doi: 10.82124/CEAS-GNC-2026-096 CEAS-GNC-2026-096

EuroGNC Madrid, Spain May 5th-7th 2026

Challenges and Opportunities in UAS Mission and Contingency Management

Pranav Nagarajan Research Scientist, Dept. of Unmanned Aircraft, Institute of Flight Systems, Germany Aerospace Center (DLR), Braunschweig, Germany. pranav.nagarajan@dlr.de

Johann C. Dauer Head of Dept. Unmanned Aircraft, Institute of Flight Systems, German Aerospace Center (DLR), Braunschweig, Germany. johann.dauer@dlr.de

Florian Holzapfel Professor and Chair, Institute of Flight System Dynamics, Technical University of Munich, Garching, Germany. florian.holzapfel@tum.de

ABSTRACT

A key challenge in increasing the autonomy of unmanned aircraft systems (UAS) lies in developing robust onboard decision-making capabilities within mission and contingency management (MCM) systems. Mission management enables the successful execution of operational goals while considering performance, safety, and regulatory constraints, whereas contingency management allows the UAS to handle plan failures, performance degradation, and system faults autonomously. Enhancing these capabilities can reduce reliance on human intervention and enable safe, scalable UAS operations. This paper systematically derives the key requirements for a highly autonomous MCM system. First, three distinct use cases – offshore wind farm delivery, regional cargo transport between fixed airports, and humanitarian aid distribution – are introduced that highlight the need for autonomous mission and contingency management in UAS. Second, requirements for a MCM system fulfilling these use cases are derived. A functional decomposition of MCM systems is performed, and state-of-the-art capabilities for each function are reviewed. Finally, gaps are identified to highlight opportunities for new MCM capabilities to advance the level of autonomy in UAS.

Keywords: Mission Management, Contingency Management, Unmanned Aircraft Systems, Mission-Level Autonomy, Onboard Decision-Making

Abbreviations

ALFUS	Autonomy Levels for Unmanned Systems
MCM	Mission and Contingency Management
MMS	Mission Management System
MTOM	Maximum Take-Off Mass
UAS	Unmanned Aircraft System/Systems

1 Introduction

The promising use of UAS, or colloquially drones, for transporting cargo – from fast food and other consumer goods to high-value and time-critical items – has attracted significant government and private investment [2][26]. Cargo drones can vary widely in the size, risk and complexity of their applications – the UAS may be small (e.g. less than 25 kg MTOM), medium (e.g. less than 600 kg MTOM) or large (e.g. similar to a Cessna Caravan or a Hughes MD500); the UAS operation may pose a low, medium or high-risk to manned aircraft and people on ground; the operational environment may vary from well-mapped to unstructured and completely unknown *a priori* [2]. Furthermore, these drones may be operated in a 1:1 manner, where one remote pilot supervises one UAS or more likely, for economic reasons, in an m:N operation, where one remote pilot is responsible for a multitude of UAS.

Correspondingly, UAS automation requirements vary widely as well. Most, if not all, UAS that are intended for commercial operation possess an automated flight guidance, navigation and control system based on on-board sensors and databases. They also possess, to the degree applicable for the use case, a level of system automation to manage their in-flight configuration and perform their mission (e.g. flap settings, payload system). In order to coordinate these functions, they also possess a mission management system [17]. The mission management system is responsible for executing the nominal mission plan uploaded to the UAS by the remote operator [4][17]. The drones may also have a contingency management system, either as a sub-function of the MMS or as a standalone function, to manage contingencies arising from system or sensor failures (e.g. engine failure, link loss, air data sensor fault) as well as external factors (e.g. collision threat, terrain warning) [20][21]. The contingency management system is responsible for triggering an alternate or terminal mission plan, e.g. collision avoidance maneuver, emergency landing at an alternate airport or flight termination [20]. The aim of this system is to ensure that the risk to people on ground (i.e. ground risk) and risk to other aircraft (i.e. air risk) is minimized while attempting to preserve the integrity of the aircraft.

For most cargo drone operations, the level of automation described above may be sufficient. However, as the mission and environmental complexity as well as the risk of the operation increases, additional challenges are introduced. Decisions such as whether to continue a mission under degraded performance or prioritize survivability require real-time onboard deliberation of mission goals (abstracted in this paper as goal-level deliberation) [9]. Dynamic changes to mission elements such as the temporary unavailability of a goal waypoint (e.g. cargo drop site is blocked), or when intermediate flight legs are temporarily blocked, may benefit from a more strategic response than a simple reaction like returning home [7][8]. The capability to deliberately replan parts of or the entire mission considering multiple dynamic planning criteria may bring new safety and performance benefits [9][17][27]. Such planning criteria may encompass different costs and constraints including but not limited to mission status, goals remaining, goals achieved, fuel remaining, landing sites available and importance of the mission. In environments where the remote operator does not have an accurate or real-time situational picture, or where the reliability of communication links between the operator and the UAS is low, providing a near-optimal response from the ground in a timely manner to strategic and tactical plan failures may not be possible [20][21]. A higher level of onboard autonomy may hereby allow for a self-sufficient strategic replanning of the mission in addition to tactical contingency management [25].

A more autonomous mission and contingency management system may thus increase the chances of mission success while guaranteeing survivability of the UAS compared to a reactive system based on simple and rigid rules, which may only guarantee survivability [25]. Moreover, it may allow for more complex missions to be performed with a high degree of self-sufficiency and minimal human intervention during the mission [9]. Building on this perspective, this paper systematically derives the requirements for such an autonomous mission and contingency management system. Existing MCM frameworks for UAS, most notably the UAS Service Abstraction Layer (USAL) proposed by Royo et al. [17], provide a good foundation for mission and payload automation. However, in the USAL architecture, dynamic changes to the flight plan, mission objectives, or payload operations remain under the authority of the pilot-in-command. Moreover, while their approach can allow for full automation of the mission, goal-level deliberation and strategic replanning based on onboard assessment of aircraft survivability and mission success are not addressed. Work on onboard multi-criteria mission planning by Wu et al. [9] demonstrates that such deliberation is computationally feasible within onboard resource constraints, but does not extend to an integrated MCM architecture that combines mission and contingency management in a unified framework. Particularly, Wu et al. focus on finding an optimal path to a single goal waypoint. While their work comes closest to the ambitions of this paper, they do not showcase the handling of multiple goal waypoints or the availability of landing sites. This paper builds on such existing works by identifying the gap between current MCM capabilities and the requirements for a higher level of onboard autonomy, and by proposing a functional structure within which deliberative planning capabilities could be incorporated.

The remainder of this paper is structured as follows. Section 2 outlines three distinct use cases that are representative of typical missions for medium and large UAS. Based on these use cases, some preliminary requirements for an autonomous mission and contingency management system are derived. Section 3 discusses a functional decomposition of MCM systems and how the state-of-the-art may match up to the requirements for MCM systems derived in the previous section. Section 4 highlights the gaps in current capabilities and other opportunities to advance the level of autonomy in UAS through new capabilities in the MCM system. Section 5 concludes this paper with a summary of the insights obtained in this work and a brief discussion on future development directions.

2 Use Cases for Mission-Level Autonomy

The three use cases presented in this section have been selected to represent a range of operational complexity (broken down into mission complexity and environmental complexity as per the ALFUS Framework [25], see Section 4), relevance for industry and technological as well as regulatory feasibility. In choosing the use cases, it should be noted that the focus is primarily on medium and large UAS for cargo delivery applications. Each represents a genuine and pressing real-world need where medium and large UAS offer significant potential but face substantial technical and regulatory challenges.

