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Research Article

Urban Air Mobility (UAM) Network. Case Study: Baku Metropolitan Area

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Abstract

The development and implementation of the Urban Air Mobility transportation system, using electric vertical takeoff and landing (e-VTOL) aircrafts are the most promising solutions to mitigate growing congestion in big cities. The multiple studies and assumed forecasts indicate a transformation of urban and regional transportation infrastructure while applying the air mobility concept. This study analyzes the feasibility of UAM operations focused on the selection of service segmentation with relevant use cases, which allows for define suitable air vehicle configurations for optimization of possible air network development for Baku city and suburban areas. The result of the study introduces air vehicle features, including flight range, payload ratio, as well as several aspects of weather condition for safe operations, and outlines approaches to defining suitable regulatory framework requirements for public departments. The findings provide a practical perspective for urban planners and involved single companies, which may be useful guidelines at the initial stages of UAM services and obtaining significant information about e-VTOL aircraft and their design configurations to overcome arising barriers in the implementation processes.

Keywords

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1. Introduction

The global aviation industry continues to evolve, increasing safe operation, applying highly automated systems (Jazzar et al., 2022) and technological changes, transferring urban ground transportation into airspace operations over large cities by implementing unmanned aerial vehicles (UAV). Unmanned flights had fascinated society's imagination for thousands of years (Balakrishnan et al., 2018), from the time of the 8th century mentioned in the "One Thousand and One Nights" flying carpet (Magic Carpet), collection of Middle Eastern tales (Schwartz, 2023). Confirmation of existing borders between seas and incredible different structures of the finger ends of each personality, now the concept of magic flying cars becomes an unavoidable reality, although nobody would believe that a hundred years ago.

Application of enhanced design concepts, development of sustainable battery technologies, and combination of distributed and electric propulsion systems, have led to the creation of various configurations of electrical vertical take-off and landing (VTOL) vehicles for urban passenger air transportation at low altitudes (Shamiyeh et al., 2018). Implementation of the UAM concept assumes an expanded market to ensure the growth of a multi-modal air transportation system with flexible and high-speed features carrying individuals around urban environments over short to medium distances. The advantage of the new transport mode is that it allows safely and efficiently faster movements through the air reducing trip times and enabling direct node-based

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routing (Antcliff et al., 2016; Straubinger et al., 2021).

In the last two decades, Azerbaijan has made large investments-billions of dollars in road infrastructure across the country - setting up new highways and renewing long distance roads. Within the biggest metropolitan area, particularly in Baku and suburban areas, there have been laid new roads, alternative crossways, bridges, and several parking zones, however traffic congestion is still a major problem. Especially the dramatic road jams in town with very slow traffic, delaying the movements over an hour in peak periods. Although the investigations by Duranton and Turner (2011) and later on Hymel (2019) suggested that building roads is not a solution to reduce urban traffic congestions. Comprehensive solutions to alleviate traffic congestion in large cities are becoming necessary for the implementation of new transportation modes that provide high-speed mobility. In this context, the Urban Air Mobility concept is the best approach to entry to service, envisioning low-volume passenger vehicles, and e-VTOL aircraft able to complete aerial missions at low altitudes (Melton et al., 2014).

The purpose of this study is to investigate the use of eVTOL aircraft in the airspace of the Baku metropolitan area, considering passenger segmentations use cases, network planning, vertiport and navigation infrastructure requirements, weather conditions and suitable aircraft selection. The theoretical setting and other presented equations formulated in this paper have practical and theoretical implications for local researchers to consider for future empirical investigations, as well as for stakeholders and decision makers to overcome the challenges, relying on the technical specification of important components of e-VTOL aircraft. In addition, the study is filling a gap in the literature dedicated to UAM operations, particularly the the point of view of Azerbaijan, which is the first represented research topic.

Therefore, Section 2 is Literature Review, Section 3 is representing a detailed e-VTOL Aircraft Design Architecture and Configuration, Section 4 implies Theoretical Setting, Section 5 consists of a Description of the Study area and weather characteristics, Section 6 demonstrates a Result and Discussion, and finally the Section 7 is a Conclusion.

2. Literature Review

Initially, Moore (2010) suggested a growth on-demand mobility (ODM) model in UAM operations, using electric propulsion aircraft. Later on, Patterson et al. (2012), studied its potential benefits and application problems. For the optimization, development, and rapid spread of highly automated systems, Alharasees et al. (2022) highlighted the air vehicle operator's role and responsibility, offering to change working conditions and apply new management methods.

