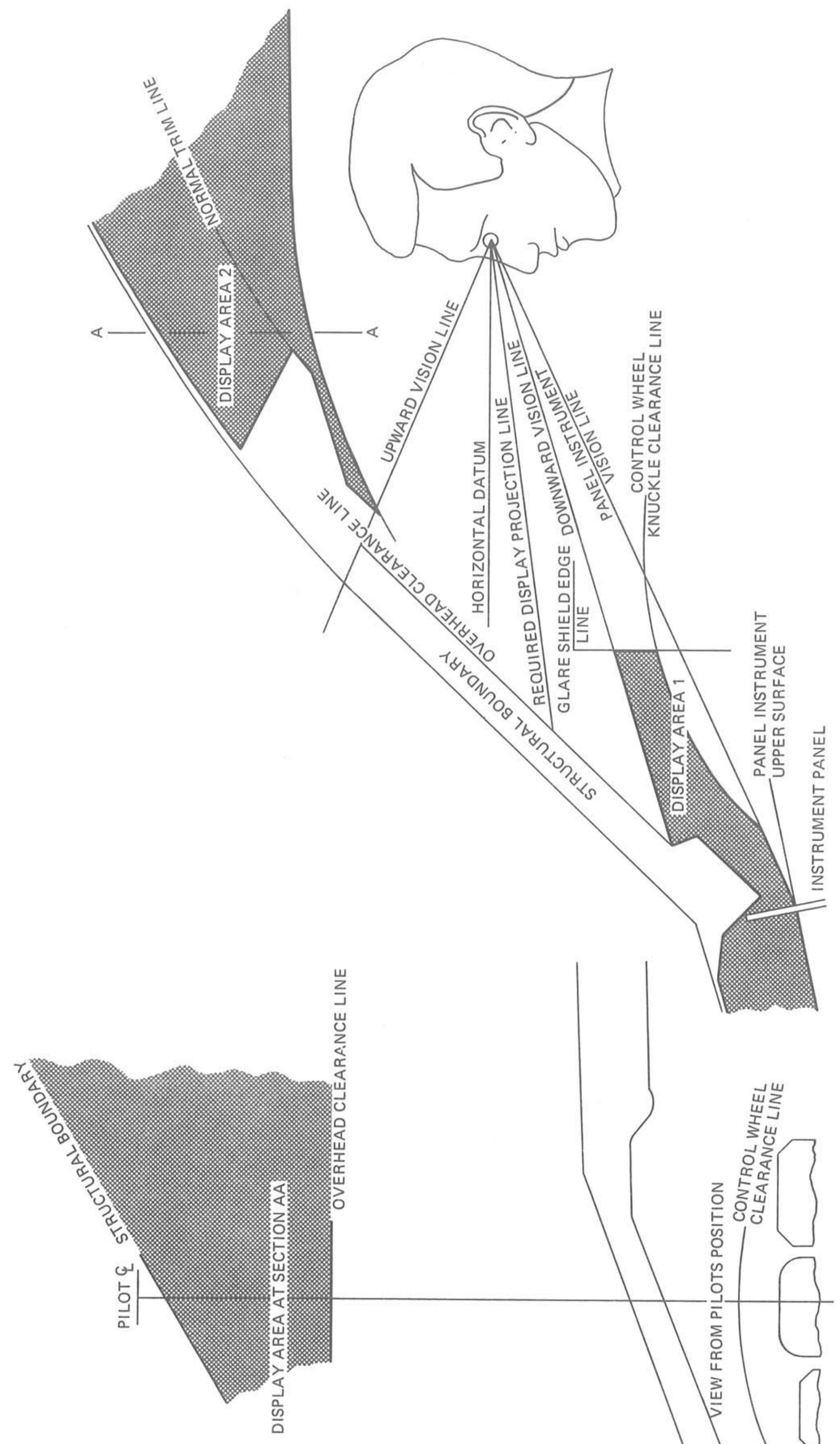

Figure 1 Head Up Display Installation Constraints

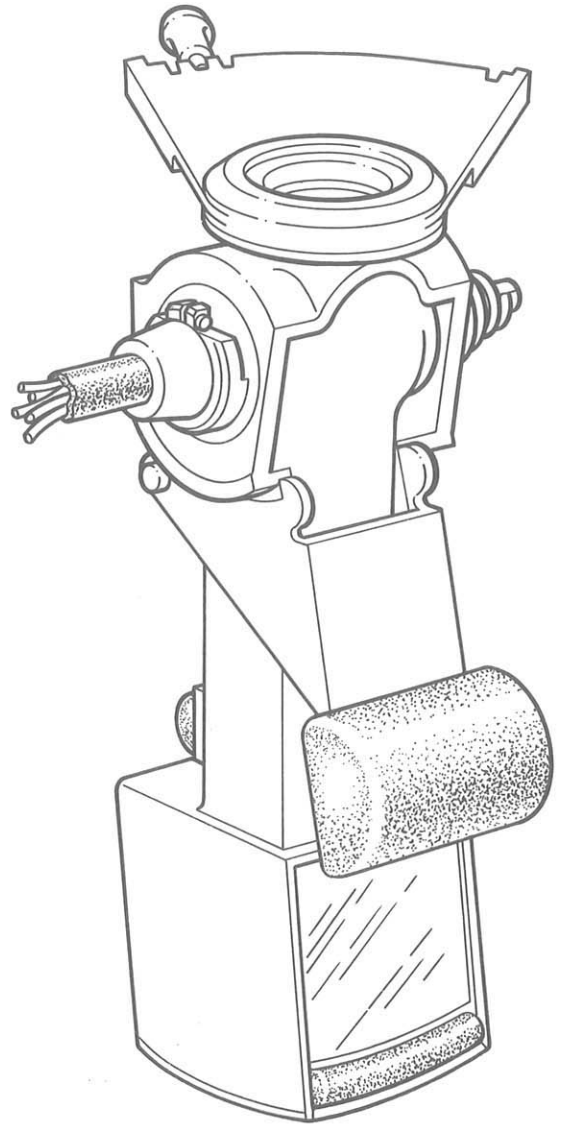

Figure 2 Monohud – Pilots Display Unit

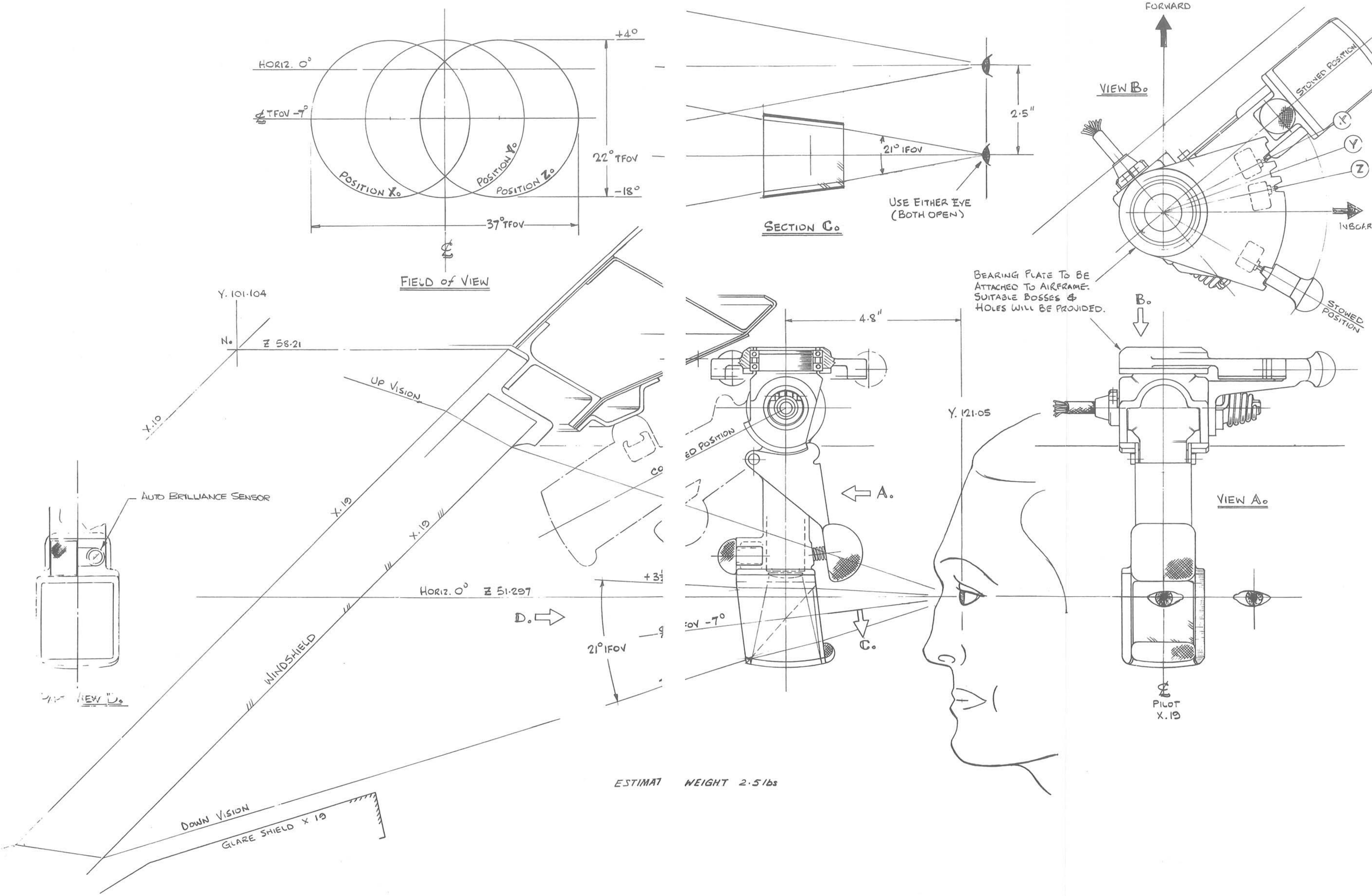

Figure 3 Monohud Installation

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4. MONOHUD

The Monohud is a small overhead mounted unit which obtains a large field of view by being located closer to the pilot's eye (Fig.2 shows a typical unit). It is viewed by one eye only but either can be used. When in operation the visual intrusion of the display unit is small. The symbology is presented on a miniature CRT (19 mm face plate) and is collimated using a spherical mirror. Light from the CRT passes through a partially reflective combiner surface and is reflected into the pilot's line of sight by the same surface after reflection from the mirror (See Fig.3).

The assembly is designed so that it can be moved into a stowed position outside the pilot's forward field of view and it has provision for rapid collapse to prevent injury to the pilot in the event of impact.

5. PROPOSED SYMBOLS AND SYSTEM OPERATION

5.1 General

Head Up Display symbol formats especially when produced using the flexibility of a CRT as a display medium tend to be subject to many different "expert" opinions. Attempts to date to apply HUD systems to civil operations have been influenced either by the military background from which the equipment has been derived or alternatively the display formats have been constrained by the technology used to produce them (e.g. the constraints inherent in an electro-mechanically implemented system).

The unique capability of a HUD system is its ability to display systems in a position which correlates to a real outside world position. For this reason the last 15
it is best to ensure that any HUD symbol which relates to the real world should correlate with it exactly. This is most true of horizon/pitch bars which experience has shown should move 1
be roll stabilized.

The symbology proposed is similar to that used on existing civil HUDs but made more elegant by the use of digital waveform generation and processing.

5.2 Basic Symbols Proposed

The proposed symbol format for this HUD is shown in figures 4 and 5. These
symbols subtend approximately the correct angular relationships to the eye when the page is held at a distance of 40 cm from the eye.

