Toward Head-Up and Head-Worn Displays for Equivalent Visual Operations

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A key capability envisioned for the future air transportation system is the concept of equivalent visual operations (EVO). EVO is the capability to achieve the safety of current-day Visual Flight Rules (VFR) operations and maintain the operational tempos of VFR irrespective of the weather and visibility conditions. Enhanced Flight Vision Systems (EFVS) offer a path to achieve EVO. NASA has successfully tested EFVS for commercial flight operations that has helped establish the technical merits of EFVS, without reliance on natural vision, to runways without category II/III ground-based navigation and lighting requirements. The research has tested EFVS for operations with both Head-Up Displays (HUDs) and "HUD equivalent" Head-Worn Displays (HWDs). The paper describes the EVO concept and representative NASA EFVS research that demonstrate the potential of these technologies to safely conduct operations in visibilities as low as 1000 feet Runway Visual Range (RVR). Future directions are described including efforts to enable low-visibility approach, landing, and roll-outs using EFVS under conditions as low as 300 feet RVR.

Equivalent Visual Operation Concept

Commercial aviation accident statistics evince the hazards associated with the approach and landing phase of flight. Boeing (2013) reported that 41% of all fatal accidents (2003-2012) occurred during the final approach and landing phase of flight, but approach and landing phases represents only 4% of flight time exposure. Low visibility is often reported as the contributing factor in as much as 90% of controlled flight into terrain (CFIT) landing accidents wherein less than 60% involve high terrain.

In 2003, the U.S. Government established the Next Generation Air Transportation System (NextGen) to transform the national air transportation system. An emerging NextGen concept, termed "Equivalent Visual Operations" (EVO), strives to replicate the airport capacity and safety now achieved under visual flight rules (VFR) in all weather conditions to mitigate, even eliminate, low visibility as an etiology (see Bailey, Prinzel, Kramer, and Young, 2011 for an alternative concept termed, "Better Than Visual").

Today, an alternative, intuitive means of conducting low visibility operations and possibly achieving EVO, is available. EFVS offers an "all-weather" capability, independent of the weather or vision obscurant, without significant aircraft or airport investment that creates real world-like visibility. The use of EFVS supports the Federal Aviation Administration (FAA) 2014 NextGen Implementation plan for "Improved Approaches and Low-Visibility Operations" (FAA, 2014).

Enhanced Flight Vision System

"Enhanced Vision" (EV) refers to an electronic means to provide a display of the external scene by use of an imaging sensor. The FAA defined, "Enhanced Flight Vision System" (EFVS), as, "... an installed aircraft system which uses an electronic means to provide a display of the forward external scene topography (the applicable natural or manmade features of a place or region especially in a way to show their relative positions and elevation) through the use of imaging sensors, ..." An EFVS uses a head-up display (HUD), or equivalent display to provide flight information, navigational guidance, and real-time imagery of external scene via imaging sensors.

On January 9, 2004, a final rule, Enhanced Flight Vision Systems, was published in Federal Register (69 FR 1620) that allows an EFVS to be used in lieu of natural vision to descend below the decision altitude/height (DA/DH) or minimum descent altitude (MDA) down to 100 feet above the touchdown zone elevation (TDZE) of intended landing runway. Under these regulations, approved operators may continue the descent below the published DH/DA/MDA if the required visual references, as per Code of Federal Regulations (CFR) 91.175 (l) and (m), are distinctly visible and identifiable using the EFVS prior to the DH/DA/MDA. No lower than 100 feet above TDZE, the required visual landing references, as per CFR 91.175, must be distinctly visible and identifiable using natural vision to continue the descent to landing. Further, the flight visibility may not be less than that prescribed for the instrument approach.

