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Tackling different aspects of drone services utilizing technologies from cross-sectional industries

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Abstract. Enabling autonomous and Beyond Visual Line of Sight (BVLOS) operation of Unmanned Aerial Vehicles (UAVs) in the Very Low Level (VLL) airspace requires further advancement of technologies such as sensing the environment or secure and reliable communication. This paper addresses these challenges by presenting solutions developed within the project Airborne Data Collection on Resilient System Architectures (ADACORSA). Here, findings from cross-sectional areas such as the automotive industry are being further enhanced to fulfill the demands of aviation, in particular for use in the UAV domain. The developed technologies include an advanced Ethernet-based deterministic network for reliable onboard communication, a multi-sensor architecture for sensing the spatial environment as well as a multi-link communication gateway that provides reliable communication to the ground and a secure handover architecture.

1. Introduction

The ever widening scope of applications for commercial UAVs in the future will range from surveillance and control missions, including search and rescue, to applications in the logistics industry, such as the transportation of goods [1]. For this type of use case, it is feasible to create possibilities to operate the UAV autonomously and BVLOS. To enable BVLOS operation, multiple technologies need to be provided in order to ensure reliable execution of the flight mission without e.g. obstacles causing an abortion [2]. This includes, for example, sensors for long-range perception of the environment such as cameras or RADAR. Moreover, algorithms to enable a fusion of both in order to reliably detect objects are necessary for enabling autonomous collision avoidance. Another aspect is reliable and secure communication between the operator and the drone over any distance, which is made possible, for instance, by the deployment of mobile network technologies such as Long Term Evolution Network (LTE) and 5th Generation Network (5G).

Since these technological solutions are already investigated for the automotive industry to enable autonomous driving in the future, it is obvious to adapt these systems for aviation. This includes object detection using camera, RADAR, LiDAR [3], the provision of Vehicle to

Everything (V2X) communication using LTE, 5G [4] and data processing on edge platforms [5]. This paper presents an overview of multiple technologies, which are developed within the project ADACORSA to address multiple aspects of BVLOS drone services by utilizing results from the automotive branch. In the following, the use of cross industry results for the aviation domain are discussed, presenting developed technologies and regulatory aspects towards enabling autonomous and BVLOS operation of UAVs.

2. Leveraging cross industry results for a competitive European drone industry

The Single European Sky ATM Research (SESAR) drones outlook study [6], estimates that the European drone market will represent EUR 10 billion/year by 2035 and over EUR 15 billion/year by 2050. To achieve this potential, business-as-usual conditions must be created, i.e., safe, regular and frictionless use of drones in the airspace, namely operating BVLOS. In Europe, the SESAR U-Space aims at enabling drone operations in the VLL (i.e., bellow 150m above ground) airspace (see [7]) through a series of services in this airspace. Other key enablers for the market full bloom are highly automated and increasingly autonomous drone operations.

As can be inferred, this market configures a great opportunity for entrance of new, non-aviation traditional suppliers of hardware, software, services and tools components. BVLOS and autonomy demand sensors, software for autonomy (e.g., Simultaneous Localization And Mapping (SLAM)), low Size, Weight and Power (SWaP) efficient computing platforms, secure and robust communications, simulation environments. These same technologies and associated knowledge are advancing today in the automotive and telecom sectors for instance. Successfully leveraging the engineering and manufacturing chains of these industrial domains opens the door for a stronger and more competitive Europe in the emerging drone market.

ADACORSA builds around this vision, arranging partners into supply chains ranging from components, systems, architecture to operational representative demonstrators in forestry, smart construction and logistics. Two final supply chains address the regulatory and social drone adoption. This functional partition aligns with the positioning of partner results into the emerging drone ecosystem. It must be emphasized that ADACORSA focus is not demonstrating an integrated drone solution. It is to advance core technologies and solutions to be adopted by different - even competing! - actors in the ecosystem (i.e., a supplier cluster paradigm, where individual partners benefit from the presence of others addressing the same operational space).

3. Cross industry technologies enabling BVLOS drone services

Synergies momentum between automotive and aerospace markets is boosting innovations in the Urban Air Mobility (UAM) domain. To deploy Commercial Off-The-Shelf (COTS) building blocks proven to be in series in one market e.g. for automated driving can be investigated and deployed for rather strict aerospace-related scenarios to support the automation for autonomous flight and contribute to a faster time-to-market for onboard drone avionics. Technologies which are applied for UAV domain according to aforementioned scheme are described below.

