THE COST EFFECTIVE HEAD-UP DISPLAY IN TRAINER AIRCRAFT

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SUMMARY

Flying with Head-Up Displays (HUD) is so different to the use of Head Down instruments, that it needs specific training. The earlier in a pilot's career it can be learned, the more beneficial will it be, when the pilot needs the HUD as his primary display in a fighter aircraft.

Aircraft and systems developed for general aviation aircraft are available at a fraction of cost of similar units built under military specifications. The difference in performance, when used for training purpose is in most areas negligible.

HUD-Systems are on the market for general aviation aircraft at reasonable cost, and primary trainer aircraft (Turbo Props) are capable to fly adapted sorties which are as demanding for pilot's as a front-line aircraft.

The combination of a primary trainer aircraft equipped with a HUD and the required sensors will result in a very cost effective HUD trainer aircraft.

This paper substantiates the installation of a HUD in a primary trainer aircraft to get a cost effective training, as the cost per flying hours are a fraction of those compared to a front-line aircraft.

HEAD UP DISPLAY BASICS

Head-Up Displays have evolved from collimating gunsights that were used in World War II. They provide a complete picture of the entire flight situation to the pilot.

Both, HUD's and the early gunsights use an optical system to present an image to the eyes of the pilot that appears to be collimated at infinity. In the case of the gunsights, the source of the image consisted of nothing more than a reticule lit by an incandescent bulb.
In today's HUD's, this image is generated by a high intensity output Cathode Ray Tube (CRT) on a tilted glass pane, called the combiner, situated on top of the instrument panel in front of the pilot. The combiner refracts the light coming from the optical system and directs it to the pilot's eyes. As the pilot looks outside forward through the canopy and trough the combiner, he can see the flight situation information superimposed with the view of the outside world. The pilot therefore has the ability to observe the environment in which he is flying simultaneously with the data provided by aircraft systems.

Head-Up Displays provide obvious benefits, including better awareness of traffic and flight environment data in visual flight conditions as well as reduced workload during instrument approaches. If used properly, the Head-Up Display leads to improved safety and improved precision in flying.

The HUD system is very similar to the EFIS as it displays the selected information, but its indication is combined to the view out of the cockpit.

As it is connected to the same on board sensors as the EFIS, it displays the same information depending on mode selection. However the symbology is different due to the nature of its display.

Today's HUD systems consist of the Pilot's Display Unit (PDU) and the Head-Up Display computer for the signal processing. A control panel can be part of the PDU or installed in a separate unit, which is used to select brightness and mode of operation.

The CRT and the optics are combined in the PDU which is installed in the front cockpit only. An optional repeater could be installed in the rear cockpit as well. The PDU incorporates the combiner mounting mechanism to hold it in a very precise position as the combiner is not adjustable. It's position is designed for an optimized view of the HUD image if the pilot's eyes are at the cockpit design eye position. The pilot may adjust his seat accordingly using the a seat positioning alignment aid.

TRAINING REQUIREMENTS FOR HUD

Training which requires a HUD

All pilots using a HUD later in their career, should be trained on such a system at an early stage of their pilot's training. They will learn the principles and limitations of HUD flying.

The HUD his useful too for all kind of aiming training, and other special missions, but principally the aircraft which is following after the trainer aircraft defines the specific requirements.

Basic IFR training

When installed, the HUD takes pilot's attention during the whole flight. Therefore every sortie with HUD equipped aircraft is a HUD flight. With a HUD, the pilot learns already the interpretation of instruments for attitude and direction, when he still is flying under VFR in VMC. The change from VFR to IFR is subsequently no more a principle change, as it will be when flying an aircraft without a HUD. A HUD pilot sees the flight situation data information all the time when looking outside through the canopy also during his VFR flying. This results in much more experience flying on instruments and with IFR guidance data superimposed on the outside VFR-world.

HUD specific sorties

Sorties which contain 'aiming' type training sequences, may use a HUD instead of a Sighting System. A great part of the basic aiming training can be conducted at a much earlier stage of the training syllabus and therefore at a fraction of the cost.
Furthermore, the aiming techniques can be trained for beginners in „slow motion“ first (Turboprop