Enhanced Flight Visibility

The 2004 final rule amended Chapter 14 of the Code of Federal Regulations (CFR) Section §91.175 and, for the first time, allowed operators to conduct instrument approaches (in other than Category (CAT) II or III operations) and operate below the published minimums using an EFVS based on a concept termed, "enhanced flight visibility". Enhanced flight visibility was defined as, "the average forward horizontal distance, from the cockpit of an aircraft in flight, at which prominent topographical objects may be clearly distinguished and identified by day or night by a pilot using an enhanced flight vision system" (14 CFR part 1, §1.1). The concept, adopted under revised §91.175, now allows for an EFVS, through enhanced flight visibility, to replace natural vision with an electronic means of vision from the DA/DH/MDA to 100 feet height above the TDZE. The European Aviation Safety Agency (EASA) has adopted similar rulemaking approvals. Advisory Circular (AC) 90-106 provides requisite information for airworthiness certification and operational approval of an EFVS. RTCA DO-315A specifies the minimum performance standards for an equivalent level of safety and performance.

Proposed EFVS Rulemaking

On December 16, 2010, RTCA SC-213/EUROCAE Working Group 79 (established December 2006) published DO-315A which developed minimum aviation system performance standards (MASPS) which extended the operational credit established under CFR 91.175 (l) and (m) enabling EFVS operations below the 100 feet TDZE to touchdown and rollout (without the requirement for a natural visual segment) down to visibilities as low as 1000 feet RVR.

On June 11, 2013, the FAA published a Notice of Proposed Rulemaking to enable EFVS-equipped aircraft to conduct operations down to touchdown and rollout. The proposed rule established the minimum reported visibility, possibly as low as 1000 feet RVR, through defined through advisory circulars and letters of authorization (LOA) and other operating approvals. The proposal further eliminated the approach ban of commercial operations; established new training and proficiency checks; modified the required visual references; defined equivalent displays; required use of flare cues or prompts; clarified single and crew piloted operations; revised pilot compartment view rules for transparent displays; and described Operational Specifications (OpSpec), Management Specifications (MSpec), or Letters of Agreement (LOA) approvals.

The benefits would significantly expand EFVS operations, which should increase efficiency, allowing access to more runways, allowing for new EFVS operations, and minimizing the need for go-arounds and missed approaches during low visibility approach and landing operations. As the FAA observed (FAA-2013-0485-0001), however, there does not exist sufficient historical data to quantify these benefits. NASA has conducted numerous high-fidelity simulation and aircraft flight test research to provide the requisite data to inform the proposed rulemaking to extend §91.175 operating rules to enable EFVS operations with lower visibility minimums. Bailey, Kramer, and Williams (2010) provide a review of NASA research that describes the efforts that helped to make “operational credit” EFVS HUD operations a reality.

EFVS Equivalent Displays

With many operational credits being provided by HUD operations (e.g., AC-120-28D; FAA Order 8400.13), one possible avenue of HWD adoption across the NextGen fleet is by providing a “HUD-equivalent capability." The requirements for a HWD to meet a HUD-equivalent capability may be derived from FAA guidance material. For instance, under EFVS operations, these “essential features" of the HUD or equivalent display were described as follows (Bailey, Kramer, & Williams, 2010):

- The display should provide the EV image and spatially-referenced flight symbology so that they are aligned with and scaled to the external view (i.e., conformal rendering).
- The display should be located so the pilot is looking forward along the flight path (i.e., looking at and through the imagery to the out-of-the window view) to readily enable a transition from EFVS imagery to the out-the window view.
- The display should not require the pilot to scan up and down between a head-down display of the image and the out-the-window view looking for primary flight reference information. This transition would otherwise be hindered by repeatedly re-focusing from one view to the other.

NASA has conducted research to evaluate prototype HWD systems as a potential replacement for a HUD as an EFVS. If this equivalence can be shown, then the unique capabilities of the HWD - that is, unlimited field-of-regard head-up operations for low visibility flight operations - can be capitalized. The design challenge (and certification challenge) is to create this equivalent capability without increasing pilot workload, or encumbrance, or obscuration of their normal vision.

