APPLICATIONS OF AI-ENHANCED LOW-VISIBILITY VISION SYSTEMS TO ROTORCRAFT MISSIONS

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Abstract

In fixed-wing aviation, vision systems enable operations below standard landing minima by providing "equivalent visual cues," with well-established operational benefits. Rotorcraft have not yet leveraged such capabilities, primarily due to their unpredictable and diverse mission profiles, which contrast with structured runway-based operations.

Today, the convergence of advanced sensing technologies, high-performance displays, and AI-driven algorithms offers new opportunities to enhance rotorcraft safety and operability in degraded visual environments (DVE) beyond the existing Instrument Flight Rules (IFR) and Performance-based Navigation (PBN). Emerging systems can provide 360° situational awareness, assist pilots in high workload conditions, and detect obstacles, including wires, with unprecedented reliability.

This paper explores the architecture and functionality of such systems, proposes operational concepts tailored to rotorcraft use cases, and outlines pathways for certification. The integration of these technologies promises to reduce weather-related mission cancellations, mitigate CFIT risk, and support safer, more capable all-weather operations across multiple rotorcraft domains.

1. NOTATION

Acronyms:

AI	Artificial Intelligence
AFCS	Automatic Flight Control Systems
CAT	Category / Commercial Air Transport
CFIT	Controlled Flight Into Terrain
CICTT	CAST/ICAO Common Taxonomy Team
ConOps	Concept of Operations
CS-AWO	Certification Specification All Weather Operations
CTOL	Conventional Take-Off and Landing
DVE	Degraded Visual Environments
EFVS	Enhanced Flight Vision System
ERF	European Rotorcraft Forum
ETCO	European Technical Standard Order
EVS	Enhanced Vision System
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System

HEMS	Helicopter Emergency Medical Services
HF/HP	Human Factors and Human Performance
HUD	Head-Up Display
HWD	Head-Worn Display
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
LWIR	Long-Wave Infrared
MAC	Mid-Air Collision
ML	Machine Learning
MFD	Multi-Function Display
MVFR	Marginal Visual Flight Rules
NAVAID	Navigation Aid
NCO	Non-Commercial Operations
NM	Nautical Mile
PBN	Performance Based Navigation
PinS	Point-in-Space
RNP	Required Navigation Performance
SAR	Search and Rescue
SAS	Stability Augmentation System
SBAS	Satellite-Based Augmentation System
SPO	Special Operations
SWIR	Short-Wave Infrared
TCO	Technical Standard Order
VFR	Visual Flight Rules
VFS	Vertical Flight Society

2. INTRODUCTION: CURRENT LIMITATIONS OF ROTORCRAFT OPERATIONS

Helicopters are vital to missions that demand flexibility, precision, and access to areas unreachable by fixed-wing aircraft, such as emergency medical services, search and rescue, offshore transport, and disaster response. Yet, their full potential is often hindered by one critical limitation: reduced capability in low-visibility conditions. Rotorcraft frequently operate in highly complex environments without the benefit of ground-based instrument approaches or communications coverage. Current solutions like IFR operations are heavily constrained by infrastructure, regulatory burden, and aircraft limitations.

Vision systems today regularly enable “equivalent visual” operations in lower than standard minima at runways around the world, providing tangible operational benefits to equipped platforms.
Rotorcraft do not yet benefit from such systems, likely because the operational benefit of these novel systems has yet to be proven to operators. Until operators can see that the technical systems have been tested to show technical efficacy and operational value, they remain undeveloped: regulators like EASA require applications for these systems before creating certification standards, while manufacturers await clear commercial demand and regulatory operational clarity before investing.

Artificial intelligence is currently making its way into the aerospace and aviation world as a powerful tool to enable increased levels of automation–from pilot assistance to remotely/optionally-piloted to fully automated and autonomous operations. Early use cases of AI demonstrate capabilities previously reserved for humans, such as identifying noncooperative air traffic and detecting wires.

While enhanced vision systems can provide equivalent vision, giving pilots “eyes” where they otherwise would be blind, computer vision and machine learning applied to Enhanced Vision Systems (EVS) could close the safety and capability gap in rotorcraft low-visibility flight.

3. PROBLEM STATEMENT

3.1. Safety Implication in Civil Perspective: Low Visibility as a Persistent Threat to Rotorcraft

While overall helicopter safety has improved significantly (2023 marks the safest year in the past decade, according to **Ref. 1)**, low-visibility operations remain a critical vulnerability. Although low visibility resulting from night, fog, cloud cover, or adverse weather is not classified as a standalone category within the CAST/ICAO Common Taxonomy Team (CICTT) framework, it severely degrades pilots' external visual references. This degradation impacts the following CICTT categories: **Controlled Flight Into Terrain (CFIT), Mid-Air Collisions (MAC), Low-Altitude Operations (LALT), and pilot disorientation due to human performance factors (HF/HP).**

3.1.1. Controlled Flight Into Terrain (CFIT)

CFIT is the second leading cause of accidents in Commercial Air Transport (CAT)—particularly relevant to HEMS operations, which face increased exposure during night flights or in degraded visual environments. In Specialised Operations (SPO), CFIT occurs but is not the dominant contributor to accidents, despite operational pressures that often involve flying close to terrain. In Non-Commercial Operations (NCO), CFIT plays a significant role in fatal accidents, frequently linked to VFR flights inadvertently entering IMC, underlining its hazardous nature even if it is not the primary cause (Source—EASA in **Ref. 2**).

