Internship Report On eVTOL At Qatar Airways

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Acknowledgement

First I would like to thank Ms. M. Shawkat, manager of Technical Training of Qatar Airways, for giving me the opportunity to do an internship within Qatar Airways in the Technical Department. Furthermore, the multiple projects that were assigned to me by Mr. Rakesh Dixit and Mr. Sandeep Shivdas allowed me to utilize my time efficiently and further my interests in the aviation industry.

Introduction

Qatar Airways is the state-owned flag carrier of Qatar. Headquartered in the Qatar Airways Tower in Doha, the airline operates a hub-and-spoke network, linking over 150 international destinations across Africa, Asia, Europe, the Americas, and Oceania from its base at Hamad International Airport, using a fleet of more than 200 aircraft.

Executive Summary

This report is a detailed overview of my internship at Qatar Airways. The internship was divided into three main periods. The first two weeks had me placed in the New Technical Building (NTB), to be briefed on the maintenance

structure and procedures of aircrafts in QA. Subsequently, I was in the aircraft hangar and assigned the project of creating a report analyzing the eVTOL concept by Mr. Dixit. Parallel to being involved in this project, I was placed on a rotation plan directly communicating with the professionals of different departments in development engineering to study their processes to a certain extent. During the last week, I was under the supervision of the development engineering for the Boeing fleet, Mr. Shivdas and was exposed to a more hands-on approach to the aircraft. The fourty-five days I spent learning the inner workings of an airline were invaluable in giving me an introduction to a professional space. During my Internship, I have learned to work in a corporate space which not only enriched me professionally but also helped me grow personally as well.

eVTOL Project

A significant portion of my internship was spent in analyzing the eVTOL space and understanding the complexities involved. Whilst on the rotation plan that introduced me to the different departments in the engineering section of QA, I was able to draw similarities in various contexts to eVTOLs and rightly so with the market being closely linked to existing aircraft manufacturers and regulatory bodies.

In addition to finding these links, I was also able to chart out a proposed path for developing the eVTOL market by describing the many variables involved. These variables include newly created ideas that require further research and the borrowed ideas from the similarities I found.

The attached file Appendix-A contains my analysis of this market and other closely related developments the contents of which I prepared during my internship under Mr. Dixit.

The Idea of eVTOLs

Electric-Vertical Take-off/Landing is the abbreviation of eVTOLs, also known as Unmanned Aerial Mobility (UAM). The notion to perform UAM operations in the form of air taxis to transport passengers has been prevalent since the 1940s and is gaining popularity again due to congestion in urban areas. As the tempo for usage of VTOL/e-VTOL grows due to inherent desire to mitigate ground transportation density, a set of technological and operational challenges must be overcome to see a true concept of operations fully realized. In São Paulo, Brazil and Mexico City, Mexico, urban air transport via helicopters is already an integrated reality but is associated with a steep financial cost. Studies have also indicated a push away from helicopter transport due to community noise complaints and limited passenger capacity. In Dubai and the United Arab Emirates, prototypes for air taxi infrastructure are in development. Major stakeholders in the UAM community are the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the U.S. Department of Transportation, General Aviation Manufacturers Association, transportation researchers, academic institutions, municipal governments, and civil aviation authorities. From these key players, conceptual development of a UAS (Unmanned Aerial System) Traffic Management system (UTM) is in the preliminary stages that is currently used as medical transports, package delivery, and weather observational data and would need to be developed for passenger transport. To address ground traffic congestion, NASA initiated the “Urban Air Mobility” concept to utilize the three-dimensional airspace to accommodate the heavy demand for cargo deliveries as well as passenger transportation in urban areas. The electric Vertical Takeoff and Landing (eVTOL). aircraft is proposed as a promising solution to implement UAM in the future. Under this direction, different types of eVTOL have been extensively investigated by researchers from the industry such as Uber, Joby Aviation and Boeing. It is envisioned that eVTOLs will significantly reduce the heavy traffic congestion during peak times and improve the efficiency of urban traffic networks. The safety and reliability of UAM have motivated extensive research works for both design and evaluation of UAM and eVTOLs. the authors primarily focused on developing different alternatives for the management of UAM with respect to different objectives however, no systematic approach is available to generate all possible alternatives. Also, most UTM alternatives are evaluated in different simulation interfaces and no common platform is yet developed for the evaluation of these alternatives. Considering these challenges, a preliminary framework with metrics and a simulation interface was developed to compare and evaluate different alternatives for UAM. In the United States alone, corporate players such as aircraft manufacturers like Bell Helicopters, Airbus, and Boeing, ridesharing company Uber, and startups such as Kitty Hawk's Cora have taken serious interest in this commercial potential. Along that wavelength, Uber Elevate is already conducting on-demand helicopter operations in New York City, NY. As the 3 commercial market landscape keeps opening, so arises the need to adopt a procedural directive to integrate and carefully monitor these aircraft during flight operations. Safely integrating these UAM aircraft into the NAS is of the highest priority. NASA's original research in UAM came from the over-arching framework of On-Demand Mobility (ODM), which focuses on the flight operations between a takeoff-site to any location without the schedule delays seen in current commercial transport. As a subgroup of ODM, UAM strictly examines the metropolitan airspace ecosystem for passenger transport of distances up to 100 nautical miles or less. As an effort to help promote public confidence in UAM and help accelerate UAM operations in the NAS, NASA's Aeronautics Research Mission Directorate (ARMD) is hosting an Advanced Air Mobility "National Campaign" which includes industry partners demonstrating aspects of actual flight missions. These mission demonstrations include simulated aircraft contingency management, advanced two-way network communications, and visual obstruction avoidance handling. It is also a desire for these industry partners to assist in developing maturity levels, what are termed as UAM Maturity Levels (UML). The higher the UML, the denser and more complex the airspace and operations become. In conjunction to hosting the National Campaign, NASA is working jointly with the FAA to develop the FAA NextGen ConOps to help provide direction to this emerging technology.