Last mile cargo delivery using drones, particularly under 25kg MTOM, is a technologically mature domain where commercial deployment has already been occurring in several markets across the world for the past few years [29-31]. Slowly but steadily, manufacturers and operators have been overcoming regulatory hurdles to deploy their drones for delivering small parcels at scale to the doorstep of their customers. However, scaling drone-based logistics to middle-mile operations – covering larger distances with heavier payloads – introduces a significantly different risk profile. The increased MTOM (from 25 up to 2000 or more kg) and kinetic energy of medium and large UAS significantly raises the potential consequences of a failure event, both for people on the ground and for other airspace users. This makes middle-mile cargo delivery with medium and large UAS one of the most technically and regulatorily demanding frontiers in civilian as well as dual-use UAS operations today, and one where advances in autonomous MCM could have a direct and measurable impact on operational feasibility.

Offshore wind farm maintenance and logistics represent a use case being actively pursued by wind farm operators and energy companies across Europe. The efficient, cost-effective, and reliable operation of offshore energy infrastructure has taken on renewed strategic importance in the current geopolitical landscape. Conventional maintenance operations using helicopters and support vessels are expensive, weather-dependent, and logistically complex while posing a significant risk to the flight crew due to dangerous offshore conditions. Drones are already being evaluated in early-stage operational campaigns [28] in Europe as a means to supplement or replace these operations. However, the safe operation of drones in the close proximity of critical energy infrastructure while coordinating with maritime and airspace users in the harsh offshore environment poses some interesting challenges for autonomous MCM that are worth considering in further detail.

Finally, the delivery of humanitarian aid in areas affected by natural disasters or conflicts is becoming increasingly challenging. Timely supply of relief goods – whether following earthquakes, floods, wildfires, or landslides, or in active conflict zones – is critical for preventing loss of life. Aid agencies face growing operational risk in these environments, and drone-based delivery offers the potential to conduct supply operations more reliably and with reduced risk to personnel. However, beyond the technical challenges of operating in unstructured and dynamically changing environments, regulatory approval for such operations requires that the drone itself does not impose additional risk to people on the ground – a requirement that places particular demands on the mission and contingency management capabilities of the UAS.

Together, the three use cases reflect a deliberate progression in the relative importance of two competing MCM objectives – mission success and aircraft survivability – as well as in the degree of available infrastructure and external support. This progression ensures that the requirements derived in Section 2.4 are not tailored to a single operational context but are grounded in a diverse set of scenarios that collectively stress-test the capabilities of an autonomous MCM system.

2.1 Offshore Wind Farm Delivery

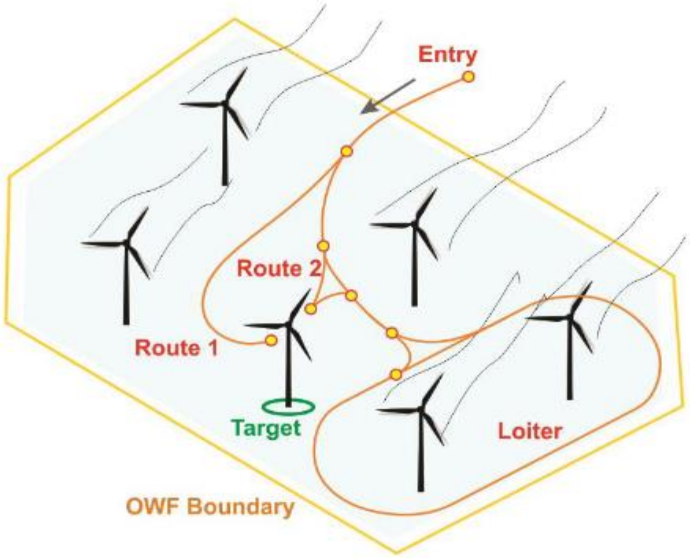

Figure 1 Conceptual Drone Transport Mission to an Offshore Wind Farm as given in [1]

Offshore windfarms form critical cornerstones of an increasingly strained energy supply chain in Europe today. The maintenance of these complex infrastructures is crucial to ensure a reliable and continuous power supply. Currently, most maintenance operations are conducted with personnel transferred onboard the offshore wind-turbines using helicopters or smaller ships. However, these operations may be impeded in high seas and poor weather conditions, which are quite common in the locations where these wind farms are located, e.g. the North Sea. Here, drones may offer a viable alternative. In [1], Donkels et. al. provides a detailed overview of an approach for the integration of drones in offshore windfarms. The authors describe a conceptual drone transport mission intended to deliver critical parts for maintenance ahead of time to the offshore wind farm *Hohe See* located within the *German Bight*. Figure 1 depicts the main phases of the mission. The authors break down the mission into four phases: a) Route planning and departure from the mainland, b) flight along a planned transport route to the wind farm, c) arrival and flight at the wind farm, and d) approach and landing at the target pad. Before entering the perimeter of the wind farm, defined by the OWF Boundary in Figure 1, the drone needs to seek permission from the wind farm operator. Further before entry, the drone has to choose its planned route from a list of available routes in the wind farm. If the wind turbine the drone is delivering to is not currently in the hoist mode ready to receive the drone, the drone needs to perform waiting laps as previously defined (the Loiter route in Figure 1). The authors currently allow for two contingency mechanisms in case of an abnormal condition – return to home and as a last resort, intentional crash into the sea to mitigate the risk of injury to personnel or damage to critical infrastructure.

2.2 Cargo Delivery between Fixed Airports

A second attractive use case for medium and large UAS is that of feeder cargo delivery between smaller regional airports, particularly in remote areas. Currently, most feeder cargo services are road-based with vans and trucks operating over medium distances, carrying payloads of hundreds of kilograms over hundreds to thousands of kilometres. A part of this market could be accessed by drones, especially for delivery in remote areas, where access by road may be non-existent, difficult and time-consuming, and much faster aerial access may be possible by leveraging or constructing simple airfields. Moreover, the market claims to have a potential for positive environmental impact by saving on emissions through reduced road traffic and more sustainable propulsion technologies on the drone. Nevertheless, the use case is attractive enough for several startups to pursue this market and many are in the process of developmental testing and certification of their automated UAS, e.g. Dronamics in Europe, and Pyka, Reliable Robotics and Xwing (now a part of Joby Aviation) in the US. The German Aerospace Center (DLR) has performed a detailed study of the regional cargo delivery use case in their project ALAADy – Automated Low Altitude Aerial Delivery – the results of which were published in [2]. Based on the ALAADy use case and taking inspiration from the proposed missions of the aforementioned companies, a fictitious mission scenario is depicted in Figure 2. This scenario highlights key elements of mission and contingency planning necessary for the middle mile delivery use case and shall help us to derive requirements for a more autonomous mission and contingency management system.