The data shown is:

- Pitch and Roll Presentation
- * Heading
- Fuselage datum reference
- Desired Flight Path
- Velocity Vector
- Potential Flight Path
- Angle of Attack
- * Indicated Air Speed Scale
- * Radio Height Scale
- Max allowable bank angle
- \+ Synthetic Runway
- Decision Height Index
- Runway distance to go
- Localizer warning
- Glide Slope warning
- Track Error Index

* Scales can be switched off by pilot.
\+ Runway is removed (a) at pilot option (b) in Take Off Mode;

In more detail the symbols have the following characteristics:

Pitch/Roll

A solid pitch bar is drawn at zero degrees (i.e. to be coincident with the horizon) and then bars are drawn at 5 degree intervals. Tl [illegible]
which angle they represent and the bars showing a negative pitch angle are dotted whilst positive pitch angles are shown by two solid lines. Tl [illegible]
range as it is assumed the HUD system would not be used as the display system for upset recovery. The bars are roll stabilized with the roll resolution being done about the velocity vector.

Heading

It is proposed that Heading will be presented as a moving tape positioned immediately above the fuselage datum reference symbol. Heading will be capable of interpretation from this scale to the nearest degree of heading. The heading scale can (with the other side scales) be switched out on the pilot's control panel.

Fuselage Datum Reference

Positioned just below the Heading read out in an inverted T shaped symbol which denotes the angular axis of the fuselage datum.

Desired Flight Path

The desired flight path angle is shown by a dotted roll stabilized line the position of which is set initially from the pilots controller. Note the angular positioning of both this symbol and the velocity vector are such as to show the desired flight path and the velocity vector for the pilots eye position.

Velocity Vector

The Velocity Vector bar shows the vertical component of the aircrafts' velocity through the airmass. The winged circle in the middle of the bar which is caged in azimuth, acts as an aircraft heading and reference point on the velocity vector and the pitch display is roll resolved about it. For aircraft which have inertial or doppler navigation systems from which track can be determined, a track symbol can be drawn on the velocity vector to indicate the point towards which the aircraft is tracking, for example, this symbol would be on the runway touchdown point when the aircraft was correctly established on the approach. Thus the winged circle indicates the aircraft heading and the track symbol indicates the aircraft track, both with respect to the real world. For aircraft without track-giving navigation systems the velocity vector is that of the aircraft within the air in which it is flying.

Potential Flight Path

A thermometer scale with a small horizontal index at its end will run from the left hand end of the velocity vector extension bar. The position of the horizontal index shows the potential flight path of the aircraft and in a go around situation for instance the pilot could pull to place the velocity vector back in line with the potential flight path and thus achieve a climb out following the missed approach. This symbol will also give early warning of wind shear conditions being experienced.

Angle of Attack

The angle of attack is shown by a similar ladder presentation but this time from the right hand side of the velocity vector extension bars. The thermometer scale ends in a small circle and the position of the circle relative to the fuselage datum reference is in fact a direct measure of incidence. In a normal approach at optimum incidence (speed as per manual for the aircraft weight) the small circle will be essentially in line with the velocity vector extensions. An increase in incidence will result in the circle moving upwards relative to the velocity vector.

Indicated Air Speed

IAS will be shown by the tape scale at the left hand side of the presentation. Each sub-division represents 10 KTS and in addition each ten division mark shows the appropriate hundreds of knot figure.

Radio Height (and decision height index)

Height will be shown by a similar presentation at the right hand side. It is proposed that each division will represent 10 ft. The digits on the 10 division mark show the height in hundreds of feet. Additionally the pre set decision height index appears as an arrow on the scale giving the pilot advance warning of his approaching decision height.

Max Allowable Bank Angle

The four indices symmetrically arranged with respect to the velocity vector show allowable bank angle. Down to 100 ft. in height they will be set at 30 degrees but below 100 ft. the limit will be progressively reduced until at 0 ft. (touchdown) the limit shown will be that which is relevant at touchdown to ensure adequate engine/runway clearance. Alternatively, indices fixed at 15° with suitable bank angle can be used.