Contribute to the realization of UAM operations in European airspace, EASA (2022) has reviewed more than 150 different e-VTOL aircraft configurations that are currently in the development stages and has issued a document named Special Condition SC-VTOL-01 to enable a fair certification specification, either for traditional aircraft or helicopters.

In addition, the collaborative document, Version 2.0 Concept of Operations (ConOps), was recently issued by FAA (2023) based on feedback from Version 1.0 Con Ops, considered by the National Aeronautics and Space Administration (NASA, 2020) and industry stakeholders. This current document describes key points of overall Advanced Air Mobility (AAM) concept aimed at upgrading an urban air transportation system and infrastructure, covering operation stages, operator function, vertiport consideration, traffic management, airspace corridor evaluation, as well as weather and obstacles within the UAM environments (FAA, 2023).

Besides scientific studies, NASA performed numerous seminars setting up road mapping for ODM aimed at identifying potential problems and appropriate solutions arising in the maturity process. The result of these workshops identified significant interest in the use of e-VTOL for inter and intra city missions and between the regions from future perspectives (NIA, 2017; Uber, 2016). Gradually growing community interest and associated with future benefits realization of UAM mobility using e-VTOL aircrafts applying in various business segments require an effective program to develop a subset of the operational infrastructures. Researchers in the UAM operation fields consider aggregate coverage of involved infrastructure through the utilization of regulatory frameworks and national civil aviation regulations.

The study by Mazur et al. (2022) introduced detailed analysis to determine the main goals of international regulatory agencies (ICAO, FAA, and EASA) and applicability of existing regulations for future operations relating to e-VTOL aircraft carrying passengers and freight over populated large cities. The authors identified that UAM operational subsystems required standard design and applications to ensure safety and efficiency under international requirements. In this context, Kale et al. (2023) argue that airspace management and air traffic control are big challenges with a high volume of air traffic in the future, prompting the funding of NextGen, SESAR, and other international large-scale programs.

The study by Alharasees et al. (2023) demonstrated the importance of communication systems ensuring effective feedback between ground station operators (vertiports, helipads, and vertihubs), ATC, and pilots, as well as high level Information Technology (IT) applications to serve, navigation and surveillance. Furthermore, environment protection (noise, pollution, emission) consequently, reduces its negative effects and other objectives closely linked to airplane operations, as recommended in the studies performed by Ekici et al. (2013), Karakoc et al., (2016) and Yazar et al., (2018). Urban Air Mobility actually consists of service segmentation with various business model operation functions within urban environments as part of public air transport depending on population demands. A detailed introduction of the rest of the infrastructure including, the air vehicle operator, airspace traffic management, ground facilities (vertiports, communication), and maintenance concerns is briefly considered as the study subject of this paper.

3. e-VTOL Aircraft Design Concept, Performance, and Configurations

The air vehicles proposed for UAM operation equipped with an electric propulsion system (rotor, propeller), fed by enhanced battery technologies, rely on high density battery packs with a protection system and an electronic speed controller system, while producing a low emission, most probably equal to zero. Most design firms work on concepts with separated propulsion and a multirotor tilting system, concentrating to reducing noise levels up to 55 decibels (dB), (Butterworth-Hayes and Stevenson, 2019; Di Vito et al., 2023) less than a helicopter.

The basic design of e-VTOL aircraft has several configurations which include wingless, fixed- wing and tilt-wing concepts providing lift and cruise, vectored thrust, and hybrid thrust functions. Wingless e-VTOL air vehicles consist of a different number of multirotor propulsions, powering the thrust for hover and forward flight simultaneously. Powered lift aircraft with fixed-wings are able to fly significantly at high altitudes with efficient speed in cruise, carrying out extended ranges which exceed the capabilities over wingless types.

The most 150 leading Original Equipment Manufacturers are in the process of design developments on the 27 different types of fixed wing with tilt-rotor and vectored thrust configurations (Hirschberg, 2019; Darvishpoor et al., 2020) in strong competition. However, fixed- wing mounted tilt-rotor configuration causes a drag during take-off and landings.

Tilt-wing design with tilt-rotor is capable for long range, and very efficient during hovering take-off and landing. On the other hand, tilt-wing configuration creates high stress and vibrations, because the tilt actuators are placed in the fuselage section and along the wing roots Kraenzler et al., 2019; Akash et al., 2021).

