POTENTIAL OF THE UNMANNED WINGMAN IN MANNED-UNMANNED TEAMING TESTED IN FLIGHT

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ABSTRACT

Current helicopter missions can achieve a huge operational benefit if manned platforms team with unmanned. Task-based operation of an unmanned aerial vehicle from a manned flying platform may reduce workload and relieve the crew of the manned helicopter. Task-based control in Manned Unmanned Teaming (MUM-T) includes variable automation of the unmanned aerial vehicle and Human Machine Interface enhancement for the crew of the manned helicopter. Research activities in a common project of ESG GmbH funded by the Federal Office for Equipment, Information Technology and In-Service Support and German Armed Forces engaged MUM-T to command and control an UAV from a manned helicopter. The manned mission avionics test helicopter (MAT) and the unmanned mission avionics test helicopter (UMAT) were operated in a common airspace and a distance down to 100m. The joint demonstration of MAT and UMAT included the provision of reconnaissance data for the crew of the manned helicopter, formation flight maneuvers, and complex mission phases. The German Army Aviation experimental pilot of the manned helicopter took the role of mission commander, coordinating with in-air displays to monitor the UMAT data. In parallel, the UMAT was operated from a dedicated control station of a passenger seat of the MAT. This paper examines conducted Manned-Unmanned Teaming flight trials during the summer of 2018 to model a level of maturity for task-based, semi-automated control of an unmanned platform from a manned platform. Flight tests demonstrated procedures of MUM-T, which were based on and transferred from procedures of manned helicopters during formation flight. Task-based control of an unmanned platform based on procedures of the German Armed Forces taking into account HMI requirements and Situational Awareness Management will be discussed. Aspects within human factors and downsizing of the control station to tablet format were examined based on the results of the flight tests and advanced MUM-T roadmap. The discussion culminates in long term human factor integration and capabilities required for task-based control of an unmanned platform to serve as Unmanned Wingman in a team with manned platforms.

1. INTRODUCTION

1.1. MiDEA Program

The MiDEA project of the Federal Office for Equipment, Information Technology an In-Service Support of the German Armed Forces, and ESG focuses on mission accompaniment by drones for surveillance and reconnaissance. MiDEA is a continuation of the Manned-Unmanned Teaming project and Vertical Take Off and Landing- Unmanned Aircraft System (VTOL-UAS) system concept study.

Within the MUM-T project, the need of operating a UAV out of a manned helicopter was examined and what a technical implementation might look like. MiDEA consists of two main parts: UAV operation out of a manned helicopter and communication between a manned helicopter and a VTOL-UAS during low level operation. Results for the first part are described in this paper.

1.2. Participating Organizations

The MiDEA program was executed for the Federal Office for Equipment, Information Technology and In-Service Support (BAAINBw) and the German Armed Forces. The participating personnel was provided by ESG Elektroniksystem- und Logistik GmbH, the Bundeswehr Technical Center for Aircraft and Aeronautical Equipment (WTD61), and UMS Skeldar AG.

2. INVOLVED VEHICLES AND EQUIPMENT

This section details the manned and unmanned test aircrafts, the air mobile unmanned aircraft control station, and its integration into the cockpit environment.

2.1. Test Aircrafts and Ground Control Station

The Mission Avionics Test Helicopter (MAT) is a universal test helicopter for pilot-in-the-loop flight tests of the military and industry. The MAT as shown in Figure 1 is flown by two test pilots and two flight test engineers. The experimental pilot (EP) is located at the right pilot seat of the MAT, while the safety pilot (SP) is located on the left pilot seat of the cockpit. In the rear seats, two flight test engineers can adjust additional settings of the experimental prototypes and ask questions to the experimental pilot in flight.

Figure 1   MAT flying

The Unmanned Mission Avionics Test Helicopter (UMAT) as shown in Figure 2 is a VTOL UAS. The helicopter can be flown with different levels of automation. The UMAT is based on the UMS Skeldar R-350 with a Minimum Take-Off Weight (MTOW) of 150 kg, including 38 kg of possible payload. Like the MAT, the UMAT is modified in order to enable experimental flights

while providing additional safety nets and multiple locations for easy payload integration. Compared to MAT and UMAT base configuration as UH-1D and R-350, these modifications make them rather unique.

