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A Multi-Platform Small Scale Drone Demonstrator for Technology Maturation of Next Generation Avionic Functions

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Abstract:

The emerging need for new types of airborne platforms that are to be operated in a System-of-Systems context, e.g. like the European *Future Combat Air System*, drives the development and maturation of new technologies for the next generation of military aircraft. A special focus is on the utilization of swarms/teams of unmanned platforms which are envisaged to be operated in highly automated collaboration with manned platforms. To accelerate the development of those technologies Airbus Defence and Space has launched a small scale demonstrator project using customized Micro Air Vehicles [2]. This enables modular and agile technology integration with low threshold to get new developments airborne. A major focus of the recent activities has been the establishment and enhancement of the development environment including test benches, mission software and ground control station. However, already a first set of new technologies for formation management, collaborative navigation and sensor management as well as multiple sensors like a radio frequency emitter localization sensor and an industrial camera have been integrated and tested comprehensively. In summary it can be confirmed that there are major benefits in the utilization of Micro Air Vehicles as rapid prototyping platform for avionics technology maturation.

Keywords: Avionics; Technology Maturation; Small Scale Drones; Micro Air Vehicles; System-of-Systems

1 Introduction

During the past decades multiple challenges have arisen in military aviation. In former times the key capabilities of an aircraft were mostly of physical nature. High maneuverability and a well-trained aircraft crew were the key enablers for successful mission execution. With the introduction of modern radars, beyond visual line of sight weapons, advanced tactical communications, and capable avionics computers the playing field of military aircraft has changed dramatically. Modern military aircraft such as sixth generation fighters are envisaged to be operated in complex mission scenarios in collaboration with multiple unmanned platforms. High performance data-links, connected mission systems, advanced avionics and digital stealth will be the key enablers for future platform capabilities. Together with partners across Europe Airbus Defence and Space is working on those key enablers within several technology programs and projects. These technologies will be integrated into various legacy

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platforms as well as newly developed systems, establishing a fully interconnected *System-of-Systems* (SoS). Especially in the context of the SoS, technologies for the highly automated management of multiple unmanned vehicles, so called swarm/teaming applications, are in special focus of the development activities. The dedicated technologies reach from mission group management, teaming intelligence, human mission group interfacing up to coordinated flight trajectory planning for multiple platforms. A spotlight is also on the development of passive sensors like cameras or novel *Electronic Support Measure* (ESM) sensors, which aid modern electronic warfare and are connected and coordinated as distributed sensor grids. As many of these technologies are still in their infancy, it could take years to finally bring them onto their target platforms in operational scale, especially when using solely conventional development processes. To accelerate technology maturation from years to month or weeks, it is obvious that disruptive changes in development paradigms are necessary. Therefore Airbus started to build up a small scale demonstrator platform based on *Micro Air Vehicles* (MAV) [Bl99], which in the first instance are realized in contrast to [HKK04, St22] by highly modular multicopter platforms. Those vehicles, built with *Commercial of the Shelf* (COTS) components, are equipped with miniaturized but high-performance mission computers and serve as rapid prototyping platform. To have a maximum of flexibility, it was one of the key requirements to keep a the barrier of operation for this platform as low as possible. Therefore the *Robot Operating System* (ROS) [Op21] has been chosen as modular software framework, which facilitates the integration of new technologies in an efficient way. Additionally an integrated testbed based on a *Software-in-the-Loop* (SIL) and *Hardware-in-the-Loop* (HIL) environment has been developed. A general overview of the system with air segment, ground segment and operator roles is depicted in Figure 1. In detail, each MAV is supervised by a separate safety operator in case manual control is required, while a payload control station (PCS) allows observation and control of payloads. In addition, a mission control station (MCS) provides a general overview of vehicle states and flightplans.