Multi-rotor e-VTOL aircraft are equipped with three or more motors with appropriate propellers that generate thrust during take-off and forward flight by sustaining aerodynamic stability. The lift and cruise configured air vehicles use one set of motors for hovering, and other sets provide thrust during cruise. In the different prototypes e-VTOL vehicles also introduced the use of electric ducted fans (Bacchini and Cestino, 2019) and reliable Distributed Electric Propulsion (DEP) systems (Fard et al., 2022). Different design architectures and battery specifications of future e-VTOL air vehicle is represented in Figure 1.

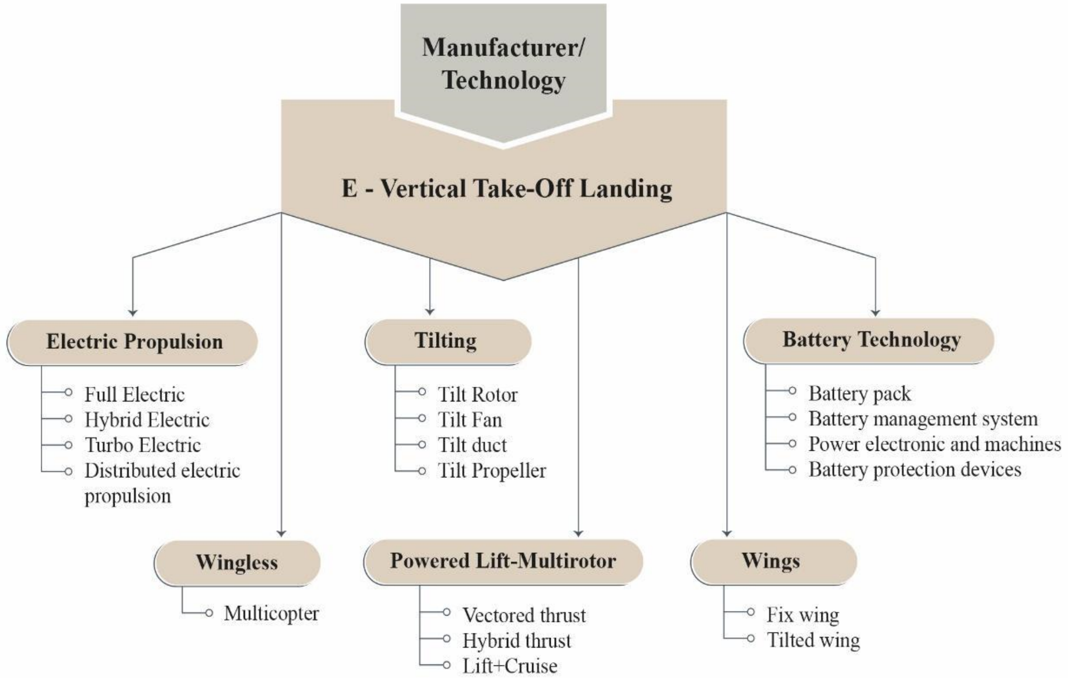

Fig. 1. The e-VTOL design type and parameters of future e-VTOL air vehicles

Table 1. Commercial performance of e-VTOL aircrafts (Source: VFS, 2023)

Manufacturer	e - VTOL	PAX	Range km	Speed km/h	ALT Meter	Empty Weight, kg	Payload kg	MTOW kg
Airbus	City Airbus	1+3	80	120	3100	1950	250	2200
Archer	Midnight	1+4	80	240	610	1050	450	1500
Beta Tech	ALIA-250	4	463	270	2438	2540	635	3175
E-Hang Intel. Tech	EHang216	2	35	130	3000	360	260	620
Jaunt Air Mobility	Jaunt Journey	1+4	129	282	1829	1633	453	2722
Joby Aviation	S4	5	290	322	3350	1950	453	2404
Lilium	Lilium jet	7	300	300	3048	1800	700	2500
Vertical Airspace	VA-X4	4	161	241	3000	2750	450	3200
Volocopter	VoloCity	2	65	110	1981	700	200	900
Wisk aero	Cora	2	100	180	900	1088	180	1268

Features and technical data of e-VTOL aircraft differed by variety of operation performances in terms of take-off weight, payload capacity, passenger seats, cruise speed, and flight distance. Those main operational parameters of UAM aircraft are important for future UAM operators to define the objective of established companies to predict their area of activity. A summary of willing aircraft mission capabilities found in the open sources is shown in Table 1. The majority of proposed features can be considered when purchasing UAM air vehicles suitable for the geographic location of the given country