Figure 2   UMAT in foreground and Flexible Mobile Ground Control Station in background

The UMAT is monitored from the UAV Control Station inside of a ground vehicle as shown in Figure 2. The UAV ground control station inside of the truck consists of redundant work stations for the UAV Pilot in Command and the UAV Payload Operator. In addition, two work stations for UAV test flight engineers are inside of the truck. This flexible mobile ground control station combines transport and operation of the entire UAV in one all-terrain truck.

2.2. Task-Based Control of a UAV out of a Manned Helicopter

This section describes the MiDEA systems of systems design.

2.2.1.   Air Mobile Unmanned Aircraft Control Station (AM UCS)

For the demonstration, an air mobile unmanned aircraft control station (AM UCS) is set up and integrated into the MAT. It is installed in the back part of the MAT helicopter instead of the right working station of the Test Flight Engineer (TFE). The UMAT is operated task-based from the AM UCS from the TFE.

Figure 3   AM UCS – Dedicated UMAT control station

The console used and as shown in Figure 3 is an available and certified equipment of the so called

'Mission Tactical Workstation' (MTA). Multiple pages were implemented for the demonstration, each providing specific functionalities. For mission execution, the payload page with a sensor image of the UAV sensor as shown in Figure 4 and the planning page showing the UMAT to execute task-based commands as shown in Figure 5 are of particular importance for further discussion.
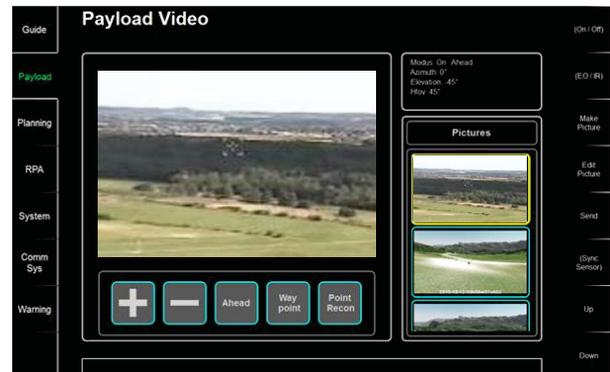

Figure 4   AM UCS payload page

Figure 5   AM UCS planning page

2.2.2.   Integration into the Cockpit Environment

The generated sensor image from the UMAT is presented to the experimental pilot acting as mission commander in parallel on the right multifunctional display from the MAT cockpit as shown in Figure 6.

Figure 6   MAT cockpit with safety pilot environment (left side) and experimental pilot environment (right sight)

The experimental pilot is placed in the right seat of the MAT cockpit, operating two Multi-Function Displays

(MFDs) as major instruments, simulating a UH-Tiger helicopter environment while the safety pilot as the flying pilot operates from the left seat of the MAT cockpit with normal BELL UH 1-D instrumentation as shown in Figure 6.

3. TEST EXECUTION

This section details the test site for the executed flight test, maneuver, mission, and participating test personnel.

3.1. Manching Test Site Dropping Area

The flight trials were conducted at the Bundeswehr Technical Center for Aircraft and Aeronautical Equipment (WTD61) in Manching (Germany). The flights were performed with the MAT and UMAT operated by the German Armed Forces and supported by ESG GmbH and UMS Skeldar AG. In total, 2 test pilots and 4 test flight engineers had evaluated the Manned-Unmanned Teaming in September 2018. During two weeks of flight trials, maneuvers as detailed in 3.1.1 and a mission as described in 3.1.2 were executed.