Synthetic Runway and Track Error

For aircraft fitted with ILS, steering information can be given in the form of a runway symbol which is displayed in such a way as to be coincident with the real runway, the runway heading and ILS glide slope angle being entered on the pilot's control panel. The difference between aircraft and runway heading, plus ILS Localizer and glide slope deviation, positions the runway symbol and varies its aspect so that it has the same appearance as the real runway. Radio Altimeter Height and achieved glide slope angle combined to give range to touchdown and this is used to make the runway symbol grow in size like the real runway as it is approached. Comparison of the runway symbol threshold and desired glide slope is used to maintain the correct glide slope and the winged circle is held into wind of the runway symbol by the estimated drift angle so that the runway symbol centre line remains vertical indicating that the aircraft is centred on the localiser beam. Localiser tracking is simplified when an inertially or doppler derived track symbol is available; in this case the track symbol is flown to coincide with the point where the runway centre line meets the horizon line.

Runway Distance to Go

By the pilot pre-setting in the runway length (in metres) the system if used with an inertial navigator can provide an alpha numeric read out of distance to go to the end of the runway. The system senses (from the ILS receiver) the ILS glide slope origin (which is assumed to be 300 metres in from the threshold) and uses this as a datum from which to integrate distance to go taking suitable inputs of along course speed from the INS. The facility is also available in take off mode in which case the zero datum is assumed to be the end of the runway and integration of distance will commence from selection of HUD take off mode.

Localizer/Glide Slope Warnings

If the localizer or glide slope beam exceeds the allowable ILS box limit angular errors at 200 ft. from which a landing approach is permitted to be continued the appropriate legend (either or both LOC or GS), will be drawn on the HUD. If this angular beam deviation occurs above 200 ft. then the legend will be drawn in a steady display on the HUD. If, however, the beam deviation occurs at or below 200 ft. then the appropriate legend will be flashed (at a frame rate of about 2 Hz) giving a mandatory go-around indication.