Recent NASA HUD/HWD EFVS Research

The following describes three representative examples of simulation and flight test research that have examined the use of EFVS of HUDs and HWDs for the revised §91.175 and RTCA SC-213 proposed extensions for EFVS operations to 1000 ft. RVR. Abbreviated descriptions of methodology and experimental results are provided with references to obtain more detailed information.

HUD EFVS HIGH-FIDELITY SIMULATION

A fixed-based experiment was conducted to evaluate the operational feasibility, pilot workload, and acceptability of conducting straight-in instrument approach procedures with published vertical guidance using EFVS for the approach, landing, roll-out, and turn-off in simulated visibility as low as 1000 ft. RVR (see Kramer, Bailey, et al., 2013).

Pilot Participants

Twenty-four pilots served as participants for the research. The pilots were paired by airline and role (Captain, First Officer) to ensure crew coordination and cohesion with regard to terminal and surface standard operational procedures. All pilots were required to hold an Airline Transport Pilot rating. The Captains had an average of over 14,661 flight hours with 21 years of commercial experience and at least 100 hours of HUD experience. The First Officers had an average of over 10,648 flight hours with 14 years of commercial experience. Selection preference was given to pilots that had prior EV/EFVS training.

Simulation Facility

The research was conducted in the Research Flight Deck (RFD) at NASA LaRC (Figure 1), which is a high-fidelity, 6 degrees-of-freedom motion-based large commercial aircraft simulator with full-mission capability and advanced glass flight deck displays. The out-the-window (OTW) scene was generated by an Evans and Sutherland Image Generator graphics systems providing approximately 200° H by 40° V field-of-view (FOV) at 26 pixels per degree. All standard audio call-outs were generated.

Figure 1. NASA Large Commercial Aircraft Simulator

The simulator database was centered around Chicago O'Hare International Airport (FAA identifier: ORD) and built from FAA source data for ORD, valid from 11 March 2010 to 8 April 2010. Day simulations were flown, with the weather tailored to create the desired visibility conditions.

Head-Up Display

The RFD was equipped with a Rockwell-Collins HGS-4000 HUD. The HUD is collimated and subtends approximately 26°H by 21°V FOV. The HUD projects the imagery from a Cathode Ray Tube source in a stroke-and-raster format. The raster input to the HUD was EV source imagery in an RS-343 format. The stroke symbology format was a modified version of the HGS Primary mode format. The stroke symbology included a conformally drawn runway outline (edgelines), removed at 50 feet Above Field Level (AFL); a flight path angle reference cue; flight-path referenced guidance cue; and a flare cue.

Enhanced Vision Simulation

The EV real-time simulation is created by the Evans and Sutherland EPX physics-based sensor simulation. The ORD database was instantiated with material code properties. From this database, an infrared (IR) sensor simulation, interacting with this material-coded database and the simulated weather conditions, created the desired test experimental conditions. The EV simulation mimicked the performance of a short-wave/mid-wave forward looking IR (FLIR) sensor, using a ~1.0 to 5.0 micron wavelength detector. The nominal enhanced visibility was approximately 2400 feet for this experiment. The EV eye point reference/parallax error was 2.5 milliradian (mrad) to a point located 2000 feet away (DO-315 specifies 5 mrad max).

Evaluation Task

Approaches were flown only to runways with Medium intensity Approach Lighting System with Runway alignment indicator lights (MALSR) installed. ORD Runways 4R, 9R, 22L, or 22R were used. All runways had available high intensity runway lights and serviceable centerline and surface markings. Airport lighting was drawn using calligraphics.

The evaluation task was a straight-in Instrument Landing System (ILS) approach that started three nautical miles (nm) from assigned runway threshold with a three degree descent angle. The weather consisted of low to moderate winds with either ten knot headwind, ten knot tailwind, 7.5 knot crosswind, or 15 knot crosswind, light turbulence (root-mean-square (rms) of 1 ft/sec), and varying OTW visibility levels (1800 feet, 1400 feet, or 1000 feet RVR). Auto-throttles were used for all approaches.

