Enhanced Helicopter Vision Systems

Output Report

Helicopter Safety Enhancement No. 91

Prepared by H-SE-01 Team in partial fulfillment of USHST efforts to encourage technology integration that can reduce the risk of fatal helicopter accidents.

USHST
United States
Helicopter Safety Team

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Background and Motivation

One of the main safety-related problems facing the rotorcraft industry today are fatal helicopter accidents, primarily those related to low visibility conditions at low altitude in marginal or inclement weather. To enhance helicopter safety, the USHST is looking at several technology/equipment solutions. A recent review by the United States Helicopter Safety Team (USHST) of the helicopter fatal accidents from 2009-2013 indicated that the majority of accidents that occurred were due to one of three causal factors: Loss of Control (LOC), Unintentional Instrument Meteorological Conditions (UIMC), or Low Altitude (LALT) Operations [1]. Within the UIMC accident subset, the team found that most of the accidents were due to the pilot's loss of situational awareness, visual cues, and spatial disorientation.

A similar review of the Low Altitude (LALT) dataset showed that several fatal accidents of this type occurred due to visibility issues that limited the pilot's ability to see and remain well clear of wires. Thus, to reduce the helicopter fatal accident rate, the USHST needs to examine operational concepts that address the operational risks of low visibility operations. Developing criteria for approving new vision-enhancing technologies and developing the regulatory basis (i.e.,, policy, guidance, rulemaking, etc.) to enable their use as part of improved low-level helicopter infrastructure can help the rotorcraft community increase the safety of low visibility operations and enhance the efficiency of their operations.

To shed light on this safety issue, following the accident reviews, the USHST came up with a series of intervention strategies. These intervention strategies, otherwise known as Helicopter Safety Enhancements (H-SEs), were born out of the USHST's data-driven process and mimic safety enhancements developed and popularized by both the Commercial Aviation Safety Team (CAST) and the General Aviation Joint Steering Committee (GA-JSC). A total of 18 H-SEs were approved by the USHST Steering Committee, including H-SE 91: "Enhanced Helicopter Vision Systems." This H-SE was found to be in the Technology/Equipment domain. The focus of the H-SE is on accomplishing the following safety action:

H-SE 91 Safety Action: "FAA and industry to research, develop, and promote the use of enhanced helicopter vision systems (EHVS) technologies (e.g., Night Vision Goggles, Enhanced Vision Systems, Synthetic Vision Systems, Combined Vision Systems, etc.) to assist in recognizing and preventing unplanned flight into degraded visibility conditions due to weather and to increase safety during planned flight at night."

The H-SE included the following three outputs:

- **Output #1:** Research and evaluate helicopter vision-enhancing technologies and operational concepts for advanced vision systems. This will require communication with existing industry vision system manufacturers to get a well-informed perspective of currently available technology.
- **Output #2:** Develop policy changes to allow for the use of vision-enhancing technologies (Update FAA Order 8260.42B, Advisory Circulars 90-80B, 90-106A, and FSIMS 8900.1). Review 14 C.F.R. § 91.175/176 and decide whether a regulatory revision through rulemaking

would be necessary for the H-SE to be implemented.

- **Output #3:** Industry and FAA to develop and conduct outreach program to promote use of vision-enhancing technologies.

Of the three outputs, this paper documents the progress made regarding Output #1 and Output #3. Output #2 has not been attempted due to the lack of industry push towards using vision-enhancing devices for operational credit and due to recent decisions by the USHST Steering Committee to only perform actions that can be managed solely within the USHST membership. Therefore, Output #2 is summarized in the Recommendations section of this document and will not be pursued further by the H-SE Team. Output #3 has already been addressed via the H-SE Team, who have conducted numerous outreach activities with various industry stakeholders, including the following events:

- HAI HELI-EXPO Rotor Safety Challenge Sessions & Helicopter Operations Working Group (sponsored and hosted by Helicopter Association International {HAI})
- Guided Discussions with Industry Associations/Safety Teams/Working Groups (i.e.,, HeliOffshore, HSAC, AMOA, ERHC, etc.)
- Vision Systems Summits (sponsored and hosted by RTCA SC-213/EUROCAE WG-79, HAI, and the Vertical Flight Society {VFS})

While Output #2 will no longer be tracked formally by the USHST, this area will not be forgotten as the H-SE Team, and the USHST will continue to advocate amongst the helicopter community to increase community awareness towards using vision systems to enhance visibility for helicopters. As H-SE 91 sunsets and moves into a predominantly outreach mode, the H-SE Team will continue to meet and advance the science of this H-SE, including examining/testing new vision-enhancing systems (sensors and displays), developing and evaluating new operational concepts for operations in degraded visual environments/low visibility conditions, and promoting vision systems technologies by engaging with operators, OEM's, and vision systems device manufacturers towards utilization of these systems for both safety and operational benefit.

Main Objective

Various technologies offer the ability to improve the safety and efficiency of the NAS. One of these technologies is vision systems, which encompasses many elements, chief among them being an Enhanced Flight Vision Systems (EFVS). An EFVS is defined as *An installed aircraft system which uses an electronic means to provide a display of the forward external scene topography (the 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, including but not limited to forward-looking infrared, millimeter wave radiometry, millimeter wave radar, or low-light level image intensification*[1].

EFVS uses the concept of Enhanced Flight Visibility (EFV) which is 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* [1] as part of an EFVS operation. Similarly, an EFVS operation is defined as *An operation in which visibility conditions require an EFVS to be used in lieu of natural vision to perform an approach or landing, determine enhanced flight visibility, identify required visual references, or conduct a rollout* [1]. An EFVS comprises several components including the display element, sensors, computers and power supplies, indications, controls, and uses a Heads-Up Display (HUD) or equivalent display to present:

- aircraft information,
- flight symbology,
- electronic real-time sensor image (i.e.,, Enhanced Vision System (EVS)) of the forward external scene.

Besides an EFVS, when one thinks of a vision system technology, there are some other terms used that describe each element. These terms are defined below:

- H-EFVS = Helicopter Enhanced Flight Vision System
- HUD = Heads-up-display
- HWD = Head-worn-display
- HMD = Head-mounted-display
- NVG = Night Vision Goggles
- EVS = Enhanced Vision System (EVS uses sensor imagery (i.e.,, infrared cameras or millimeter wave radar or LIDAR) to display features like runway obstructions and terrain in bad weather or on a dark night)
- SVS = Synthetic Vision System (SVS uses information from a look-up database (i.e.,, terrain, airports/heliports) to create an artificial rendering of the outside world)
- CVS = Combined Vision System (CVS combines elements of EVS and SVS imagery to create a fused image of the flight environment)

Of these technologies, Enhanced Flight Vision Systems (EFVS) and Synthetic Vision Systems (SVS) are the two main forms when one looks at vision systems' imagery. These systems have been developed to provide additional safety and operational capabilities to aircraft instrument operations. Combined vision systems (CVS), as its name implies, combine both synthetic and enhanced vision systems (and may even combine two sensor images) to provide the benefits of both systems in one.

CVS technologies have been under development for several years, with the first system certified for fixed-wing business jets in 2020. SVS was first certified for use on the primary flight display for Part 25 aircraft in 2005 and for HUDs in fixed-wing aircraft in 2011. Synthetic vision is defined as *a computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles, and relevant cultural features* [1], whereas a Synthetic Vision System (SVS) describes *An electronic means to display a synthetic vision image of the external scene topography to the flight crew* [1].

The certification of a standalone Enhanced Vision System (EVS) allows the system to provide advisory information, not operational credit. Approvals for these EVS installations have occurred for several model Part 23 and Part 25 fixed wing and Part 27 helicopters. Unlike EFVS, EVS does not require a full system with a HUD display per the FAR 91.176 regulation and has typically presented as a sensor image on a head-down display.

Today, all EFVS certification and operational approvals have been exclusively for fixed-wing aircraft operating to a runway environment. Although the FAA certification process defined in AC 20-167A was established to include Part 27 and Part 29 rotorcraft, no full EFVS systems (with HUD) have been adopted for helicopter operations. Corresponding guidance or authorizations exist for rotorcraft when using EFVS on straight-in instrument approach procedures (IAPs) to runways but have not been defined for using EFVS for other types of rotorcraft operations (i.e.,, Point in Space, Offshore, etc.).

The reasons for this are many, but they can be surmised by the key observation that helicopters differ from their aircraft counterparts, especially in how and where they operate during takeoff, landing, approach, departure, and en route operations. That said, there are some similarities between rotorcraft and aircraft operations, and the past research, development, and regulatory changes implemented to serve the fixed-wing community offer a starting point for the vertical-flight community to examine the way to support future operations.

The FAA has been evaluating vision systems technologies for rotorcraft for several years. Preliminary examinations have expanded FAA knowledge of the use and operational capabilities of some of the systems tested, and are helping to identify regulatory and policy gaps. This testing has included various sensor and display technologies as well as human factors considerations (i.e.,, form, fit, function, and workload) of HWDs/HMDs and Vision Systems technologies. These results have yielded some promising findings while also identifying areas of further development needed for these systems to provide the necessary safety and operational benefits to the rotorcraft community.