3.1. Communication systems facilitating BVLOS drone services

For taking automated decisions by a system performing autonomous flight tasks, safety is an essential aspect to be taken into design consideration ensuring non-erroneous system behavior, while addressing the challenges as big data, reliable end2end communication, secure data processing and control. ARINC 664 p7 is the common communication system used for Integrated Modular Avionics-architectures (IMA) widely used in commercial aviation domain which is promising to investigate also for the communication between the components onboard the UAV [8]. It is compliant with the following design features, it: (i) is based on an open standard, (ii) provides resource sharing, (iii) provides robust partitioning and (iv) provides determinism and availability. However, the current implementations are mainly supported by heavy Line

Replaceable Units (LRUs) and Shop Replaceable Units (SRUs) and have protocol limitations – only ARINC 664 p7 traffic is allowed over the network. The solution proposed in this project can contain both host unit and communication unit on one PCB, thus leading to significant SWaP and cost optimization highly suitable for evaluation in lab, utilization in EASA Class C4 drones or even UAM domain. Moreover, architectures based on the other above-mentioned data-handling technologies are typically customized and highly mission-specific, which makes them difficult to extend or adapt. On the other hand Ethernet-based solutions, which are employed within the scope of this paper, tend to provide higher performance and built-in intelligence, and, which is even more important, can be more easily integrated. To the best of our knowledge, there is no similar approach implemented so far. Consequently, the level of innovation for the ADACORSA project according to our perception and market study is exceptionally high.

The drone avionics system presented in this paper combines automotive and aerospace-graded components with the developed deterministic high-speed Ethernet backbone which is the main building block providing very high reliability and making it suitable for certifiable avionics in aeronautics and space. The automotive TÜV-certified AURIX$^{\mathrm{TM}}$ safety microcontroller extended for multi-core processing tasks and equipped with an innovative Power Management IC (PMIC) is deployed to guarantee the functional safety up to the highest needs. Further, the highly security- and safety-certified real-time operating system PikeOS is integrated to support up to Design Assurance Level (DAL) A aerospace applications. In addition, an advanced open-source compiler and related development kit for a migration of PikeOS to AURIX$^{\mathrm{TM}}$ compatible with the ARINC infrastructure, widely deployed in commercial aviation domain, is used. Finally, deterministic Ethernet network backbone consisting of deterministic Ethernet end system and the corresponding driver is developed to enable the sensor data to be delivered to actuators in fully reliable way, i.e. guaranteeing: (a) non-interference of traffic of different criticality, (b) worst-case latency, (c) high-availability (due to dual redundancy architecture) and (d) high diagnostic coverage and safety.

This ADACORSA demonstrator providing deterministic Quality of Service (QoS) and utilizing dedicated bandwidth for safety-critical applications is based on a fail-operational drone avionics architecture concept presented in Figure 1 which is a simplified version of representative practical examples consisting of more networking devices to build dual, triple or quad redundant computers depending on a flight mission. High Performance Computing (HPC) modules or System on Chip (SoC) are responsible for efficient sensor data processing which is delivered via

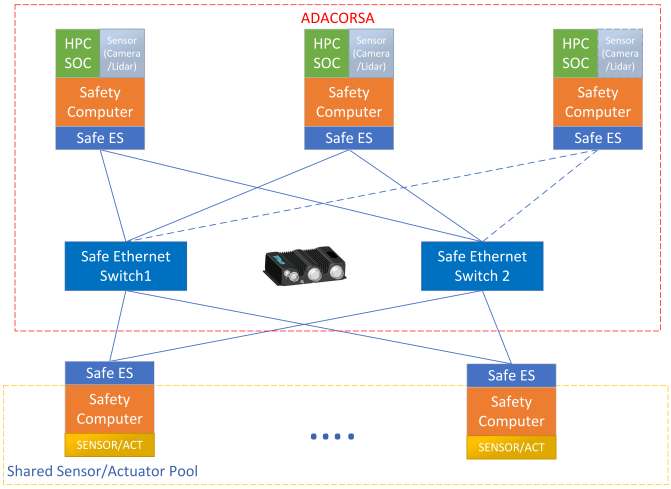

Figure 1. Fail-operational avionics architecture.

deterministic Ethernet-based end system to the safe Ethernet switches which are responsible for the low-latency communication. It is executed in specific cases using time-triggered Ethernet before delivering the data to actuators, e.g. of a flight control system.