When used experimentally, the FLIR visibility was 2400 feet RVR. The crew was trained in the 'monitored approach' procedures and were instructed to follow modified EFVS crew procedures (14 CFR §91.175 (l)) to fly the aircraft as if there were passengers aboard.

Experimental Results

Table 1 presents those quantitative for the EFVS approaches at simulated 1000 feet RVR visibility and MALSR approach lighting system. Landing criteria of Joint Aviation Authorities All Weather Operations (JAR-AWO) and AC-120-28D (Appendix 3, section 6.3.1) was adopted from CAT III requirements for the purpose here to evaluate EFVS landings. Overall, the touchdown statistics evinced to be within the "desired" range for both longitudinal and lateral position and "adequate" for sink rate at touchdown. No go-arounds were conducted for trials with the EFVS HUD and the positional performance was excellent. Pilots reported "moderate, easily managed" (Ames & George, 1993) workload.

Table 1. EFVS HUD Touchdown Statistics for 1000 feet RVR

	Without TDZ and CL Lights	With TDZ and CL Lights
Take-off/ Go-Around (# of Runs)	0/12	0/11
Touch-Down (T/D) Long. Position	798.6 ft. (358.5)	1026.3 (288.9)
T/D Lateral Position	-1.2 (14.7)	0.6 (12.7)
T/D Sink Rate	-7.7 (3.7)	-7.6 (3.0)

HUD EFVS FLIGHT TEST

The flight test evaluated synthetic and enhanced vision systems in partnership with Honeywell and Gulfstream with the objectives to determine (see Shelton, Kramer, Ellis, & Rehfeld, 2012):

- Operational feasibility, pilot workload, and pilot acceptability of conducting a straight-in instrument approach with published vertical guidance using EFVS during approach, landing, roll-out, and runway exit in visibility of 1000 feet RVR; and
- Operational feasibility, pilot workload, and pilot acceptability of conducting an instrument landing system approach to a 15 feet DH using synthetic vision systems (SVS) followed by a transition to natural OTW visual cues for landing with the visibility as low as 1400 feet. RVR.

Pilot Participants

Six pilots participated in the flight evaluations representing a cross-section from commercial, military, corporate, and the FAA (FAA test pilot). Average total flight time was 9108 hours with a max/min of 16250 and 4800 hours, respectively. Average commercial pilot experience was 28 years (range of 35 to 19 years). All pilots had flight experience with EFVS (379 average hours).

Test Aircraft

The flight test was conducted using Gulfstream's G450 flight test aircraft N401SR, S/N 4001. The test aircraft was equipped with certified avionics and software including the Honeywell SV-Primary Flight Display (PFD) and monochromatic EFVS HUD with display of conformal symbolic information, flight information, and FLIR imagery (Figure 2).

The G450 test aircraft's systems are certified for ILS and Localizer Precision with Vertical guidance approaches and nominally operates in Approach Categories C & D. The G450 is certified for auto-flight down to 60 feet height above touchdown zone elevation (HAT). The aircraft's certified avionics are described in Shelton, Kramer, Ellis, and Rehfeld (2012).

Figure 2. Test Aircraft and G450 Flight Deck

Enhanced Flight Vision System

The certified EFVS onboard consisted of a Rockwell-Collins' model HGS 6250 and Kollsman Enhanced Vision System (EVS) II infra-red camera (FLIR) and approved to conduct EFVS operations, based on electronic flight visibility, to descent below published minima to 100' HAT (14 CFR §91.175(l), (m)). The HGS6250 commercial HUD is collimated and subtends 42°H by 30°V FOV with a 1600 x 1024 display resolution and greater than 4,000 fL display brightness. The Kollsman II EVS has a FLIR sensitivity of less than 5mK, IR spectrum 1 to 5 Micron, and 30°H x 22.5°V FOV.