The remainder of this report documents potential operational concepts for the utilization of helicopter vision-enhancing systems in low-visibility operations (i.e.,, night, IMC, etc.) and enhanced VFR. It also chronicles results from some of the outreach events, including several Vision Systems Summits, which further detail the desires of the community towards vision systems technologies for enhancing safety.

Use Cases for Rotorcraft Vision System Technologies

Helicopters typically fly at low altitudes, often at night, and in obstacle-rich environments. They frequently operate to or from sites lacking the equivalent infrastructure to those that support fixed-wing aircraft (i.e.,, instrument approach lighting and instrument landing systems at an airport). Additionally, there are many diverse mission segments for rotorcraft, far more than just typical commercial air transport or charter operations (i.e.,, business aviation) for fixed-wing aircraft. Amongst the many mission segments are several well-known uses of helicopters that are flown in high visibility conditions. These include missions as diverse as air tour, flight training, aerial newsgathering, aerial application, and aerial lift.

Since these operations primarily operate under visual meteorological conditions (VMC) in good visibility, they were not considered primary use cases for the application of vision systems technologies to enhance the safety of low visibility operations on rotorcraft. However, these mission segments and others may benefit from vision systems technology to prevent the occurrence of or enable escape from unintended instrument meteorological conditions (UIMC). Further, there are several additional rotorcraft mission segments, including Offshore Operations, Helicopter Air Ambulance, Corporate/VIP Transport, Search & Rescue, Aerial Firefighting, and Law Enforcement that do frequently operate under instrument meteorological conditions (IMC) and/or in marginal or low visibility conditions.

Several activities associated with this research included a series of discussions held with rotorcraft operators as well as a vision systems summit. These activities included educating the operators on current and future vision systems technologies, understanding the operators' desires regarding the use of vision system technologies in their current or future operations, and gauging the operators' interest in investing in these technologies to enhance safety or pursue operational credit/benefit.

A synopsis of the results of these discussions is listed in the following subsections of the report for several key mission segments. Several of the supporting material for the operational concepts outlined in the subsections that follow were also extracted from elements within the EUROCAE WG-79/RTCA SC-21/SG-4 document on *Current rotorcraft operations and the impact of reduced visibility conditions* [49]. These insights are helpful in identifying potential operational concepts as well as highlighting regulatory and knowledge gaps that future studies on vision systems could seek to address.

Offshore Operations

Offshore operations include any operations off the coast over a body of water. Typically, they involve:

- Transportation of oil and gas workers commuting from an onshore airport or heliport to an offshore oil or gas rig via an offshore helideck
- Delivery of personnel to ships
- Operations to wind farms with helidecks which can include delivery of personnel or equipment, for wind farms both with and without helidecks

- Hoist operations for construction or maintenance of offshore oil, gas, or wind farm installations

Offshore operations to helidecks (which can be located on oil rigs, production platforms, vessels, etc.) are conducted worldwide wherever oil and gas exploration takes place [49]. These operations typically take place from mainland airports and bases to offshore helidecks at sea, as well as between offshore helidecks. Helidecks may be stationary or moving (due to sea conditions), comprising physical infrastructure like offshore wind farms, floating or anchored drilling rigs and small pump stations, or seafaring vessels ranging from small ships to large tankers.

An offshore outbound flight typically consists of a departure from an onshore airport or heliport under VFR or IFR and continues via the Enroute environment offshore at a specified altitude and on a specific course to an offshore helideck. Transitioning from the Enroute environment, the flight culminates with an approach to a helideck via either a visual approach if VFR weather conditions persist or an instrument approach procedure in IFR weather conditions with a visual segment flown inbound to the offshore helideck platform.

During an offshore flight featuring an offshore instrument approach procedure, one of the highest workload and riskiest segments manifests itself during the transition from the instrument segment to the visual segment (i.e.,, from the Missed Approach Point (MAPt) to the Helideck). At this key point in the flight, the pilot(s) are looking outside the helicopter to acquire the visual references (i.e.,, Helideck, Helideck lights/markings, sea, etc.) needed for continuing the approach and landing. This is a time when reduced visual cues due to low visibility from night or poor weather can result in the crew becoming spatially disoriented.

In extreme cases, the crew may experience visual illusions that may result in an accident due to a loss of control of the helicopter. Night adds to this challenge since no reference to the sea surface other than the radar altimeter (RADALT) is available, and it is common to encounter a low cloud ceiling or reduced visibility due to the formation of maritime fog, which can completely obscure the Helideck or the entire offshore oilrig platform. Obstacles like cranes in their stowed position may also be encountered, adding to the complexity of this operation and highlighting the need for enhanced visibility during the visual segment.

Recent advances in Helideck lighting have helped; however, two problems persist. First, at typical distances (i.e.,, the Missed Approach Point) at minimum altitude, helideck lights can be hard to distinguish from other lights on the structure. Second, the majority of lights now are LED-based, which makes them harder to see via IR sensors or with Night Vision Goggles (NVGs).

On an offshore inbound flight, the departure is from the offshore oil rig under VFR or IFR and continues via the enroute environment offshore at a specified altitude and on a specific course to an onshore airport or heliport under VFR or IFR. Transitioning from the Enroute environment, the flight culminates with an approach to an onshore airport or heliport via either a visual approach if VFR weather conditions persist or an instrument approach procedure to a runway under IFR weather conditions or a Point in Space (PInS) instrument approach procedure to an onshore heliport.

We reviewed these operational considerations and concepts during discussions with several offshore operators. We spoke with representatives from Petroleum Helicopters Inc. (PHI), Helicopter Safety Advisory Conference, HeliOffshore, and others who provided their feedback on vision systems devices and associated concepts for improving safety and operational efficiency. Our conversations included the benefits of augmented reality and enhanced vision systems in offshore environments, as these technologies have been analyzed by Maibach et al. [20], demonstrating a reduced pilot's workload with an increase in rotorcraft safety.

PHI is a leader in providing offshore helicopter support to companies operating in the Gulf of Mexico as well as across the globe in more than 45 foreign countries. PHI operates the majority of its flights in the Gulf of Mexico to various oil rigs/platforms and back onshore to their bases in Houma and Lafayette, Louisiana. Their focus was on how vision system technology would integrate with other avionics and navigation solutions, as there would need to be a clear benefit to their operations if an investment were to be made.

PHI would expect a vision system to prevent controlled flight into terrain and loss of control, among other safety events, since the pilot would be able to see potential hazards near/on an oilrig (i.e.,, drill ship on approach course, rig booms from the cranes and flare stacks, and other hazards). Ideally, the vision system would be able to prevent spatial disorientation from flight over featureless water during night operations and allow the pilot(s) to maintain visual references in low visibility conditions, such as maritime fog.

HeliOffshore is the global, safety-focused association for the offshore helicopter industry. Through collaboration with and between members, HeliOffshore delivers an industry-wide safety program that enhances safety worldwide. HeliOffshore represents operators in the Gulf of Mexico, the North Sea, and other locations around the globe. HeliOffshore had some of the same interests as far as safety that PHI and other HSAC members had. Their main safety considerations from a vision system were to prevent controlled flight into terrain (reminiscent of several accidents that occurred in the North Sea during the past two decades), loss of control, and other unsafe events by seeing the hazards of an oil rig during approach & landing and takeoff & departure scenarios, as well as preventing spatial disorientation from flight over featureless water during night operations by enabling the pilot to maintain visual references in low visibility conditions.

HeliOffshore also indicated potential operational benefit from reduced minima via their Offshore Standard Instrument Approach Procedures (i.e.,, OSAPs) and some of their runway approaches, as well as low visibility takeoffs. They mentioned approaches for various offshore oil rigs that they would like lower minima for if they can use something in conjunction with the Sikorsky Rig (i.e.,, https://news.lockheedmartin.com/2013-11-13-PHI-flies-first-Rig-Approach-Customer-Flights-in-the-S-92-helicopter), which is an automated system for flying the GPS OSAP parallel offset offshore approach procedures on S-92 helicopters. The operators also expressed interest in using such a conceptual system for some of the other offshore helicopters that do not have such a system (i.e.,, Bell 407s/206s, S76s, AW139s, etc.). They also noted an area where a vision system could show benefit, namely, by providing the visual cues/references from MAP to the Rig down to a minimum of 50’ above the helideck. They would be interested in lower minima down to ¼ statute mile or less as well as reducing the offset distance on the parallel OSAP procedure to enable them to get closer to the rig for offshore operations with some additional benefit in terms of dispatch reliability. Basically, they want to shift the MAP inside the 3/4nm rather than fly the visual segment with an EFVS (move MAP close to the rig) – as it has to meet the current operational minima.

For onshore operations, HeliOffshore can already get at least CAT1 system minima for some ILS or RNAV approaches down to ¼ statute mile, so a vision system is not of much use for those approaches. However, other onshore approaches along the coastline are limited, and they can’t go below 1/2 statute mile visibility with 200/300’ MDH (OSAP or ARA) in the U.K. (1/4 mile miss distance) on their Offshore Standard Instrument Approach Procedures (i.e.,, OSAP’s).