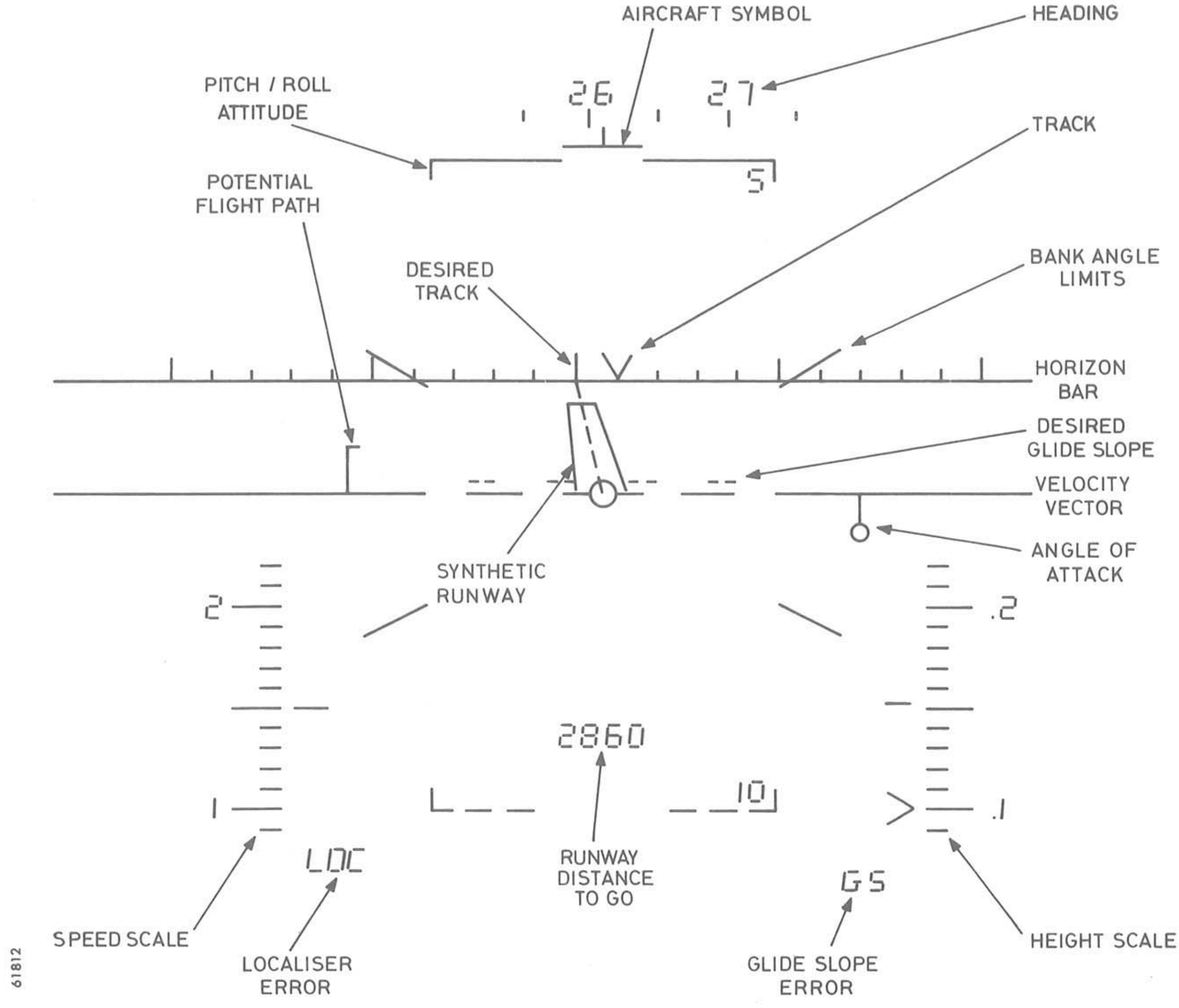

Figure 4 HUD Symbols Landing Mode

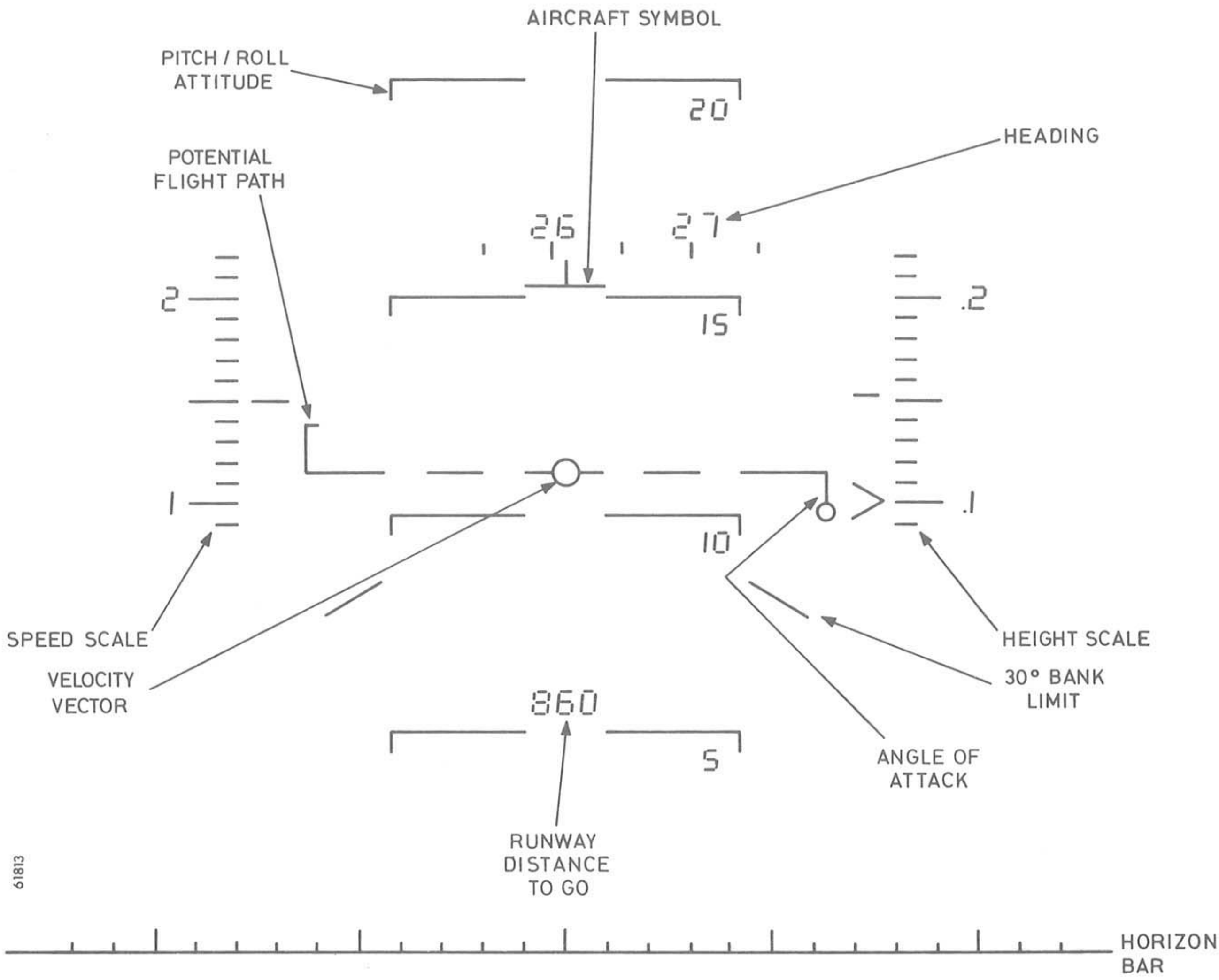

Figure 5 HUD Symbols Take-off Mode

6 INTEREST AND ACTIVITY

In brief the world wide interest and activity in the use of HUDs in civil aviation is:

Airlines

- The French Air Inter fly to Cat.3 limits using HUD to monitor a duplex autoland system.
- A few airlines use an electro-mechanical Visual Approach Monitor (VAM) for operations into non ILS airfields, e.g. Pacific Western 737 and C-130.

  (N.B. The introduction of VAM on the Pacific Western C-130 led to a reduction of aviation insurance premium).
- Several airlines appear ready to instal HUDs when the consensus decides the optimum form, fit and function of the equipment.

Airline Pilot Associations (ALPA, IFALPA, BALPA)

These associations are campaigning with vigour in ICAO downwards for the introduction of HUDs as soon as possible. The main planks to their argument for a HUD are:

- It does not replace head-down instrumentation.
- It will be used for all landings so that bad weather approaches are flown as routine.
- It will allow both pilots to have both visual and instrument cues simultaneously.
- HUD is best for monitoring the autopilot during automatic approaches and landing.
- HUD avoids the dangerous transition between instrument and visual control in the final stages of the approach when poor visual cues are often inadequate for vertical guidance, and the effect of windshear probably catastrophic.
- Training will be facilitated.

The world wide interest in an Economic Category 3 system using fail passive autoland systems has merely hardened the pilot's demands for HUDs to monitor the autopilot and provide guidance for them to continue the approach to a safe manual landing in the event of failure.

Certification Authorities

In the United States the FAA has been monitoring the progress of HUDs for many years and has now determined that a comprehensive evaluation of the HUD should be made. The objective is to determine whether or not use of a HUD could contribute significantly to aviation safety in the operation of civil jet transport aircraft.

The programme will include simulation and operational flight evaluation of HUDs and a final report is due in 1979. All roles and applications for HUD will be investigated.

In the event that the FAA decide that HUDs make a positive contribution to safety the fitment of HUDs for certain classes of operation is likely to become mandatory.

In the United Kingdom the CAA has also responded to the increased interest in civil HUDs with a steady programme to complement that of the FAA.

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