3.1.2. Mid-Air Collisions (MAC)

MAC are an increasing safety concern in helicopter operations given rising airspace congestion. Between 2018 and 2023, according to **Ref. 3**, several helicopters were involved in MACs or serious near-misses, including three fatal mid-air collisions, often in busy controlled airspace. In NCO operations, MACs rank as the fifth most common occurrence (**Ref. 2**). Low visibility significantly elevates MAC risk by impairing visual traffic avoidance in the growing presence of drones as well as other airspace users.

3.1.3. Low-Altitude Operations (LALT)

LALT are a leading cause of helicopter accidents in Europe, particularly for SPO and NCO. Helicopter operations classified under LALT frequently expose crews to obstacles—such as wires, towers, and cables—well outside the structured environments of takeoff and landing zones. EPAS (**Ref. 4**) cites obstacle collision in flight, defined as "collision between an airborne aircraft and obstacles raising from the surface of the earth," among the 10 key risk areas.

According to NTSB accident data (**Ref. 5**), wire strikes were responsible for 214 accidents on helicopters, leading to 124 fatalities between 1994–2018 within the US alone. In 2010, the FAA estimated that there are 76 collisions with power lines per year on average (across all low-altitude aviation) and that 30% of them resulted in fatalities (**Ref. 6**). Most fatal strikes took place in daytime VMC, showing that good weather and visibility do not lessen this hazard.

FAA and NTSB (**Ref. 5)** identify "inconspicuousness of power lines," "low angle of the Sun," and "darkness and lack of visual cues" as main factors to wire strikes. Power lines can be very difficult to see even in broad daylight, and at significant distances they remain difficult to detect even with high-resolution imaging systems.

There are systems that rely on a database of known obstacles, such as FLARM. However, these systems have limitations (**Ref. 7**, Section 2): obstacles may not be in the database (as existing obstacle databases may be updated infrequently, lack ground validation, or rely on incomplete source data), and if the GPS onboard is spoofed or jammed, the data from the database becomes useless.

3.1.4. Human Factors and Spatial Disorientation (HF/HP)

Spatial disorientation and rapid loss of situational awareness become much more likely when visual cues are degraded. From 2018 to 2022, human factors contributed to nearly one in four helicopter accidents and serious incidents (**Ref. 8**). Of 1,213 events coded with HF/HP factors, 442 involved loss of situational awareness (Appendix 3 of **Ref. 2**, "Advanced Statistics for Helicopters"), confirming that even well-trained crews are vulnerable when flying without external visual reference.

3.1.5. Wildlife Strikes

Bird strikes are a persistent and serious threat to aviation safety, as evidenced by the high and rising volume of reported incidents worldwide. Between 2016 and 2021 alone, over 273,000 wildlife strikes were reported to ICAO (**Ref. 9**) by 136 member states, a sharp increase from previous reporting periods. While some increase in reports is due to improved data collection, the absolute numbers show that bird strikes remain a significant operational hazard. The consequences can be dire: severe power loss during critical flight phases or loss of aircraft control. In the U.S. alone, these strikes cause more than $900 million in annual damage to civil and military aircraft (**Ref. 10**).

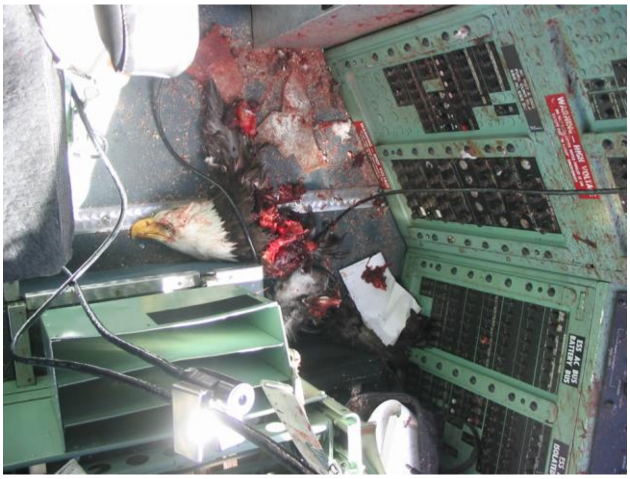

Fig. 1. Example of a cockpit of a military aircraft after a bird strike. Credits: SKYbrary / (EUROCONTROL/ICAO)

3.2. Safety Implication in Military Perspective: DVE As a Critical Operational Hazard

Military helicopter crews routinely operate in DVE conditions where visibility is compromised by dust, smoke, haze, snow, or darkness. U.S. Army data (**Ref. 11)** show that between 2002 and 2012, 87 DVE-related helicopter accidents resulted in 108 fatalities and nearly $900 million in damages. Further analysis **(Ref. 12)** indicated that nearly 25% of Army helicopter crashes involved loss of situational awareness or disorientation. In **Ref. 13**, the U.S. Helicopter Safety Team attributed 130 fatal accidents between 2000 and 2019 to spatial disorientation, many DVE-related. Whether in combat, rescue, or training contexts, DVE remains a major operational and safety challenge for military helicopter missions.

3.3. Additional Implications: Mission Cancellations

"In bad weather conditions, people cannot get rescued." — Rega (Swiss Air Rescue)

The inability to operate in low-visibility conditions forces emergency services to either cancel missions entirely or delay response until conditions improve.