Air Ambulance

Helicopter Air Ambulance (HAA) operations include flights to/from a base, hospital, or landing zone (i.e.,, accident scene). Typically, they involve:

- Flights to and from the HAA base (airport or heliport) to a hospital heliport or landing zone for patient pickup
- Patient transport from one hospital heliport to another hospital heliport
- Flights to an airport or heliport from a hospital heliport for refueling
- Repositioning flights to/from a new HAA base for picking up crew members or for completing helicopter maintenance

HAA operations occur worldwide in various terrain, times of day, and in all sorts of locations. As such, they tend to require a high degree of flexibility from an operational perspective, meaning that routes are often unpredictable and vary based on the emergency response call; especially for patient pickups at accident scenes. Patient transports and pickups at hospitals, repositioning flights, and refueling flights tend to follow direct routing, although, for some scene flights, there are a set of agreed-upon landing zones utilized by the HAA operator. Regardless of the type of landing zone, obstruction awareness is essential; as wires, towers, fences, and other obstructions can pose large risks to the operation.

Further complicating this is the fact that in most HAA operations, landing sites are very diverse. They range from the home bases, where usually there is an adequate obstacle-free Final Approach and Takeoff area (FATO), to rooftop or ground-based hospital heliports to unknown, unsurveyed outside landings on all kinds of surfaces. Usually, the crew will not know the destination for their primary mission until minutes before launching. Often this will require operations to temporary unprepared landing sites. In some countries, there is a known network of preferred rendezvous landing zones – either official helipads or known landing sites such as soccer fields, etc. These sites are used mainly at night to mitigate the risk of landing at unknown/unprepared sites.

Typical landing surfaces may be fields, roads, stony or sandy areas, and even include intersections in urban areas. Unlike actual helipads at hospitals or airports, the common feature of such landing sites is that little or no data exist describing the obstacle environment and prevailing weather conditions (wind, visibility, cloud base, etc.). Thus, the flight crew must visually identify all obstacles (i.e.,, sloping terrain, vegetation, vehicles, antennas, traffic signs, power lines, telephone cables, people, vehicles, etc.). Additionally, loose objects near the intended landing zone must also be identified visually, as they can pose considerable danger to people on the ground or the aircraft if they become dislodged and propelled by the helicopter's downwash (i.e.,, accident debris, pylons, or tape used to secure the roadside scene, blankets, backpacks, jackets, bicycles, motorcycles, etc.). Typically, to mitigate these risks, a helicopter will perform high/low reconnaissance maneuvers to survey the area, check for possible obstacles and hazards, and determine the safety of the landing zone before making an approach to land.

An HAA flight usually starts on the base or at one of the other locations listed previously, where the crew waits for dispatch to begin their flight operation. HAA flights are flown primarily VFR, although some operators do fly IFR at low altitudes featuring a diversity of landing zones. HAA flights typically consist of a departure from a heliport or an airport under VFR or IFR and continue via the Enroute environment at low altitude to either a hospital heliport, airport, or landing zone. Transitioning from the Enroute environment, the flight culminates with an approach to an airport or hospital heliport (elevated rooftop or on the ground level) via either a visual approach if VFR weather conditions persist or a standard instrument approach Point-In-Space (PInS) instrument approach procedure (usually a COPTER RNAV GPS approach) in IFR weather conditions.

On a PInS approach, the approach culminates at the Point In Space (i.e.,, Missed Approach Point) with a visual segment of the IFR Approach flown inbound to the heliport for a Proceed Visual Approach, or with a transition to VFR flight if flown inbound to the heliport or landing zone under VFR for a Proceed VFR Approach. There are variations and exceptions to these approaches, but just like the offshore flights featuring instrument approach procedure, one of the highest workload and riskiest segments manifests itself during the transition from the instrument segment to the visual segment (i.e.,, from the Missed Approach Point (MAPt) to the Heliport or Landing Zone). At this key point in the flight, the pilot(s) are looking outside the helicopter to acquire the visual references (i.e.,, Heliport, Heliport lights/markings, windsock, heliport beacon, etc.) as well as looking for any obstacles to avoid. For a flight to a landing zone, the approach might terminate with a high/low reconnaissance maneuver with a visual approach to the final landing zone. Regardless of the landing zone (airport, heliport, or site), this is a time when reduced visual cues due to low visibility due to night or poor weather conditions over the heliport or landing site may result in the crew becoming spatially disoriented or experiencing visual illusions. In extreme cases, this can result in an accident due to a loss of control of the helicopter or hitting an obstacle. As one can see from this depiction, throughout an HAA flight, the flight crew depends heavily on available visual cues.

We reviewed these operational considerations and concepts during discussions with several HAA operators. We spoke with representatives from Lifeflight of Maine, Rega Air Ambulance, the Air Medical Operators Association (AMOA), and others who provided their feedback towards vision systems devices and associated concepts for improving safety and operational efficiency. Our conversations included the benefits of augmented reality and enhanced vision systems in helicopter air ambulance operating environments; as these technologies have been analyzed by Maibach et al. [20], demonstrating a reduced pilot's workload with an increase in rotorcraft safety.

LifeFlight of Maine operates across the northeastern United States from Maine to Massachusetts. As such, they experience a variety of challenges due to both the climate and the terrain in their operational area. Their top priorities for the immediate future are enhancing situational awareness, preventing controlled flight into terrain, preventing loss of control, preventing spatial disorientation, and terrain/obstacle avoidance. Other near-term interests were enabling low-level infrastructure enhancements and enhancing safety during flights at night or in low visibility. Far-term interests besides operational credit on PInS and standard airport instrument approach visibility minima reduction focused on relief from IFR alternate airport requirements due to worries of fuel capacity as well as relief from rules on mandatory radar altimeters for aided night operations (i.e.,, with NVGs) that a vision system might provide.

LifeFlight of Maine was also interested in harmonizing standards with European operators (i.e.,,, Rega Air Ambulance) in regards to Required Navigation Performance (RNP) 0.3 and low-level IFR routes. Their concern was in regards to ensuring that the adoption of vision systems technology supports other technologies like Aviation Weather Cameras, Automated Surface Observing Systems (ASOS)/Automated Weather Observing Systems (AWOS) stations, Night Vision Goggles (NVGs) and other technologies that help pilots make better decisions and operate safely in challenging operational environments such as those faced by HAA operators.

The Air Medical Operators Association (AMOA) includes over a dozen helicopter air ambulance operators in the U.S. Together they comprise over 90% of onshore Instrument Flight Rules (IFR) helicopter operations. In our discussions, we spoke to eight AMOA members – 7-Bar, AirEvac, Air Methods, Guardian, Palm Beach, MedTrans, Lifeflight Network, North Memorial, and Reach Air Medical. They operate a range of helicopters ranging from EC135's to AW109's and AW139's.

One of AMOA's members, Reach Air Medical referenced using vision systems technology to enhance safety in degraded visual environments and to mitigate hazards in low-level environments, primarily along low-altitude routes or during the final segments of an instrument or radar approach, where technology could assist in a safe final approach segment – assisting the pilot(s) in converting from an instrument to a visual scan. Furthermore, other AMOA members saw enhanced vision systems as a way of mitigating threats from weather, terrain and obstacles via a 360-degree all-weather Visual Flight Rules (VFR) capability in degraded visual environments.

Corporate / VIP Transport

Corporate/VIP Transport operations include flights to/from airports, heliports, or temporary landing zones (i.e.,, racetrack, stadium parking lot, concert venue). Typically, they involve:

- Flights from one location to another to pick up/drop-off corporate or charter clients as well as very important persons

- Repositioning flights to/from a location where the helicopter is based to pick up clients or to another location for maintenance

Corporate/VIP transport flight operations typically take place under scheduled service, similar to the airlines, but on the schedule of various corporate clients. A scheduled onshore operation will normally have a known network of routes and a minimum altitude Enroute of at least 500 ft. VFR. This means that hazards are often known, charted and the landing area surveyed with a runway of helipad approach. This reduces the risk of obstacles during the Enroute phase of flight, but visual references are still required during all phases if VFR flight is being conducted, especially during the take-off and landing phases of flight.

Similar to an HAA flight, a Corporate/VIP flight usually starts at an airport, heliport, or landing zone and proceeds to a destination airport, heliport, or landing zone with a drop-off or pickup of passengers at either location. Depending on the operator, these flights are flown VFR or IFR. Transitioning from the Enroute environment, the flight culminates with a visual or instrument approach to an airport, heliport (elevated rooftop or on the ground level) via either a visual approach if Visual Meteorological weather Conditions (VMC) persist or a standard instrument approach Point-In-Space (PInS) instrument approach procedure (usually a COPTER RNAV GPS approach) if Instrument Meteorological weather Conditions (IMC) persist.