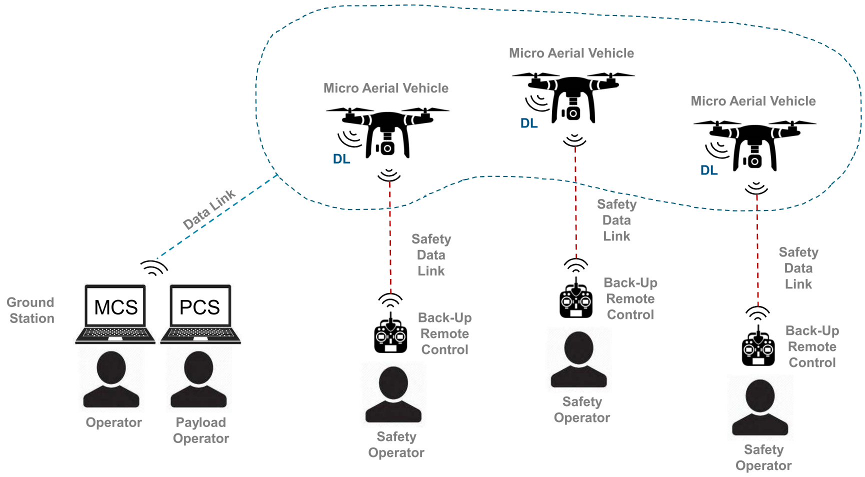

Fig. 1: Drone Demonstrator System Overview

2 Avionics Technology Maturation

Based on the approach of using COTS MAV platforms for technology maturation, this chapter provides an overview of the avionics technology trend in association with a common concept to measure advancement levels and establishes ties to the aviation industry.

2.1 Avionics Technology Trend

New emerging avionic technologies are ranging widely across various fields. This includes next generation *Integrated Modular Avionics* (IMA), new computing technologies such as multi-core processors (which are basically state-of-the-art in the commercial domain, but still are critical in avionics context due to stringent qualification and specifically certification requirements for safety-critical applications), new processing paradigms like *General Purpose Graphics Processing Units* (GPGPU) driven by *Artificial Intelligence* (AI) applications [Sc21] (e.g. for image and video processing and massive parallel computing in general), and the use of *Field Programmable Gate Arrays* (FPGA) or *System-on-a-Chip* (SoC) components. Furthermore new concepts for on-board data networks using cutting edge high bandwidth fiber-optics are becoming more and more relevant. These are complemented by off-board communications technologies enabling secure and ad-hoc networking across collaborating systems. Massive amounts of sensor data will be collected, processed and shared in the next generation of avionic systems in a SoS context. This adds an additional level of complexity, since novel avionic functions and associated technologies need to be matured not only on an individual platform level, but in the scope of the entire SoS, i.e. a distributed *Avionics SoS* (AVSoS) establishing a virtual *Cloud Avionic* system.

2.2 Technology Readiness Levels

In the context of modern avionics the process of technology maturation is key to translate new technologies into safe and reliable operational products. More than ever the commercial consumer market is driving the pace for technological developments in electronics, computing, communications and algorithms. This requires to be even more stringent when adopting this technology push in the domain of avionics, where requirements on safety and reliability are more stringent than in other domains. The so-called *Technology Readiness Level* (TRL) scheme [Ma95] was developed by NASA to systematically evaluate the maturity of technologies in the context of space systems development. Since that the TRL scheme has been adopted to readiness of technologies in various other domains and in a much more general sense.

In the domain of avionic systems the technology maturation based on TRL assessment is well established today and has led to a couple of best practices with respect to interpretation of the TRL levels, specifically concerning the rigor in associated *Systems Engineering* (SE) processes, *Software* (SW) technology, and *Hardware* (HW) technology. Table 1 gives an overview on the original NASA definitions and the emerged best practices for avionics technology.

Level	Description	Avionics Best Practices (SE/SW/HW)
TRL 1	Basic principles observed and reported	Avionics technology scouting
TRL 2	Technology concept and/or application formulated	SE: Costumer needs, requirements and solution concepts
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept	SE: Studies, simulations, down-selection
TRL 4	Component and/or breadboard validation in laboratory environment	SE: Specification and design SW: Function implemented in any programming language on simulation host HW: Initial prototype, interacting systems (e.g. payload) simulations
TRL 5	Component and/or breadboard validation in relevant environment	SE: Small-scale integration and verification SW: Function implemented in any programming language on target system HW prototype (target programming programming language preferred) HW: Avionics Rig environment subsystem scope, representative interacting systems (e.g. payload) simulations or mock-ups
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space/airborne)	SE: Large-scale integration and verification SW: Function implemented in target programming programming language on target system HW prototype HW: Avionics Rig environment system scope, interacting systems (e.g. payload) in target configuration
TRL 7	System prototype demonstration in a space/airborne environment	Demonstrator SE process, SW/HW prototypes in target configuration
TRL 8	Actual system completed and *flight qualified* through test and demonstration (ground or space/airborne)	Full SE process, SW/HW target configuration
TRL 9	Actual system *flight proven* through successful mission operations	Full SE process, SW/HW target configuration

Tab. 1: TRL Scheme with avionics best practices for associated SE processes, SW technology, and HW technology.

In support of the modern avionics technology maturation in a SoS context the multi-platform drone demonstrator system introduced here aims to provide a modular platform, in which specifically the critical technology elements for the TRL levels 4/5/6 can be flexibly integrated, adapted and validated.