As previously mentioned, urban air transport has been a part of the airspace infrastructure since World War II and became more popular in the 1950s with helicopter operations. The operational intent is similar to that of helicopter operations but the design intent behind a UAM vehicle differs in that there is a market need for a "greener" design philosophy and the need for 4 noise reduction. After World War II, the commercial use of helicopters integrated into many roles, including firefighting, police work, agricultural crop spraying, mosquito control, medical evacuation, and carrying mail and passengers. Figure 2.0 depicts an early aerial military UAM vehicle. Certain configurations of the multirotor design, which is discussed in this paper, resembles this early depiction of an “aerial jeep”. By the 1960s, urban public living reached a space age of new ideas ranging from monorails to modular housing. By the 1980s, most urban VTOL services, including in the San Francisco Bay Area, were out of business, due to the following reasons: noise pollution, danger inherent in operations, and expensive costsFrom the 1940s – 1970s, both Los Angeles Airways and New York Airways conducted helicopter flights to transport passengers from major airport terminal areas to different locations within those metropolitan areas. In that timeframe, both airways experienced a series of tragic accidents, which led to crippling financial consequences and complete termination of operations. Currently, companies such as Airbus’ Voom and BLADE Bounce have taken over a majority of these intercity on-demand helicopter operations. The shift between use of helicopter to UAM vehicles for ODM is due to community-based regulations requiring a stricter requirement for noise reduction and engine output pollution. The aerospace industry’s attitude is shifting towards a “greener” approach as fossil fuel consumption is a quarter already of a typical flight profile. For this reason, many aerospace manufacturing companies are investigating the usage of hybrid aircraft to satisfy the current need but steering towards all electric designs for the future. Safety is also another factor for considering VTOL aircraft, as 45 percent of the total number of airplane accidents and fatalities occur during take-off and landing from 1959 through 2016.In terms of current e-VTOL aircraft technology, a flight mission could be potentially limited on certain design characteristics such as battery capacity and weight loading. The need for a lightweight vehicle that can accommodate for the weight of passenger transport is inclusive of this industry research in these "novel" operations. Currently, technology forecasts that it will be another 5-10 years before e-VTOL aircraft can successfully perform these mission profiles; however, that technology gap is rapidly closing.

To engage this emerging market for VTOL/e-VTOL aircraft to satisfy a need for rapid urban air travel, several companies have intensified the development of prototype aircraft. Future maturity models depict that these aircraft will eventually become autonomous, but early stages will have a pilot onboard being directed by conventional air traffic management personnel. Currently on the market, three configurations of UAM aircraft are leading the stage. These configurations are the multi-rotor design (wingless), the lift and cruise design, and the vectored thrust design. The multi-rotor design, as depicted in Figure 4.0, offers a unique advantage in that it has a faster certification time but has the disadvantage of having a shorter flight range and a reduced speed; hence making this aircraft suitable for short range city operations. Wingless e-VTOL are multirotor aircraft. The E-Hang 184 and the Volocopter 2X are already in the certification phase. Hoverbikes are considered a subset of multi-rotors and are usually characterized by a single seat where the rider sits on a saddle or stands up while in flight.