On a PInS approach, the approach culminates at the Point In Space (i.e.,, Missed Approach Point) with a visual segment of the IFR Approach flown inbound to the heliport for a Proceed Visual Approach, or with a transition to VFR flight if flown inbound to the heliport or landing zone under VFR for a Proceed VFR Approach. There are variations and exceptions to these approaches, but just like the offshore flights featuring instrument approach procedure, one of the highest workload and riskiest segments manifests itself during the transition from the instrument segment to the visual segment (i.e.,, from the Missed Approach Point (MAPt) to the Heliport or Landing Zone). At this key point in the flight, the pilot(s) are looking outside the helicopter to acquire the visual references (i.e.,, Heliport, Heliport lights/markings, windsock, heliport beacon, etc.) as well as looking for any obstacles to avoid. Advancements in Performance Based Navigation (PBN), including the proliferation of WAAS GPS approaches into heliports (i.e.,, COPTER RNAV PInS approaches) and airports, have allowed instrument approaches to predominate for those operators who routinely fly these missions.

We reviewed these operational considerations and concepts during discussions with several Corporate/VIP operators. We spoke with representatives from the Eastern Regional Helicopter Council (ERHC), as well as two of their members, Pfizer and Mass Mutual who both operate helicopters in the busy northeastern U.S. They provided feedback towards vision systems devices and associated concepts for improving safety and operational efficiency. Our conversations included the benefits of augmented reality and enhanced vision systems in Corporate/VIP transport operating environments; as these technologies have been analyzed by Maibach et al. [20], demonstrating a reduced pilot's workload with an increase in rotorcraft safety.

The Eastern Regional Helicopter Council (ERHC) is an industry group that represents numerous stakeholders who operate helicopters for various mission segments including Corporate/VIP, as well as other mission segments like air tour, law enforcement, and helicopter air ambulance. Their biggest focus was on the safety benefits of technologies like a vision system for terrain/obstacle avoidance rather than operational credit. Although operational credit would be beneficial, it could end up being a lengthy process and ERHC felt that there are safety benefits that could be gained from these technologies today. They mentioned a fatal crash of an AW109 in downtown New York during a period of poor visibility as a driver for fast tracking this type of technology to enhance safety and alleviate Air Traffic delays that pilots face due to issues with airspace access and priority routing in the IFR infrastructure within the New York Metroplex.

Pfizer and Mass Mutual, who are both members of ERHC, also expressed their desires for enhancing safety using vision systems technology. These operators have had some exposure/knowledge of vision systems from their previous fixed-wing/military backgrounds. They already fly some of the safest and most advanced helicopters in the Corporate/VIP mission segment; however, these operators still see the value in vision system technologies for improving the safety of normal operations.

Search and Rescue

Search and Rescue (SAR) operations include onshore and offshore flights to both central and remote locations with various climates, topography, and infrastructure. Typically, they involve:

- Onshore and Offshore Search Operations originating from a base (normally an airport or heliport or a ship) and terminating at a search area which might be in remote, mountainous terrain, or over the ocean
- Onshore and Offshore Rescue Operations (including hoisting of rescue and rescued personnel) originating from a base (normally an airport or heliport or a ship) and terminating at a rescue site which might be in remote, mountainous terrain, or over the ocean including rescues from distressed vessels (i.e.,, boats, ships)
- Training Operations to practice SAR techniques
- Aerial Intercept Operations where the helicopter is used to intercept a rogue or non-compliant general aviation or commercial aircraft (i.e.,, USCG operation in the U.S. near the DC SFRA)

SAR flight operations can be conducted anywhere including onshore in various terrain and obstacle-rich environments, and offshore with challenges such as reduced visual cues and degraded visual environments. During offshore SAR operations, flight crews look directly down from the helicopter to see the water surface, and can descend lower if the surface of the water is visually acquired. SAR pilots also constantly monitor weather patterns & sea state conditions for offshore and onshore missions, and are constantly on the lookout for threats obstacles, mountain flying hazards (i.e.,, turbulence, obscuration/fog, etc.).

The flying techniques utilized by SAR operators involve an instrument scan to ensure that there are no false horizons, especially in low clouds and poor visibility which can occur in areas of low cultural lighting such as in the mountains or offshore over the water. High winds and altitudes can have a detrimental effect on the performance of the helicopter, so SAR pilots have to be extremely careful on how they approach and depart the landing zones.

In the case of mountainous flights, weather plays a key part in decision making due to the added factors of high terrain creating a high IFR Minimum Enroute Altitude (MEA), Minimum Obstruction Clearance Altitude (MOCA), or Minimum Safe Altitude (MSA) as encountered on instrument approaches. This often encourages SAR operators to fly VFR in bad weather, or escape down valleys with obstructions such as wires and cables possibly strung across a valley floor. Over the water, SAR operators face similar challenges with little to no visual references during both normal flight and while in a hover; the latter of which is necessary during the rescue portion of the flight.

SAR operations also typically feature a number of search patterns, which are typically not encountered in other types of helicopter operations. These include:

- Rising Ladder
- Expanding Square
- Race Track
- Sector
- Orbit
- Border Patrol
- Drifting Target

While flying these search patterns, the flight crew's attention is divided between flying the helicopter and maintaining adequate visual references as well as searching for aircraft/vehicle/ship accident debris/wreckage, survivors, missing people/animals, or other items as part of the search operation.

Unlike the other types of flight operations, SAR operations usually start at the same location (i.e.,, the SAR base that can be located at an airport or a heliport), proceed to a destination site, which is often unknown other than possibly some Lat./Lon. grid coordinates representing the search and/or rescue area, and return to either the SAR base or go direct to the nearest hospital heliport (usually a trauma center), returning to the SAR base at the completion of the flight. Depending on the SAR operation, an operator may make multiple flights with multiple helicopters to cover the search area and/or to rescue survivors. After departure and transiting the en route portion of the flight, to establish on scene in poor weather conditions, the SAR operator may execute a Point-In-Space Approach to the grid coordinates for the search operation or may execute a descending turn similar to a high/low reconnaissance maneuver.

Per the FAA's Helicopter Flying Handbook [52], a High-Reconnaissance Maneuver is basically an orbit or flight pattern at 300-500' AGL over the landing area while a Low-Reconnaissance Maneuver is performed at 100'-300' AGL or during the approach to landing. Either or both of these maneuvers may be flown by SAR pilots to establish on scene for the SAR operation. Once on scene, the flight will enter one of the search patterns listed previously or it may enter a hover over the ship or person to be rescued; with rescuers being lowered to the ground via a hoist/winch/basket or via departing the helicopter after landing at an unprepared site (onshore) or on a vessel (offshore).

Departing the SAR scene, the flight culminates with a visual or instrument approach to an airport or heliport (elevated rooftop or on the ground level) via either a visual approach, if Visual Meteorological weather Conditions (VMC) persist, or a standard instrument approach (for an airport) or a Point-In-Space (PInS) instrument approach procedure (for a heliport usually a COPTER RNAV GPS approach) if Instrument Meteorological weather Conditions (IMC) persist. On a PInS approach, the approach culminates at the Point In Space (i.e.,, Missed Approach Point) with a visual segment of the IFR Approach flown inbound to the heliport for a Proceed Visual Approach, or with a transition to VFR flight if flown inbound to the heliport or landing zone under VFR for a Proceed VFR Approach. There are variations and exceptions to these approaches, but just like other operators featuring instrument approach procedures, one of the highest workloads and riskiest segments manifests itself during the transition from the instrument segment to the visual segment (i.e.,, from the Missed Approach Point (MAPt) to the Heliport). At this key point in the flight, the pilot(s) are looking outside the helicopter to acquire the visual references (i.e., Heliport, Heliport lights/markings, windsock, heliport beacon, etc.) as well as looking for any obstacles to avoid.

We reviewed these operational considerations and concepts during informal discussions with the leading U.S. SAR operator, the U.S. Coast Guard. We spoke with several of the U.S. Coast Guard's pilots and flew with them during several training flights to better understand their SAR operation and the challenges that it presents. They provided feedback on vision systems devices and associated concepts for improving safety and operational efficiency.

The U.S. Coast Guard is an agency under the U.S. Dept. of Homeland Security. Aside from the active U.S. military (i.e., Army, Navy, Air Force, and Marines), the Coast Guard flies the most operational hours of any rotorcraft operator in the U.S. and is the leading U.S. SAR operator. As such, their helicopters are already equipped with NVGs and FLIR cameras. However, in speaking with several of their pilots, they had a keen interest in additional vision systems technologies to help increase safety during low visibility and degraded visual environment (DVE) flight conditions. Indeed, both (DVE) and low visibility operations remain a real challenge for the Coast Guard and other SAR operators. Depending on their area of operation, the USGC can experience whiteout conditions in the winter, maritime or mountain fog during certain times of year along the coastline, and instances of low cultural lighting in remote locations over featureless (i.e., water) terrain (i.e., mountains). These can provide little to no visual references, making this a tough operation to perform safely. DVE and low visibility challenges can occur during multiple phases of flight (i.e., during forward flight and during a hover).

Like other operators, the USCG experiences challenges with low visibility during approach operations. This is further complicated by the fact that the Coast Guard operates in all-weather conditions and occasionally may dispatch a SAR team who often will conduct a search and return to base or to a hospital heliport low on fuel and at close to approach minima. Hence, the USCG would benefit from technologies that ensure the safety of flight is maintained during transit to/from SAR operations as well as offer lower minima during instrument approach procedures to an airport or heliport. Low-speed flight (i.e., hover) segments often present other challenges to the Coast Guard as this is where they might spend the majority of their time during the rescue portion of a SAR flight.