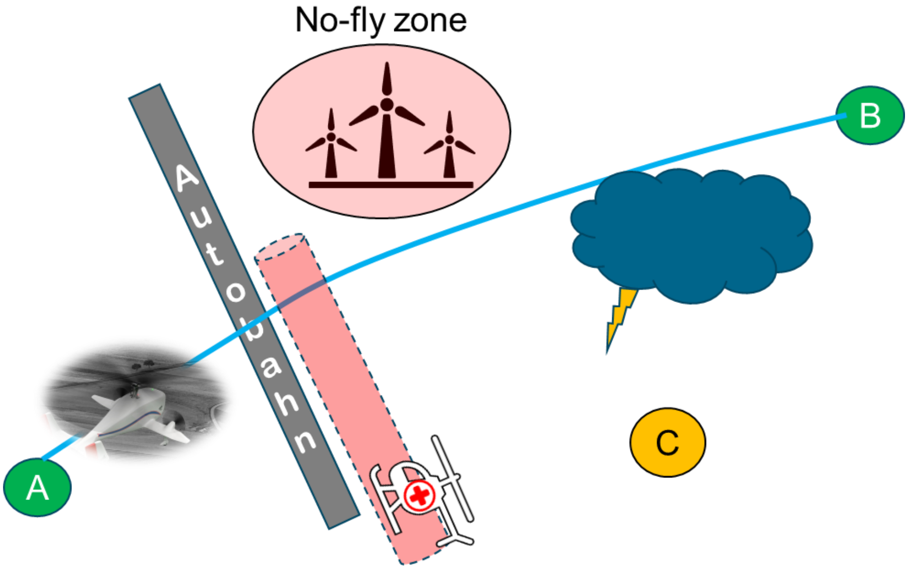

Figure 2 Conceptual mission for drone-based cargo delivery between regional airports

In the scenario depicted above, a cargo drone takes off from an airport *A* with a goal to deliver cargo at destination *B*. Along the way, it has to traverse a road highway (in German, *Autobahn*), avoid no fly-zones to protect critical infrastructure (e.g. wind parks) and deal with enroute weather events. The drone is permitted in case of contingencies to land at a designated alternate airport *C*. In nominal cases, the drone should return to its start airport *A* to be restocked for its next mission. If there is an accident on the highway, there may be rescue helicopter services deployed along the route preventing the continued flight of the drone over the highway. The drone has to ensure that it does not pose any risk to the manned air traffic and to the accident site on the ground. If the upcoming weather event on the route exceeds the operational limitations of the drone, continuation of the flight is not safe and the drone has to return to its home base at *A* or divert to its planned alternate airport at *C*.

2.3 Humanitarian Aid Delivery

A third and final use case for our discussion deals with that of humanitarian aid delivery using drones. It is similar to the second use case of regional cargo delivery, but in unstructured environments without fixed airports at the destinations. This kind of operation deals with the delivery of humanitarian relief goods in remote areas or in areas affected by natural disasters such as floods or hurricanes. The latter leads to a destruction of infrastructure in the affected area and may make previously accessible areas inaccessible by road. Here, delivery of relief goods and essential supplies by air is associated with a level of urgency. Moreover, unlike the offshore wind farm delivery use case, the drone cannot crash intentionally as a last resort due to the lack of knowledge of a safe termination area and that the drone may be critical for further supply missions. The delivery to remote areas is usually constrained topographically by mountains, forests, or large rivers which make access by road extremely challenging if not impossible. These areas usually already have a certain level of aerial access by bush planes and drones can supplement or replace these operations in a larger scale. In contrast to the second use case, humanitarian missions may aim to deliver supplies to more than one destination in a single mission. Especially for disaster relief efforts, where the intended destination may not be clear from the outset, the drone has to aerially detect potential victims and deliver cargo to them. This kind of operation with multiple drop zones is already possible and the company Wings For Aid has been demonstrating these operations in cooperation with the World Food Programme in Africa [32]. In the past, DLR has supported these missions with its expertise in safe drone operations and especially in the EASA SORA framework of operational risk assessment [33]. Therefore, this operation is adapted to a representative but fictitious concept as depicted in to derive the requirements for an autonomous MCM system.

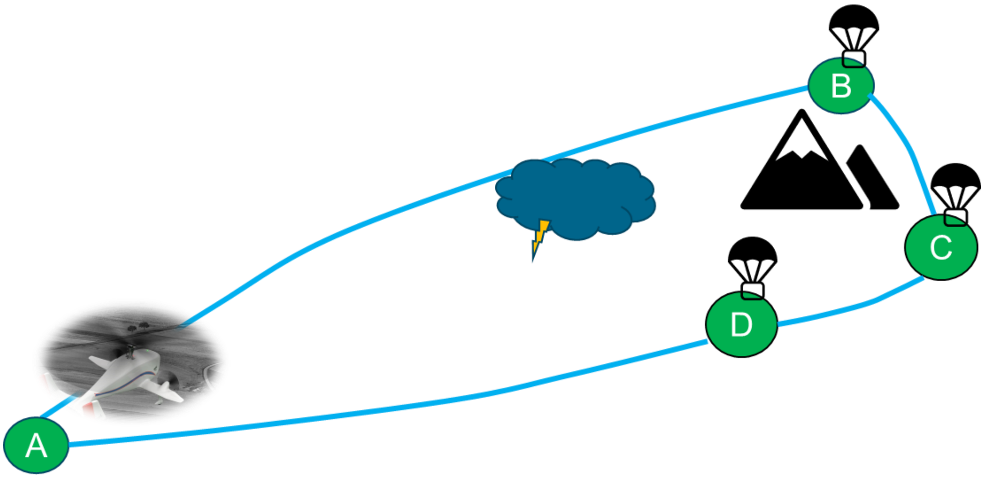

Figure 3 Conceptual drone delivery mission for humanitarian aid in remote areas

2.4 Requirements

An inspection of the use cases above leads to the conclusion of some common attributes across the missions and some distinct mission-specific attributes of the drone's capabilities. Irrespective of the mission type, the drone has to be able to plan its route and navigate it autonomously. This implies the need for a specification of the mission in terms which can be used for route planning. Task planning is also essential for the drone to perform its mission tasks at the designated time and location. Constraints for enroute flight have to be able to be specified to ensure the drone does not violate no-fly zones or pose a risk to people or property on ground. Manned air traffic should not be at risk due to the operation of the drone, be it offshore helicopter operations in the first use case or rescue services in the second or third use cases. While a high degree of autonomy is important for a viable use case, the drone still has to interact with its environment and services on ground to ensure it has permission to traverse different airspaces, enter the wind farm, and get updates on weather, availability of its destinations etc. The drone needs a knowledge of alternate airports and other contingency measures available to it, so it can consider them in its onboard planning process. The three use cases each have at least one distinct attribute to each of them. In the case of offshore wind farm delivery, the level of autonomy is quite low and robust automation of procedures is required. A tight integration of the drone in the wind farm service process is key to safe operation around critical infrastructure. While enroute planning from the mainland to the wind farm is still performed by the drone, the operation within the wind farm itself is highly coordinated with the wind farm operator. In the case of regional cargo delivery, the operation takes place between fixed airports and over rural areas. This implies the availability of a certain level of infrastructure that the drone can leverage to enhance the safety and efficiency of its operation. The drone needs to perform onboard replanning to ensure its mission success and own survivability, but the information aiding this planning is mostly provided by service providers on the ground. In contrast, in the case of humanitarian aid delivery, there is little to no support that can be provided by external service providers and the drone has to self-sufficiently navigate its mission in an uncertain, unstructured environment. The trade-off between mission success and survivability is not complicated for the offshore wind farm delivery use case. Due to the critical nature of the infrastructure, care must be taken to not operate the drone under degraded conditions within the boundary of the wind farm. Due to the fact that the drone must return to shore in order to land safely, there are few options to increase the survivability of the drone. Furthermore, the potential adverse ecological impact of a drone terminating its flight or crashing into the sea may lead to an inherently conservative bias towards aircraft survivability over mission success. However, in the other two use cases, the trade-off is more dynamic as there may be more options to increase the survivability along the route of the drone operation. So, an autonomous MCM system on the drone should consider the right trade-off between mission success and survivability of the drone. This aspect will be discussed further in a later section of this paper.