Fragmentation of the development

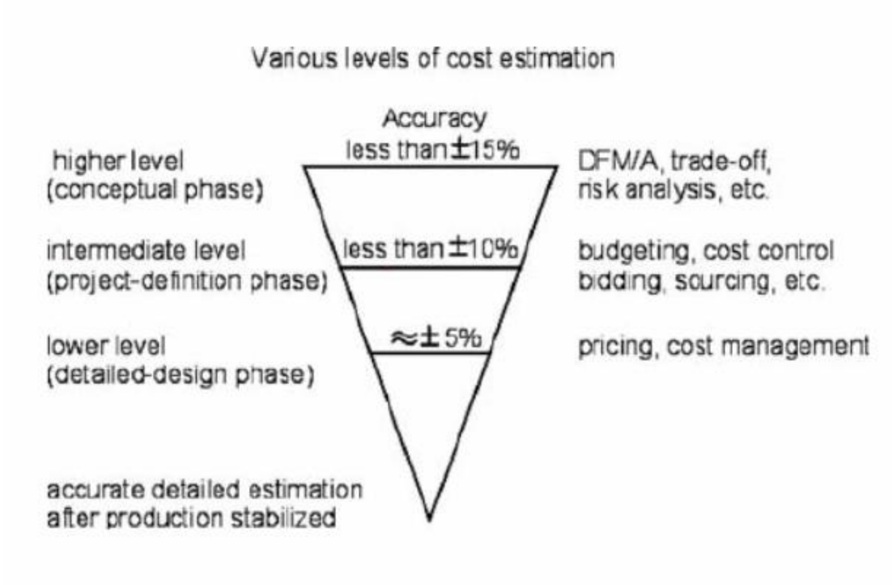
The following concepts were derived from my experience at the different engineering teams during my internship. The reason why the aircraft scenario works , w.r.t deriving foundational concepts in the development and operation of uam, is due to the prevalence of civil aircrafts in the history of aviation and the direct borrowing of standard ideals and processes. Although in the UAM market, there may be several borrowed ideas and processes, much of it must built from the ground up, essentially replicating over a century of civil aviation development in a little over a decade.

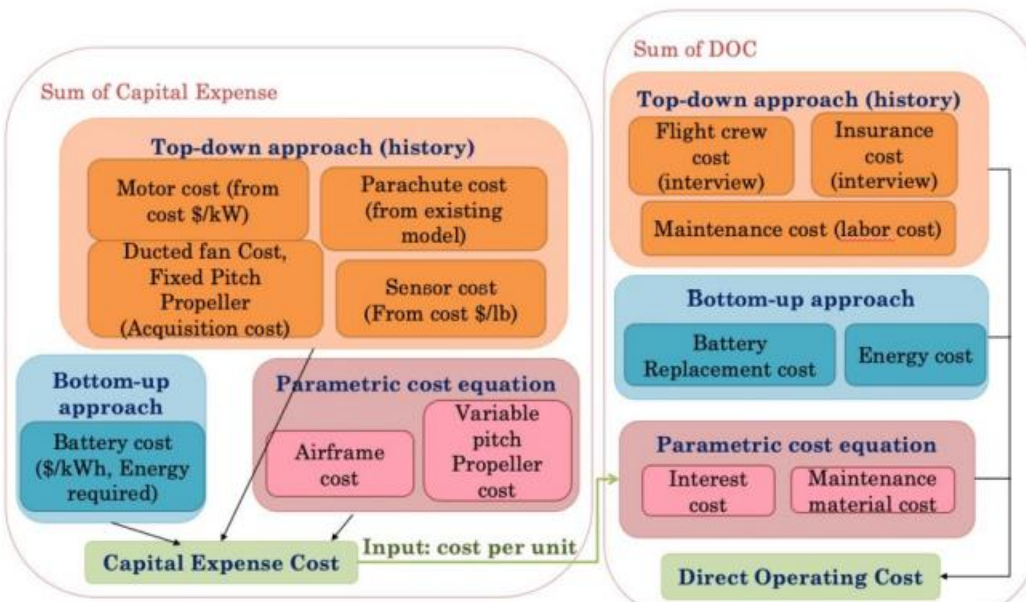
Subsection 1: **Cost Estimation of Development and Operation of UAM**