Procedures

All instrument approaches were flown with the evaluation pilot manually flying the aircraft below 1000 feet above ground level (AGL) to landing. A Gulfstream safety pilot acted as a confederate and detailed call-out and EFVS procedures, for both pilots, were utilized for all approaches. NASA/FAA approved safety procedures required the safety pilot to have positive visual acquisition of the required landing references by 50' HAT. Shelton, Kramer, Ellis, and Rehfeld (2012) describe the training, airport and runway selection criteria, and crew procedures.

Evaluation Task

Nine test flights were flown in Gulfstream's G450 flight test aircraft and pilots flew 108 approaches (SVS, EFVS, and baseline displays) in low visibility weather conditions (600 feet to 3600 feet reported visibility) under different obscurants (mist, fog, drizzle fog, frozen fog) and sky cover (broken, overcast). A total of 73 useable EFVS approach evaluations were conducted with 53 touchdowns, and 20 (27%) missed approaches; the 20 go-arounds were all conducted safely based on decision criteria established for the FAA exemption waiver (FAA "Certificate of Waiver" was issued April 1, 2011 thru March 31, 2012) to conduct the approaches below published DH/DA/MDA to landing using an EFVS.

Experimental Results

Out of the 80 EFVS approaches, seven were culled out of the data analysis for various extraneous reasons such as: Approach Lightning System (ALS) automatically turning off, or the evaluation pilot mistakenly left autopilot on during much of the approach, etc. These events were anomalous and caused significant deviations from the nominal operation and therefore, were not representative of the other approaches.

Of the 73 useable EFVS approach evaluations, 53 (73%) resulted in a touchdown and 20 (27%) resulted in missed approach. Eight of the EFVS approaches were to an offset runway. The 20 missed EFVS approaches were all conducted safely with the go-around decision correctly determined based on conditions. All approaches were within Category II approach minima, as outlined in AC120-29A, for the glideslope vertical CAT II minima (0.46 dots) and localizer lateral CAT II minima (0.33 dots), with the exception of one approach (lateral deviation = 0.37 dots), in a challenging crosswind, that resulted in a safe successful touchdown. RMS EFVS Landing Decision Altitude call-out for touchdowns was 126 feet radar altitude versus. 163 feet for missed approaches. The touch-down means reported were for longitudinal (2058 feet, δ = 501 feet) and lateral (3.47 feet, δ = 3.28 feet). Pilot workload ratings (Ames & George, 1993) ranged from "easily managed" during landing (2.5 rating) and go-around (2.9 rating).

In addition to quantitative and qualitative approach performance, the flight test provided a unique opportunities to evaluate "visual advantage" of EFVS compared to natural vision OTW. Visual advantage is defined as an increase in average forward horizontal distance from the cockpit of an aircraft provided by an imaging sensor, such as FLIR, over that provided by natural vision. Kramer et al. (2014) describe the methodology and detailed statistical analyses across multiple visibilities, obscurants (e.g., mist, fog), sky cover (e.g., overcast, broken) and approach points. As example, at 100 feet radar altitude (RA), the average visual advantage of EFVS compared to OTW was 843 feet (EFVS 1425 feet; OTW 582 feet) across all reported visibilities. Broken down by visibility obscurants at 100 feet RA, drizzle fog provided a 1583 feet advantage (3.1 factor), mist averaged 1074 feet (3.0 factor), frozen fog yielded 947 feet advantage (2.3 factor), and fog provided the least at 653 feet (2.2 factor). Specific to 1000 feet RVR visibility condition, the visual advantage at 100 feet radar altitude was reported to be 484 feet for EFVS compared to 0 feet OTW (i.e., nothing could be seen) of the aircraft. Effects of sky coverage and ceiling also increased the visual advantage of the EFVS compared to OTW (cf. Kramer et al., 2014).