The above-mentioned shortlist is considered to be high-level propulsion technologies for today's design concept of UAM vehicles introduced by the top ten Original Equipment Manufacturers. Among them there are different e-VTOLs with different design philosophy as a wingless multi-copter, hybrid, lift + cruise, tilt-rotor, tilt rotor + wing, and thrust vector concepts (Vieira et al., 2019). CityAirbus, EHang, and Volocopter have a range less than 100 km which is suitable for short distances within metropolitan areas; Joby S4, Alia-250, and Lilium Jet have a long-distance capability of over 300 km, while ensuring connectivity between regional cities, the remaining aircraft aiming to operate between city centers and suburbs/rural areas. The airspace coverage area consists of a maximum cruise altitude of up to 3350 meters, which makes it very important to follow noise requirements at every range of height levels.

Requirements applicable for air vehicles to ensure UAM network operation are manifold and depend on particular regions. In order to evaluate their mission effectiveness, profitability, and economic feasibility, a vital role plays in determining the specific required power of motors and propellers as well as the energy efficiency of batteries to meet the operational objectives of UAM operations at selected routes. Table 2 stipulates the current design configuration of ten e-VTOL aircraft manufacturers with a number of rotors, motors, and propellers specifications for optimization of future operation of the offered vehicles types. However, the given parameters may differ from real characteristics taking into account several factors. The presented characteristics are important relative to cruise, landing maneuvering, and hover/vertical flight efficiency, which would shift the initial design accounts and lead to completely different optimal features.

Table 2. Design configuration of future e-VTOL air vehicles (Source: VFS, 2023)

Manufacturer	e - VTOL	Design Configuration
Airbus	City Airbus	Multicopter, 8 pitch rotors and 8 ducted propellers
Archer	Midnight	Vectored Thrust 12 Elec. Propellers, 6 Tilt and 6 Fixed Propellers
Beta Tech	ALIA-250	5 Electric Motors, 5 Propellers, 4 Fixed and 1 pusher Propeller
EHang Intel.Tech	EHang216	Multicopter, 16 lift thrust rotors and 16 propellers
Jaunt Air Mobility	Jaunt journey	Electric Rotorcraft 4 Propellers, 1 Rotorblade, 5 Electric Motors, Tilted Rotor
Joby Aviation	S4	Vectored Thrust 6 tilt propellers and electric motor
Lilium	Lilium jet	Vectored Thrust 36 ducted Fans 36 electric motors, Tilted controllable flaps
Vertical Airspace	VA-X4	Multicopter 8 propellers and electric motors, Tilted Rotor
Volocopter	VoloCity	Multicopter, 18 pitched propeller, 18 rotors
Wisk aero	Cora Gen 5	Multicopter, 12 propellers and1 Forward flight pusher propeller

4. Theoretical Setting

Theoretical setting considers the importance of reliability of key components, mainly powertrains and battery technology. Electric motor/propeller parameters are important, because of their direct relations to the power (required) requirement (called specific power) during vertical flights, called hovering phases ((take-off (TO) and landing)). During hover (TO/landing) the e-VTOL aircraft use all motors, flying in multi-rotor mode, until switching to cruise mode.

Efficiency and high performance vertical and cruise powers, classified as power required, of electric propulsion systems for e-VTOL aircraft, largely determine their capacity in terms of payload and range of operation (Palaia et al., 2021a; Ugwueze et al., 2023).

The initial energy source of e-VTOL aircraft has been highlighted as a determinant of payloads that rely on battery specific energy density depending on battery weight, which consists of packs, energy management, and thermal protection systems.

The variation of the battery weight depends on the specific energy density controlled by its rates, and the payload range is calculated considering the battery weight for the fully loaded aircraft using the total energy availability. Moreover, the availability of total energy is computed by adding the energy required for each mission phase, which the flight range is extended with a decreasing number of passengers (Akash et al., 2021).

The introduced equations (1-10) describe electric propulsion modeled according to the actuator disk theory, which is similarly applicable for wingless and powered lift configurations. The battery system power models presented in this study are used to classification battery specifications in operational and demand terms for each mission phase of e-VTOL vehicles.