1.1 Design of the UAM

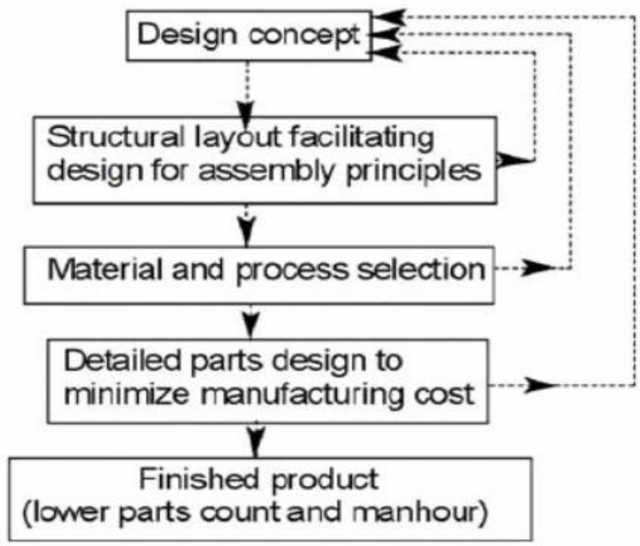
The following figure depicts cost estimation of the design of UAMs considering both development and usage. The reason why a theoretical figure cannot be presented, barring sufficiently backed R&D programs generally sanctioned by the government or large organizations, is because of the exponential increases in costs to improve the accuracy of the study to point of viability in real-world scenarios. The success or failure of an uam project depends on its cost-effectiveness. Cost-consciousness starts in the conceptual design phase to ensure competitive success. Cost analysis and manufacturing technology must be considered during the conceptual design study and integrated with classical aeronautical subjects. An increase in product value is achieved through improved performance (better), lower cost (cheaper), and in less time (faster).

Specifically with regards to UAM, the main cost of development arises from the design of a hyper-efficient model combined with an energy source(battery)***[Appendix 1-section 1(further information on battery technology]***. that has not yet been built. Akin to designing an aircraft without an engine, development must include a range of values in energy, weight, efficiency calculations which further decreases the accuracy of the study and further requires additional spending to bring the accuracy to a level acceptable by the public and by civil aviation authorities.





A general design procedure adopted by aircraft manufacturers can be used in this case.



1.2 Value of Travel Time Savings

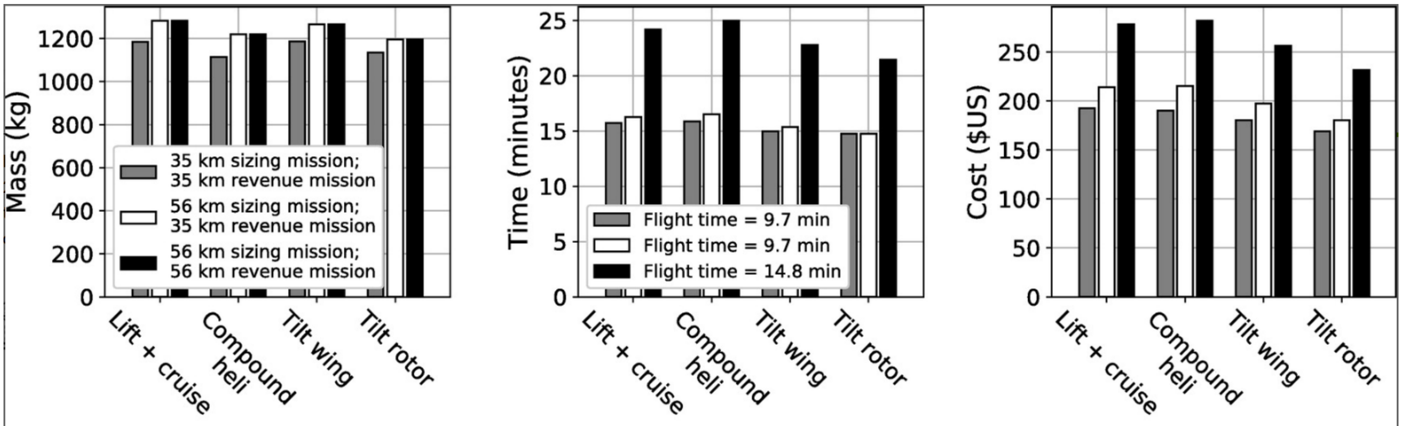
This concept allows for a more concrete understanding of why there would exist an inflow of consumers for this service. Within the ground transportation literature, a wide body of literature focused on understanding how individuals' attitudes, beliefs, personality, and similar factors influence travel behavior choices, including the adoption of new technologies which can further be extended into the aerial space given additional constraints and advantages.