3 Demonstrator System Architecture

With the goal of providing a universal platform to cover as many use-cases as possible, the MAV concept is designed to be modular in both hard- and software. To reach a low-cost goal, off-the-shelf (OTS) components are used wherever possible. For maximum modularity, the platform is divided into a ground control part, basic core platform and a payload capability. While the ground control part takes care of high-level flight commands, the core platform consists of the minimum for basic flight functionality. The payload space allows for the mounting of sensors or other relevant hardware on the defined interfaces. For continuous additions of new software modules, the platforms use the publish/subscribe-based framework ROS2. Its popularity simplifies many aspects of the software design due to many reusable software packages for robotics-based applications.

Figure 2 details the general hardware architecture of the described MAV platforms and their components.

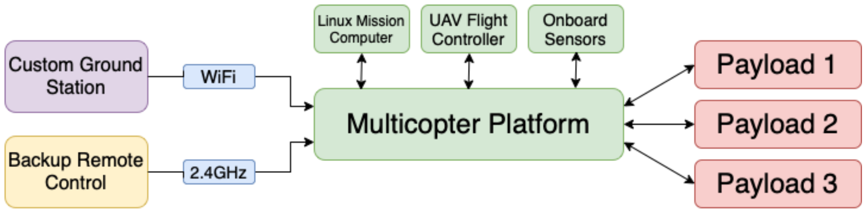

Fig. 2: System Architecture Overview

Beginning with the custom ground station (purple), primary communication with the MAV is achieved via a long-range WiFi connection. The high bandwidth allows for transmission of all onboard sensor data including flight telemetry, onboard sensors and other relevant information. For maximum safety, an OTS backup remote control (yellow) allows to safely abort a mission for any reason. A safety pilot can either initiate a mission abort via a takeover command, or a simple MAV kill switch command. Due to the separate transmission, this method adds a level of redundancy regarding safety.

The core architecture (green) consists of the multicopter platform itself, a Linux-based mission computer, a MAV flight controller, as well as onboard sensors. While the multicopter platform itself consists of an OTS carbon fibre multicopter frame including motors, the MAV flight controller takes over the low-level interface between maneuvering inputs (manual or automated) and motor speeds. The Linux mission computer connects directly to the flight controller and provides high-level flight command inputs such as GPS waypoints or speed vectors. A wide range of Linux-based software tools ensures maximum flexibility in case flight controls need to be adapted to specific use-cases. Onboard sensors such as the installed GPS and camera allow for a multitude of enhancements. With MAV positioning being an obvious application for GPS, a camera is currently used to determine coordinates of detected ground objects. The onboard sensing capabilities are continuously updated to provide additional handling of more complex mission scenarios such as the need for automated obstacle avoidance in low-level flight.

Lastly, any actual payloads (red) are powered by the onboard power supplies that fulfill most electrical requirements. Due to a simple interface, the hardware can be mounted in a modular way and swapped within minutes.

3.1 Physical Architecture

As described in the previous section, the overall goal is to provide a platform for as many use-cases as possible. While larger platforms may appear as the most universal, restrictions regarding commercial flight authorization are an important factor during evaluations. Therefore, a smaller hexacopter platform was selected to enable flight tests with fewest possible restrictions. To serve a particularly important use-case that requires a significantly heavier payload, an additional octocopter platform was modified to allow flights with such payloads.

3.1.1 Hexacopter Platform

After evaluating the use-cases and restrictions of local test ranges, an OTS hexacopter platform was considered to be a valid tradeoff between maneuverability and payload capabilities. As detailed in the initial architecture overview, the core platform adds the minimum of hardware components to enable enhanced functionality such as control through a custom mission software. By optimizing component placements and developing a compact power supply board, the additional mission computer section adds a mere 30 mm of height on top of the platform. The minimal design keeps the platform mass at around 3 kg, leaving sufficient room for payloads of up to 2 kg. Depending on the takeoff weight, flight times range from 12 to 25 minutes. Furthermore, the low-cost aspect of this platform allows a risk-free prototyping approach, leading to a recent fleet expansion to 6 vehicles.

Fig. 3: Hexacopter Platform

3.1.2 Octocopter Platform

While low-cost and -mass may be an important factor when choosing the airframe, certain use-cases cannot be covered by the 2 kg payload limit of the hexacopter platform. To approach this problem, a more capable octocopter platform is used. This platform consists of a basic OTS airframe with additionally developed hardware to provide mounting for the core architecture and the target payload. Due to the unique nature of the use-case requirements, the base frame is designed for maximum stability while protecting the mounted payload. With a significantly more powerful propulsion system, the octocopter platform is able to lift payloads of up to 9 kg, with a total takeoff mass of 22 kg. To enable a clear line of sight for sensitive sensors, the landing gear is retractable during flight, while optionally protecting the payload when lowered. Depending on the takeoff weight, flight times range from 10 to 15 minutes.