The following high-level requirements may be derived from an inspection of the three use cases described above. The mission and contingency management system shall:

- **R-I.** Respond strategically and tactically to dynamic changes in the operational environment (e.g. weather events, manned air traffic on the drone's flight path, sudden increase in ground risk due to road accidents, dynamic no-fly zones)
- **R-II.** Respond strategically and tactically to changes in system performance, including degradation of system health and system or payload failures (e.g. link loss, engine degradation or failure, payload system stuck or faulty)
- **R-III.** Respond strategically and tactically to mission goal unavailability detected during mission execution (e.g. destination airport temporarily blocked, alternate airport blocked, persons detected at the cargo drop zone)

Here, a brief explanation of the use of strategic and tactical response may be necessary. In this work, we mean strategic response or replanning to mean a replanning at the goal level, i.e. is the drone continuing or aborting its current mission, modifying it to remove or add goals or changing the order of its goals. Tactical response or replanning on the other hand is intended to signify a more immediate response to the causal situation, e.g. aircraft reconfiguration upon engine failure, emergency landing, avoiding a weather front without first changing the mission goals. Both are necessary in our opinion, and usually a tactical response may require a strategic one as well depending on the deviation from the original mission.

The following section discusses state-of-the-art capabilities in MCM that could help address the requirements posed by the use cases discussed in Section 2.

3 State-of-the-Art Capabilities in MCM

The literature surveyed in this section was identified through a search of academic databases including IEEE Xplore, AIAA Aerospace Research Central, and Google Scholar, using search terms related to mission management, contingency management, route planning, trajectory planning, and system automation for UAS. The survey focuses on works published from 2007 [25] onwards (with the exception of a foundation paper on A* with bounded costs from 1998 [15]), with an emphasis on contributions directly relevant to the three use cases described in Section 2. Rather than aiming for exhaustive coverage, the survey is scoped to representative works that illustrate the state of the art for each functional capability identified in the decomposition below. Works addressing multi-UAS task allocation and swarm operations are acknowledged but not discussed in depth, as the primary focus of this paper is on single UAS autonomous mission and contingency management. The maturity of each capability is assessed qualitatively based on whether existing approaches address the strategic and tactical requirements derived in Section 2.4, with gaps identified where current capabilities fall short of these requirements. It is noted that this paper is not intended to be a systematic literature review. The review of existing literature for the highlighted mission and contingency management functions is instead used to showcase the general direction prevalent literature focuses. This paper highlights areas of potential focus that could enhance the level of autonomy in mission and contingency management systems, particularly as it applies to the onboard capabilities of one unmanned aircraft.

Functional Decomposition

The previous discussion gave an overview of the challenges associated with different use cases and the requirements for mission and contingency management. However, it is easier and more effective to understand the challenges associated in a more systematic manner. For this purpose, a simple functional decomposition is performed in Figure 4 to assess the various capabilities that constitute MCM. Each capability is then discussed briefly and relevant literature is cited.

The internal faults listed in the contingency management branch of Figure 4 – link loss and loss of propulsion – are among the most widely discussed in the UAS contingency management literature and are therefore treated in dedicated subsections in Section 3. Other internal faults such as sensor degradation, battery health degradation, and payload system failures are equally relevant, particularly in the context of the use cases described in Section 2, but a detailed discussion of the handling of these faults is out of the scope of this paper. However, they are implicitly considered in the strategic and tactical mission and contingency management system proposed in Section 4.

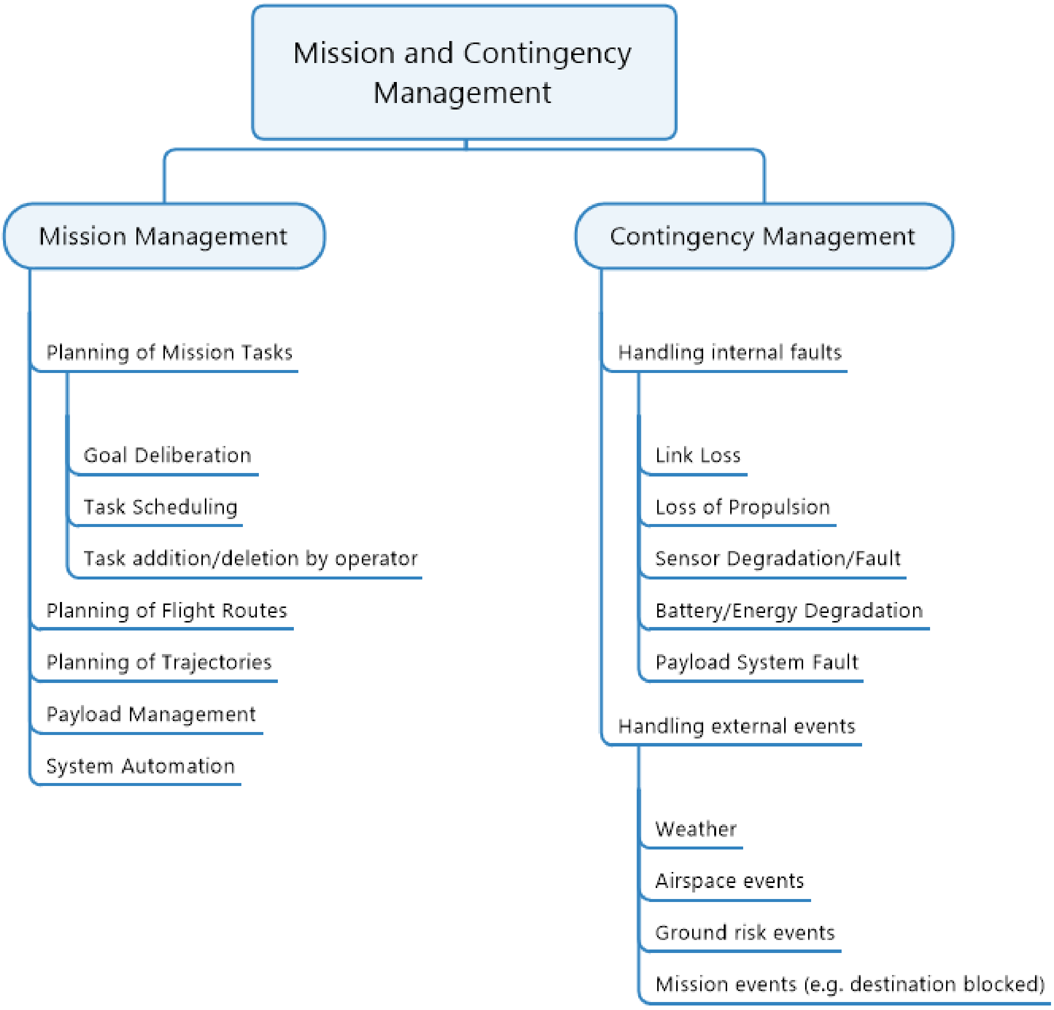

Figure 4 Proposed functional decomposition of mission and contingency management capabilities

