

Head Up and Eyes Out Enabling Equivalent Visual Operations with the Head Up Display

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ABSTRACT

Following the introduction of Head-Up Displays (HUD) into commercial airplanes over 30 years ago, many aircraft manufacturers are now installing HUDs as baseline or as a selectable option on their latest designs. Most pilots that have used the HUD in difficult flying conditions prefer it to classic flight deck configurations with head-down displays only.

This paper describes the features and benefits of the HUD that allow the pilot to remain head-up and eyes-out throughout the flight, especially in the crowded skies around an airport. This is achievable because the HUD provides all the primary flight information needed to fly the airplane. Some of the information is conformal to the outside world and the whole image is focused at optical infinity, eliminating the need for the pilot to refocus between the HUD symbology and real world features viewed through the HUD.

Flight path based flying is intuitive, reducing workload and improving safety by allowing the pilot to maintain better situational awareness of the airplane's energy state. Use of HUD symbology enables increased flight and navigational accuracy to be achieved. Additionally, the HUD provides an advanced monitoring capability for the pilot while the airplane is in automated flight, and allows him/her to independently monitor the control loop, even when not in physical control of the airplane.

This paper also discusses the capabilities of the Head-Up Guidance System (HGS™) as related to low visibility operations. Where these operations have been conducted traditionally with automatic guidance systems, the HGS provides the opportunity for pilots to manually conduct the approach, landing and rollout in visibilities as low as 600RVR and takeoffs to 300RVR. Several regulatory "Special Authorizations" have been developed to specifically take advantage of the HUD's low visibility capabilities, to allow increased operational flexibility.

The Federal Aviation Administration (FAA) Next Generation Air Transportation System will provide opportunities for Equivalent Visual Operations, which may allow VFR operational tempos, and potentially VFR procedures, to be maintained under low visibility conditions. Vision System technologies, already available on some airplanes, allow HUD symbology to be underlaid with a conformal view of terrain features ahead of the airplane. These technologies, supported by NASA research, allow for the integration of sensor-based Enhanced Vision, Synthetic Vision, and Combined Vision imagery for use both in the air and on the ground.

An RTCA committee is defining performance standards for such Vision System technologies. These range from the use of Synthetic Vision, to achieve lower operational minima and increased situational awareness, to the use of sensor-based Enhanced Vision for approach, landing and taxi in visibilities as low as 300RVR.

Both analysis and simulator/flight demonstrations, some sponsored by the FAA and NASA, continue to substantiate and quantify the safety benefits that can be realized in flying head-up with a HUD. The results of these studies continue to justify claims that the use of the HUD improves a pilot's accuracy and consistency in performing flight operations, particularly in the terminal area, leading to increased flight safety.

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HISTORICAL/TECHNICAL DEVELOPMENT

Rockwell Collins developed and certified the first wide-field-of-view Head-up Guidance System (HGS) brand Head-up Display system in 1985. The initial HGS not only supported the presentation of conformal flight path, but also introduced manually flown Category III approach and landing guidance as an alternative to autoland systems. The lower overall relative cost of the HGS in comparison to the installation and maintenance costs associated with a traditional autoland system was actually the economic benefit which convinced Alaska Airlines to add the Model 1000 HGS to their fleet of Boeing 727 airplanes. Since then, Rockwell Collins has certified over 30 HGS designs on a variety of aircraft types including business jets, regional turbo-props, regional jets, air transport aircraft, and military transport aircraft.

HGS related technical and operational innovations introduced over the past 30 years include manual low-visibility takeoff, landing and rollout guidance, runway remaining information, tailstrike awareness cueing, unusual attitude awareness, windshear awareness and recovery guidance, RNP capabilities, Enhanced Flight Vision System and Synthetic Vision System certification. Combined Vision and Surface Guidance will soon add to this list of features that add value for operators while contributing to market differentiation of the aircraft platforms.

BENEFITS OF FLYING WITH A HUD

There are a number of specific HUD features that enhance the pilot's level of situational awareness, and thereby improve the overall safety of certain operations. The HUD related features which ultimately impact safety include:

- Directing the pilot's eyes outside the aircraft instead of inside and down, while still providing all the information needed to fly the aircraft
- Providing intuitive and conformal attitude, flight path, air mass, energy and speed information resulting in reduced flight technical error and improved situational awareness
- Displaying special symbology that will help the pilot recognize and react to non-normal flight situations

With intuitive and instantaneous airplane state information available, pilots can "stay ahead of the aircraft" and monitor system response during automated flight. By having a better understanding of the interaction of thrust, lift and drag the pilot can quickly stabilize the aircraft on path and recognize when the aircraft is reacting in a non-normal manner, or is close to the edge of its performance envelope.

Flight Path Flying

The HUD is designed to provide all of the primary flight information that is available on a head-down Primary Flight Display. However, the most important innovation that the

HUD brings to the modern flight deck is the conformal display of aircraft flight path, and the ability to fly the aircraft based on that flight path.

The flight path information on the HUD is earth referenced, and therefore indicates where the aircraft is actually going in space rather than where the airframe is pointing. Modern sensors are able to provide these earth referenced parameters in addition to the traditional aircraft referenced parameters such as pitch and roll.

The pilot controls the flight path of the aircraft by "flying" the HUD's Flight Path symbol to the desired point in reference to the real world view. Therefore, flight path flying automatically reflects the effects of crosswinds, angle of attack, drag, thrust and other factors which impact the dynamic state of the aircraft. This has proven especially useful to the pilot in recognizing and controlling the vertical path of the aircraft.