The communication protocol time-triggered Ethernet AS6802 [9] for the proposed architecture will be compliant with the following design features: (i) provides resource sharing, (ii) provides robust partitioning, and (iii) provides determinism as well as a high availability. A laboratory demonstrator which is currently in a preparation will be up to Technology Readiness Level (TRL) 4 and will be finalized in the second half of 2023.

In addition to the onboard communication system, for the BVLOS operation of UAVs, reliable and secure communication between drone and ground is mandatory. Due to availability and ability to cover long distances, the mobile network is considered the most obvious. However, there are problems with the LTE network in particular, such as down- and up-link interference, utilization of side-lobes and an increase in handovers due to the height [10]. For this reason, the 5G network is additionally employed and models are developed that predict the QoS of the mobile network. For example, in the event of poor transmission prediction, only prioritized data such as Command and Control (C2) data can be sent. In addition, an IEEE 802.11p link for low-latency, short-range communication is considered for the transmission of larger amounts of data such as sensor data for tracking the environment during take-off and landing. Finally, a Long Range channel is provided, which can be used to receive the status or send commands in the event of a fault in the primary communication links.

The multi-link communication gateway as shown in Figure 2 provides support for the aforementioned links, whereby it is designed to be expandable so that other transmission technologies, such as SATCOM, could also be connected. The gateway is located on the UAV, with parallel transmission supported on multiple links. To make the data available to the operator, it is consolidated on a server. For this purpose, a User Datagram Protocol (UDP)-based multi-link protocol is developed, which is deployed on both the gateway and server side.

Towards security, the gateway provides a Wireless Safety and Security Layer (WSSL) library that can be applied to encrypt both application and C2 data, as shown in Figure 2. Within the gateway, the encrypted data is routed by the Scheduler packet by packet over the available links according to their prioritization. The Link Manager prioritizes the links based on the measured Link and Transfer Metrics as well as the QoS prediction. The Link Metrics are fetched directly from the transmission interfaces and include, for example, signal strength and signal to noise ratio. The Transfer Metrics, on the other hand, are collected within the scheduler and include parameters such as packet delay variation and packet loss rate. In addition, the Link Manager passes the metrics of the mobile network channels to the QoS Prediction module. The including

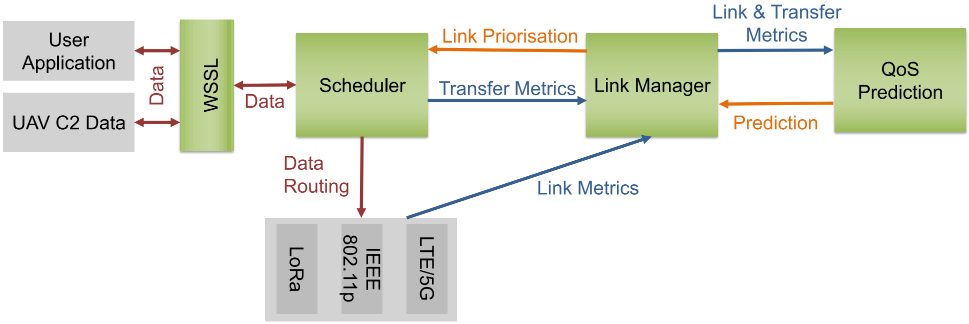

Figure 2. Architecture of the multi-link communication gateway enabling reliable BVLOS communication for UAVs.

prediction model is based on Machine Learning respectively Deep Learning. It is trained on previously recorded measurement data containing the same parameter set as retrieved by the Link Manager. To keep the prediction spatially independent, a time-based model is generated, which should learn and map causalities. For example, the change in the round trip time is to be modeled on the basis of trends in the signal characteristics of the serving and surrounding cells.