A resultant case study examines this parameter more closely (Brown, A., & Harris, W. L. (2020). Vehicle Design and Optimization Model for Urban Air Mobility. Journal of Aircraft, 57(6), 1003–1013. https://doi.org/10.2514/1.c035756)

Trip distances of 35 km (19 nmi) for the direct flight and 56 km (30 nmi) for the overwater flight were selected. A comparative study was conducted, using three sets of mission inputs:

1. A 35 km sizing mission and a 35 km revenue mission: This vehicle is solely capable of flying the direct route.
2. A 56 km sizing mission and a 35 km revenue mission: This vehicle flies the direct route when carrying passengers but has the range to fly the overwater route if necessary.
3. A 56 km sizing mission and a 56 km revenue mission: This vehicle always flies the overwater route.

a) The longest direct route: West 30th Street to JFK b) The longest overwater route: East 34th Street to JFK



a) Maximum takeoff mass **b) Mission time** **c) Trip cost**

Fig. 4

Figure 4a shows that vehicle mass is not strongly affected by the mission selection. In particular, there is no difference between options 2 and 3. However, Fig. 4c shows that the effect on trip cost is significant. Flying a direct route results in substantial cost savings, even if the vehicle is sized to fly the overwater mission; this is mainly due to the reduced pilot and maintenance costs. Flight time is independent of configuration

Figure 4c shows that costs for a two-passenger trip range from $170 to $280 ($85 to $140 per passenger), depending on configuration and mission. For comparison, New York Helicopter quotes a price of $1900 per airport transfer (i.e., $950 per passenger for a two-passenger trip) on their website. Uber estimates that their service costs $200–$225 per passenger (i.e., $400–$450 for a two-passenger trip), whereas Blade announced that its service costs only $195 per passenger ($390 for a two-passenger trip). Acomparison of cost numbers must be qualified appropriately. However, the analysis presented here shows that a UAM service is, at worst, comparable to existing helicopter services in terms of cost.

A UAM service would also have to compete with existing car ride-sharing services. UAM service may cost more relative to car ride-sharing, but is superior in terms of trip time. Cost per trip values from Fig. 4 ($170–$280) are somewhat higher than those for UberPool, UberX, and UberBlack rides, and are comparable to those for UberBlack SUV rides. However, Fig. 4b shows that UAM mission times are much shorter: 15–25 min, of which only 10–15 min is flight time. By contrast, a ride-sharing trip requires at least 59–85 min, depending on the heliport of origin.

This trip time benefit can be analyzed using a value of travel time savings (VTTS) approach. Airport transfers are assumed to form part of intercity trips, and so the intercity VTTS values are used. Three trip purposes are represented: personal, business, and all purposes (average of the two, weighted by number of person-trips). A "VTTS penalty" is then defined, based on the difference between the trip time via car ride-sha ring and that via air taxi:

$$\text{VTTS penalty} = \text{VTTS} \times [t_{\text{rideshare}} - (t_{\text{flight}} + t_{\text{ground}} + t_{\text{boarding}})]$$