Fig. 4: Octocopter Platform

3.1.3 Flight Control

Flight control of the platforms currently depends on the mission scenario. In the case of a mission with fixed waypoints and no need for dynamic maneuvers such as collision avoidance, flight missions are pre-defined on ground and executed during flight. The mission file is directly uploaded to the flight controller, which takes care of the low-level requirements such as checking whether a mission point has been reached. To work with a broad range of use-cases, a custom script was developed to import waypoint information from various filetypes. Since a pre-uploaded mission does not require active communication with ground station equipment or other swarm/team members, it is considered the safest option to fly specific maneuvers.

In more complex situations, the MAVs may need to dynamically react to certain conditions and therefore require a different, non-static, interface for maneuvering. The open source flight controller software supports the popular Micro Air Vehicle Link (MAVLink) [Dr21a] protocol for high-level input from the mission computer. While the open source solution MAVROS exists to communicate with the flight controller via a native ROS1 interface, this package is unfortunately incompatible with the ROS2 that is currently deployed on the mission computers.

Due to this, a custom ROS2-based mission software was developed to provide MAVLink compatibility. By having full control over the modular package, the full suite of flight controller features, more high-level processing (e.g. visual collision avoidance) can easily be added in future versions.

3.1.4 Communications

Communication is currently based on 5.8 GHz WiFi for all network traffic and a 2.4 GHz connection as backup via a remote control. A 5.8 GHz router connects all MAVs with any ground-based computers. In order to extend range and keep steady bandwidth, omnidirectional antennas are used on the MAV side while a ground unit with high-gain directional antennas can be manually turned towards the vehicles. For scenarios that require even longer range communications, a GPS-based automated gimbal keeps the ground antennas consistently aligned in case that the deployed MAVs are not visible.

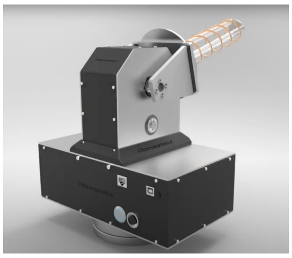

Fig. 5: Directional High-Range Antenna Gimbal

3.1.5 Onboard Mission Computer

As previously described, the entire system is Linux-based to provide maximum flexibility during development. For larger headroom regarding computation intensive applications (e.g. image processing), an NVIDIA Jetson Xavier NX [NV21] was chosen as onboard mission computer. Its compact design and relatively low cost makes it ideal for small-scale platforms, while the integrated graphics chip and CUDA cores pave the way for accelerated AI applications such as real-time object detection.

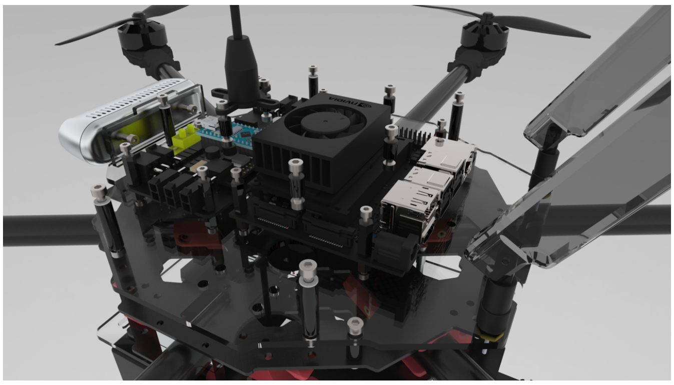

Fig. 6: Jetson Xavier NX Mission Computer

3.1.6 Payloads and Sensors

At the current state of development, three main payloads have been developed to cover various use cases and are described in the following sections. The focus of the payload mounts lies within both payload safety, as well as custom design for fast adaptability by using COTS mechanical components and rapid prototyping technology.

Industrial Camera Sensor

One of the use-cases required calibration footage from an industrial camera, that is targeted to fly on a large target drone in the near future. With a mass of about 1 kg, the camera could be mounted to the smaller hexacopter platform, while drawing power from the onboard supply. The payload is designed to be low-cost and easy to prototype by using OTS while protecting the expensive camera from potential damage.

Fig. 7: Industrial Camera Payload

Inertial Measurement Unit

This use case demonstrates the simple addon-capability of the core platform. A sandwich construction with a mounted inertial measurement unit attaches with only four screws and is directly powered via a single port on the core MAV.

Emitter Localization Sensor

A much heavier 6 kg payload required a more complex approach with the octocopter as its experimental platform. The payload mount consists of a rigid sandwich structure and four retractable carbon fibre landing gears. This feature protects the expensive electronics during takeoff and landing, while allowing an obstruction free sensor field of view during the data collection.