A pilot flying conventional head-down symbology has to mentally estimate the flight path of the aircraft during an approach. Displaying computed flight path information conformally on a head-up display significantly reduces the pilot's workload. Pilots welcome this additional information and require very little additional training to become proficient at flight path control.

Aircraft Control

Other HUD symbols intended to assist in the task of controlling the aircraft's flight path are referenced to the Flight Path symbol. The Flight Director cue is a circular symbol that fits within the Flight Path symbol - to stay on path the pilot maneuvers the aircraft so the "large circle is over the small circle" as shown in [Figure 1](#).



Figure 1. HUD Flight Director Cue

Many pilots use the HUD symbology to monitor the aircraft path - especially in the terminal area. The pilot can continue to monitor flight information while keeping his/her eyes outside the aircraft. This is particularly important during an instrument approach where the position of the Flight Path symbol and the appearance of the Runway symbol assist in the transition from instruments to visual sighting and aligning with the runway. With a HUD, the pilot can be head-up throughout the approach avoiding the sometimes difficult head-down to head-up transition prior to decision height.

As an extension of the Flight Director cue, the HUD has a special algorithm that calculates the optimum flare maneuver, intended to ensure a smooth landing on the runway. This algorithm utilizes descent rate and radio altimeter information

to guide the pilot through this maneuver even at steeper than normal approach path angles. This feature is especially useful when flying to unfamiliar runways which may be sloped or during nighttime approach and landing.

Energy Management

Energy information is also referenced to the Flight Path symbol with speed error shown as a variable length tape on the wing of the Flight Path symbol and acceleration/deceleration represented as a caret. This intuitive symbol combination makes it easy to stay at the target airspeed, as shown in [Figure 2](#).

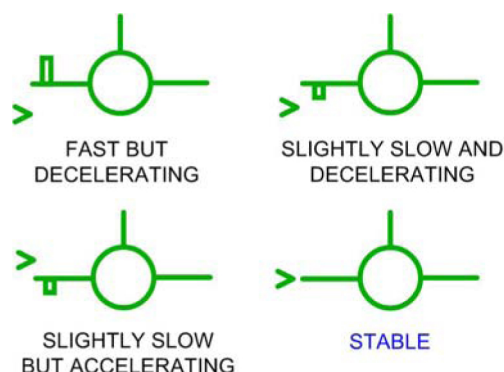


Figure 2. Energy Management

This combination of path and speed awareness makes the task of establishing and maintaining a stabilized approach a quick and easy set-up even with a crosswind and turbulent conditions.

During the landing rollout, a readout of the runway distance remaining helps the pilot optimize braking, while a braking effectiveness scale helps the pilot confirm that brakes are slowing the aircraft down as expected.

Non Normal Situation Response

The Flight Path symbol and other information on the HUD help the pilot to both recognize and recover from several non-normal situations, such as:

- **Windshear** - Sudden changes in wind speed or direction are instantly recognized when the pilot is monitoring flight path acceleration. A sudden rise or drop in the Flight Path Acceleration caret is a signal that the aircraft could be entering a dangerous situation and the pilot should abandon the approach and potentially apply full power while traversing the windshear region.
- **TCAS alerts** - The HUD presents a TCAS climb or descend command as either a “fly to” box or a “keep-out” region. The pilot maneuvers the aircraft so that the Flight Path symbol remains in the safe traffic avoiding region.
- **Unusual attitude** - If the aircraft enters an unusual attitude with larger than normal pitch or roll angles, the symbology

on the HUD changes to a simplified mode that alerts the pilot to the situation and helps the pilot recover to a normal attitude.

Head Down to Head Up Transition

A pilot's transition from instrument reference to visual reference during a landing approach involves three separate but interrelated behaviors:

- Physical movement of the head and eyes
- Refocus of the eye lenses and brightness adaptation
- Cognitive processes involved in switching one's perceptual frame of reference from one set of cues to another

A 1980 FAA/NASA study [1] attempted to quantify these behaviors with the following conclusions:

“Perhaps the most general conclusion that can be drawn from these data is that pilots require a relatively long period of time after looking up from the instrument panel to critically assess available runway environmental cues. Mean head-up transition-decision times were about 3.5 sec for ceilings of 300 ft or less and RVR of 2,400 ft and 1,600 ft. At an approach speed of 124 knots, this is equivalent to a distance of 733 ft along the approach path and 38 ft of vertical travel, assuming a 3° glide slope. Evidence was also found suggesting that this visual-cue-assessment process is not altitude dependent per se (for the present set of conditions) but rather breakout ceiling dependent, which might point to perceptual processing of relative changes of the ground detail more than absolute changes.”

The NASA report went on to state that the number of transitions between head-down instruments and head-up visual references was substantial and could potentially lead to problems depending on the situation:

“The present pilots made from 4 to 14 separate head-up transitions, depending on RVR and ceiling height. The smallest mean number of transitions was 4.6. If this number of transitions is made in an actual cockpit by pilots possessing relatively long eye-focus response times (from instrument panel to runway distances), the potential exists for significant visual cue evaluation problems. These problems, involving poorly focused retinal images, will be compounded by the reduced visual contrast of ground detail caused by low visibility (e.g., fog) conditions.”

Safety Impact

The benefit of the HUD in allowing the pilot to continuously fly head-up and “eyes-out”, and not having to transition back to the head down instruments for primary flight information, naturally lends itself to safer flight operations. In 2009, an independent Flight Safety Foundation study [2] concluded that Head-Up Guidance System Technology would likely have positively influenced the outcome of hundreds of accidents included in a study of turbine-powered, modern glass cockpit aircraft accidents. The study found that 38% of all accidents were likely or highly