HUD/HWD EFVS HIGH-FIDELITY SIMULATION

The HUD/HWD EFVS simulation study was conducted to evaluate "equivalent displays" of head-worn displays (HWD) for manually flown approach and landing EFVS operations under simulated visibilities as low as 1000 feet RVR (see Arthur et al., 2014).

Pilot Participants

Twenty-four commercial airline transport pilot-rated pilots participated in the research and had familiarity with the Memphis International Airport (FAA identifier: MEM). All pilots were required to have significant HUD experience (>100 hours) and preference was given to those with EV/EFVS training. Pilots were paired by airline and role, as in previous studies, forming twelve flight crews.

Simulation Facility

The RFD simulation facility was used for Experiment (see above for description).

Head-Up Display

The HGS6700 commercial HUD is collimated and subtends 46°H by 34.5°V FOV with a 1400 x 1050 display resolution and greater than 4,000fL display brightness. The HUD system was measured to be 14 kg in weight. The HUD provided stroke FLIR imagery.

Head-Worn Display

A prototype head tracker was used to provide head orientation and was mounted on the left side of a pair of Lumus© DK-32 glasses. The head tracker was a hybrid-inertial tracker with image processing to correct for inertial drift and standard methods were used for ensuring accurate head tracking. The HWD is see-through, full color (green monochrome only used to be consistent with HUD) which utilizes patented Light-guide Optical Element (LOE) technology. The HWD was collimated and subtends 35°H by 20°V FOV with a 1280 x 720 display resolution and greater than 1,000fL display brightness (these specs are markedly lower than the HUD used). The image focal plane matched the HUD at infinity (using LOE). The measured weight was 0.20 kg.

Enhanced Vision Simulation

The same Evans and Sutherland EV real-time, physics-based sensor simulation was used as in the HUD EFVS simulation experiment described earlier, which is capable of modeling a wide range of sensors (image intensification, low-light, and infrared) and wavelengths. The MEM database was instantiated with material code properties. From this database, an IR sensor simulation, interacting with this material-coded database and the simulated weather conditions, created the desired test experimental conditions. As in previous experiments, the EV simulation mimicked the performance of a short-wave/mid-wave FLIR, using a ~1.0 to 5.0 micron wavelength detector. The nominal enhanced visibility was approximately 2400 feet for this experiment with a 2.5mrad eye reference/parallax error.

Evaluation Task

Flight crews conducted manually flown approach and landing operations to MEM runways (36L, 36C, 36R) starting at 1000 feet HAT. The EFVS crew procedures were trained and utilized for all HUD EFVS approach trials. The experiment conditions replicated actual operating conditions, lighting systems, operational procedures, required call-outs, and air traffic controller-pilot communications. All pilots reported that the simulation emulated real-world operations and workload typically experienced during low-visibility operations.

Experimental Results

An Analysis of Variance (ANOVA) was conducted on Flight Technical Error between HUD and HWD displays for localizer dot error and glideslope dot error tracking performance from an altitude of 1000 feet to 50 feet AGL. The results found no significant effects for RMS localizer, glideslope, or sink rate.

The same dependent measures were analyzed via ANOVA to examine the effect of the display concepts at published decision height (200 feet) to threshold crossing height (50 feet HAT); this is the "equivalent visual segment." The statistical results showed that the display concepts were not significantly different from each other, during the equivalent visual segment. For the landing phase, the results on touchdown statistics further showed no significant differences between the HUD and HWD for longitudinal distance from threshold, lateral distance, or sink rate. The landing results evince that all landings using either the HUD or HWD were within the AC 120-28D CAT III minima criteria of "desired" (albeit these criteria are based on auto-land performance). The qualitative data also showed that pilots rated the HUD and HWD equivalents in terms of situation awareness and workload measures.