Fig. 8: Inertial Measurement Unit Payload

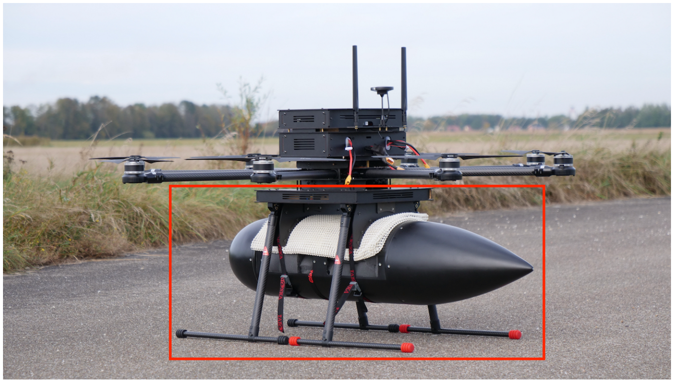

Fig. 9: Emitter Localization Sensor Payload on Octocopter Platform

3.2 Functional Architecture

The functional architecture describes both the structure of the mission software, i.e. all the parts of the software that are not responsible for flight and attitude control, as well as the communication interfaces to other system components, such as the *Flight Control Computer* (FCC), the *Ground Control Station* (GCS) or to other MAVs. The flight controller itself, including the software running on it, is a COTS product and will not be modified as part of the project. The basis for the mission software is ROS2. This robotics framework runs in a Linux environment and makes it easy to connect self-developed and third-party software components together. For communication between these software components, the framework uses a so-called *Data Distribution System* (DDS). Furthermore, this framework already offers software libraries, for example for the connection of various sensors, but also with path planning and localization algorithms. This enables easy and, above all, fast prototyping of new software functions, as it is possible to concentrate on the essential parts that are under development and not the entire software including the communication infrastructure between the software components.

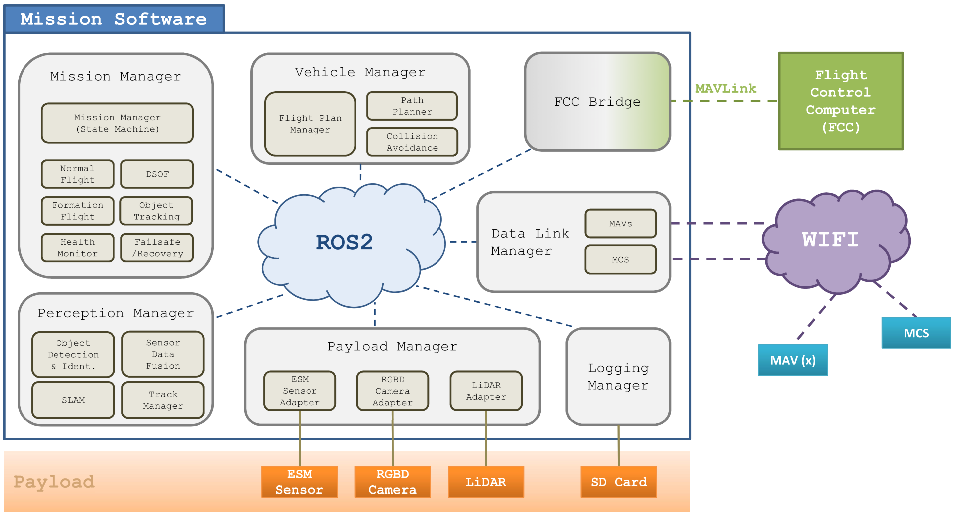

Fig. 10: Mission Software Architecture

The general concept of the Functional Architecture is depicted in Figure 10. The blue box labeled as *Mission Software* contains all software components which are hosted on the mission computer. The figure depicts also the MAVLink interface to the flight critical FCC. By using ROS2 it is easy to achieve a highly modular architecture of the mission software. This modularity takes into account a clear segregation of flight-critical HW/SW and the mission critical elements and thus enables an easy way to exchange, add or remove functionality, as all of these functions are implemented in so-called ROS packages. In this way, the software can be easily adapted for special use-cases. Both the functional components of the software and the communication channels between the components and between the mission software and other participants are visualized. A publish-subscribe middleware is used for both, the internal and the external communication. Therefore ROS2 offers the possibility to use various DDS and Real Time Publish Subscribe (RTPS) systems like RTI Connext [Re21], Vortex Opensplice [AD21] or eProsima Fast DDS [eP21].