The model describes the assumption that air flow across the rotor disk is constant and weight (W) is equal to the thrust (T) produced by rotor disk, therefore ideal specific power (SP) during hover stage is consequently, equal to product of rotor thrust and induced velocity (T_{v_i}), *which* ($SP_{hover,i} = T_{v_i}$), where;

$$T_{v_i} = \frac{T^{3/2}}{\sqrt{2\rho A}} \tag{1}$$

For accurate estimation of hovering power and to account losses because of the profile drag acting on the rotor blades introduced a figure of merit (FM), which represents the actual specific power (SP) required for hover ($SP_{hover} = SP_{hover,i} \,/\, FM$) is expressed as following (Eq 2)

$$SP_{hover} = \frac{T^{3/2}}{FM\sqrt{2\rho A}} \tag{2}$$

The specific power for the climb and descend determinants as ratio between specific power during climb and descent (P_{climb} and $P_{descend}$) to the power during hovering (P_{hover}) that use the e-VTOL aircrafts $\left(\frac{P_{climb}}{P_{hover}} \; and \; \frac{P_{descend}}{P_{hover}}\right)$ whereas, climb and descend velocity is equal to vertical velocity ($V_{climb} = V_{descend} = V_v$).

In the case if the ratios (V_v/v_{hover}) more than or equal to zero, the vehicle is moving to upward direction, and vice versa, if the value is less than or equal to zero, the vehicle is in the downward position. Consequently, the specific power (SP) for climb and descend is expressed as follows, according to (Eq 3 and 4);

$$SP_{climb} = \frac{V_v}{2v_{hover}} + \sqrt{\left(\frac{V_v}{2v_{hover}}\right)^2 + 1} \tag{3}$$

and

$$SP_{descend} = \frac{V_v}{2v_{hover}} + \sqrt{\left(\frac{V_v}{2v_{hover}}\right)^2 - 1} \tag{4}$$

Equations (2, 3 and 4) represent the specific power that complete the power models required for vertical flights (Mattingly et al., 2002; Newman, 2007; Johnson, 2012; Gudmundsson, 2013; Palaia et al., 2021b; Ugwueze et al., 2023). However, depending on technological improvement, in the future it can be replaced with new design configurations applying modern concepts and theories.

NOTE: Power required is used as actual power required and expressed as specific power (SP) requirements.

However, at cruise altitude, the flight dynamics differ between the powered lift and wingless types. The powered lift type is considered a fixed-winged aircraft, and the corresponding fixed-wing power models are applied, with adaptations for a battery energy source. The SP to cruise for the powered lift (PL) aircraft types ($SP_{PL\ cruise}$)

is expressed referring to (Eq 5).

$$SP_{PL\ cruise} = \frac{1}{\eta_{prop}} D\, V_{cruise} \tag{5}$$

The specific power required at cruise flight level is lower than the in vertical modes (hover, TO and landing) accordingly, a variable pitch propeller has been assumed in order to avoid a reduction in propeller efficiency (η_{prop}).

Meanwhile, the wingless e-VTOL type is modeled as rotorcraft in forward flight and the SP to sustain the wingless (WL) air vehicle types during forward flight and the SP to sustain the wingless (WL) air vehicle types during forward flight ($SP_{WL\ cruise}$), the applicable (Eq 6) is given as;

$$SP_{WL\ cruise} = T\,(V_{cruise} \sin \sin \alpha + v_i) \tag{6}$$

The function of total drag (D) and its thrust (T) determinants the angle of attack (α) in variation during flight depending on taking the cruise velocity (V_{cruise}).

Specific energy demand during vertical flights which covers hover, climb and landing phases absolutely obtained from the (Eq 7) as follow;

$$BSP_{hover} = \frac{1}{\omega_{bat}} \frac{g}{\eta_h} \sqrt{\frac{\sigma}{2\rho_{air}}} \qquad (7)$$

Analysis of the power requirements and demand of e-VTOLs batteries reveal high discharge rate during vertical flights, however during cruise flight the battery consumes less energy slowing down the discharge trend. The energy estimation is adjusted to account for two aspects of flight, which include the cruise flight and trip duration (Yang et al., 2021). The battery requirements for specific power during a cruise are as follows (Eq 8);

$$BSP_{cruise} = \frac{1}{\omega_{bat}} \frac{g}{\eta_c} \frac{V_{cr}}{\frac{L}{D}} \qquad (8)$$