CONCLUSIONS

The research on HWDs and HUDs extend beyond the need to evaluate the efficacy of these technologies to achieve EVO. The experiments described are representative examples of NASA efforts to enhance the flight deck to revolutionize how low-visibility approach operations, using an EFVS, are conducted today and in the future. If successful, these works will establish the precedence that an electronic means of visibility can be used in lieu of a pilot's natural vision – a *first* that will open up many new capabilities. The research delineated here evince that a head-up (HUD or HWD) EFVS can safely enable 1000 feet RVR approaches without need of all the many expensive ground-based requirements and significantly reducing airport costs and expanding the number of runways operational under low-visibility conditions. The research establishes the advance of HWD technology that is fast approaching HUD EFVS "display equivalency" while also substantiating the advantages afforded these unlimited field-of-regard displays.

Since 1929, Instrument Flight Rules (IFR) has been conducted by pilots using abstract cockpit instrumentation and navigational aids to allow penetration of the weather until a pilot can see to land. For extremely low visibility conditions, auto-land systems were developed in the 1960s for use when a pilot's vision out-the-windows was almost completely obscured during the landing. However, these auto-land systems cost millions of dollars per airplane, and require millions of dollars in annual maintenance and pilot/crew training costs. Further, only 144 airports are equipped world-wide with expensive landing and lighting systems that enable safe operations at less than 1000 feet visibility.

The value of the EFVS research can be traced to the substantial promise of these head-up display concepts (HUDs, HWDs) to reduce reliance on expensive ground-based landing and lighting systems and significantly increase the number of possible operational runways in use when the weather reduces visibility. Both the HUD and HWDs have been demonstrated to permit low-visibility flight operations in conditions as low as 1000 feet RVR. Recently completed research (December 2014) have extended the HUD EFVS application, using a multi-sensor EVS, to 300 feet RVR approaches. Today, the HUD enjoys operational credit to allow manual approaches (700 feet RVR) and departures (300 feet RVR). Enhanced vision (an EFVS) may further that credit to allow CAT IIIb approaches and departures without need of certified CAT III auto-lands, landing (e.g., CAT III ILS) and lighting systems (e.g., ALSF-2). Further, other "vision technologies", in particular SVS, may complement EFVS to potentially permit EVO to all phases of flight (SVS provides database-based imagery of the flight environment independent of real-time imaging sensors). Taken together, the research may pave the way toward true "all weather" operations and revolutionize future low-visibility operations. Indeed, the EFVS concept may actually best the EVO NextGen idea; and, rather than "equivalent visual operations," may allow instead "better-than-visual-operations" (Bailey, Prinzel, et al., 2011) as the standard for Next and Future Generation Air Transportation Systems.

The path toward "better-than-visual" operations shall require many changes, and there remains significant hurdles to realities. Although EFVS has been certified and today allows manually flown approaches to continue below published DA/DH to a required visual segment at 100 feet HAT and current regulatory efforts likely will permit no visual segment landings to 1000 feet RVR, there are many challenges that remain. These include the quality of the enhanced vision sensor; the weight and costs of these systems; the use of head-down EVS as an EFVS "equivalent display"; to name a few. Further, the transformation requires solution to issues of restricted flight visibility in other operational phases, such as issues of high runway occupancy time and need for expensive surface movement guidance and control systems and surface operational procedures. However, given the tremendous potential of the EFVS and combined vision system (e.g., EFVS + SVS), envisioned applications abound and with continued research and practice, the distinctions between IFR and VFR may become a moot distinction. Examples include operational requirements that exist today to preserve level of safety under instrument meteorological conditions (IMC), such as need for airport alternates and emergency fuel; IFR procedures, such as IMC traffic spacing or precision instrument approaches; or certain avionics, such as auto-land systems, may no longer be necessary. Much work remains but the existing body of work and continued advancement in the technologies evince the tremendous potential capability of these vision-based technologies toward a singular operational concept of "equivalent visual flight rules".

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