In various cases, the percentage of weather-related cancellations ranges from 5% to 30%, depending on the geographical area. In Switzerland, according to Rega officials (**Ref. 14**), over 12,000 patients were cared for in 2021, but bad weather still remains the biggest obstacle for its operations, “preventing some 600 patients from being treated every year.” A 2017 study of the Finnish northernmost HEMS unit (**Ref. 15**) showed that 391 missions (20%) out of 1,940 total missions could not be operated by helicopter because of poor weather conditions. Swedish HEMS data (**Ref. 16**) indicates that during the 12-month period the HEMS attendance was requested on 1,607 occasions, and in 13.2% of EMCC requests, poor weather was registered as the primary reason for cancellation. “Weather cancellations displayed great seasonal variation. In July 2016, only 4.6% of missions were cancelled due to weather. Weather then deteriorated in the autumn months. In November, 26% of requests were cancelled due to weather after which conditions gradually improved.”

This operational limitation is particularly problematic given that emergencies often occur during adverse weather conditions when helicopter assistance is most needed but least available.

3.4. Additional Implications: Lost Profits

Relevant for commercial helicopter operations, including industrial use of helicopters, e.g., offshore or inspections. The costs in this category include direct revenue losses from cancelled flights, opportunity costs of idle aircraft and crew, reduced operational efficiency and asset utilization, crew change delays and accommodation costs, and supply chain disruptions. 74.26% of air traffic delays, according to **Ref. 17**, of more than 15 minutes in the US National Airspace System are weather-related.

Analysis of financial statements from a major North Sea helicopter operator (**Ref. 18**) shows the economic impact of weather-related flight cancellations on their offshore operations. In the statements, the company explicitly acknowledges (Ibid., page 8) that harsh weather conditions and reduced daylight hours during fall and winter months significantly limit their operations, with weather grounding helicopters 60 days a year (a conservative estimate for the North Sea). This operational disruption creates a cascade of financial implications.

Standstill costs: With total operating expenses of $1.042 billion supporting a fleet of 192 helicopters (Ibid**.,** page 9) (including 86 heavy helicopters such as S92 and AW189), the daily operating cost per helicopter averages approximately $15,000 (if it flies normally). Europe represents about 30% of their total flight hours, so we assume that roughly 30% of their fleet (55-60 helicopters) might be allocated to North Sea operations. During weather standstills, when revenue generation ceases, substantial costs remain: personnel expenses ($340.6 million annually) continue at roughly 50%, as crews must remain on standby; insurance costs ($24.9 million) and leased equipment expenses ($103.5 million) continue at 100%; and maintenance activities ($273.3 million annually–Ibid., page 65) proceed at (again, our assumption) 40% to ensure fleet readiness. This results in estimated standstill costs of **$8,000-10,000** per helicopter per day, or **$30-35 million** for the North Sea fleet for the assumed 60 days of weather-related groundings annually.

Lost revenue opportunity: The 10-K filing indicates that their European offshore operations, primarily focused on the North Sea, generated $427 million in revenue from 38,284 flight hours in 2024 (Ibid**.,** page 44), which means approximately $11,000 per flight hour, or 7.76 million of annual revenue per aircraft. When combined with the standstill costs, **the cumulative impact of weather-related disruptions can amount to $50-75 million annual cost** for this single operator. It extends to the oil production itself: a single day of weather-related groundings can affect thousands of workers across 184 rigs, resulting in lost oil production that represents millions of dollars in daily revenue for operators like Shell and BP.

4. CRITICAL USE CASES

4.1. HEMS & SAR

The operational demands of certain helicopter missions require compromising mission requirements and mission success, in order to maintain the maximum safety standards, particularly in critical services such as Helicopter Emergency Medical Services (HEMS). These missions frequently involve flying at low altitudes over challenging terrain to reach patients in remote or inaccessible areas, where the margin for error is minimal and recovery options are limited. In some countries and specific critical situations HEMS operations are conducted with reduced safety margins: low visibility operational aids such as vision systems deployed to improve these margins would be welcomed by the community.

Ecosystem and Scale: The global HEMS industry operates over 2,000 helicopters worldwide, with the US alone fielding more than 1,000 aircraft serving 400,000 patients annually (**Ref. 19**). This represents a substantial operational footprint where low visibility challenges affect a significant volume of critical missions. The market is concentrated around medium-class multi-engine platforms.

Mission Profile: Unlike fixed-wing aircraft, which operate between prepared airports, HEMS missions require off-site landings in uncontrolled environments—such as freeway crash sites, mountainous terrain, deserts, and volcanoes—where pilots must navigate wire hazards, confined spaces, whiteout and brownout landings, and variable surface conditions under DVE, often with minimal advance preparation. Most helicopter EMS operators are not instrument-qualified due to the high cost of training and the ongoing requirements for certification maintenance. This limitation forces operations to be conducted under Visual Flight Rules (VFR). A particularly dangerous scenario is “scud running”—flying beneath cloud layers at low altitudes to maintain visual contact with the terrain. These operations frequently take place in Marginal VFR (MVFR) conditions, defined as a 1,000-foot ceiling and 3-mile visibility.

Economic Pressure: 50% of the global HEMS fleet is operated in the US, and over half of US HEMS programs are private-equity owned (**Ref. 20**). Economic factors can lead to operators’ management pushing pilots to complete missions even in less than ideal weather conditions, which compromises safety.

Accidents Stats: HEMS operations face significantly elevated accident rates compared to other aviation sectors. Studies (**Ref. 21)** comparing international HEMS systems show crash rates per 10,000 missions ranging between 0.4 and 3.05, with fatal crash rates between 0.04 and 2.12.

Analysis of US helicopter air ambulance accidents from 2010-2021 in **Ref. 22** reveals a decrease in the proportion of fatal accidents, from 45% (21/47) in 2010-2015 to 17% (6/36) in 2016-2021. Weather-related accidents account for 19% of all HEMS incidents, with 56% of weather-related accidents proving fatal. Contributing factors include marginal weather conditions, nighttime operations with reduced illumination, poor visual references, and

Inadvertent Instrument Meteorological Conditions (IIMC) encounters leading to spatial disorientation and loss of control.