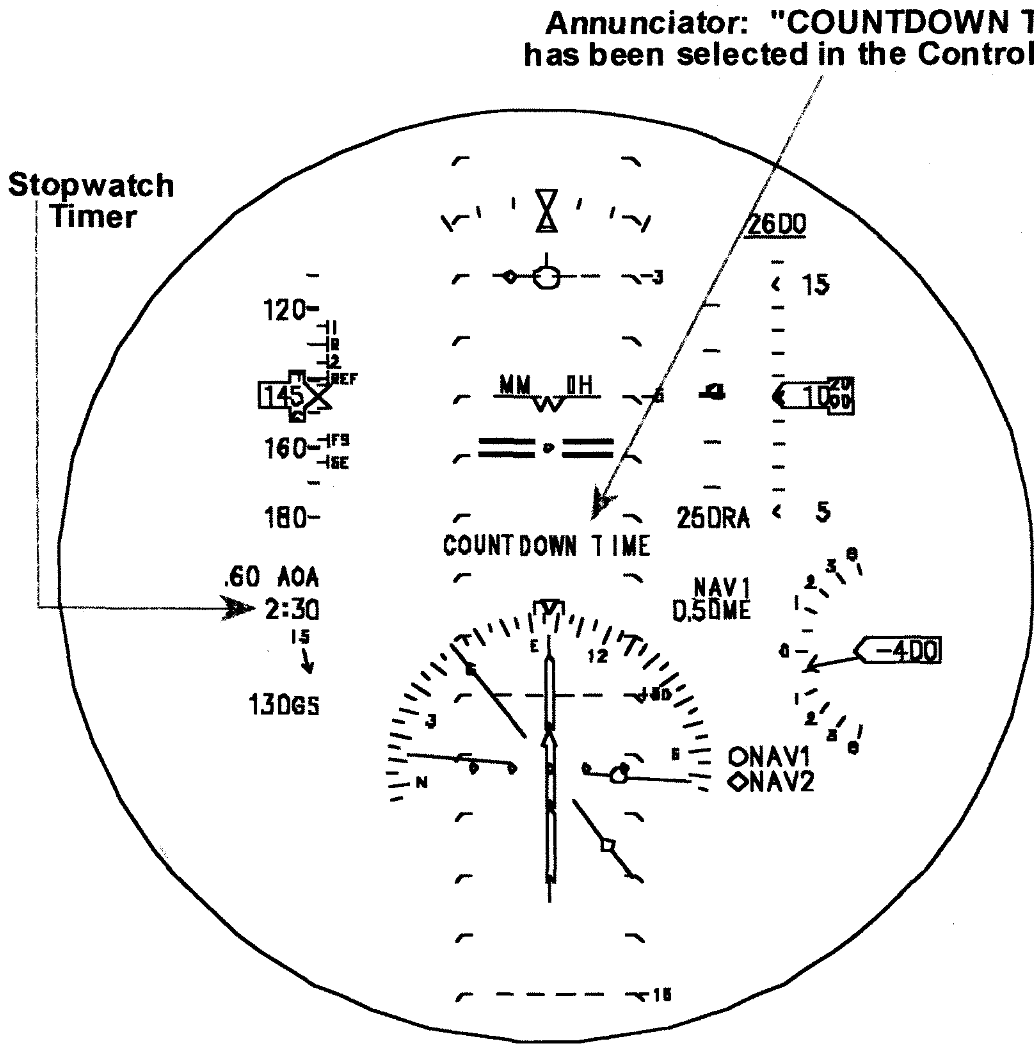

Figure 1: Typical presentation during an ILS approach

A HUD also advances the pilot's interpretation of the conventional instruments, especially in IMC, therefore improving his performance. This phenomenon can be explained by the fact, that a pilot

Trainer), which results in shorter training sessions in a high performance and expensive aircraft. With additional features, such as simulation of various functions, special missions could be defined, where a HUD plays a major role.

HUD SYMBOLS

General

A Head-Up Display has the advantage that it may be adapted to different operational environments by selecting an appropriate set of HUD symbols. However, the definition of the correct symbol function and presentation, also balanced to the type of aircraft is a time consuming task involving test pilot's, aircraft engineers and HUD software / hardware engineers. This results in a situation that the definition of HUD symbology never is completed and improvements are always possible. Even major Air Forces admit that the HUD systems used at present are perfectly acceptable for all phases of flight, regardless of weather or mission. However, at the same time activities are underway to make the use of HUD still easier and more efficient. The same comments are received from civil operators, using the HUD for all weather operation and an improvement of precision approaches. And here exactly is the problem with HUD symbology, as there is not a single set of symbols and functions available satisfying all operational requirements and wishes.

As per today, no FAA TSO requirements or other formal civil minimum requirements are issued to the aviation industry. Several HUD integrations in civil aircraft were done so far and approved by the relevant certification authorities. The following discussion on symbology is based on civil IFR requirements and intended to show operational requirements for the presentation of flight and navigation data to the pilot. As already mentioned, there are mission specific symbols depending on the role of the „training bed", normally defined by the operator in cooperation with the HUD manufacturer.

HUD Symbols

As the HUD symbols are the main Man-Machine-Interface (MMI) parameters, they have to be understood for an understanding of the use of a HUD.