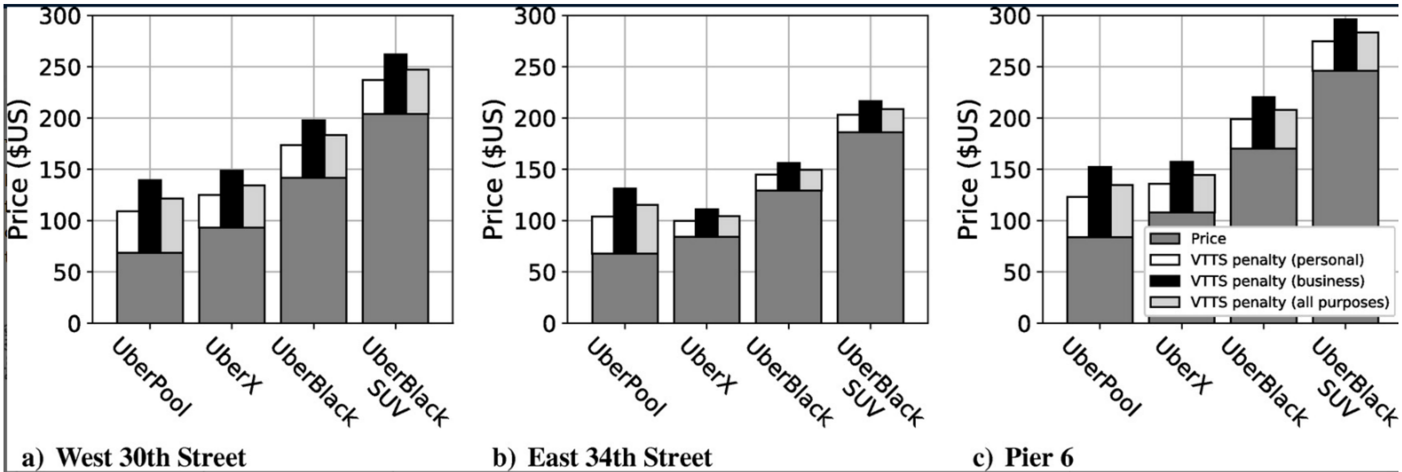


Fig. 5

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Trideshare is the time required for a car ride-sharing trip. The time required to travel via air taxi is the sum of the flight time, ground time (time required to travel to the heliport), and boarding time: tflight, tground, and tboarding, respectively. tflight is obtained from Fig. 4b, assuming an overwater revenue mission; tground is set to 1 5 min; and tboarding is set to 5 min.With VTTS penalties included, Fig. 5 shows that prices vary from \$100 to \$300. This is comparable to the aforementioned costs for a two-passenger trip via air taxi: \$170–\$280. Therefore, with VTTS effects included, a UAM service may be comparable to existing car ride-sharing services on cost.

An example of inability to operate UAM would be in New York Citybecause the primary restrictions on market size are particularly acute there. Vascik et al. [20] identified three primary constraints on UAM market size: availability of ground infrastructure, interaction with air traffic control, and community acceptance of aircraft noise. New York City has some of the highest real-estate prices in the world, so obtaining space for additional heliports, charging stations, and maintenance facilities would be very expensive; with three large international airports and numerous smaller ones in the area, the airspace ranks among the world's busiest (second only to London); and community opposition to noise is already a major issue for the city's helicopter tour operators. UAM operators must take these factors into account.

1.3 Direct Operating Costs

Direct operating costs can be subdivided into crew, maintenance, maintenance-material, battery replacement, interest, energy, and insurance costs. Subject to automation, current legislation restricts operation of UAM to active pilots with a certain degree of automated systems similar to aircraft but on a more condensed level.

From my experience at the Qatar Airways engineering dept., I've learned that maintenance of aerial vehicles is a major factor in the airline and the same could be said for eVTOLs to comply with the strict aviation rules. Therefore, streamlining of maintenance processes could be done by studying the shortcomings of the airline industry and adapting those implementations to the eVTOL industry.

With regards to personnel costs, it can be further subdivided into piloting(either remote piloting or on-board pilots)*[**Appendix 1-section 2(piloting in UAM)**]*: piloting estimates are $50k per year with the need of 1.5 pilots per aircraft, with an estimated 60,000 pilots by 2028. Subject to EASA Certification SC-VTOL-01 for VTOL/eVTOL aircraft in European airspace for automated operation. The following chart provides an overview of expectations for automated systems at different levels of regulation. The highly scrutinized level of security and safety in aerial vehicles could mean additional regulations and intensive testing and fault-reduction since autonomous systems have not been presented in a similar widespread-usage scenario in any other sector.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Subsection 2: **Airspace Model for Unmanned Aircraft Systems Traffic Management**

2.1 **UAM Traffic Management (UTM)**

UTM refers to community-based traffic management system coordinating the flights of different UAVs to avoid collisions and conflicts to ensure the safe operation of multiple UAVs into a controller shared airspace. UTM is designed to ensure UAS operations are authorized, safe, secure, and equitable in terms of airspace access. UTM imposes requirements on operations and performance commensurate with Operator, vehicle, services, operational environment, and airspace class considerations. In the summer of 2019, the FAA performed UAS UTM demonstrations under the initiative of the UAS Pilot Program (UPP) for low altitude management of the airspace. UTM Operators are ultimately responsible for maintaining separation from other aircraft, airspace, weather, terrain, and hazards, and avoiding unsafe conditions throughout an operation. Separation is achieved via shared intent, shared awareness, strategic de-confliction of airspace volumes, vehicle tracking and conformance monitoring, technologies supporting tactical de-confliction, and the establishment of procedural rules of the road (e.g., right-of-way rules). UTM Operators are required to obtain a Performance Authorization prior to conducting a class or type of UTM operation, in which they substantiate their ability to meet flight performance capabilities in their intended area of operation. Performance Authorizations are envisioned to provide credibility, stability, uniformity, and accountability to Operators participating in UTM. A Performance Authorization substantiates an Operator's ability to meet flight performance capabilities in their intended area of operation, while an Airspace Authorization grants access to operate in controlled airspace and provides the air traffic facility with jurisdiction over the airspace access to information about operations being conducted.