During nighttime operations, 49% of accidents occur during scene-based patient missions, highlighting the particular challenges of low-visibility operations in uncontrolled environments.

4.2. Offshore Operations

Ecosystem and Scale: The offshore sector operates 1,417 helicopters globally (**Ref. 23**) with estimated $7B annual revenues, representing a substantial market where weather-related operational limitations directly impact profitability.

Mission Profile: The North Sea (184 rigs) and Gulf of Mexico (175 rigs) represent the highest operational density in regions known for challenging weather conditions. Offshore oil and gas platforms operate continuously, requiring helicopter services that span both routine and emergency operations around the clock. Offshore operations combine crew transport, search and rescue, and medevac functions using the same aircraft, often requiring rapid mission transitions. The remote maritime environment means that helicopters serve as the primary lifeline for offshore workers; when medical emergencies occur on platforms 100+ miles from shore, helicopter transport is the only viable option for reaching timely medical care.

Economic Pressure: Offshore operations can defer non-critical missions during poor weather, but that creates substantial opportunity costs from both standstill expenses and lost revenue. See the section 1.4 above for the detailed analysis.

The industry is also economically vulnerable which was demonstrated during the 2014-2015 oil price collapse when major operators including CHC, PHI, and Bristow filed for bankruptcy between 2016 and 2019 (**Ref. 24**).

Accidents Stats: Oil rig workers in the U.S. are seven times likelier to die on the job compared to all other U.S. workers, per **Ref. 25** (27.1 versus 3.8 deaths per 100,000 workers during 2003-2010), and more than half of offshore workers' deaths were due to transportation incidents.

For the 2014-2018 period, the offshore helicopter industry recorded an overall accident rate of 7.8 per million flight hours and a fatal accident rate of 3.8 per million flight hours (**Ref. 26**).

According to safety data from 2013-2018, CFIT accounted for 32% of fatal accidents in offshore helicopter operations. Compared to HEMS, offshore operations face the added challenge of operating over water, where depth perception and horizon references can be severely compromised under DVE.

5. EXISTING SOLUTIONS

5.1. Instrument Flight Rules

IFR for helicopters enables safe flight in low visibility conditions by relying on instruments rather than visual cues. Under IFR, pilots follow procedures governed by air traffic control with preplanned routes and standardized approach procedures in order to maintain separation from (cooperative) air traffic and terrain. In order to operate under IFR, helicopters must be equipped with the basic six pack instruments, navigation instruments, and stabilization and/or automatic flight control systems (AFCSs), for instance, Stability Augmentation Systems (SASs), autopilots, and flight director systems.

By enabling pilots to maintain precise navigation through clouds, fog, and low light conditions, IFR can significantly enhance safety of operations and expand operational availability. Still, IFR has limitations, particularly in low-altitude operations, mountainous terrain, and night operations. IFR is highly dependent on ground-based or satellite navigation infrastructure that supports controlled airspace coordination. Therefore, IFR may not be available in remote and mountainous areas with uneven terrain, as these may not have sufficient coverage to support safe operations. Hence, operational safety can be highly improved when IFR is complemented by advanced technologies like enhanced vision systems or synthetic vision.

5.2. Performance-Based Navigation (PBN) and RNP 0.3

Performance-Based Navigation (PBN) is an advanced navigation framework that enables aircraft and helicopters to fly precisely defined trajectories using satellite-based and onboard systems rather than traditional ground beacons.

Unlike conventional **routes** tied to radio beacons, PBN is based on **area** navigation. This capability is especially crucial for rotorcraft, which often operate to off-airport sites where ground-based navigation aids (NAVAID) are absent. In countries like Canada, according to **Ref. 27,** "point-in-space" (PBN - PinS) VFR-GNSS approaches have essentially replaced older helicopter procedures, demonstrating how instrument routes can be created to virtually any location.

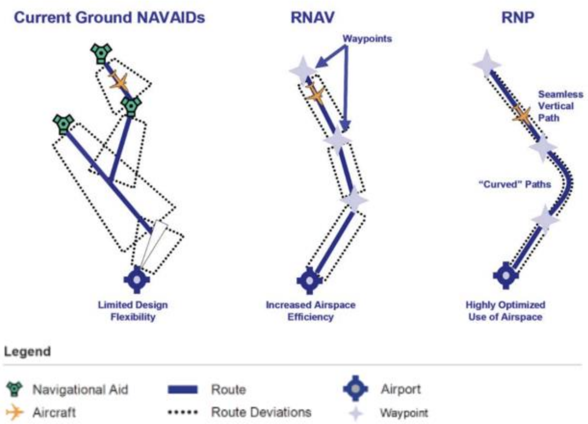

Fig. 2. Navigational Comparison: Conventional/RNAV/RNP. Source: Federal Aviation Administration

A cornerstone of rotorcraft PBN is the **Required Navigation Performance 0.3** (RNP 0.3) specification. This performance standard requires the aircraft's navigation system to maintain lateral accuracy within ±0.3 NM for 95% of flight time. The helicopter's Flight Management System (FMS), typically augmented by SBAS-capable GPS receivers meeting TSO/ETSO-C145/146 standards, constantly monitors position and alerts the crew if accuracy degrades beyond 0.3 NM.

Standard en-route airways allow far more precise flight tracks through challenging terrain or airspace. This strict containment *theoretically* enables helicopters to safely navigate dense, obstacle-rich environments without drifting off course.