The human factors associated with DVE during this phase of flight are such that often, the pilots may target and fixate on inappropriate references, resulting in drift close to the ground or the water. This is especially apparent with the use of NVGs, where the pilots may lose peripheral vision and cues that usually provide an indication of drift/ground speed and altitude. Thus, DVE and low visibility environments represent areas within SAR flight operations where vision technology enhancements could reduce risks and enhance safety.

Aerial Firefighting

Aerial Firefighting (AFF) operations include onshore flights to remote locations with various climates, topography, and infrastructure. Typically, they involve:

- Aerial Extinguishing Agent Drop operations originating from a base or a source of extinguishing agent (i.e., lake, bay, ocean, etc.), culminating in a drop over the fire source, terminating in a return to base or the source of the extinguishing agent to refill for another drop operation
- Water Ingest flight operations originating from a base and terminating at a source of water (i.e., lake, bay, ocean, etc.) in a hover or low approach to fill the tanks of the helicopter prior to firefighting operations
- Aerial Firefighting Reconnaissance operations where sensors on the helicopter monitor the spread of the fire and direct resources on the ground and in the air to coordinate a response
- Rescue Operations to drop off or retrieve firefighters and equipment on the ground that are working to fight the fire

AFF flight operations can be conducted anywhere in the world, but are prevalent in the western U.S. as well as in Australia. These operations often occur in mountainous terrain and are plagued by low visibility conditions stemming from the smoke and haze from the fires themselves. During extinguishing agent pickup or agent drop operations, AFF operators look outside the helicopter to maintain visual references with the bucket or with the hoses used to fill their auxiliary water tanks during a hover or low-altitude flight. Their primary concern is striking wires or terrain with the helicopter during this part of the mission, but they also need to be aware of the change in weight and balance due to the increased loading and the challenges this presents. AFF pilots also constantly monitor weather patterns & conditions that can change by the minute during firefighting operations due to the unique weather patterns generated by the fire. They also are on the lookout for threats such as obstacles, turbulence, obscuration due to haze/smoke, and other mountain flying hazards.

Like SAR operations, AFF operations usually start at the same location (i.e., the SAR base, which can be located at an airport or a heliport), and proceed to a destination site which is often unknown other than possibly some Lat./Lon. grid coordinates representing the fire area, and return to either the SAR base or go back to the site to pick up more extinguishing agent (i.e., water) before returning to the drop site and then the AFF base at the completion of the flight. Depending on the AFF operation, an operator may make multiple flights with multiple helicopters to cover the fire area and/or to pick up/drop off firefighters to work the fire at ground level. After departure and transiting the en route portion of the flight, to establish on scene in reduced visibility weather conditions, the AFF operator may execute a descending turn similar to a high/low reconnaissance maneuver or coordinate with an air boss to establish altitude and heading on the fire scene for the AFF operation.

Once on the fire scene, the flight will perform its intended function; with firefighters being lowered to the ground via a hoist/winch/basket, the helicopter dropping extinguishing agent, or the helicopter performing aerial reconnaissance of the fire. Departing the fire scene, the flight culminates with a visual or instrument approach to an airport or heliport (usually on the ground level) via either a visual approach, if Visual Meteorological weather Conditions (VMC) persist, or a standard instrument approach (for an airport) or a Point-In-Space (PInS) instrument approach procedure (for a heliport usually a COPTER RNAV GPS approach) if Instrument Meteorological weather Conditions (IMC) persist.

On a PInS approach, the approach culminates at the Point In Space (i.e., Missed Approach Point) with a visual segment of the IFR Approach flown inbound to the heliport for a Proceed Visual Approach, or with a transition to VFR flight if flown inbound to the heliport or landing zone under VFR for a Proceed VFR Approach. There are variations and exceptions to these approaches, but just like other operators featuring instrument approach procedures, one of the highest workloads and riskiest segments manifests itself during the transition from the instrument segment to the visual segment (i.e., from the Missed Approach Point (MAPt) to the Heliport). At this key point in the flight, the pilot(s) are looking outside the helicopter to acquire the visual references (i.e., Heliport, Heliport lights/markings, windsock, heliport beacon, etc.) as well as looking for any obstacles to avoid.

Unfortunately, we did not speak to any specific AFF operators in detail regarding their operations; however, we did address HAI’s Aerial Firefighting Conference 2020, where several operators were present. These operators expressed interest in using a vision system to aid them in reaching the fire scene or returning from the scene, as last year, many of the firefighting operations were halted due to low visibility from the smoke of all of the fires. This left many of the AFF helicopters unable to depart due to takeoff minima or, more importantly, unable to dispatch due to alternate requirements and fears of not being able to return to base, ultimately resulting in the continued spread of more wildfires.

Currently, there are several vision systems manufacturers who are developing concepts of operation with operators in the community to try to address this issue. Columbia Helicopters and Aurora Flight Sciences are one operator-vision systems OEM pair that are working on this, while Elbit/Universal is also exploring this space with several interested helicopter AFF operators.

Law Enforcement

Law Enforcement operations include onshore flights over urban and rural environments. Typically, they involve:

- Aerial Reconnaissance operations where sensors on the helicopter monitor a suspect or provide overwatch and security for an event on the ground
- Tactical Support operations where teams of law enforcement personnel are inserted/extracted from an operational location or are stationed on the helicopter to provide live fire against a target
- Aerial Chase operations, where the helicopter is used to assist ground personnel chasing a suspect
- Search and Rescue Operations to retrieve victims from natural disasters
- VIP transport of public figures and local/state officials

Law enforcement flight operations can be conducted anywhere in the world, but are prevalent in most large U.S. cities as well as states that maintain their own fleets (i.e., NJ State Police, NY State Police, LA Police Dept., etc.). These operations often occur in urban environments, although there are some law enforcement operations that occur in rural environments in mountainous terrain. Just like other operations, law enforcement operations can also be affected by low visibility conditions. Law enforcement operators look outside the helicopter to maintain visual references during all of their operations. Thus like others, their primary concern is striking wires or terrain with the helicopter during this part of the mission. However, other threats, such as turbulence, low visibility, and degraded visual environments, are also a concern.

Like AFF operations, Law enforcement flight operations usually start at the same location (i.e., the Law Enforcement base, which can be located at an airport or a heliport), and proceed to a destination site, which is often unknown other than possibly some Lat./Lon. grid coordinates representing the area of interest, and return to the base at the completion of the flight. The difference is that a Law enforcement flight might cover several hours over the same area in an orbit or hover often within very close proximity to the base (i.e., within the boundaries of a city). After departure and transiting the en route portion of the flight, once on the scene, the flight will perform its intended function. Departing the incident scene, the flight culminates with a visual or instrument approach to the base usually an airport or heliport (elevated or on ground level) via either a visual approach, if Visual Meteorological weather Conditions (VMC) persist, or a standard instrument approach (for an airport) or a Point-In-Space (PInS) instrument approach procedure (for a heliport usually a COPTER RNAV GPS approach) if Instrument Meteorological weather Conditions (IMC) persist.

On a PInS approach, the approach culminates at the Point In Space (i.e., Missed Approach Point) with a visual segment of the IFR Approach flown inbound to the heliport for a Proceed Visual Approach, or with a transition to VFR flight if flown inbound to the heliport or landing zone under VFR for a Proceed VFR Approach. There are variations and exceptions to these approaches, but just like other operators featuring instrument approach procedures, one of the highest workloads and riskiest segments manifests itself during the transition from the instrument segment to the visual segment (i.e., from the Missed Approach Point (MAPt) to the Heliport). At this key point in the flight, the pilot(s) are looking outside the helicopter to acquire the visual references (i.e., Heliport, Heliport lights/markings, windsock, heliport beacon, etc.) as well as looking for any obstacles to avoid.

We spoke to several Law Enforcement operators in detail regarding their operations. In particular, the NYPD, NJSP, and LAPD provided feedback on how they would benefit from a vision system. All of these operators expressed interest in using a vision system to aid them in reaching the incident scene and navigating in the low altitude obstacle-rich environments of New York and Los Angeles, as well as combatting fog and low visibility stemming from operating near the coasts. They also expressed interest in interfacing with their existing FLIR cameras and NVGs as well as enhancing visual cues during flight operations to prevent spatial disorientation and loss of control.

The NYPD and NJSP also expressed interest in enabling better vision of wires and obstacles using vision systems devices as well as expressing a desire, though not as strong as the safety consideration for lower minima, both for standard instrument approaches to airports and PInS approaches to heliports, primarily the NYC heliports (KJRB, KJRA, 6N5). Primarily, their thought was that with a vision system, there would be an ability to provide helicopter operators like themselves with better visual cues in marginal conditions, such as on a flight over the Verrazano Narrows Bridge and up the Hudson and East Rivers, which can be challenging in lower visibility or DVE conditions.