The WSSL within the gateway further provides safety guarantees for BVLOS flights, as it facilitates a secure communication architecture between the drone and two Ground Stations (GSs). So, the flight controller gains the capacity to perform handover of authority over the drone flight between GSs with safety guarantees in case of communication failures. A typical goods delivery mission requiring handover is illustrated in Figure 3. The handover architecture is validated using an open-source simulator, PX4, with the implementation of a Software in the Loop (SiL) model, minimizing the differences between the system implemented in the simulation and the one to be implemented in the actual drone.

A SiL implementation is applied to avoid common testing problems by keeping the devices and algorithms that do not require validation in simulation. Simultaneously, the same hardware is deployed that will be used in the real device to validate the security handover module. This application combines the fidelity of the hardware being used with the flexibility and low simulation cost. Thus, code reuse can be maximized and validation time minimized [11]. The PX4 simulator is integrated, emulating the PixHawk controller, providing a standard for delivering hardware support and software stack, allowing hardware and software ecosystems to be build and maintained in a scalable way. The drone simulator contains, besides the PX4, being responsible for flight control, a module in charge of handover, and a data security module.

On the drone side, the integrated SiL platform acts as a layer between the PX4 controller and the interface for receiving the messages sent by the GSs. For the initial implementation, the Nvidia Jetson Xavier NX is chosen, which is used for the security analysis of the messages and for performing command handover between the GSs. On the GSs side, the SiL was implemented as a software block, receiving the data from the Mission Planner in the GS and transmitting it to the transmission layer. The onboard SiL development of the drone contains two independent applications, one responsible for the Security Module (SM) and message identification, while the other is handling the Handover Application (HA) process between the GSs.

The implemented architecture is shown in Figure 4. It shows the main modules of the virtual testbed, composed of the proposed simulations and implemented models. The validation of the drone flight, including take-off, handover, package delivery, and return home, is performed in several test missions and demonstrated in the following link: https://youtu.be/wrre-1YXL8c. For the initial testing, the communication between the GSs and drone is performed over an Ethernet link encapsulating the Robot Operating System (ROS) topics communication. Additionally, tests within the multi-link communication gateway facilitating wireless communication will be performed.

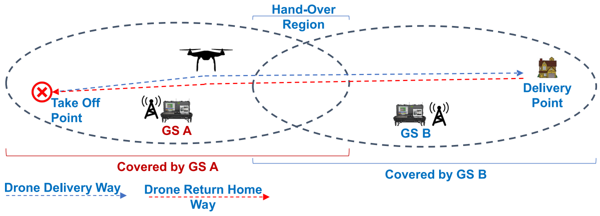

Figure 3. Handover process.

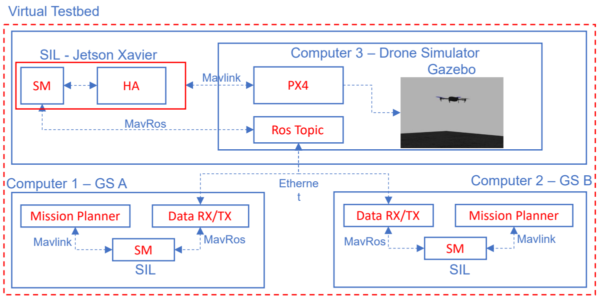

Figure 4. Virtual testbed implementation.

3.2. Multi-sensor perception architecture for BVLOS drone services

Sensor fusion is a critical aspect in autonomous drone navigation as it involves the combination of data coming from heterogeneous sources. The state of the art offers a wide variety of hardware components and software architectures, but sensor fusion remains an unsolved problem [12, 3]. The proposed solutions should be validated with the support of a hardware drone architecture, equipped with an adequate set of sensors and edge computing platforms. In this project a fail-operational avionics architecture is under development, combining COTS elements from the aviation, the automotive and the Artificial Intelligence (AI) industry. It is equipped with a collaborative sensor setup that allows testing heterogeneous sensor fusion solutions. Three different computing platforms are included. A Tricore architecture running on AURIX$^{\text{TM}}$ enables the execution of sensor fusion and supervision tasks, a NVIDIA Jetson Nano accelerates the execution of AI applications and an FPGA enables the design and implementation of power-efficient AI networks. An open source module (Pixhawk 4) serves as a flight controller. The main goal of the proposed hardware architecture is to support the benchmarking of sensor fusion algorithms for autonomous drone navigation.