The selection on the type of information to be presented to the pilot can be found in numerous specialized papers on this subject. Most front-line aircraft have similar but different display logic. In general it can be said that information where the pilot has to understand the exact value are displayed digitally (frequencies, time, distance etc.) whereas information for which he has to read to change in a parameter are displayed as analog values or as a 'tape' displays.

Symbology optimization

The quantity of symbols available may immediately lead to a screen cluttered with information, which can not be properly interpreted by the pilot any more. It is therefore a very important task to optimize the presentation of information depending on the phase of the flight. Furthermore, it has to be considered, that under a g load of more than 3 g, the pilot eyes ability to read is reduced as well as the capability of his brain power to make complex conclusions. In a training environment, it could be a task of a specific mission to make the student pilot aware of these facts, by overloading his PDU with information.

A flexible adaptation to the symbology is required. The training requirements define the final layout, which means, only a customized symbology harmonically embedded in the training syllabus will make a HUD an useful training tool.

RECORDING CAMERA

A video recording system, consisting of a camera installed as part of the PDU and connected to the onboard communication system is a powerful tool for the pilot training in combination with the HUD.

Such a system allows recording of all relevant parts of a mission. It gives the student pilot a way to debrief himself at any time after the flight and to compare his results with the flight order. Having the possibility to repeat critical sequences several times and to analyze them with his instructor, he can prepare himself much better for the next flight.

For the instructor, the video is a tool to qualify his students much better, and he can get exact results from solo flights as well.

IMPLEMENTATION IN TRAINER AIRCRAFT

The PILATUS PC-9 Turbo Trainer Aircraft is designed as an advanced training system. As such, the airplane can produce high g loads (+7g/-3.5g) without speed or altitude decay, and is therefore suitable for various training purposes.

The airplane and HUD could also be used as a HUD procedures trainer for those pilot's just graduating from flying school and ready for the transition to HUD equipped airplanes. Such a curriculum would entail ten to twenty hours of instrument training using head-up and head-down electronic instruments.

The standard PC-9 IFR HUD with the current symbology and functions is easily adaptable to customer requests.

One of the most useful recent innovations of the HUD's being offered for civil aircraft today is the generation of a velocity vector. This shows the pilot the airplane's instantaneous flight path, which is not necessarily the direction its nose is pointed. The velocity vector is a new piece of highly useful cockpit information, not available on head-down instrument panels. The symbol can be used in several ways: for precise flight guidance, as a pseudo-guide slope, as a distinct cue to the onset of wind shear, and for overall situation awareness.

To generate the velocity vector, however, the HUD needs inertial type inputs. This is a limiting factor for light and medium turbine-powered airplanes since they are not likely to be able to afford the weight and cost of an IRS . However relatively small and lightweight attitude and heading reference system (AHRS) that uses three FOG (fiberoptic gyros) at nearly the same cost as conventional systems with precise mechanical gyros which support the FPA and VV function are available on market for general aviation aircraft at reasonable cost.

For navigation data, conventional means such as VOR; DME, ILS as well as the new features of the „unlimited“ sensor based on GPS are available as commercial systems. Their performance of these system is very competitive compared with military specified systems

For all systems, the fact that the instructor needs immediate access and constant indication, a tandem compatible installation is required.

Today's technology from the general aviation allows to build an aircraft in the class of an advance trainer, but this at the same cost as the previous primary trainer

It may also be stated, that a better pilot's performance is resulting with same or even less flying hours, than with an aircraft without a HUD.

SIMULATION OF SPECIFIC TRAINING FUNCTIONS

Having a HUD programmed with simulation data such as missionized functions implemented, a complete fighter sortie could be simulated, imposing real fighter environment. Combined with a video recording system, debriefing and scoring may be done with these features as well.

Air to Ground simulation

The simulation for aiming for air to ground missions, may be implemented as a customer option, where the characteristic may be adapted to the means to be simulated. For the recording, the video may be used, but it is also possible to record flight and system data, to replay instead of the video a synthetic picture. The scoring for the synthetic picture may be automatically generated, whereas the video needs interpretation.

Air to Air simulation

Simulation in air to air missions allows the trainee to fight against real aircraft. As all releases results in an appropriate simulation, the target itself does not get destroyed, and is therefore available for unlimited use. But every manipulation as required in the front-line aircraft may be trained, not only the aiming itself. This means, the proper preparation by selecting in the required sequence up to securing the system after the mission may be defined and recorded as well.

A rocket can be simulated by its characteristics, but not only the release can be simulated, even the rocket itself an their impact could be displayed on the HUD, as soon it will get in to the field of view.

If required, also navigation and attitude and air data may be recorded to replay a full training mission.