Other Use Cases

The use cases in which vision system technologies could enhance safety that are listed in the previous sections may not be inclusive of all potential use cases. There are other industry segments that were purposely not mentioned. Air tour operators typically do not fly in low-visibility conditions. Thus, they have no requirement for a vision system for the majority of their operations. Similarly, flight training schools teach the basics of helicopter maneuvers, so they would not typically expose a student to advanced technology like vision systems that are not prevalent in the market today and for which civil aviation training standards for rotorcraft for not exist. Aerial newsgathering, aerial application, and aerial lift usually conduct operations in clear VMC VFR conditions. Thus, they also were not considered for additional use cases.

Vision Systems Operational Concepts, Use Cases, and Potential Areas of Study

From the listed use cases, some potential opportunities to enhance safety and/or provide operational benefits become apparent. However, to truly provide some semblance of possible operational concepts, these areas need to be combined with the areas noted and requested by operators as areas that might benefit from vision systems technology within specific industry segments (i.e., Offshore, HAA, Corporate/VIP, SAR, Law Enforcement, etc.). By examining these areas, we can align the research to potential operational concepts/use cases to help focus the examination of specific topics on enabling or ruling out these types of operational concepts based on the technology that exists today or might be available in the future.

It is important to note that **these concepts are listed for discussion purposes only**. They **do not represent FAA policy or positions,** and in some cases, given current FAA policy direction, **may not be feasible in any form**. Still, the authors feel it is worth listing these areas to try and derive some bounds on the operational profiles and to develop as many new use cases as possible in order to tailor the appropriate future research questions, and studies from topics found earlier in the document to tangible safety or operational benefits. Thus, the areas for possible further examination include the following:

Vision Systems Operational Concepts and Use Cases:

1. Enhance Safety of VFR Flight during Low Altitude Operations

This use case draws on several aspects of vision systems technology and supports several regulatory topics. It was also the primary use case cited by nearly all the operators, with some aspects that feature across mission segments and other aspects that are unique to specific mission segments.

a. Visual Surface/Ground Reference – EASA regulation Annex V SPA.HEMS.130 and FAA regulation §135.207 – VFR: Helicopter surface reference requirements both describe the need to maintain visual contact with the visual surface or ground reference for commercial VFR operations, which include HAA. Other regulations reference the need to see the ocean/water for offshore flights. A vision system could be used to enhance safety by allowing the pilot(s) to "see" the visual surface/ground/ocean. The vision system would need to provide visual imagery that clearly delineates the surface/ground/ocean.

b. VFR Required Visibility – FAA regulation §135.205 – VFR: Visibility requirements & §135.609 – VFR ceiling and visibility requirements for Class G airspace and corresponding EASA regulations describe the need to maintain the required flight visibility (in the U.S. ½ sm for uncontrolled airspace (i.e., Class G)). A vision system could be used to allow pilot(s) to maintain VFR visibility minima. In the past, systems such as HTAWS or NVIS (i.e., NVGs) have been used to reduce the VFR weather minima at night, so this could be a potential outcome of this use case. The vision system would need to provide equivalent flight visibility along the flight path.

c. Wires/Obstacles/Obstructions – Several FAA and EASA regulations, as well as countless material in the AIM and other advisory circulars, FAA orders, and other documents, highlight the need for the pilot to avoid obstructions during low altitude flight where helicopters typically spend a majority of their time operating. This is a major safety-of-flight issue as a wire strike or flight into a known obstacle can result in significant damage to the helicopter. While systems such as Helicopter Terrain Awareness and Warning Systems or Enhanced Ground Proximity Warning Systems (HTAWS/EGPWS) can provide some of this information, they do not handle all types of obstacles, especially those that may appear temporarily (i.e., construction cranes) outside of database update cycles, and often don't contain all of the wires, towers, and other obstructions that can cause real issues for helicopters in the low altitude environment. A vision system could be used by pilot(s) to identify and remain clear of these obstacles as well as provide ground clearance to reduce the chance of CFIT encounters. The vision system would need to provide imagery of the obstacle/obstruction/wire/tower/etc. along the flight path.

d. Loss of Control (LOC) – Several FAA and industry safety campaigns have highlighted the importance of recognizing the onset of and preventing loss of control (LOC), as it is the leading cause of fatal accidents in helicopters. A vision system could be used to prevent LOC by providing the pilot(s) with an instantaneous view of the natural horizon, the attitude-airspeed-altitude of the helicopter, unusual attitude recovery symbology, terrain awareness and sensor imagery, Rotor RPM during an autorotation, and pedal position and/or rotor torque during a Loss of Tail Rotor Effectiveness (LTE) or Vortex Ring State (VRS) event. The vision system would need to provide symbology and synthetic, enhanced, or combined vision systems imagery depending on the intended safety mitigation.

e. Unintended Instrument Meteorological Conditions (UIMC) – Just like LOC, several FAA and industry safety campaigns, as well as fact sheets and other safety campaigns, have highlighted the importance of preventing Unintended Instrument Meteorological Conditions (UIMC), as it is the 2^{nd}-leading cause of fatal accidents in helicopters after LOC. A vision system could be used to prevent UIMC by providing the pilot(s) with a view of clouds/fog or other weather phenomena; especially in difficult marginal or low visibility conditions enabling a retreat from UIMC before the condition develops. The vision system would need to provide enhanced or combined vision systems imagery to allow the pilot to maintain cloud and visibility clearances.

f. Night Flight – Flight at night is inherently dangerous for helicopters operating in a low-altitude environment. It is typically harder to see obstacles and obstructions during the night than during daylight hours, and the lack of cultural lighting or the expanse of city lights may both cause issues in locating heliports or landing zones as well as hinder avoidance of obstacles. A vision system could help to illuminate the ground and enable the pilot to identify features in the natural terrain or obstacles in urban and rural environments. The vision system would need to integrate with other technologies (i.e., NVGs) that perform similar functions for operators today.

2. Low Visibility Approaches

a. This use case examines the desire of the operator community to utilize vision systems devices to aid in performing various Standard or Special Instrument Approach Procedures including Helicopter specific variations of these procedures (i.e., PInS, Offshore, etc.). This could include just using the vision system for awareness of obstacles and to assist in locating visual references/cues during the approach to eventually using the system to provide credit to meet existing visibility requirements on the instrument approach procedures using an H-EFVS system rather than natural vision during the visual segment of the approach procedure.

b. Visual Approaches to a Runway, Helipad, or Landing Zone – In cases of marginal visibility or at night, flights may still struggle with low visibility conditions, even during VFR weather. The FAA's AIM defines conditions of high and low lighting and provides examples of determining when one condition or the other might exist, particularly in areas of high or low cultural lighting (i.e., in an urban/city environment or a rural environment, or over water). A vision system could be used during a typical normal visual approach by the pilot(s) to aid in enhancing the visual cues needed when operating to a landing site (i.e., airport, heliport, or landing zone). The vision system would need to provide imagery of the landing location (i.e., runway, heliport, or landing zone) with the basic visual cues to establish a safe trajectory (i.e., lateral cues and vertical cues like the runway or heliport width and/or a vertical guidance system like a VASI/PAPI/HAPI). A secondary requirement of a vision system might be to acquire or cue the pilot(s) to traffic or other hazards (i.e., obstacles) along the final approach path and potentially during other legs of the traffic pattern too.

c. Instrument Approach Procedures to a Runway – FAA regulation §91.175 – Takeoff and landing under IFR & §91.176 – Straight-in landing operations below DA/DH or MDA using an enhanced flight vision system (EFVS) under IFR along with their EASA counterparts describe the visual references required to proceed past the DH/DA or MDA and continue the approach during the visual segment to land at a runway using either natural vision or an EFVS. This is already provided via the regulations currently, although, to the authors' knowledge, no helicopter operators currently utilize this rule in the U.S. to perform low visibility approaches using an EFVS to a runway. However, the current rule utilizes a Heads-Up Display (HUD), which may not be conducive for most helicopter operations vs. a Head-Worn Display (HWD) or Helmet-Mounted Display (HMD) that have traditionally been used on military rotorcraft platforms. These displays might interface better with Night Vision Goggles (NVGs), but it remains to be seen if they would meet the intent of the rule for HUD equivalency.

d. Instrument Approach Procedures to an Onshore Heliport (Point In Space (PInS) Proceed Visually) – The FAA Aeronautical Information Manual (AIM) section 10-1-3. Helicopter Approach Procedures to VFR Heliports describes a PInS Proceed Visual approach. The AIM actually refers to this as "an approach to a specific landing site." However, the rotorcraft community often terms this a PInS approach. Regardless of the terminology used, during this approach, the pilot(s) must acquire the visual references at or before the MAP and proceed visually to the heliport on the visual segment of the instrument approach procedure. A vision system could be used by pilot(s) to identify and maintain visual contact with the visual references identified in the AIM for this specific approach. The vision system would need to provide imagery of the visual references for the given flight trajectory from the MAP to some predetermined point (i.e., 100' above the heliport) prior to landing or all the way to where the pilot(s) would transition to natural vision. A secondary requirement of a vision system on this type of approach would be to provide awareness to the pilot of pertinent obstacles along the flight path to ensure adequate ground and obstruction clearance.