However, strict adherence to precise navigation channels does not guarantee those channels are free of obstacles, especially airborne intruders in dense operational environments such as large-area firefighting events or mass casualty/evacuation situations. PBN also relies on GNSS and is therefore vulnerable to degradation if GNSS is compromised–a significant issue due to increasing rates of jamming and spoofing. PBN assures the aircraft's own position, not the uncontested nature of that position. This is why real-time **vision systems** are a critical augmentation method for PBN operations.

6. PROPOSED SOLUTION: AN AI-ENHANCED LOW-VISIBILITY VISION SYSTEM

To solve the problem of low-visibility operations, we need three major components to the system: one, knowing where you are (PBN-enabled positioning), two, seeing your environment (vision systems), and three, actionable processing of the vision system output for pilot or machine consumption.

While PBN is a key navigation component in common use today, it has limitations in low visibility and obstacle-rich environments. PBN-enabled positioning only solves the problem of knowing where one is, not complete environmental awareness, which in VFR operations typically comes from attentive pilots carefully scanning the outside world. Vision systems augment or replace pilots' natural vision using real-time sensing methods that operate in alternate electromagnetic spectrum bands, providing improved penetration of atmospheric obscurants.

Vision systems provide the fundamental sensing capability to "see" through low visibility conditions. The imagery can be delivered to pilots in real time through appropriate displays: transparent Head-Up Displays (HUDs), Head-Worn Displays (HWDs) and Head-Down Displays (HDD), in a stand-alone solution or integrated presentation within primary displays. Pilots then interpret the imagery and act upon it.

An additional refinement consists of algorithms that process the signal stream from the vision systems and provide higher-level functions to the operation through automated analysis of the imagery. This can be deployed as a pilot aid, either "silently" as a background monitor providing notifications during non-normal situations, or explicitly by highlighting deviations from planned flight paths or unexpected obstacles.

6.1. Enhanced Vision Systems

While enhanced vision systems have been deployed in fixed-wing aviation for decades, their adoption in rotorcraft has been limited.

Modern vision systems are based on multi-spectral imaging channels, each targeting specific environmental characteristics. For approach and landing applications in the fixed-wing world, these systems provide total visual awareness in night-VFR and very low visibility conditions caused by airborne water content (snow, fog, rain) and other obscurants (smoke, smog and battlefield particulates).

Fig. 3. Example of low-visibility “equivalent visual” operation from an enhanced vision system such as those proposed in this paper. Left: out-the-window (unaided) view. Right: same view, through an enhanced-vision system (video can be seen in Ref. 28). Credits: Collins Aerospace.

These systems integrate various combinations of short-wave infrared (SWIR), long-wave infrared (LWIR), and visible spectrum high-resolution cameras to create a fused display that enables passive terrain and obstacle detection without active illumination. This sensor fusion ensures that each sensing channel detects and delivers critical features of the surrounding environment, providing consistent imaging through fog, precipitation, smoke, and darkness. The technology enables improved ground definition, earlier landing zone identification, and passive detection of dynamic objects including vehicles and wildlife.

Fig. 4. “Exploded” view of a modern enhanced vision system showing the three independent multispectral channels that are fused into a single real time image for the cockpit crew. Credits: Collins Aerospace.

Studies and operational experience over the deployed lifetime of these devices show measurable improvements in key performance areas: reduced approach and landing incidents, decreased maintenance costs from hard landings, and lower mission cancellation rates. For emergency medical services, search and rescue, and firefighting operations, these systems extend operational windows by reducing weather-related limitations.

The technology's primary benefit is lowering operational minima, where degraded visual environments directly impact mission success and safety outcomes. By providing visual references independently of lighting and obscuration conditions, these systems address a fundamental constraint on helicopter operations in challenging environments.

For fixed-wing operations, multispectral vision systems are certified for operations at lower than standard minima on almost every commercial air transport category aircraft and business jet. US Federal Regulations (14 CFR Part 91.176) and EASA regulations (CS-AWO) describe and permit "visual equivalent" manually flown operations for approach and landing at Type I equipped airfields in conditions bordering CAT III. No additional ground-based equipment beyond a relatively widespread Type I ILS (or equivalent) and no additional aircraft equipment beyond the Enhanced Flight Vision System (EFVS) itself (including the regulatorily required transparent display) are necessary for the operation: little investment for considerable operational value.

While some simple cameras are mounted on a few helicopters today, providing no operational benefit whatsoever, rotorcraft have yet to adopt Enhanced

Vision Systems that deliver tangible operational credit and safety benefits.

There are a number of likely reasons for this shortcoming (in which each reason feeds into the next):

- lack of operator awareness
- lack of demand
- lack of regulatory operational guidance and diversion of regulatory focus to other more urgent topics

In a Catch-22 vicious circle, development investment also lags operational needs. A rotorcraft vision system would fundamentally consist of the same technology base and regulatory and certification precedent as today's certified fixed-wing systems but with some important modifications to meet the flight and mission profile of rotorcraft platforms. Among these, the geometry and dynamics of rotorcraft operations would probably require a much larger field of view than fixed-wing platforms (that generally fly in alignment with the aircraft axis).

Additionally, while the mission, environment and conditions of a fixed-wing EFVS are well described in approach and landing regulations, rotorcraft regulations are far less prescriptive, and the missions that would benefit from enhanced vision are far more varied. Each mission would have to be developed, tested, and formally certified as a separate intended function.

Some of the key intended functions include: safe departures and landings in degraded environments from a variety of sites such as helipads, airports, offshore platforms, and unprepared locations; navigation close to the terrain (nap-of-the-earth); operation in GNSS-denied or degraded environments; support for Category A performance requirements; as well as enhanced situational awareness capabilities like obstacle detection (including wires and terrain) and traffic detection to mitigate collision risks.