The architecture can be easily customized to fit different use case scenarios. In more detail, two adaptations are under development, one targeting outdoor scenarios such as forest monitoring and last-mile delivery, and the other customization referring to construction sites and indoor logistics as main use case scenarios. The differences between the two customizations are highlighted in Figure 5.

In the current state, the outdoor demonstrator supports the acquisition of multimodal data for the creation of datasets and real time object detection running on the NVIDIA Jetson Nano. In its final version, power optimized AI networks running on FPGA should take over this task. In this scope, a framework to train, optimize and implement such algorithms has been developed [13]. Furthermore, a self-pose estimation system running on the NVIDIA Jetson Nano is under development.

On the other hand, the indoor version of the demonstrator is being tested in a detect-and-avoid use case based on Stereo Camera, ToF Camera and RADAR. The data coming from the different sensors are processed on the NVIDIA Jetson Nano, which sends the pose vectors of the detected targets to the AURIX$^{\text{TM}}$ microcontroller. The latter supports the execution of Tricore software architecture executing data fusion based on a Triple Modular Redundant (TMR) voter and a Kalman Filter while checking the correct functioning of the other components.

The outdoor customization will be showcased as a laboratory environment demonstrations by the end of 2023, while a flight demonstrator is currently available for the indoor adaptation.

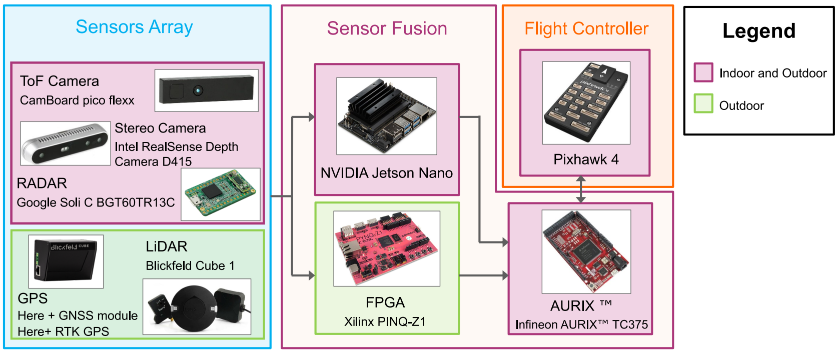

Figure 5. Overall architecture schema. In purple, the elements employed in both sub-demonstrators. In green, the elements included in the outdoor sub-demonstrator.

4. Lowering barriers to enter the aviation domain

In addition to the development of new technologies, ADACORSA also aims to ease deployment for small and medium sized organisations by helping with a better understanding of the process. To this end, two studies have been conducted: (1) future operational and market scenarios as well as (2) guidelines to achieve approval for specific operations of drones under EU regulations.

4.1. Scenarios for future drone operations

BVLOS capabilities offer great opportunities for the public, society and industry, as extended autonomy enables operations over greater distances at a lower cost and reduced risk to human life. Several key areas have been identified as facilitators of future growth and development for drone technologies. In the area of data collection, hyperspectral sensors promise to record hundreds of spectral bands with precision and efficiency. Data fusion has also been implemented to integrate heterogeneous data from multiple sources creating accurate navigation output [14]. The surge of deep learning algorithms for path planning and collision avoidance further extends the potential of autonomous navigation.

As UAVs have limited on-board energy, monitoring applications based on repeated flights have brought focus on development of recharging stations that enable landing and recharging batteries through wireless power transfer techniques without human intervention. ADACORSA integrates data from stereo cameras and their virtual verification through computer vision algorithms and autonomous controllers, as well as sensor fusion algorithms aimed at solving diverse tasks for autonomous drone navigation, such as Target Detection and Simultaneous Localization and Mapping. In terms of communication it will enable secure 5G links through handover as well as failover management, reconfigurable antennas, QoS prediction, trust management and decentralized authentication in networks of drones.

4.2. Guidelines and checklists

To navigate regulations, two tracks to derive safety objectives are identified: operational and technical. The operational ones are derived from Specific Operations Risk Assessment (SORA) [15], and technical ones from Failure Hazard Analysis (FHA) for both air and ground risks:

Table 1. Safety objectives derived from SORA and FHA.