The main components shown here, such as the *Mission Manager* or the *Vehicle Manager* combine different functional parts of the software and are implemented in the form of ROS2 packages. The functions contained therein and all necessary central logic for their coordination are implemented as ROS2 nodes within these packages. The *Mission Manager* is responsible for the execution of the mission, the *Vehicle Manager* contains all functions that are necessary for flying of pre-defined or on-board generated flight paths, the *Perception Manager* is responsible for situational awareness and the *Payload Manager* realizes the connection and control of the sensors and actuators of the vehicle. There are also two special communication packages, the *FCC Bridge* and the *Data Link Manager*. The ROS2 package named *FCC Bridge* is responsible for the communication between the Mission Software and the Flight Control Computer. This interface is implemented using the MAVSDK library [Dr21b], which is a wrapper for MAVLink to simplify the usage of standard MAVLink messages from a C++ ROS2 node. By means of the *Data Link Manager*, the Mission Software is able to to communicate with a ground control station as well as with the Mission Software of other vehicles.

4 System Operation

In its current configuration the system can be operated for experimentation, test and demonstration according to various regulatory and safety constraints [De17, Jo19] as summarized subsequently:

- **Spatial**: System operation is allowed in a pre-defined *Mission Area* within the overall test range with limited altitude and adequate safety margins around. In the Mission Area the drones can be operated manually via remote control. Within the Mission Area there is an *Operational Area* in which the drones are also allowed to be primarily controlled by their automatic mission system functions with a remote control operator as safety backup. Automatic means for Geo-fencing are implemented. For illustration of the areas see Figure 11.
- **Weather, Visibility and Lighting**: System operation is allowed only at good weather conditions without rain or snow and under adequate temperature conditions. Limits for wind and gusts are applicable. The operation in clouds or fog is prohibited and the remote pilot always needs to have visual line of sight to the drone at any time of operation.
- **Dynamic**: Limits are applicable for maximum speed and climb rate of the drones. Furthermore the distances between the drones and the remote/ground controls shall not exceed their defined limits during operation.
- **Temporal**: System operation is only allowed at daytime and in pre-defined time slots that are to be aligned with Air Traffic Control (ATC).

In addition to these constraints various functional, mechanical, and electrical safety measures are applied to prevent harm and damage during operation. Supportive checklists and standard operating procedures have been implemented.

5 Experimentation Use Cases

During the first year of operation, several use-cases could successfully demonstrate the benefits of an agile small-scale platform. While the conventional approach of maturing new

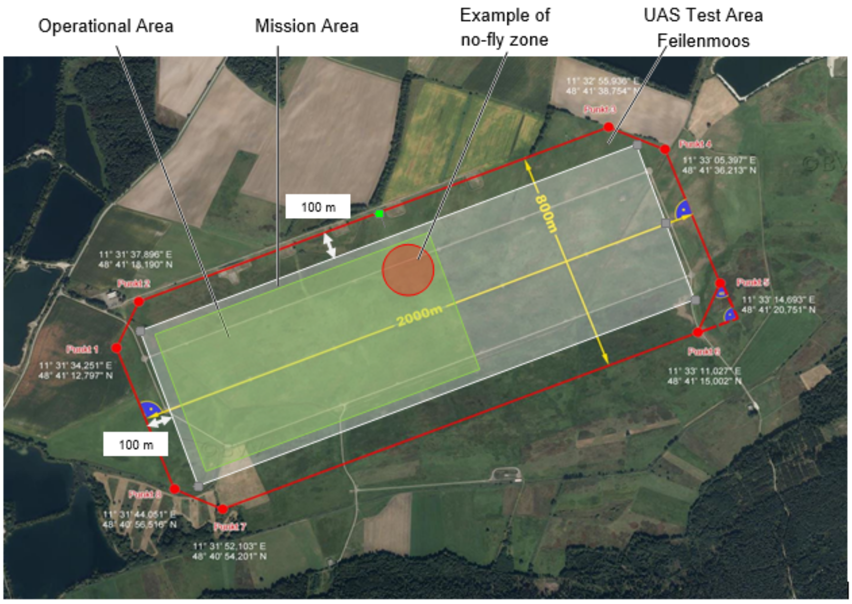

Fig. 11: Mission Area and Operational Area within test range Feilenmoos, Germany

technology is either the use of a laboratory environment or the deployment of large and expensive drones, a small-scale multicopter platform provides a step in between and allows to rule out early problems that typically occur when deploying technology to a real-world scenario. The following sections describe the main use-cases that apply to such small-scale MAV platforms.