Mission Management

Traditionally, mission management systems manage the flight plan and the various primary and auxiliary systems (e.g. flight control, payload system, electric system) of a UAS to execute a given mission, e.g. cargo delivery, surveillance, search and rescue. The flight plan is typically described as a series of waypoints with four attributes – position in latitude, longitude and altitude, and time/speed at which a waypoint is to be flown. Every waypoint has a flight behavior associated with it, e.g. Take-Off, FlyTo/FlyBy, Loiter/Hover, Land etc. Each waypoint may also have a mission-related task to be performed at that waypoint such as cargo drop, image capture or signal transmission. Based on the task associated with the waypoint, the mission management system interacts with the payload system to perform the required task. Once the waypoint is reached, the required flight behavior and task are performed, the mission management system executes the next leg of the mission, i.e. the next waypoint, behavior and/or task. Missions may be uploaded ahead of flight or manually in real-time as mission segments, however the latter requires significant manual intervention from the remote pilot. If a mission is to be uploaded in real-time, then a waiting behavior (e.g. holding pattern, hover etc.) needs to be programmed to ensure a safe behavior of the aircraft while new mission segments are updated. The flight plan may also define the order in which the waypoints are to be flown and the tasks are to be performed. The flight plan usually includes a description of permissible flight volumes, no-fly zones and geo-cages or geo-fences to ensure that the aircraft does not violate any airspace constraints. Alternatively, a separate database may contain information on the aforementioned aspects and may be used to validate the flight plan before accepting and executing it. If the uploaded flight plan is found to violate airspace or ground risk constraints, then the operator may be prompted to upload a revised flight plan or the mission management system may itself propose minor revisions to the flight plan for the operator’s approval. In the following sections, a brief overview of the four main capabilities of mission management – task planning, route planning, trajectory planning and system (incl. payload) automation – are discussed with relevant literature.

3.1 Task Planning

The purpose of any UAS flight is to serve a specific mission or perform *mission tasks*, e.g. cargo delivery, surveillance etc. This may involve the operation of a payload sensor (e.g. camera, gimbaled sensor) or a payload delivery system (e.g. mechanism for cargo drop, cargo bay doors) when the UAS arrives at the intended location. The flight legs before, during and after the mission task are therefore purely for bringing the UAS to that particular point of interest to execute the mission and return the UAS safely to base for the next mission. In literature, mission management for a single UAS usually does not distinguish between route planning and task planning, seeing as one aspect serves the other. The mission management system may incorporate certain checks before delivering the payload to ensure there is no risk to people on ground, e.g. by checking the delivery area before releasing the payload as in [3]. In order to perform the mission tasks at their intended location (i.e. *goal waypoint*) and in the correct sequence, a mission scheduler may help combine the mission tasks with flight behaviors to form plans, as shown by Niendorf et al in [4].

Literature on single UAS task planning however, particularly with respect to deliberation of tasks and mission goals, seems to be generally sparse. Instead, the state of the art focuses on distributing and allocating tasks to a fleet of UAS in the most optimal manner, both before the mission is started and dynamically during the mission. This may be so because the tasks required to be performed are well known and fixed a priori in the case of a single UAS. Some planning is required to consider the optimal order of performing the tasks when no explicit order is given, however this problem is mostly associated with the optimality of the route flown by the UAS. The order of tasks is then automatically given by the order in which the points of interest are connected by the most optimal route. The underlying assumption in all these cases is that all mission tasks are essential and must be performed unless a contingency prevents it. In contrast, the prevalent literature focuses on task assignment and distribution in the case of multiple UAS flying in swarms [5][6]. However, in our opinion there is a case for task planning even for a single UAS beyond classical route planning problems. While the order in which tasks are performed may be decided by the route planner, the strategic deliberation whether to perform a task or not depending on certain constraints is a task planning problem. Moreover, when a task cannot be performed immediately, then a decision needs to be made whether to continue the mission and attempt to complete the task after achieving the remaining tasks. Alternatively, the UAS may persist in completing the task until the aircraft's survivability is imminently threatened and a deviation to a designated alternate airport is unavoidable. This depends on how important each task is both by itself and with respect to other tasks. However, this deliberation at the strategic level needs to be incorporated in the onboard planning framework to increase the level of autonomy in MCM systems today.

3.2 Route Planning

Route planning seems to take a primary place in most of the literature on intelligent mission management and also seems to be used as a proxy for task planning for UAS. Attenni et al [26] provide a thorough survey of route planning literature for different kinds of UAS operations. However, their survey highlights only one paper for single-drone-single-delivery route planning and five papers for single drone multiple delivery. In contrast, their survey shows the availability of multiple sources in literature for route planning and task scheduling for a fleet of drones performing multiple deliveries. As shown in their work, Sorbelli et. al. [27] discuss the problem of energy-constrained route planning under consideration of changing wind conditions, a challenge that is particularly applicable to the offshore wind farm delivery use case. Grzegorz et. al. in [7] provide an interesting overview on both proactive and reactive online route planning for a fleet of UAVs in response to dynamic changes in the operational environment, focusing on weather events. In a separate work, they apply their solution to address the problem of route planning for disaster relief missions [8]. Wu et. al. discuss the problem of online mission planning, whereby they concentrate on route planning as a multi-criteria decision-making problem which needs to be solvable using onboard computational resources [9].

3.3 Trajectory Planning

Trajectory planning is another dominant aspect of prevalent literature, where the route planning solutions are converted into actual trajectories that can be flown by the aircraft. In the context of offshore wind farm delivery, Heinze et. al. demonstrate an approach to solve the enroute planning problem for the drone from the mainland to the wind farm [10]. They hereby consider an approach based on the Probabilistic Roadmap Method (PRM) for planning with respect to spatiotemporally varying winds and wind forecast data, respecting arrival time and round-trip fuel constraints, and runtime efficiency for onboard execution. Schopferer et al. discuss in [11] how risk can be minimized in the path planning process for low altitude aerial delivery missions, based on the ALAADy concept. In a further work, Schopferer et. al. incorporate time-annotated population density maps that can be accounted for in the minimization of risk in the planned trajectories [12]. In [13], Schlapbach et al propose time-aware probabilistic roadmaps for multi-query path planning in dynamic environments, extending on the work on temporal PRM by Hüppi et. al [14]. The works of Heinze, Schopferer and Schlapbach are ideally suited to address the routing and trajectory planning challenges in the use cases of offshore wind farm delivery, regional cargo delivery and humanitarian aid delivery, particularly for tactical response to dynamic changes in the operational environment. A strategic replanning is still not possible in their work due to their focus on achieving the given goal within the operational constraints. A failure of the algorithm to produce an optimal solution could be avoided by relaxing planning constraints as shown by Logan et. al. [15], but their proposed approaches do not extend to goal deliberation.

3.4 System Automation

A key aspect of mission management, besides the execution of the mission plans, is the operation and correct configuration of aircraft systems for the given flight phase. This also includes the operation of payload systems related to the mission, which may be independent of the aircraft systems. However, this area does not seem to be widely addressed in literature. Krause et. al. discuss the system automation of a novel unmanned demonstrator aircraft in [16]. The system automation module, as discussed by them, is responsible for activating and transitioning through various flight modes (e.g. take-off, trajectory following, landing, return to base) as well as dealing with contingencies such as link loss both on ground and in air. In [17], Royo et. al. propose a service-oriented architecture, the *UAS Service Abstraction Layer* (USAL), as a means to automate mission management including systems and payload automation. Santamaria et. al. extend on the USAL approach to show how UAS can be reconfigured automatically [18]. In [19], Ippolito et. al. provide a unique perspective and automate the flight to serve the needs of the payload in an approach called payload-directed flight. In this manner, the state of the aircraft is manipulated to fulfil the needs of the mission and the payload (e.g. sensor) instead of flying to a desired waypoint and then operating the payload.