The diverse missions flown by rotorcraft significantly increase pilot workload, especially when visibility falls below minimums. To maintain safety, crews need vision aids and real-time, actionable analysis of visual data. This can be achieved through traditional computer vision techniques or emerging AI-based approaches known as "Situational Intelligence."

6.2. AI-Assured Situational Intelligence

Establishing trust in AI systems requires ensuring predictable operation, adequate performance, intended functionality, and absence of unintended behaviors. Unlike with generative AI, formal methods and development processes exist for machine learning applications. These methods focus on proving that neural networks can generalize models developed during training to real-world environments while maintaining laboratory-demonstrated performance levels under real-world uncertainty. This requires ensuring and formally demonstrating that learning datasets are sufficiently large, diverse, and unbiased; that testing and training datasets remain independent; and that models remain static post-training to ensure reliable, predictable behavior. These processes and methods are currently being developed for civil aviation certification, though the applicability of this approach is much broader and can be applied to any mission-critical or safety-critical ML application in any field.

6.2.1. Overview of the Current State of Certification of AI/ML for Civil Aviation

6.2.1.1. Drawbacks of AI Assistance

As Durak notes in **Ref. 29,** “Certifying AI-enabled systems is the critical step forward. We need to ensure these AI systems are safe, reliable, and compliant with regulatory requirements. This is not solely a technical challenge—it's a challenge for industry, academia, and regulators working together.” Current FAA and EASA policies still treat most machine-learning components as novel technologies that must prove equivalence with DO-178C/ED-12C-style determinism. The core challenge lies with demonstrating–as is the case for all novel technology– that the system meets safety requirements and will not exhibit dangerous unexpected behaviors under all operating conditions. In practice this means:

Safety-level limits: Both authorities restrict supervised-learning functions to Design Assurance Level C (or lower) until more operational evidence is gathered.

Learning assurance overhead: Every neural-network version must be tied to a frozen training data set, documented model lineage and quantified generalisation bounds (requiring what regulators call the "W-shape" lifecycle).

Explainability & Human trust: Regulators now expect developers to supply both developer-level trace artefacts and pilot-level cues (heat-maps, confidence bands, clear failure annunciations) so crews can understand and override the AI when necessary. Failure to deliver intuitive explanations risks pilot disuse or, worse, over-trust in edge cases the model was never trained for.

Probabilistic performance & Data bias: ML outputs are statistical, so rare weather/light-scatter combinations or wire geometries absent from the training corpus can produce silent mis-detections. Mitigations may add cost, weight and integration complexity.

Divergent regulatory pathways: The FAA's bottom-up Issue-Paper approach (**Ref. 30**) and EASA's top-down "AI Levels" roadmap (**Ref. 31**) today impose different documentation styles and evidence packages. While the EASA is partnering with the SAE to draft the ARP6983/ED-324, the FAA has stated that they will only begin standards development after multiple applications are approved. Multiregional operators may therefore face duplicated effort until the harmonised standards are formally recognised.

In short, AI assistance is certifiable today for advisory and workload-reduction roles, and the increasing levels of automation will facilitate further maturity of the standards. One of the FAA's principles in **Ref. 30** for the safety assurance of AI is "starting with lower-risk applications to gain experience and inform broader applications and safety methods." Currently, the first applications are proceeding through the certification process with the FAA and EASA, which could significantly move the industry toward the full convergence between the regulators and broad adoption of ML for safety-critical and mission-critical use.

6.2.1.2. Learning Assurance

ML model parameters are derived from data rather than being hand-coded, and the guidance for the traceability of software or complex hardware cannot be extended to an AI system. The FAA in **Ref. 30** identifies the fundamental issue: "The unique characteristic of AI is that the implementation is learned, rather than designed". Therefore, the primary ML-driven functions cannot undergo traditional verification and validation processes, and the DO-178C does not apply.

To address this challenge, EASA developed an approach centered on "Learning Assurance." In **Ref. 31**, EASA defines this as "all of those planned and systematic actions used to substantiate, at an adequate level of confidence, that errors in a data-driven learning process have been identified and corrected such that the AI/ML constituent satisfies the applicable requirements at a specified level of performance, and provides sufficient generalisation and robustness capabilities."

This approach builds on the W-shaped process introduced in EASA's guidance and two foundational research reports — **Ref. 32, 33**. The process ensures ML-based software adheres to safety standards by decomposing system-level requirements into the ones related to the dataset and the learning algorithm, using Statistical Learning Theory to provide assurance on the system's behavior within the operational domain.

Further methods and tools, followed by their preliminary testing on simple use cases, and subsequently, the validation of those primary results on complex, real-world aviation use cases, were presented at **Ref. 34**. However, challenges remain, particularly regarding standardization. The report notes that "the literature on stability and robustness is not entirely homogeneous across standards or the state of the art," highlighting ongoing work needed to harmonize concepts across different regulatory frameworks.The convergence between them explains why AI-assured applications in aviation are only now beginning to appear. Until recently, the industry lacked both a theoretical foundation for certifying learned systems and practical methodologies for demonstrating their safety**.**

6.2.2. AI Use Cases

6.2.2.1. Traffic Detection

Modern AI systems can act as another pair of eyes in the cockpit, continuously scanning the environment and tracking potential hazards with greater performance than human vision alone. These systems can detect and categorize both cooperative and non-cooperative threats, including bird flocks, balloons, paragliders, gliders, and drones that do not appear on traditional radar or transponder systems.