3.1.1. Maneuver

In the following, join-up and breakaway maneuvers during flight of the two aircrafts MAT (GPS recorded flight paths in green color flown clockwise) and the UMAT (recorded flight paths in purple color flown anti-clockwise) are described as shown in Figure 7.
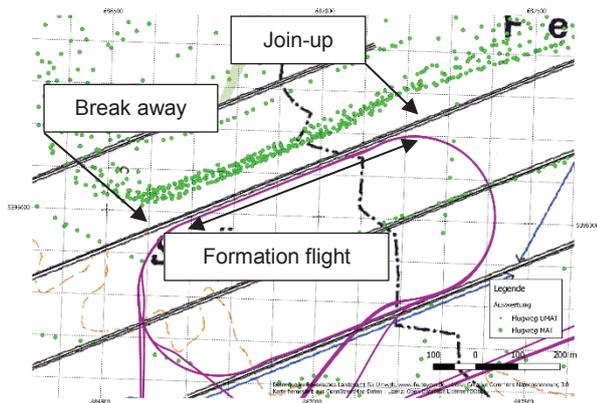

Figure 7   Join-Up and Break Away maneuvers - recorded flight paths of MAT (green) and UMAT (purple) on 2018/09/27

Flight performance was limited due the size of the test site available. Nevertheless, the results that were gained are representative. The MAT and UMAT both operate between 40 to 60 kts Groundspeed (GS) in 100 ft – 350 ft AGL. For join up maneuvers, the MAT approaches from a 45° sector behind the UMAT up to a horizontal safety distance of 100 m. The MAT and UMAT fly in formation for about 20 sec. For breakaway maneuver the MAT turns outward to 45° course relative to the flight direction of the UMAT.

3.1.2. Mission

In this chapter, a mission for reconnaissance of a landing zone of the two aircrafts MAT and UMAT aircrafts is described as shown in Figure 8.
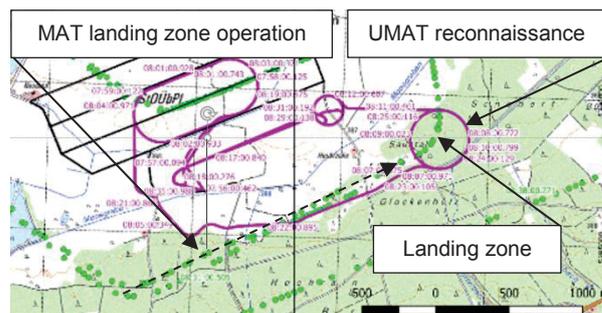

Figure 8   Landing zone operation - recorded flight paths of the MAT (green) and UMAT (purple) from 2018/09/27

The MAT and UMAT both operate between 0 kts to 80 kts GS and 0 ft AGL to 250 ft AGL. The UMAT and MAT proceeded the mission staggered in time and distance. During the mission, the UMAT was used as a pre-flying reconnaissance component for the flight path and landing zone of the manned helicopter. The MAT simulated a landing zone operation and therefore instantaneously used the reconnaissance information obtained by the UMAT video sensor.

3.2. Evaluating TPs

Two experienced test pilots (TPs) (mean age 40 y, mean total flight hours 1750 h) of the German Armed Forces and four test flight engineers participated in the conducted surveys. Both TPs acting as commander of the manned helicopter as described in 3.3.2, have multiple type-ratings on the helicopters NH90, CH-53, EC135, BELL-UH 1D and MAT. One test flight engineer (TFE) of the ESG (age 37 y, total flight hours 60 h) acted as UAV operator from the AM UCS as investigated in 3.3.1. Two additional TFEs of the German Armed Forces supervised the flight tests: One TFE of those monitored flight tests out of the manned helicopter sitting beside to dedicated control station as described in 2.2.1. One TFE of those observed flight tests from inside the ground control station as detailed in 2.1.

3.3. Task-Based Control of an UAV out of a Manned Helicopter

The MUM-T flight tests are described in the following sections. Results are orientated with a time horizon of system implementation by 2025 and 2045. Often, Level of Interoperability (LOIs) as defined by NATO Standardization Agreement 4,586 (STANAG 4586) [1] are used to describe UAS capabilities. With respect to MUM-T, LOIs are not useful. The LOI scheme does not give any information regarding platform capabilities with the regard to automated mission execution, required operator workload or fault tolerance. A scheme more useful with the regard to MUM-T are the Autonomy Levels for Unmanned Systems (ALFUS) [2] as shown in Table 2. Beside mission complexity, ALFUS levels include environmental difficulty and Human Independence.