Due to the immense size and complexity of UTM operations in a much smaller airspace compared to civil aircraft, a more efficient form of communication between UAM is under consideration by the FAA known as LAANC (Low Altitude Authorization and Notification Capability).

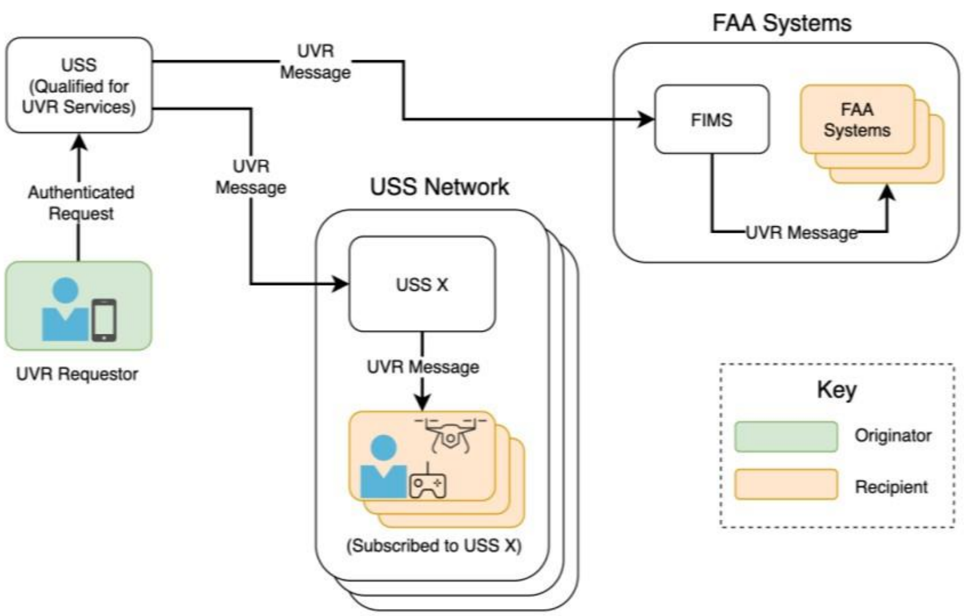
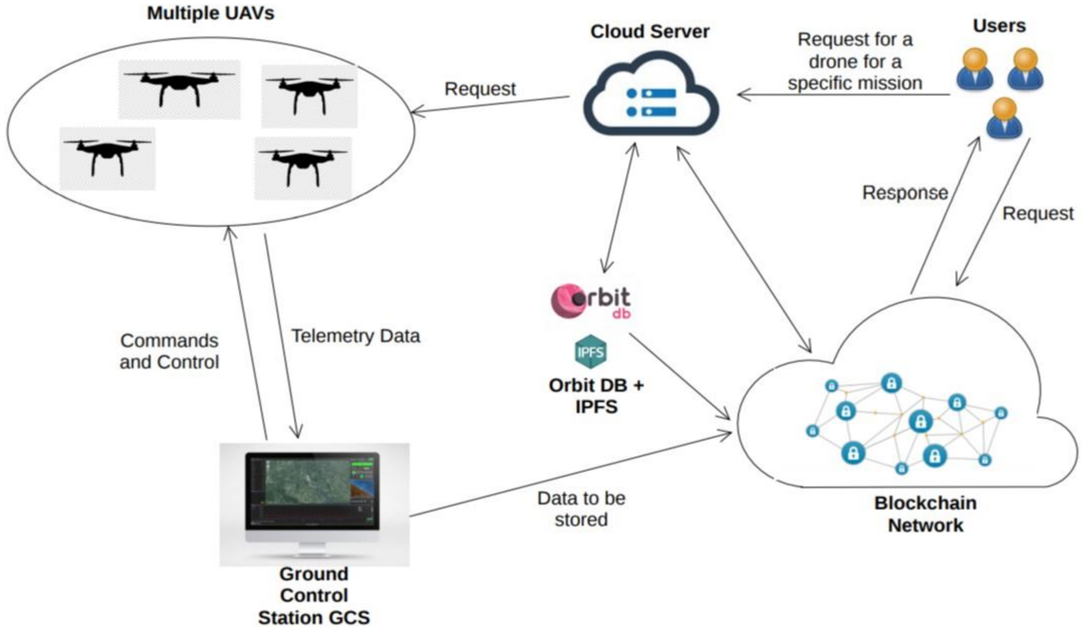


Figure 10. Notional UVR information flows



The above figures presents a blockchain solution for communication between the control center, different eVTOLs, and regulatory authorities in certain instances.