5.1 Formation Flight

A common problem of controlling multiple UAVs is the positioning of all formation members within the restrictions of an ongoing mission. As an example, a neighboring no-fly zone may require several MAVs to change their flight pattern from a wide to a narrow formation. Since a narrow flight corridor does not allow for the room of a side-by-side configuration, all members must re-arrange in a maneuver that prevents collisions with each other. Besides restricted flight corridors, formation changes may also be necessary in case of properly positioning sensors or other equipment that may only be present on certain swarm/team members. For example, a sensitive RF-based sensor may produce more relevant data if the field of view is not influenced by another formation member. Both examples demonstrate the needs of formation algorithms for UAV swarms and teams. While the first objective is to prevent the collision of swarm/team members, another important point is to

Fig. 12: Simulated flightpaths for 3 member formation re-arrangement.

plan the formation paths quickly enough to allow for rapid replanning in case of unexpected scenarios.

The contribution of small-scale platforms is the early demonstration of newly developed formation flight algorithms in a real-life environment. To lay the foundation for such future developments, a formation planning algorithm that allowed simultaneous flight of 3 team members was successfully integrated in the MAV architecture and demonstrated in a real flight scenario.

5.2 Collaborative Navigation

Another use-case that greatly benefits from a low-cost real-world flight is the navigation in GPS-denied areas. In this particular scenario, multiple vehicles fuse their data from inertial measurement units and calculate their global position without the use of GPS data. Since the specific sensor properties such as noise are difficult to simulate, this use-case could greatly benefit from data collected in real-flight scenarios.

To accelerate developments in this area, the MAV platform is currently utilized to record sample data of inertial measurement units. To improve and validate the algorithm, positional calculations can later be compared with the actual GPS positions recorded with the MAVs custom mission software. In addition to sensor recordings from a single platform, the data exchange between multiple of the small-scale MAVs is currently under development, laying the foundation for the final target application of collaborative swarming and teaming navigation.

Fig. 13: Real-world results of 3 member formation flight.

5.3 Collaborative Emitter Localization

A technology currently under development is the use of multiple UAV-mounted RF sensors to triangulate the position of a ground-based radar emitter. Besides the newly developed path planning algorithms for optimal sensor positioning, hardware developments such as an RF-based sensor require the most accurate representation of the actual world. For example, since the measurements of RF-based sensors can be susceptible to environmental parameters such as surrounding geometry, air humidity and other factors, the interpretation of sensor data can be greatly improved by testing the setup in a real-world environment. Due to the complexity of the UAV target platforms, a real-world demonstration beyond the laboratory is however a cost-intensive and time-consuming undertaking that may require many iterations to provide the relevant feedback for future development.

In the scope of the described emitter localization problem, the MAV platforms were used to demonstrate the main components of the triangulation approach. As a first milestone, the sensor fusion and path planning algorithms could be deployed in a real-world scenario on a fleet of several vehicles. Within a first approach, the vehicle exchanged simulated emitter bearings respective to all current vehicle positions. By fusing this data across all platforms, the path planning element could continuously update the MAV flight instructions for the fastest possible ground emitter localization. Due to a low integration effort to interface with the small-scale MAVs, these platforms now provide a feasible method of further real-world testing.

In a second step, a first hardware iteration of the newly developed emitter localization sensor was tested by developing a separate platform with payload capabilities of up to 9 kg. This

Fig. 14: Small-Scale multicopter platform carrying new sensor prototype.

allowed a fully integrated sensor to be carried in a real-world calibration flight with known ground truth data. The evaluation of the collected sensor data already provided feedback for the second iteration, all in a minimal timeframe while greatly reducing organizational efforts and costs of a conventional flight campaign.

5.4 Camera Calibration Imagery

In another application the MAV platforms are currently contributing to the evaluation of industrial cameras for larger drones that are for example tailored towards future use in reconnaissance. Since the output quality of the use-case relevant camera hardware depends on a multitude of parameters, frequent settings adjustments in various scenarios are required to produce optimal image results. As an example, camera compression plays an important role to minimize the required data rates to a UAV ground station. Since the quality of camera compression depends on the amount of change between camera frames, it is highly important to determine the optimal settings for many scenarios.

For example, a camera aiming towards aerial targets may produce an image consisting of constant grey sky for the most part with a small section of ground scenery. While high compression rates may produce sufficient quality in this case, results may be much poorer in scenarios with downward facing cameras and highly varying imagery. In developing a camera payload for the MAV platforms, video streaming tests with various settings helped to optimize the settings and to show the camera limitations. By scaling down visual target markers on the ground respective to the lower MAV altitudes, flights could provide the data to scope the influence of important parameters.

Fig. 15: Camera Target Scale Calibration Images

6 Educational Aspects

Beside the characteristics and technical aspects of the drone demonstrator system that have been discussed in the previous sections, this chapter discusses additional educational and training aspects related to it.