Goals of the NATO Industrial Advisory Group (NIAG) study group 227 until 2025 include technologies available on the market and therefore enable system solutions on ALFUS Level 3-5. Goals based up to 2045 aims for the concept of an Unmanned Wingman and therefore identifies system possible solutions to ALFUS level 6-8.

Level	Mission Complexity
10	Highest adaptation, decision space, team of teams collaborative missions. Fully real-time planning. Omniscient, highest level fidelity SA. Human level performance.
9	High adaptation, decision space, team collaborative missions/ tasks. High real-time planning. Strategic level, high fidelity SA.
8	
7	
6	Limited adaptation, decision space, vehicle tasking. Limited real-time planning. Tactical level, mid fidelity SA.
5	
4	
3	Simplest, binary tasks.
2	
1	
0	Simplest, binary tasks

Table 1   ALFUS levels for UMS Framework

Furthermore, both variants of time lines as detailed below are partitioned to a dedicated control station and integration of needed interfaces to cockpit environment. Section 3.3.1 and 3.3.2 describe the proceeding during the flight trials (ALFUS 3 – 5) and related approaches (ALFUS 6 – 8) of the NIAG study group 227. The focus is set to execute MUM-T tasks out of a manned helicopter.

3.3.1.   Dedicated Control Station

3.3.1.1.   UAV Sensor Information

Based on the necessary ALFUS 3 to ALFUS 5, the UAV operator generated UAV based information from a dedicated control station out of a manned helicopter. To generate reconnaissance information, the UAV operator benefited from the sensor information of one UAV. The UAV operator reported displayed sensor information via intercom and radio to all parties involved in the mission. Sensor information were displayed in a limited range to the cockpit crew of the manned helicopter. Regarding operational limitation, a collision avoidance system was only available for the UAV operator, so that a spatial separation of the manned and unmanned platform was necessary. Separation by operating manned and unmanned platforms in different altitudes might be expedient. The collision avoidance system acted as a layer against mid-air collisions to enhance flight safety and Situational Awareness of the UAV operator in the end.

Regarding ALFUS 6 – 8, the UAV operator may generate reconnaissance information by using more than one UAV. The UAV operator reports displayed sensor information via intercom and data link to all mission parties. Sensor information can be shared directly with mission participants. Displaying the sensor information is synchronized to on-board data and integrated into existing user interfaces. Regarding operational limitation, teaming of manned and unmanned platforms will behave like teaming of manned and manned platforms in flight.

3.3.1.2.   UAV Automation

The UAV operator allocated tasks to the UAV and supervised execution of the tasks. During the allocation, the UAV operator considered flight characteristics of the UAV and environmental influences such as wind, focusing on ALFUS 3 to ALFUS 5. During the task execution of the UAV, the UAV operator sporadically monitored specific parameters of the UAV to detect possible failures of the UAV at an early stage. The UAV operator commanded flight abort or destruction to the UAV in case of an event of a failure detection of the UAV. In addition, the UAV operator evaluated displayed sensor signals of the UAV with rudimentary system support. Individually generated sensor images and video sequences created by the UAV operator could be provided with additional information and made available directly to other mission participants.

Taking risks into account, the UAV operator had an increased risk of motion sickness, since he was strongly fixed to the displayed video image of the UAV, which behaved completely independent to his own motion in all axes.

In the longer term for ALFUS 6 – 8, the UAV operator may act as commander and coordinator for the unmanned platforms. Therefore, the UAV operator distributes the information generated by the UAV after viewing and prioritizes them to mission participants. In exceptional cases, the commander could accomplish sensor information evaluation and control individual UAV platforms. The commander may usually assign task-based orders to the UAVs. Each UAV details its task, considering mission and environmental knowledge. The UAV reports results to the commander and monitors the UAV's execution of the tasks at his own discretion, just like a mission commander does for his swarm. Regarding sensor evaluations, the commander may use automated evaluation of the UAV sensor information as far as possible and distributes information via radio data transmission to the respective mission participants. In the event of a failure of a UAV system, the UAV purposes measures to the commander or proceeds them out independently. The mission commander can make corrective actions to the UAV.