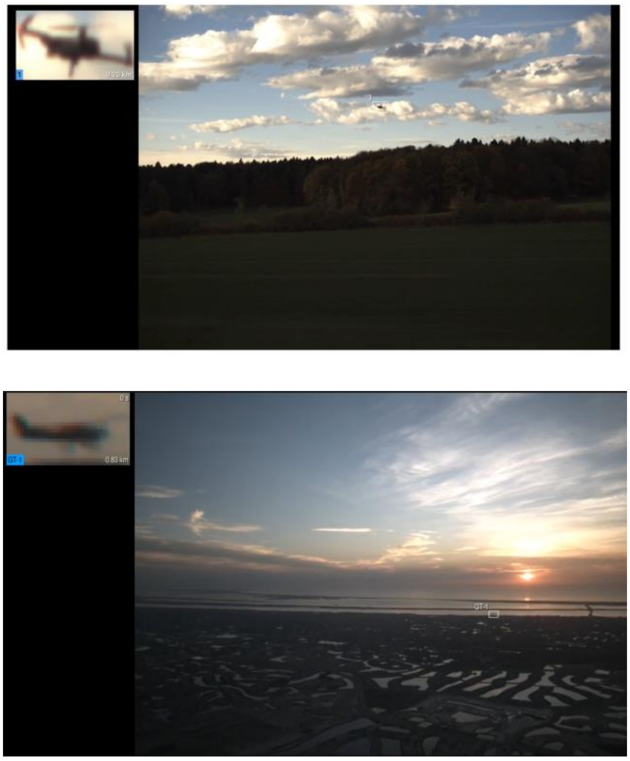

Fig. 5-6. Example of an AI-based visual traffic detection system such as those proposed in this paper, detecting both a non-cooperative and cooperative threat: a drone (3) and aircraft (4), video can be seen here: Ref. 35. Credits: Daedalean

Current models have shown success at detecting non-cooperative traffic such as birds, even when they have not been trained specifically for this intruder.

Fig. 7. Example of an AI-based visual traffic detection system, detecting birds. Credits: Daedalean

6.2.2.2. Obstacle Detection

AI-assisted detect and avoid (DAA) capabilities provide continuous monitoring of both airborne and ground-based threats, processing visual, radar, and sensor data to identify obstacles that might be invisible to pilots in degraded visual environments. This includes critical infrastructure like power lines, towers, and unmarked obstacles that pose significant risks during low-altitude operations.

Offshore operations at large oil rig superstructures are often dense, conducted in challenging meteorological conditions, and require awareness of moving ground obstacles (cranes, etc.) and marine surface obstacles (pilot boats, masts, etc.) for safe completion—all of which can be mitigated by vision systems.

In **Ref. 36,** Section 3, authors compare the existing prevention instruments. The broadly used electromagnetic-based systems can detect active power lines as far as 1.5 km, but critically "cannot detect non-active power lines" and "cannot detect other types of wires," meaning the wire types which do not emit electromagnetic signatures. Another option is LIDAR (laser scanning) devices that can detect wires regardless of their electrical status, but their detection ranges are more limited: 300-620 meters (in good visibility), and they are weight prohibitive for lightweight aircraft. At typical low-altitude flight speeds, pilots would have only seconds between initial detection and potential collision to recognize the hazard and attempt to avoid it.

Recent advances enable the use of video-based deep convolutional neural networks to automatically identify power lines, cables, and transmission towers from aircraft-mounted cameras. According to **Ref. 37**, these neural networks are first pre-trained on large image datasets and then fine-tuned specifically for wire detection tasks, allowing them to learn the visual patterns and characteristics of barely visible cables against various backgrounds and estimate their distance.

Such systems can simultaneously detect both energized and de-energized wires, guy wires, static wires, and transmission towers (regardless of their electrical status). They also estimate time to cables and alert the pilot during critical phases of flight through various interfaces including head-mounted displays, Multi-Function Displays (MFDs), tablets, or cockpit audible alert systems. Their detection and warning distances are longer than those of LIDAR (2 km for detection, 1 km for threat classification and warning the pilot). This extended range provides pilots with crucial additional reaction time, preventing potential accidents.

Fig. 8-9. Visualisation (a prototype interface) of a visual wire detection system output, showing highlighted power lines in comparison to the "naked eye" view of the same landscape with the system off. Credits: Daedalean

Fig. 10. Development view of the AI-based system showing the raw output of a neural network over visual frames from onboard cameras, highlighting objects (wires, masts) potentially recognised as hazards. Video can be seen here: Ref. 38. Credits: Daedalean

6.2.2.3. Precision Landing

Currently the large majority of approaches to oil rigs are radar approaches with obstacle clearance done by the weather radar, which exhibit poor resolution and precision.

Perhaps most critically for low-visibility missions, AI systems can enable precision landing capabilities even when GNSS signals are degraded or unavailable. Through sensor fusion combining multiple data sources, these technologies can identify suitable landing zones, assess ground conditions, and guide aircraft safely to the surface in conditions where human pilots would struggle.

Beyond precision landing, emergency landing could be of great benefit to pilots. When, for instance, there is an engine fire or loss of power, the pilot has seconds to initiate an autoland procedure by lowering the collective and initiating autorotation. In such a case, the pilot must also identify a safe place to land. In the future, AI could reduce pilot workload by surveying the landscape and recommending a landing spot, even in dynamic environments where the landing spot may become unavailable during flight. In such cases, AI could update the preferred landing zone in real-time.