e. Instrument Approach Procedures to an Onshore Heliport (Point in Space Proceed VFR) – The FAA Aeronautical Information Manual (AIM) section 10-1-3. Helicopter Approach Procedures to VFR Heliports describes a PInS Proceed VFR approach. The AIM actually refers to this as "an approach to a Point in Space." Unlike the Proceed Visual Approach, the Proceed VFR may be used when there is a course change of greater than 30° at the FAF, or the landing site (i.e., heliport) is located a distance of more than 2 sm from the MAP. Unlike the Proceed Visual, the pilot(s) do not need to have the visual references in site at or before the MAP. Instead, they transition from the instrument segment of an instrument approach to VFR flight, maintaining VFR weather minima for ceiling and visibility or whatever the highest weather minima provided by their OpSpec or the operating rule provides until reaching the landing site/heliport. A vision system could be used by pilot(s) to identify and maintain the weather minima for the VFR segment of the approach allowing them to meet such regulations such as §135.613 – Approach/departure IFR transitions, which mandate certain weather minima. The vision system would need to provide imagery of the external environment to maintain the prescribed visibility and ceiling prior to landing or all the way to where the pilot(s) would transition to natural vision. A secondary requirement of a vision system on this type of approach would be to provide awareness to the pilot of pertinent obstacles along the flight path to ensure adequate ground and obstruction clearance, as well as to provide imagery of the visual references needed to land at the landing site/heliport.

f. Instrument Approach Procedures to an Offshore Heliport (Delta 30, Parallel, ARA, ARA Cluster, HEDA) – The FAA's Advisory Circular 90-80.C Approval of Offshore Standard Approach Procedures, Airborne Radar Approaches (ARA), and Helicopter En Route Descent Areas (HEDA) describes offshore approaches. Similar to their onshore counterparts, they can best be described as an approach to a Landing Site or Point-In-Space where the pilots either "Proceed Visually" or "Proceed VFR," depending on the type of approach flown. For the offshore approaches in the U.S. Gulf of Mexico, the Delta 30, Parallel Offset, ARA, and ARA Cluster are Proceed Visual approaches, and the HEDA is a Proceed VFR. For the offshore environment, a vision system could be used by the pilot(s) for the same purposes as during the onshore approaches, to maintain VFR weather minima, or to proceed visually on the visual segment of an instrument approach while maintaining visual contact with the specified visual references. The difference, though, for an offshore approach is that the visual references also include the oil rig itself in addition to the helideck (in lieu of the helipad/heliport) and the other visual references listed in the AIM. The vision system would need to provide imagery of the external environment to maintain the prescribed visibility and ceiling prior to landing or all the way to where the pilot(s) would transition to natural vision. It would also need to provide awareness to the pilot of pertinent obstacles along the flight path *(Note: During an ARA Approach, the onboard weather radar is used to identify the rig and to make sure that the approach path is clear. Any obstacle along the approach path within a certain boundary (i.e., like a drill ship) triggers a missed approach/go-around.)*, and in the case of a Proceed Visual approach (Delta 30, Parallel Offset, ARA, ARA Cluster), to ensure adequate ground and obstruction clearance as well as to provide imagery of the visual references for the given flight trajectory from the MAP to some predetermined point (i.e., 100' above the heliport) prior to landing or all the way to the where the pilot(s) would transition to natural vision at the helideck.

3. Low Visibility Departures

a. This use case examines the desire of the operator community to utilize vision systems devices to aid in performing various Departure Procedures, including Helicopter specific variations of these procedures (i.e., COPTER RNAV Departure, etc.). This could include just using the vision system for awareness of obstacles and to assist in locating visual references/cues during the takeoff from a heliport, runway, or landing site to eventually using the system to provide credit to meet existing takeoff visibility requirements on the Standard Instrument Departure Procedure, Obstacle Departure Procedure, or during a COPTER RNAV Departure Procedure using an H-EFVS system rather than natural vision during the visual segment of the takeoff procedure.

b. Normal Visual Takeoff – In cases of marginal visibility or at night, flights may still struggle with low visibility conditions, even during VFR weather. The FAA's AIM defines conditions of high and low lighting and provides examples of determining when one condition or the other might exist, particularly in areas of high or low cultural lighting (i.e., in an urban/city environment or a rural environment, or over water). A vision system could be used during a typical normal visual takeoff by the pilot(s) to aid in enhancing the visual cues needed when operating from a landing site (i.e., airport, heliport, or landing zone). The vision system would need to provide imagery of the takeoff location (i.e., runway, heliport, or landing zone) with the basic visual cues to establish a safe trajectory (i.e., lateral cues and vertical cues like the runway or heliport width). A secondary requirement of a vision system might be to acquire or cue the pilot(s) to traffic or other hazards (i.e., obstacles) along the takeoff flight path and potentially during other legs of the traffic pattern too.

c. GPS Departure Procedure – Similar to a PInS approach procedure and flown as a COPTER RNAV, the GPS Departure Procedure is typically a charted instrument departure procedure from a hospital or offshore heliport. The Departure Procedure is designed to ensure obstacle clearance during departure and may be flown at lower minima than is typically allowed for certain operations (e.g., HAA, VIP, Offshore, etc.). A vision system could be used by pilot(s) to identify and maintain visual contact with the visual references during takeoff and departure until the transition to instrument flight. The vision system would need to provide imagery of the visual references for the given flight trajectory from the takeoff location to some predetermined point (i.e., 100' above the heliport) prior to transitioning to the climb segment, where the pilot(s) would transition to instruments. A secondary requirement of a vision system on this type of approach would be to provide awareness to the pilot of pertinent obstacles along the flight path to ensure adequate ground and obstruction clearance.

d. Standard Instrument Departure (SID) – Just like fixed-wing aircraft, helicopters sometimes will utilize a Standard Instrument Departure (SID) when operating at airports. A SID is a preplanned instrument flight rule (IFR) air traffic control (ATC) departure procedure printed for pilot/controller use in graphic form to provide obstacle clearance and a transition from the terminal area to the appropriate en route structure. SIDs are primarily designed to expedite traffic flow and reduce pilot/controller workload. A vision system could be used by pilot(s) to provide additional awareness of the given route of flight along with highlighting the various obstacles and traffic along the flight path to reduce the risk of ground or airborne collision during the transition from takeoff to departure during a SID.

e. Obstacle Departure Procedure (ODP) – Just like fixed-wing aircraft, helicopters sometimes will utilize an Obstacle Departure Procedure (ODP) when operating at airports. An ODP is a preplanned instrument flight rule (IFR) departure procedure printed for pilot use in textual or graphic form to provide obstruction clearance via the least onerous route from the terminal area to the appropriate enroute structure. ODPs are recommended for obstruction clearance. A vision system could be used by pilot(s) to identify and maintain visual contact with the pertinent obstacles along the flight path to ensure adequate ground and obstruction clearance during the execution of the ODP.

4. VFR/IFR Weather Minima Reduction

a. This final use case examines the desire of the operator community to utilize vision systems devices to aid in performing various Standard or Special Instrument Approach Procedures, including Helicopter specific variations of these procedures (i.e., PInS, Offshore, etc.). This could include just using the vision system for awareness of obstacles and to assist in locating visual references/cues during the approach to eventually using the system to provide credit to meet existing visibility requirements on the instrument approach procedures using an H-EFVS system rather than natural vision during the visual segment of the approach procedure.

b. Alternate Minima Requirements – FAA regulations §91.169, 135.221, 135.223, and corresponding EASA regulations define alternate minima requirements for IFR flight. Alternate weather minima are typically lower for rotorcraft than aircraft. Additionally, the flight time required after performing a missed approach and diverting to the alternate airport is also less, but this is offset by the fact that helicopters typically burn more fuel per hour than aircraft and also carry less total fuel loads, especially when filled with passengers and/or equipment. Several operators have remarked that having a vision system that allows for performing an instrument approach at suitable minima for a procedure could help alleviate or lower the ceiling/visibility minima for the alternate requirement. This would appear in two forms. The first proposal would eliminate or lower the rule for specifying when an alternate would be required if you had a vision system on board the helicopter (i.e., modifying the "1,2,3" rule), while the second proposal would lower the alternate site's actual alternate minima (i.e., 2 miles visibility and 800' ceiling for a site with non-precision approaches or 2 miles visibility and 600' for a site with precision approaches). The operators feel that this would be a big help in remote areas onshore and offshore where there often is barely enough fuel to complete the mission, and if the weather is close to minima, they simply cannot fly. In this case, the vision system would be used as a dispatch tool; knowing a helicopter was equipped with a vision system could lead to relief from or lowering of the IFR alternate requirements.

c. Radar Altimeter Requirements – Several FAA and EASA regulations prescribe visibility limits based on the assumption of a functioning Radar Altimeter. In certain cases, this is further limited based on the assumption of dual-functioning Radar Altimeters. Loss of one or both radar altimeters results in higher minima for the instrument approach. Some operators believe that a vision systems device could serve as the safety risk mitigation for a failed radar altimeter; since, with a functioning vision system, operators could ensure clearance from terrain and obstacles during an instrument approach. For this operation, a vision system would need to provide the pilot(s) with imagery of the terrain and obstacles to ensure adequate obstacle clearance.