	Air risks (accidents in the air)	**Ground risks (accidents to persons or installations on the ground)**
SORA-derived objectives	Operational, also related to air traffic management, including U-space	Operational risks of causing accidents on the ground (e.g. crashes or controlled flight into terrain or buildings)
FHA-derived objectives	Technical failures causing air risks (mid air collisions)	Technical failures, e.g., crashing or erroneous sensor or control signals

ADACORSA focuses on the SORA process, and has developed a checklist with questions that operators must consider. As an example, see an excerpt regarding Operation Safety Objectives (OSO) #06, on communication links in Table 2. For more details, see [16].

Table 2. Excerpt of information to include in a SORA application.

a.	Details of hardware and software update processes
b.	Command unit functions and capabilities
c.	Radio signal strength and/or health indicator or similar display to the remote pilot
d.	What alerts, such as warning, caution and advisory, does the system provide to the operator
e.	How is the radio signal strength and health value determined?

5. Summary

In summary, ADACORSA is making an important contribution in advancing European autonomous and BVLOS aviation. The project addresses important technological challenges in order to provide ready-made building blocks for common problems. Topics addressed include communication, e.g. between individual components of the UAV or between UAV and GS, sensor technology for environmental perception as well as the related data processing in the form of software architectures and algorithms, whereby AI is used as well. The origins are often cross industry technologies from the automotive sector, which are adopted. The key design criteria that are taken into account in all of these addressed topics are reliability, safety and security. In addition to the technological challenges, ADACORSA also approaches regulatory aspects by contributing to the development and acceptance of standardized processes, guidelines or checklists. In the end, all these efforts should make it easier for new organizations to enter the market of autonomous or BVLOS aviation and thus strengthen European aviation as a whole.

References

[1] Merkert R and Bushell J 2020 *Journal of Air Transport Management* **89** 101929
[2] Davies L, Bolam R C, Vagapov Y and Anuchin A 2018 *2018 X International Conference on Electrical Power Drive Systems (ICEPDS)* (Novocherkassk, Russia: IEEE) pp 1–6
[3] Bai Z, Wu G, Qi X, Liu Y, Oguchi K and Barth M J 2022 *2022 IEEE Intelligent Vehicles Symposium (IV)* (Aachen, Germany: IEEE) pp 1366–1373
[4] Naik G, Choudhury B and Park J M 2019 *IEEE Access* **7** 70169–70184
[5] Liu S, Liu L, Tang J, Yu B, Wang Y and Shi W 2019 *Proceedings of the IEEE* **107** 1697–1716
[6] Single European Sky ATM Research 3 Joint Undertaking 2017 *European drones outlook study : unlocking the value for Europe* (Publications Office)
[7] SESAR Joint Undertaking 2017 *U-space :blueprint.* (Publications Office)
[8] Mercury Systems Inc 2019 URL `https://tinyurl.com/53uzj88j`
[9] Kopetz H, Ademaj A, Grillinger P and Steinhammer K 2005 *Eighth IEEE International Symposium on Object-Oriented Real-Time Distributed Computing (ISORC'05)* (Seattle, WA, USA: IEEE) pp 22–33
[10] Purucker P, Schmid J, Höß A and Schuller B W 2021 *2021 International Conference on Unmanned Aircraft Systems (ICUAS)* (Athens, Greece: IEEE) pp 1499–1508
[11] Demers S, Gopalakrishnan P and Kant L 2007 *MILCOM 2007 - IEEE Military Communications Conference* (Orlando, FL, USA: IEEE) pp 1–6
[12] Bresson G, Alsayed Z, Yu L and Glaser S 2017 *IEEE Transactions on Intelligent Vehicles* **2** 194–220
[13] Molina M, Mendez J, Morales D P, Castillo E, Vallejo M L and Pegalajar M 2022 *IEEE Internet of Things Journal*
[14] Nex F, Armenakis C, Cramer M, Cucci D A, Gerke M, Honkavaara E, Kukko A, Persello C and Skaloud J 2022 *ISPRS journal of photogrammetry and remote sensing* **184** 215–242
[15] JARUS-RPAS 2019 Jar doc 06 SORA URL `http://jarus-rpas.org/content/jar-doc-06-sora-package`
[16] Larsen M, Politi E, Varlamis I, Cecelja O, Reis R, Kellert W and Voss A 2022 D2.10 List of guidelines and processes for approval of drones and operations Forthcoming

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