We can define different functions of a UTM center:

1) **FAA Messaging-** Services that provide on-demand, periodic, or event-driven message exchange capabilities with FAA systems to satisfy applicable regulatory/policy requirements
2) **USS Network Discovery-** Services enabling authorized UTM stakeholders to discover relevant active USS providers and operations within a specified geographical area. The network operates in accordance with applicable standards. Each USS's access to the network will be qualified against the

performance requirements necessary to be connected with the FAA portion of the network

3) **Operator Registration-** A service which provides the ability for vehicle owners to register data related to their UAS and a query function to allow appropriate stakeholders to request registration data.
4) **Airspace Authorization-** A service which provides Airspace Authorization from the Airspace Authority/Air Navigation Service Provider to a UAS Operator
5) **Constraint Management-** A service which supports provision of operational constraint information related to public safety activities, as well as applicable constraint information from the Airspace Authority/ANSP and other non-FAA authorized sources, to UAS Operators.
6) **Operator Messaging-** A service that provides on-demand, periodic, or event-driven message exchange capabilities in support of UAS Operator activities. Examples of exchanged information include position reports, intent information, and status information.
7) **Strategic De-Confliction-** A service that arranges, negotiates, and prioritizes intended Operation Volumes/trajectories of UAS operations with the objective of minimizing the likelihood of airborne conflicts between operations

8) **Operation Planning-** A service that supports flight planning - accounts for various operational impacts, including other known operations, aircraft performance, weather forecasts, ground constraints, airspace constraints.
9) **Mapping-** A service that provides airspace constraint (e.g., airspace restrictions, special use airspace, NOTAMs, UVRs) and ground constraint (e.g., public gatherings, sensitive areas, obstacles) data necessary to meet the safety and mission needs of UAS operations and support in-flight and planning-related services.
10) **Dynamic Reroute-** A service that provides real-time modifications to intended Operation Volumes/trajectories to minimize the likelihood of airborne conflicts and maximize the likelihood of conforming to airspace restrictions and maintaining mission objectives. This service arranges, negotiates, and prioritizes inflight Operation Volumes/trajectories of UAS operations while the UAS is aloft.

UAVs are sources of both air-based (i.e. near-midair collision) and ground-based risk. Mitigating one form of risk may not fully address the other, so it’s important to consider a wide range of failure modes and the effects of various mitigation efforts. a modular approach to building the risk model will capture those mutually independent hazards and failure modes. At the same time, the model must capture the interdependencies that multiple simultaneous failures can have on each other.

Appendix-1(Further Information)

Section 1- Present Battery Technology and expected advancements

Improvements in rechargeable batteries are enabling several electric urban air mobility (UAM) aircraft designs with up to 300 mi of range with payload equivalents of up to seven passengers in High-Capacity Commercial Sizes (This means the easier it is to manufacture a battery product, the cheaper it would be in mass production). Novel UAM aircraft consume between 130 Wh/passenger-mi and ~ 1,200 Wh/passenger-mi depending on the design and utilization, compared to an expected consumption of over 220 Wh/passenger-mi and 1,000 Wh/passenger-mi for terrestrial electric vehicles and combustion engine vehicles, respectively. A minimum of 400 Wh/Kg is required for Sustainable operations. In Creating a Battery that satisfies the 400 Wh/kg threshold we must also look at

1) The charge rate (how quickly the battery can be brought back to a nearly full charge, which determines operational idle time) of batteries today is also too slow to support high-frequency ridesharing operations (Uber Elevate 2016).

2) Cycle life (the number of charge/discharge cycles the cell can sustain before its capacity is less than 80% of the original, which determines how often the battery must be replaced); Trade-off between energy storage density and cycle life because of the high power required in transition flight
3) cost per kilowatt-hour (which determines the overall battery cost)
4) safety standards are met-new framework created in collaboration with CAA, transport authorities and global(UN) authority; In use and post electric crash electric safety requirements with preference for performance-based safety requirements in order to provide the necessary flexibility to accommodate future innovations sufficiently comprehensive requirements without options will avoid the need for country-specific regulations

We also find that several UAM aircraft designs are approaching technological viability with current Li-ion batteries, based on the specific power and energy, while rechargeability and lifetime performance remain uncertain. Presently, there is active development in different types of battery cells, most notably SION power(phoenix) creating a licerion(ev) cell achieved 400 Wh/kg in a pouch cell(focused on ev sector), quantumscape solid state battery- 380 to 500 wh/kg, tesla nextgen batteries aim for 380 wh/kg.