Contingency Management

In general, contingency management is dealt with in literature as a means to recover the UAS to a safe state as per EASA SORA or to deal with system failures, e.g. link loss, engine failure, battery health degradation etc. In some cases, it may be sufficient to pre-program contingency procedures which are triggered when certain threshold conditions are met (e.g. automatic geo-caging, automated emergency landing under low power). In other cases, situations may demand a more complex deliberation of suitable alternatives, which is usually performed by the remote operator on ground and communicated in terms of new plans to the UAS. However, this may not be possible if the situation requires an immediate reaction by the UAS or the communication link to the remote operator is not reliable.

Today, UAS typically rely on a range of pre-defined contingency procedures which encode the response to different foreseeable situations such as collision avoidance of other aircraft, link loss, loss of powerplant or low fuel/remaining energy. These responses are purely tactical in nature and do not allow for a deliberation of strategic mission objectives and do not necessarily consider trade-offs of aircraft survivability vs. mission success. In other cases, aircraft survivability may not even be considered and a conservative procedure for reaction to a system failure or mission performance degradation may be to trigger a flight termination or an emergency landing. Changes in mission plans are usually communicated from the ground and new plans are updated manually by the remote operator or chosen from a list of previously defined plans.

However, as previously discussed the operator may not always possess a reliable link to the UAS. Moreover, the operator may not have an accurate and updated situational picture of the UAS's current operational environment. Especially for use cases such as aerial firefighting and humanitarian aid delivery in disaster-affected areas, conditions may change dynamically and the environment may not be adequately mapped or defined. The operator may therefore not possess all the information to decide the right course of action. Furthermore, the operator may not have the bandwidth (i.e. in terms of workload) or the cognitive/computational resources to consider the multitude of alternatives available for the UAS and provide a near-optimal solution in real-time. In the following sections, a brief overview of selected contingencies is given and discussed with relevant literature.

3.5 Link loss handling

The loss of command and control (C2) link during UAS operation is one of the most widely discussed problems in literature on contingency management along with loss of engine. In [20], Usach et al propose an approach to produce reconfigurable mission plans that can execute certain contingency procedures when the C2 link is lost. The reconfiguration in their work primarily deals with regaining the link by flying to a higher altitude or the previous waypoint where link was still available. While this behavior is predictable, it may not always represent the safest option in terms of airspace integration. The predictable contingency behavior of the UAS may still be unpredictable to other airspace users, who may not be aware that the UAS has lost C2 link. In [21], Sakakeeny et. al. assess a procedural approach to C2 link loss contingencies with a focus on loss of separation between the UAS and other air traffic in integrated airspace. In our opinion, the loss of link to the UAS operator should not be a critical issue for highly autonomous operations. However, there is a requirement of persistent link to external service providers to have a level of situational awareness onboard the drone, unless this can be augmented and completely provided by onboard sensors.

3.6 Loss of propulsion

The loss of engine power is the second most discussed problem in literature on contingency management and is even the most discussed problem in manned aviation contingency management due to the severity of the consequences associated with it. Most contingency strategies for dealing with loss of propulsion relate to the capability to glide to an alternate airport or a suitable field in the case of fixed wing aircraft and autorotation in the case of rotorcraft. While link loss handling relates to unpredictable behavior in the airspace and may persist over longer periods of time, loss of propulsion leads to a lack of predictability of ground risk as the aircraft needs to be brought down safely away from people at risk. The problem of loss of propulsion is dealt with in a two-fold way – choosing a landing site and executing the landing maneuver. The aspect of first detecting an engine failure is ignored for the scope of this paper. In [22], Di Donato et al evaluate the risk to people and property on ground for aircraft emergency landing planning. In lieu of an onboard pilot making decisions on where to land, they show how candidate landing sites are selected based on a variety of data sources including mobile phone activity. In [23], Coombes proposes an approach for fixed wing aircraft to assess the reachability of a landing site based on glide range and decide on the best landing site given aircraft performance and wind conditions. Mejias et. al. demonstrate using flight tests the effectiveness of previously developed path planning and guidance algorithms for autonomous emergency forced landings in [24]. The area of emergency forced landing seems therefore to be well researched and will be leveraged as an existing capability for the purpose of our discussion on contingency management.

3.7 Handling external events

External events affecting the safety and conduct of the UAS operation may appear in at least four forms. Weather events may impede the progress of the UAS flight and need diversions to be accounted for. If the aircraft is not resilient against adverse environmental conditions, then the replanning may lead to sacrificing some mission goals or even a return to home. As discussed in previous sections on route and trajectory planning, literature currently attempts to plan with reserves or with projected weather estimates in the original mission plan [7][8][10]. However, this may not be sufficient in mountainous areas where weather can change suddenly and in a geographically local area. More real-time weather updates are required for the UAS to operate safely in these regions. Alternatively, the UAS may possess onboard sensor-based weather detection capabilities which the MCM may then consider for replanning of the mission. Airspace events such as dynamic airspace closures to accommodate emergency rescue services or other higher priority traffic as well as non-cooperative traffic encounters need to be dealt with both strategically and tactically. A strategic response to airspace closures deals with the replanning of the mission itself. A tactical response would be to exit the closed airspace if the UAS is already in it, geofencing systems to prevent incursion into no-fly zones and finally detect-and-avoid for avoiding collisions with other airspace users. In some occasions, the initially assumed ground risk of the mission may change due to unexpected events, e.g. road accident leading to increased traffic density below the flight path. The UAS then needs to modify its mission to mitigate the ground risk to its operationally acceptable levels. This can be considered in the spatiotemporally aware trajectory planning approaches discussed in Section 3.3. Finally, mission elements may change dynamically leading to a need for replanning, e.g. destination airport being blocked. In all these cases, an autonomous mission and contingency management system needs to adapt the mission plan to ensure the maximum possible success of the mission and UAS survivability while mitigating the risk to people, property and other airspace users.

4 Gaps and Opportunities

4.1 Gaps in MCM capabilities

Based on the discussion in Sections 2 and 3, we can see that several aspects of mission and contingency management that are required for the use cases have been individually addressed in literature. However, there is few existing literature on integrated autonomy architectures for UAS incorporating advanced mission and contingency management capabilities. The closest to such an architecture specifically for UAS is provided by the USAL approach from Royo et. al. [17]. However, in their work, the dynamic changes to the flight plan, payload or mission objectives are still under the realm of the pilot-in-command. This approach may work well in situations where there is a pilot-in-command or when standardized procedures are acceptable. However, they do not lend to the advancement of full autonomy using onboard computational capabilities. There is no task or goal deliberation based on trade-off metrics of survivability and success, which is handled by Wu et al [9], but only in the form of a multi-criteria decision-making problem to find an optimal path under given constraints for a single goal. The current USAL architecture already provides an excellent starting point for a higher level of mission autonomy and could be expanded to include onboard deliberation capabilities. This could allow for increased scalability and commercial viability of the use cases presented in Section 2.