For the replay of a mission, it even be considered, to simulated the whole flight on a simulator, by uploading the video and navigation data to the simulator computer. However such an approach could lead into an extreme system, which can impose itself so much cost, that the achieved training effect will better achieved with a few additional flying hours in the relative low cost primary trainer.

Many flying training organizations in several countries are now pursuing HUD training. We feel that the turboprop trainer, equipped with a HUD, is very suitable for this mission and this at a fraction of cost.

TRAINING EFFECT OF HUD IN TRAINER AIRCRAFT

In order to use the HUD trainer properly, a flight syllabus should be created which will address the issues appropriate to HUD instrument flying (for the HUD trainer) or to teach basic flying skills with the HUD as a training aid (for the HUD-equipped primary trainer). The syllabus should be addressed to the particular organization's operations and to the airplanes that the students fly after the trainer.

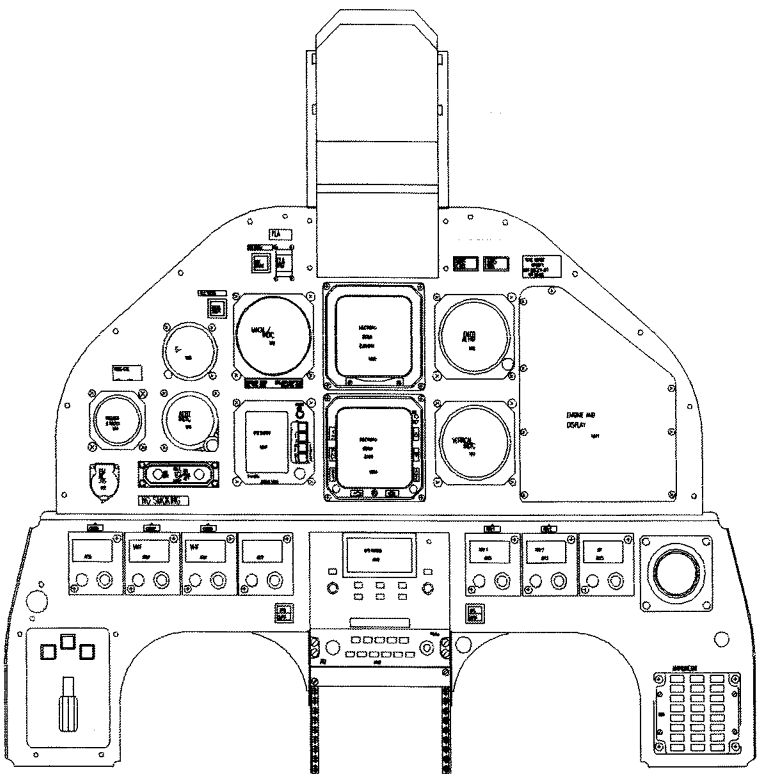

Figure 2: Panel layout of a Pilatus primary Trainer aircraft equipped with a HUD

As an example, an appropriate first sortie in a HUD instrument program would be to present attitude information only to draw the student's attention to the similarities between his previous instrument experience. Thereafter additional functions and symbols would be introduced with respect to the syllabus requirements

The syllabus should also incorporate HUD-panel cross-checks as well as failure detection and unusual attitude recognition and recovery. The airplane systems should be representative of any airplanes that the student he will fly.

Particularly for a HUD instrumented trainer for pilot's moving into fighters, the airplane cockpit should include enough systems to provide some task loading. The overall syllabus should help with task management training as well as simple HUD flying.

With the incorporation of the features listed above, the Pilatus PC-9 airplane with the HUD could be used as the base for a primary training syllabus which would incorporate the concepts of head-up flying from the beginning. Such a syllabus should enhance the ability of the student pilot to understand the concepts of basic and advanced IFR and advanced mission training.

Recent accident histories of front-line aircraft indicate that spatial disorientation (SDO) is perceived as a major problem in military air forces. Quite often the Head-Up Display is blamed for causing the pilot to loose his spatial orientation. As is usually the case, blaming an accident on a single isolated cause is over simplifying the matter. Nevertheless, it is becoming more and more obvious that there is a problem. Many factors are involved, but one seems to be clear: pilot's are inadequately trained to fly the airplanes by reference to the HUD.

Concluding the above, it can be stated, that the use of a HUD in a trainer aircraft can significant reduce the HUD training on a front-line aircraft, and therefore the corresponding training costs.

FUTURE DEVELOPMENTS

I am of the opinion that, the ideal HUD would no more consist of a PDU with a combiner. I would like to see my information all around on my windscreen in the front, and certain information such as other aircraft's in my vicinity would be shown on my side windows as well. Further information, such as a synthetic picture (supported by radar or FLIR) of my environment without clouds would fulfill my dream. Various developments in today's industry are moving toward this direction, called virtual reality.