Incorporating risks, the commander acting as UAV operator may have an increased risk of motion sickness, because he is strongly focused on monitoring the mission progress of the unmanned platforms.

3.3.2.   Integration to Cockpit Environment

3.3.2.1.   UAV Sensor Information

Based on the necessary ALFUS 3 – 5, the commander of the manned helicopter used one available UAV to obtain additional situation-related sensor information. If necessary, he passed on the information gained to other mission participants via intercom. Sensor information was a live video image displayed on the MFD, which was controlled by the UAV operator in relation to the sensors of the own helicopter. Regarding operational limitation, the commander of the manned helicopter could not monitor the UAV during operating its tasks. Monitoring was carried out by a ground control station, from which more than one UAV can be controlled. Interaction between the commander of the manned helicopter and the ground control station was required and conducted

via radio communication and data transmission. As described in 3.3.1.1, the collision avoidance system was only available for the UAV operator, so that a separation to different altitudes of the manned and unmanned platform is necessary.

Regarding ALFUS 6 to ALFUS 8, the commander of the manned helicopter could monitor and delegate one or a few UAVs like in a Vic formation. Vic formation comprises three aircraft flying in close formation with the manned helicopter as the leader at the apex and the rest of the flight en echelon to the left and right, the whole resembling the letter "V". The UAVs are commanded task-based and proceed with the tasks independently as far as possible. Information obtained from the UAVs is automatically processed and displayed to the displays in the cockpit of the manned helicopter. At specific points in time of the mission, the commander of the manned helicopter views generated and proceeded data from the UAVs, such as an image of a preplanned landing zone. Other mission participants of the unit can access generated and processed sensor data from the UAVs.

Operational restrictions arise when derivations from the initial mission plan occur, for example due to an enemy impact or technical problems with the manned or unmanned own platforms. As described in 3.3.1.1, manned and unmanned platforms both may have an integrated collision avoidance system. The manned-unmanned flight proceeds identically to the manned-manned flight.

3.3.2.2. UAV Automation

Considering ALFUS 3 - 5, the commander of the manned helicopter allocated task-based instructions to the UAV operator. Released instructions from the UAV operator to the UAV were cleared by the supervising ground control station. The UAV operator in the manned helicopter controlled the imaging sensor of the UAV depending on the phase of the mission or the information needed for mission participants to fulfill the mission. The sensors of the UAV were synchronized with the sensors of the manned helicopter, so that the same position was observed automatically. As described in 3.3.1.2, the commander of the manned helicopter evaluated the generated sensor signals of the UAV. He communicated aspects from the generated sensor signals concerning the mission via radio communication.

Regarding ALFUS 6 to ALFUS 8, the commander of the manned helicopter may act as commander and coordinator for the unmanned platforms and distribute the sensor information generated by the UAV after viewing and prioritization. In exceptional cases, the commander of the manned platform operates individual UAVs directly. Equally to 3.3.1.2, the commander of the manned platforms allocates task-based instructions to the UAVs. Each UAV plans its own task-based instructions for in detail, taking into account mission and environmental knowledge. UAVs report results to the commander of the manned helicopter. The commander monitors the execution of the tasks of the UAVs at his own discretion, the same as a mission commander does in a manned mission. The commander uses mostly automatically generated evaluations of the UAV sensor information and distributes them to all mission participants via data link.

4. RESULTS AND DISCUSSION OF TASKED-BASED CONTROL OF AN UAV OUT OF A MANNED HELICOPTER

The potential of the unmanned wingman in manned-unmanned teaming tested in flight was investigated during flight trials during the summer of 2018. Flight trials planning, preparations and execution were connected to the ALFUS levels 3 – 5 and 6 – 8 regarding the time horizon of 2020 and 2045.

Chapter 2 described the test method of the manned and unmanned test aircrafts MAT and UMAT. Task-based control of the unmanned test helicopter out of the manned test helicopter of the Air Mobile Unmanned Aircraft Control Station was examined as well as displaying the UAV sensor data to the mission commander on board of the manned helicopter.