The gaps identified above can be framed within the Autonomy Levels for Unmanned Systems (ALFUS) framework [25], which characterizes the autonomy of a unmanned system along three axes: the complexity of the missions it can perform (Mission Complexity, MC), the degree of difficulty of the environments in which it can operate (Environmental Complexity, EC), and the level of independence from human interaction it can maintain during operations (Human Independence, HI). Mapping the three use cases discussed in Section 2 onto this framework, the offshore wind farm delivery use case represents a relatively low MC and EC scenario with moderate HI — the mission is well-defined and the environment is structured, but the operation is tightly coordinated with a ground operator. It is important to note that the low environmental complexity does not imply that the maritime environment is easy to operate in. Indeed, the harsh environmental conditions (e.g. salt spray, mist, fog, humidity, precipitation high winds and gusts, waves) present some of the most challenging circumstances for the operation of an unmanned aircraft. However, most of this environment, at least within the operational volume of the unmanned aircraft, is well known. Shipping routes are clearly defined and overflight of these routes can be strategically deconflicted through the drone or the offshore wind farm operator. Highly accurate weather forecasts are available with a good prediction of dynamic weather events. The physical protection of the unmanned aircraft against the corrosive effects of the sea can be considered in the design phase. However, for mission and contingency management, it is only important to consider the dynamic wind conditions affecting fuel consumption and the changing conditions for proper functionality of the perception suite onboard the aircraft. The regional cargo delivery use case represents a medium MC and EC scenario with higher HI requirements — the drone must replan dynamically in response to airspace and weather events with limited ground support. The humanitarian aid delivery use case represents the highest MC and EC scenario, requiring near-complete HI — the drone must operate self-sufficiently in an unstructured and dynamically changing environment with multiple competing mission goals and no fixed infrastructure.

The state-of-the-art capabilities reviewed in Section 3 address the lower end of the autonomy spectrum well. Route and trajectory planning approaches handle medium EC scenarios effectively, and existing contingency procedures provide adequate HI for link loss and loss of propulsion in structured environments. This is evident also with the recent demonstration of preliminary offshore wind farm operations by the energy provider RWE in the North and Baltic Seas off the coast of Germany [28]. However, the main gap identified in this paper – the absence of goal-level deliberation and integrated strategic and tactical replanning – directly corresponds to a ceiling in the achievable HI and MC under the ALFUS framework. Without onboard goal deliberation, a UAS cannot increase its HI beyond the level at which a ground operator must intervene to make strategic mission decisions.

4.2 Opportunities for MCM capability advancement

We believe that the advances in onboard decision-making capability would result from work in three core areas: plan generation, plan evaluation and plan execution. Plan generation would deal with the automated generation of suitable plans that satisfy mission goals and constraints defined by the operator. This includes adaptation of existing mission specification formats to suit automated planning and scheduling problems while ensuring that manual updates to plans can still be made during the mission. The plan generation capability would also have to consider the compatibility of planning at the mission level (usually discrete problems of task scheduling) to planning at the trajectory level (continuous problems under consideration of aircraft performance and mission constraints). The generated plan or set of plans would have to be evaluated to assess their contribution to mission success as well as the survivability of the aircraft. If, for example, a mission plan can achieve all mission goals but does not have any alternate landing sites reachable, then it would be ranked lower than a mission plan which fulfils all mission goals and has one more landing site reachable. The plan evaluation capability would thus have to define a set of metrics based on which to evaluate mission plans, while ensuring compatible interfaces to the plan generation and plan execution capabilities. It is noted here, that the areas of plan generation and plan evaluation can often be combined under the umbrella of optimal planning, an area of work addressed widely in literature, as discussed in Section 3. However, if in addition to the optimal planning of the flight path, deliberative capabilities to evaluate which goals to sacrifice based on what criteria may significantly enhance the level of autonomy onboard the drone. Therefore, the algorithmic implementation of these capabilities will have a significant impact on the resultant architecture. The third capability, that of plan execution, needs to consider how to initiate, modify, interrupt, execute and safely terminate a given plan. It also needs to consider how to incorporate tactical planning responses to different situations, e.g. loss of link, loss of propulsion, unexpected air traffic etc. These tactical responses do not need goal-level deliberation and need to be performed reactively. The work of Usach et al. [20] may serve as useful guidance on the kinds of reactive plans the MCM may need to execute in abnormal operation. Finally, the integration of onboard deliberation with all the decomposed capabilities in a flight stack and demonstration in flight tests for representative scenarios based on the discussed use cases presents a significant opportunity to advance the level of autonomy in UAS. Such an integration would expose new challenges on interface compatibility and shape the software architecture significantly. The flight-testing scenarios would need to be planned carefully to validate the decision-making of the MCM system, particularly to test for emergent behavior arising from the integration of the deliberative capabilities. The three core capabilities proposed in this section – plan generation, plan evaluation, and plan execution – would directly advance the MC and HI axes of the ALFUS framework, enabling UAS to autonomously handle higher mission complexity with reduced reliance on human intervention, as required by the middle mile cargo delivery use case between fixed airports as well as the humanitarian aid delivery in unstructured environments.

5 Conclusions

This paper gave a brief overview of the main challenges associated with mission and contingency management based on three representative use cases for the operation of medium and large UAS. Requirements for a more autonomous MCM system were derived and state-of-the-art capabilities addressing these requirements were discussed. The gaps in these capabilities, particularly on task level planning and goal deliberation, were highlighted and opportunities for advancing the level of autonomy in current MCM systems were identified. Furthermore, an integrated architecture for incorporation of the deliberation capabilities together with existing mission and contingency management capabilities in a representative flight stack will be created. The developed architecture will be tested in flight for prototypical scenarios based on the use cases discussed in this paper and the results discussed in the broader context of autonomous mission and contingency management. This paper contributes to that discussion in a preliminary manner and encourages the reader to look at MCM from a planning perspective.

Declaration of Use of Artificial Intelligence

Artificial intelligence was not used in the work presented.

References

[1] A. Donkels *et al.*, “An Approach for Integration of Transport Drones Into Offshore Wind Farms,” presented at the DLRK Deutscher Luft- und Raumfahrtkongress, Stuttgart, Deutschland, Sept. 2023. Accessed: Jan. 24, 2025. [Online]. Available: https://elib.dlr.de/196952/

[2] J. C. Dauer, Ed., *Automated Low-Altitude Air Delivery: Towards Autonomous Cargo Transportation with Drones*. in Research Topics in Aerospace. Cham: Springer International Publishing, 2022. doi: 10.1007/978-3-030-83144-8.

[3] N. Merkle *et al.*, “Drones4Good: Supporting Disaster Relief Through Remote Sensing and AI,” in *2023 IEEE/CVF International Conference on Computer Vision Workshops (ICCVW)*, Oct. 2023, pp. 3772–3776. doi: 10.1109/ICCVW60793.2023.00407.

[4] M. Niendorf, F. Adolf, and T. Gerhard, *Behavior-Based Onboard Mission Management for an Unmanned Fixed-Wing Aircraft*. 2012. doi: 10.2514/6.2012-2567.

[5] J. Lee *et al.*, “A mission management system for complex aerial logistics by multiple unmanned aerial vehicles in MBZIRC 2017,” *Journal of Field Robotics*, vol. 36, no. 5, pp. 919–939, 2019, doi: 10.1002/rob.21860.

[6] Y. Khosiawan, Y. Park, I. Moon, J. M. Nilakantan, and I. Nielsen, “Task scheduling system for UAV operations in indoor environment,” *Neural Comput & Applic*, vol. 31, no. 9, pp. 5431–5459, Sept. 2019, doi: 10.1007/s00521-018-3373-9.

[7] R. Grzegorz, B. Grzegorz, D. Bogdan, and B. Zbigniew, “Reactive Planning-Driven Approach to Online UAVs Mission Rerouting and Rescheduling,” *Applied Sciences*, vol. 11, no. 19, Art. no. 19, Jan. 2021, doi: 10.3390/app11198898.

[8] G. Radzki, P. Golinska-Dawson, G. Bocewicz, and Z. Banaszak, “Modelling Robust Delivery Scenarios for a Fleet of Unmanned Aerial Vehicles in Disaster Relief Missions,” *J Intell Robot Syst*, vol. 103, no. 4, p. 63, Nov. 2021, doi: 10.1007/s10846-021-01502-2.