Fig. 11-12: Example of a visual vertical landing system detecting a suitable landing zone in unprepared terrain, video can be seen here: Ref. 39. Credits: Daedalean

6.2.2.4. Operation in GNSS-denied or Degraded Environments

All of the state-of-the art IFR systems rely on GNSS. But in recent years, there has been an increase in both intentional and unintentional navigational disruptions, including jamming for GNSS-based navigation, putting pilots in danger.

Alternative vision-based systems enable precise navigation in GNSS-denied environments. For instance, a visual positioning system (an example can be seen in **Ref. 40**, starting from 1:00) provides real-time data on position, heading, velocity, and height, using a fisheye camera and onboard computer, and operating independently of GPS or ground infrastructure. It serves as a backup to GNSS, ensuring uninterrupted navigation when GNSS is denied. Two functions—the precise but slow global localization and the real-time but error-accumulating local localization (simultaneous localization and mapping, SLAM)—compensate and complement each other, combining to provide a single, accurate global position in real-time without need of satellite navigation input.

6.2.2.5. Locating Missing Persons

AI-powered technologies today can help search and rescue services locate missing persons even in challenging, visually complex environments (e.g. mountainous terrain with dense tree cover, rock formations, boulders, shrubs) where the human eye quickly becomes fatigued.

In one of such systems, (**Ref. 41**) there is a 4K camera mounted on a drone or integrated into the belly of a helicopter, connected to a computer. The software analyzes the live video stream from the camera using AI algorithms to detect human silhouettes and objects on the terrain below. The technology can detect people from a drone flying at 50m altitude or from a helicopter flying at 150-200m height - capabilities that were impossible with previous technology.

When the AI detects a human silhouette (even if only partially visible, such as recognizing just a limb or part of a torso), it automatically captures an image of the detected person. The operator can view this live video stream and when a detection occurs, they can see the enhanced captured image for assessment. The system may also provide GPS coordinates of the detection if coupled with aircraft or drone navigation. The operator then communicates to ground rescue teams for immediate intervention.

Fig. 14-15: Example of an AI-based missing person locating system detecting a human during a search and rescue mission. Video can be seen here: Ref. 41. Credits: Leonardo

6.2.2.6. Reduced Pilot Workload

By automating routine monitoring tasks and threat detection, AI systems significantly reduce pilot cognitive load, allowing human operators to focus on higher-level decision-making and mission objectives. This enhanced automation doesn't replace pilot judgment but augments human capabilities, creating a more resilient and capable flight system that can operate safely in conditions that would otherwise ground aircraft or require extremely risky manual flight operations.

7. EXAMPLES OF CONOPS AFTER INTEGRATING THE PROPOSED SOLUTIONS

7.1. Offshore Oil and Gas Operations

With the integration of EVS cameras, PBN-enabled positioning, and AI algorithms, offshore helicopter operations will gain significantly improved operational capability and safety. Crews departing from Stavanger, Norway, for example, will no longer face mission aborts due to the inability to visually confirm crane positions and helipad clearance in low-visibility conditions. Instead of the challenging manual process of looking down and to the right toward the helipad while flying sideways—without being able to monitor critical flight instruments—pilots will receive real-time algorithmic guidance and automated helipad clearance confirmation displayed on their flight displays. The visual positioning system becomes increasingly accurate as the helicopter approaches the rig, providing precision guidance that surpasses traditional map-based and weather-radar navigation. These capabilities will significantly increase flight availability, reduce weather-related operational limitations, and enable safe crew transport operations that would previously have been impossible or too risky to attempt.

7.2. HEMS/Search and Rescue Operations

For this ConOps, the integration of EVS and AI will revolutionize emergency response capabilities in challenging terrain and adverse weather conditions. The AI system's ability to detect wires in urban environments, navigate complex mountainous terrain in poor visibility, and provide automated landing site assessments will dramatically expand the operational envelope for critical missions.

Instead of aborting rescue operations due to visibility constraints, helicopter crews will be able to safely navigate to emergency locations using AI-enhanced terrain mapping and obstacle detection algorithms. The combination of multi-spectral imaging and intelligent analysis will enable operations in conditions where traditional visual flight rules would prohibit mission execution. This integrated technology will result in substantially more flight hours dedicated to life-saving missions, while enhancing safety for both flight crews and patients. The reduced dependency on weather conditions will lead to improved patient outcomes by ensuring more reliable access to critical care transport regardless of visibility.

8. CONCLUSION

We are proposing an AI-enhanced low-visibility vision system on rotorcraft that could enable increased safety and operational envelope expansion. Such a system could provide:

1. **Enhanced life-saving capability**
   Improved search and rescue in challenging environments.
2. **Pilot workload reduction**
   Reduced cognitive load in challenging operations such as military missions and emergency response.
3. **Expanded operations**
   Extended weather-related conditions that become operable, GNSS-denied aiding to navigation, emergency operational assistance
4. **Safer operations**
   Visualization of obstacles and wires, detection of uncooperative targets
5. **Financial advantage**
   Preliminary analysis of the financial impact of low visibility on current operations clearly shows that systems solving this problem will provide significant return on investment.

We have established both the existing operational challenge and the availability of potential solutions, which will benefit the entire rotorcraft community if created and certified.

The fixed-wing systems that exist today do not address the specific needs of rotorcraft operations: for these platforms, the optimal combination of application and system design that delivers tangible operational benefit remains unrealized.

There is a need for rotorcraft operators to experience the benefits that vision systems can bring, as well as AI's safety-enhancing capabilities that today aren't as critical to fixed-wing operations.

There is also a need to encode in regulations the approval to carry out operations leveraging these benefits. The combination of a proven useful system, supported and enabled by official regulations, provides the catalyst for high-volume production, low system costs, and platform integration.

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