In chapter 3, test execution put a focus on maneuver and mission during MUM-T operations. The MAT and UMAT both operated in one airspace down to distance of 100m in formation flight in the same altitude layer. All crew members of the MAT noted, the closer they operated to the UMAT, the more comfortable they felt: The crew of the MAT felt capable to react faster to any normal or abnormal maneuver of the UMAT within a lower distance to the UMAT. It may be stated, that the crew of the MAT was able to see almost small changes in the flight path of the UMAT based on a higher detailed view of the UMAT shape. However, the safety distance must be kept, as common in the manned-manned formation flight. The UMAT generated a benefit for the MAT proceeding the landing zone operation by generating reconnaissance information. Provided UMAT sensor video data was therefore presented to the MAT crew instantaneously in flight.

Results discussed aspects respecting available technologies on the market on the one hand and aimed for the concept of an unmanned loyal wingman on the other: MUM-T on ALFUS 3 - 5 may be ready to be implemented now. In the long term, regarding ALFUS 6 - 8, situational awareness management of the mission commander and automation of the unmanned platform has to be considered to allow task-based control of more than one UAV out of a manned helicopter.

In the error analysis of the MIDEA system, following aspects were identified by the execution of the flight trails, that have to be considered to reach ALFUS 6 - 8:

1) Increase of automation [3] and the maturity of task-based, automated mission execution of a UAV.
2) Investigation of methods for automated fault detection and handling between manned and unmanned platforms.

5. CONCLUSIONS

Based on the flight trials performed, the following conclusions regarding advanced MUM-T could be achieved:

1) MUM-T can provide an operational benefit even today, while still limited due to the available level of mission automation.
2) For an unmanned wingman, efforts must be taken to operational aspects, integration, and role of the operator.

The second aspect may be discussed in detail regarding

the timelines of 2025 and 2045. Operational aspects, integration, and operator tasks are separate from the topics of the use of a dedicated control station and the integration to the cockpit environment. Therefore, the following conclusions are considered from the flight trials and the ongoing discussions of the NIAG study group 227.

First, the operational aspects due to a dedicated control station as flown in the flight trials included a single UAV in a MUM-T mission, with its generated sensor signals supporting the mission A spatial separation of the manned and unmanned platform in different altitude layers will be required. The spatial separation is a main outcome of the flight trials as detailed in this paper to enhance safety, and SA of the crew of the manned helicopter.

Second, cockpit integration in the short term may be based on a single unmanned sensor platform. The generated sensor signals from the unmanned platform regarding the mission could be communicated via radio communication and radio data transmission. Equal to the aspect of the dedicated control station, separation will be required between the manned and unmanned platform in different altitude layers during the operation. Furthermore, the monitoring of the unmanned sensor platform should be guaranteed by a ground control station. However, in the longer term, the unmanned sensor platform may be extended to an unmanned wingman in its role. In comparison, the future concept of an unmanned wingman of the NIAG study group 227 includes a few UAVs and radio data communication only. Over all, in short term, MUM-T may consist of an unmanned sensor platform controlled by a tablet which is integrated into the cockpit environment. In the longer term, the unmanned sensor platform could be replaced by an unmanned wingman and an HMI which is integrated into the cockpit itself.

Third aspect focuses on the tasks of the UAV operator during a MUM-T mission. Therefore, the following actions may be executed by the operator with respect to the flight trails: Simple task-based orders to the UAV, analysis of raw sensor information and limited possibilities in error analysis due to a failure of the UAV. In the long term, the operator may give abstract task-based orders to the UAV. Raw sensor data analysis and failure correction due to a failure of the UAV should be performed automatically while observation of the UAV may decrease to a level of sporadic monitoring.

Taking these three aspects into account, using a dedicated control station will keep the UAV as an unmanned sensor platform to be observed constantly in the short term and sporadic in the long term. In contrast, a cockpit integration may lead from one UAV as an unmanned sensor platform up to one more several loyal unmanned wingmen in the longer term. Overall MUM-T is a concept, not an equipment to be integrated.

6.   ACKNOWLEDGEMENT

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