As one can see from this overview, there are quite a number of unique use cases/conops for vision systems devices that could serve both to enhance safety and increase operational benefit for rotorcraft. From these conops and the earlier literature, there appear several areas of study based on current gaps in knowledge within the rotorcraft domain. Those areas are listed below for further consideration.

Potential Areas of Study

Visual Cues/References

There is quite a lot of literature on various means of cueing pilots to provide pertinent or ancillary information. However, there is a gap in the literature in terms of what visual cues or references helicopter pilots use during various phases of flight. This includes certain helicopter approaches such as offshore oil rig approaches, onshore approaches to a Point in Space (PInS) proceeding to a heliport, onshore approaches to a landing zone, and even some instrument approaches to a runway. While there has been some work done in these areas, specifically in terms of workload experienced by the pilot or in terms of new technology (i.e., Highway in the Sky), there has not been an exhaustive effort to really understand the visual cues necessary for a particular operation/safety benefit or the effect of losing these cues during critical phases of flight such as low visibility conditions during both routine flight operations as well as emergencies. Examining the required visual cues and how to possibly provide them with several aspects of a vision system (i.e., H-EFVS, HWD, HMD, CVS, etc.) is seen as a foundational task for implementing vision systems technology on helicopters.

Field of View/Regard

While there appears to be a lot of literature on the performance of sensor technologies in various weather conditions, including degraded visual environments, there does not appear to be a lot of literature on the optimal field of view or field of regard for these sensors for a given operation. This is a particular gap for rotorcraft, given the unique nature of their flight operations, which are inherently different from their fixed-wing aircraft counterparts.

We know from past experience and flight testing that the field of view for a helicopter during an approach and landing is larger in both the vertical and lateral directions than for an airplane on a standard straight-in instrument approach. Combine that with the operations to unimproved, obstacle-rich environments, and it becomes clear that the field of view/field of regard for fixed-wing aircraft is insufficient for rotorcraft. At this time, the sensor field of view is seen as the more critical parameter. However, one cannot neglect the display field of view, particularly as we start examining both HWDs and HMDs in addition to traditional HUDs and HDDs.

Pilot Workload/Performance

There has been a lot of literature in the past dedicated to examining how pilot performance and workload vary with different devices and technologies. This information provides a foundation. However, there is still more that can be done. As a follow-on to the cognitive load and physiological study done in the International Journal of Aerospace Psychology on offshore helicopter pilots during emergencies [51], more work could be done to capture the workload and understand the effects on pilot performance using various types of vision systems technologies for rotorcraft. Primarily, a question to study might be something akin to "During critical phases of flight or tasks that are workload intensive or visually taxing, does the vision system provide performance benefits that can be used to enhance safety?"

Other questions that look at reducing the workload of the flight crew might be useful to examine in order to quantify best practices and opportunities for increasing the safety of the device, which align with the goals of Helicopter Safety Enhancement (H-SE) 91 on Vision Systems technology. While some of these questions have been asked before in various experimental studies, the opportunity to reconfirm them as well as to expand into other areas of cognitive workload that have not yet been studied might be a good topic to examine within the realm of vision systems for rotorcraft.

Symbology and Sensor Imagery

The combination of symbology and sensor imagery appears a lot in the literature; as most trials include some type of basic EVS or SVS in addition to symbology in the field of vision systems research (although some studies look only at symbology and exclude EVS, SVS, or CVS). However, rarely do the authors examine specific effects of the combination of symbology and sensor imagery in terms of which element provides useful information to the pilot at any given time. Similar to the visual cues, even though there has been a lot of work performed, there are still quite a few gaps, even with basic symbology as it is presented to the pilot(s). Questions like which flight parameters to show, how to represent the flight parameters (i.e., size/font type, color, shape, etc.), declutter options, and which ones should be removed during various phases of flight come to mind.

The answers to these questions are not well-understood for rotorcraft, although they have been studied significantly for fixed-wing aircraft. Significant variations exist between various HWD/HMD manufacturers, which are not seen as much with HDD displays, although differences do exist for rotorcraft. Similarly, sensor imagery revolves around “What objects can the sensor show?” rather than “How does the sensor imagery interact with the display symbology to provide the pilot with additional information to operate safely?” Thus, the interaction between sensor imagery (i.e., SVS, EVS, CVS) and display symbology to understand how they can complement each other to provide key safety information to the pilot is a key topic that could use more analysis/study.

These areas of potential study represent the amalgamation of all of the areas examined during the review. However, they are not the only possible areas that could be explored. There are plenty of other areas that are not listed here that are rich for further study/exploration depending on the direction of the research and the desires of the user community (i.e., the operators). Rather, these areas represent the topics that the authors believe would yield the highest benefit to safety and increasing knowledge of vision systems as a research area. Thus, they and other areas are worthy of further discussion as we begin to develop a research plan to address the topics of interest.

Summary

This Literature Review examined the elements of vision systems, visual cues, vision, and visibility within the literature available today on past studies of the technology, pilots, and the regulations, policy, and guidance material that exist from two authorities, the FAA and EASA. It included technical reports, concept of operations documents, standards documents, and other material from various industry and trade organizations. Specifically, it examined:

- An overview of vision systems technologies
- Applicable use cases for rotorcraft vision systems from discussions with operators and industry representatives
- Operational concepts/use cases and potential study areas in future research plan(s)

Some of the key findings of the review included the types of operations and their unique visual cues/references that are required during each operation and further during various phases of flight. This is not an area that has been examined to a great extent in the literature, and there is a definite gap between the low-speed/hover of brownout/whiteout for a DVE and the more typical instrument approach procedures to a runway, heliport, or landing zone. Another area that is lacking in definitive research is that of the field of view for sensor imagery. There has been a lot of work done on field of view in regards to Head-Down Displays and some work on Heads-Up Displays, but the authors did not find much material on field of view requirements for visual references in various phases of flight, especially during an approach. This remains a key gap left to explore.

One final note is that while the authors did review several journal papers from the Vertical Flight Society, which documented the work that the U.S. military has done on DVE, that does not appear to be an exhaustive list. During the course of the literature review, the authors made contact with individuals from the U.S. Dept. of Defense and are working to arrange some knowledge transfer meetings. It is envisioned that these sessions might uncover additional material that will help guide the research effort, particularly in regards to sensor performance and cueing as well as low-speed hover flight in DVE. However, it is not expected that these additional papers and topic material will significantly change the course of the direction of the research for the operational concepts listed previously, which appear well-aligned with the needs of the rotorcraft community and offer great potential to enhance safety and operational efficiency for vertical flight operations.

Recommendations

The rotorcraft industry identified the need to enhance visibility during degraded visual environments or during periods of low visibility (i.e., night, IMC, etc.). A review of the fatal helicopter accident dataset indicated that a vast number of accidents occurred during these conditions due to a lack of adequate visual cues.

The objective of this H-SE was not only to determine what vision-enhancing technologies are currently present and what operational concepts they may support (Output #1) but also to educate the community on these technologies, including their benefits and pitfalls to promote the safe use of these technologies (Output #3). To support the community via education in this area, the H-SE Team organized and held several vision systems summits, including one in Jun. 2021 that was attended by over 150 attendees from multiple segments of the helicopter industry. This summit featured expert speakers and a discussion from several operators regarding not only their challenges and successes with vision-enhancing technologies, but their desires for operational concepts and use cases for enhancing safety and deriving operational benefit in the future from this technology on board helicopters.

Responses from this event were compiled, and future events like this are being planned to help guide follow-on research and outreach efforts. Additionally, a literature and product/technology review was performed, which identified several vision-enhancing technologies. Although the results of this review cannot be shared due to the proprietary nature of the sensors/displays, it did help to point out the technologies and help focus the team on developing operational concepts and use cases that are not limited by any one technology, but rather by the regulatory framework of the current U.S. aviation system.

Call-To-Action / H-SE Overall Recommendations

In closing, the H-SE 91 Team would like to propose the following recommendations to be championed by the USHST, VAST, and other interested parties to advance the state of the art of helicopter-enhanced vision systems:

1. Continue the development, testing, and exploration of vision systems technologies by periodically updating the literature and product technology reviews as new technologies gain acceptance in the market.

2. Proceed with additional flight and simulator studies of pilot performance and human factors aspects of vision systems technologies (sensors and displays).

3. Develop policy and operational changes to allow for the use of vision-enhancing technologies (Update FAA Order 8260.42B Advisory Circulars 90-80B, 90-106A, and FSIMS 8900.1). Review 14 C.F.R. §91.175/176 and decide whether a regulatory revision through rulemaking would be necessary.

4. Communicate with vision systems device manufacturers, operators, OEMs, and other community stakeholders regarding the need for, promotion of, and the accepted use cases/operational concepts for vision systems technologies to encourage their adoption into the global helicopter fleet.

The H-SE 91 Team believes that by adopting these recommendations, the USHST will have a positive impact on safety for the vertical flight community by advancing state of the art in vision systems technologies to advance safety and operational efficiency for the vertical flight community.

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