6.1 Systems Engineering

While in large scale products and programs the engineering disciplines tend to become highly specialized in specific disciplines along the systems development cycle (i.e. system architects, system design engineers, SW/HW developers, test engineers), the small-scale system allows to educate and train in particular the next generation of engineers such as interns, students, and young professionals on a fast track hands-on experience over the full technology maturation and development cycle of airborne platforms in a SoS context, see Figure 16. This includes the following activities, but is not limited to:

- **Systems Engineering**: Needs identification, use case definition, requirements engineering, system concepts/architecture/design, model-based systems engineering (MBSE), safety assessment
- **Development**: SW Development, HW Development, decision making make/buy/re-use, component and platform assembly
- **Integration & Test**: V&V processes, integration & test plan definition/execution/evaluation, flight test preparation/execution/evaluation, qualification/certification, airworthiness, safety assurance, capability demonstration

Since the start of the drone demonstrator system development in 2019 more than 20 internships, (dual) student projects and bachelor/masters thesis have been performed in

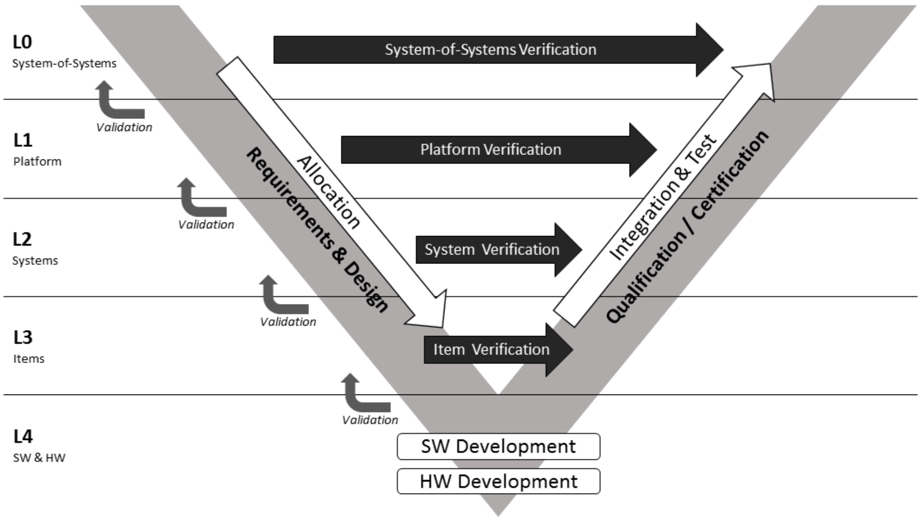

Fig. 16: Generic and simplified V-Model for systems development according to ARP4754A [SA10] with extension towards System-of-Systems.

collaboration with various universities and research institutes, confirming the educational value of the pursued approach.

6.2 Responsible Engineering

In addition the demonstrator system allows to discuss and elaborate aspects related to the responsible use of new avionic technologies in terms of safety and ethics in highly automated systems, which will affect the design of future avionics in the civil and military domain [Az21]. Specifically the aspects related to human control in such complex SoS becomes an emerging topic to be considered in order to engineer safe, reliable, and sustainable systems in a responsible manner [Sh02]. A key question of this ongoing discussion is in which of a system's potentially highly automated functions there is the need to insert human control points and whether these are to be understood as *Human-in-the-Loop* or *Human-on-the-Loop*. In this context the presented drone demonstrator can help to showcase and understand the related problems and challenges in a practical sense.

7 Conclusions

In this paper a multi-platform small scale drone demonstrator was introduced. The purpose of this system is the support of avionic technology maturation with focus on TRL 4-6 and advanced avionics in a SoS context, where HW and SW are seamlessly integrated as a virtual Cloud Avionic system, i.e. AVSoS. The rotary wing multi-copter platforms, which are assembled from OTS components, allow to fit small to medium level avionics payload, i.e. mission computing boards, communications and sensors. For the flight control, platform, and ground control infrastructure re-use is made of open source and publicly available SW frameworks like ROS. The functional and physical architecture of the drone demonstrator is kept modular and generic in order to enable various use-cases, and four of them have been presented in the paper. In its current setup the demonstrator has limitations to integrate larger components that exceed the platform's capabilities in terms of size, weight and power (SWaP). However, an extension towards integration of bigger and an even fixed wing platforms is not excluded for the future, but would require significantly more efforts and raise complexity in terms of safety, airworthiness regulations, and operating permissions. In the next step further use-cases will gradually extend the demonstrator's capabilities. These include for example AI-based mission planning and execution, multi-platform computer vision for ISR applications, and a target simulation system for a nearby large-scale airborne mission sensor test and qualification laboratory.

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