[9] P. P.-Y. Wu, D. Campbell, and T. Merz, “On-board multi-objective mission planning for Unmanned Aerial Vehicles,” in *2009 IEEE Aerospace conference*, Mar. 2009, pp. 1–10. doi: 10.1109/AERO.2009.4839608.

[10] J. Heinze, S. Schopferer, and M. U. de Haag, “Trajectory Planning for Offshore Wind Farm Logistics with Unmanned Aircraft,” in *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*, Sept. 2024, pp. 1–10. doi: 10.1109/DASC62030.2024.10749539.

[11] S. Schopferer and S. Benders, “Minimum-Risk Path Planning for Long-Range and Low-Altitude Flights of Autonomous Unmanned Aircraft | AIAA SciTech Forum.” Accessed: Nov. 10, 2025. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2020-0137

[12] S. Schopferer, J. Schlapbach, G. Strickert, L. G. Combrink and S. Fendel, “Minimum Ground Risk Trajectory Planning Based On Time-Annotated Population Density Maps | AIAA SciTech Forum.” Accessed: Nov. 10, 2025. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2024-0233

[13] J. Schlapbach and S. Schopferer, “Time-Aware Probabilistic Roadmaps for Multi-Query Path Planning in Dynamic Environments,” in *2024 Eighth IEEE International Conference on Robotic Computing (IRC)*, Dec. 2024, pp. 9–16. doi: 10.1109/IRC63610.2024.00008.

[14] M. Hüppi, L. Bartolomei, R. Mascaro, and M. Chli, “T-PRM: Temporal Probabilistic Roadmap for Path Planning in Dynamic Environments,” in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, IEEE, 2022, pp. 10320–10327. doi: 10.1109/IROS47612.2022.9981739.

[15] B. Logan and N. Alechina, "A* with bounded costs," in Proceedings of the Fifteenth National/Tenth Conference on Artificial Intelligence/Innovative Applications of Artificial Intelligence (AAAI '98/IAAI '98), Madison, Wisconsin, USA, 1998, pp. 444–449.

[16] C. Krause and F. Holzapfel, “Designing a system automation for a novel UAV demonstrator,” in *2016 14th International Conference on Control, Automation, Robotics and Vision (ICARCV)*, Nov. 2016, pp. 1–6. doi: 10.1109/ICARCV.2016.7838813.

[17] P. Royo, R. Cuadrado, C. Barrado, E. Salamí, M. Pérez-Batlle, and E. Pastor, “Towards the automation of the UAS mission management,” in *2013 IEEE/AIAA 32nd Digital Avionics Systems Conference (DASC)*, Oct. 2013, pp. 6D6-1-6D6-14. doi: 10.1109/DASC.2013.6712626.

[18] E. Santamaria, C. Barrado, E. Pastor, P. Royo, and E. Salami, “Reconfigurable automated behavior for UAS applications,” *Aerospace Science and Technology*, vol. 23, no. 1, pp. 372–386, Dec. 2012, doi: 10.1016/j.ast.2011.09.005.

[19] C. Ippolito, M. Fladeland, and Y. H. Yeh, “Applications of payload directed flight,” in *2009 IEEE Aerospace conference*, Mar. 2009, pp. 1–15. doi: 10.1109/AERO.2009.4839612.

[20] H. Usach and J. A. Vila, “Reconfigurable Mission Plans for RPAS,” *Aerospace Science and Technology*, vol. 96, p. 105528, Jan. 2020, doi: 10.1016/j.ast.2019.105528.

[21] J. Sakakeeny, D. Thipphavong, T. Lauderdale, and H. Idris, “Initial Assessment of Lost Command and Control Link Procedures,” in *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*, San Diego, CA, USA: IEEE, Sept. 2024, pp. 1–10. doi: 10.1109/DASC62030.2024.10748981.

[22] P. F. A. Di Donato and E. M. Atkins, “Evaluating Risk to People and Property for Aircraft Emergency Landing Planning,” *Journal of Aerospace Information Systems*, vol. 14, no. 5, pp. 259–278, May 2017, doi: 10.2514/1.I010513.

[23] M. Coombes, “Landing site reachability and decision making for UAS forced landings,” thesis, Loughborough University, 2016. Accessed: Jan. 16, 2024. [Online]. Available: https://repository.lboro.ac.uk/articles/thesis/Landing_site_reachability_and_decision_making_for_UAS_forced_landings/9216053/1

[24] L. Mejias and P. Eng, “Controlled Emergency Landing of an Unpowered Unmanned Aerial System,” *J Intell Robot Syst*, vol. 70, no. 1, pp. 421–435, Apr. 2013, doi: 10.1007/s10846-012-9767-5.

[25] H.-M. Huang, E. Messina, and J. Albus, “Autonomy Levels For Unmanned Systems (ALFUS) framework, volume II: framework models,” National Institute of Standards and Technology, Gaithersburg, MD, NIST SP 1011-II-1.0, 2007. doi: 10.6028/NIST.SP.1011-II-1.0.

[26] G. Attenni, V. Arrigoni, N. Bartolini, and G. Maselli, “Drone-Based Delivery Systems: A Survey on Route Planning,” *IEEE Access*, vol. 11, pp. 123476–123504, 2023, doi: 10.1109/ACCESS.2023.3329195

[27] F. B. Sorbelli, F. Corò, S. K. Das, and C. M. Pinotti, “Energy-Constrained Delivery of Goods With Drones Under Varying Wind Conditions,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 9, pp. 6048–6060, Sep. 2021, doi: 10.1109/TITS.2020.3044420.

[28] RWE, “RWE successfully pioneers cargo drone operations at offshore wind farms.” Accessed: Apr. 08, 2026. [Online]. Available: https://www.rwe.com

[29] “Rwanda Expands with Zipline to Become First Country in the World with Nationwide Autonomous Delivery Including Africa’s First Urban Drone Delivery Network | Zipline Drone Delivery & Logistics,” Zipline. Accessed: Apr. 08, 2026. [Online]. Available: https://www.zipline.com/newsroom/news/announcements/rwanda-expands-with-zipline-to-become-first-country-in-the-world-with-nationwide-autonomous-delivery-including-africa-s-first-urban-drone-delivery-network

[30] "'We don't stop for red lights': drone deliveries take off as Australian regulators prepare for air traffic boom," *The Guardian*, Aug. 25, 2024. Accessed: Apr. 08, 2026. [Online]. Available: https://www.theguardian.com/australia-news/article/2024/aug/26/australia-drone-parcel-delivery-amazon

[31] "DroneUp Achieves 500 Deliveries Per Day - A New Industry Milestone," DroneUp. Accessed: Apr. 08, 2026. [Online]. Available: https://www.droneup.com/news/droneup-achieves-500-deliveries-per-day

[32] "WFP Uses Unmanned Aircraft to Deliver Life-Saving Nutrition in Madagascar," African Pilot Magazine. Accessed: Apr. 08, 2026. [Online]. Available: https://africanpilot.africa/wfp-delivers-life-saving-nutrition-supplies-to-remote-madagascar-communities-via-unmanned-aircraft/

[33] "Easy Access Rules for Unmanned Aircraft Systems (Regulations (EU) 2019/947 and 2019/945) - Revision from July 2024 – Available in pdf, xml, and online format | EASA." Accessed: Apr. 08, 2026. [Online]. Available: https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-unmanned-aircraft-systems-regulations-eu