The energy requirement for cruise flights is based on load factor, depending of the trip length, which calculating according to Breguet range formula (Eq 9), (Patterson et al., 2012; Kasliwal et al., 2019),

$$R_{trip} = SE_{trip} \frac{L}{D} \frac{\eta_c}{g} \omega_{bat} \qquad (9)$$

Energy storage capacity is measuring its operational suitability, which average usable battery efficiency typical for lithium-ion batteries varies between 80% and 90% (Yu et al., 2020; Zhao et al., 2021), while specific energy density is between 170 Wh/kg and 350 Wh/kg (Adu-Gyamfi and Good, 2022). The number of charging cycles of lithium-ion batteries impacts their life cycle and longevity, as well as charging level over time. The charging times of batteries are accounts according to (Eq 10),

$$t_{char} = \frac{SE_{trip}}{SP_{char}} = \frac{R_{trip}}{SP_{char}} \frac{g}{\eta_c \omega_{bat} \frac{L}{D}} \qquad (10)$$

The minimum state of charge is 20%, and setting the minimum capacity protects the battery from damage, improves the overall battery life, and reduces maintenance costs. Full-electric e-VTOL aircraft operating for UAM missions, may also utilize the extra battery reserve to be able to use if an exceptional emergency occurs at a low battery level (Ugwueze et al, 2023). The given main technical data statements for electric motors/propellers and battery characteristics have the same purposes for the safety operation of e-VTOL aircraft as well as a visual introduction for readers and future stakeholders. The aim is to accept the importance of systems upon operation and to consider future fleet management and maintenance actions to ensure prescriptive safety in the proposed region.

5. Description of the Study Area

Baku is selected as a large and most traffic congested city during the daily working hours, which proposes to analyze the feasibility to applying UAM mission models to solve the intra-city transportation challenges. However, suburban road connections with city centers also desire improvement to mitigate congestion by using the UAM concept. In order to satisfy the explored mission requirements, it is necessary to define accurate population distribution, flight destinations, air routes, landing areas for vertiport locations, and weather conditions that are not specifically ordinary for air transportation at low altitude, particularly in Baku megapolices. For this study, the first priority junctions are air-routes between the city center and nearby districts that have a tighter relationship relating to business and cultural matters. Because of excessive traffic congestion between these geographic areas, it has become necessary to create air connection routes in order to mitigate the challenges on the roads entering city centers from four directions. Due to the allocation of most administrative authorities, health care service centers, universities, and entertainment facilities in downtown surroundings congestion remains a huge problem for the urban population and its guests.

The considered network design area is the city center and surrounding suburban places, which have 12 administrative regions, and 59 townships (Presidential Library, 2019). These township cover 2140 sq.km of land surface, with total populations consisting of 2.464.162 at the end of 2023, and average density 1092 people per 1 sq.km (WPR, 2024).

According to Baku General Plan, developed until 2040, the city center will be classified into applied three types;

1. The main center-which includes the central districts of Baku city (Nasimi, Sabail, Yasamal, Narimanov, Khatai) ensures a hub of administrative and business services, as well as cultural events and touristic purposes.

2. Municipality centers-located nearby from downtown (Hovsan, Sabuncu, Lokbatan, Zigh, Khirdalan*Binagadi) as a suburbanly populated area providing access to city centers from several efficiently managed public ground transportations.

3. The regional urban centers-located far away at the edge of the metropolitan area, were assigned the strategically important entry gate directions to Baku center from the North (Sumgait*), West (Alat) and East (Mardakan). These three regional centers hold significant land capabilities, enabling the expansion of useful territory and population growth advantages in the region.

Note*: Khirdalan and Sumgait are out of the Administrative Boundaries of Baku City.

The Baku General Plan proposes a polycentric development model based on the existing context, which aims to ensure equal levels and opportunities of appropriate services for each city resident. Thus, the proposed multiple urban centers system is a guide for common spatial development, which in turn will improve the quality of life of the population (Arxcom, 2024).

5.1 Weather Characteristics of the Study Area

Baku metropolitan area has its own specific environment, especially geographical location surrounding Caspian Sea and vulnerable weather conditions accompanied by intensive north winds and gusts. Boundary conditions for flight operation existed a long time upon entry into commercial aviation, which limited even the life cycle of the airframe because of high humidity. Air vehicles suitable for this study most certainly will combine various technical and commercial characteristics, taking into account the unstable weather conditions typical of Baku city and suburban areas.

(A). Density altitude (DA) is the pressure altitude above mean sea level (MSL) corrected for non-standard temperature, in which the air has a certain value of density. DA is a unit describing the performance metric of the aircraft; thus, air density is an important weather factor impacting aerodynamic and engine power output features accordingly, the calculation of density altitude allows to define the accurate elevation for landing and take-off for aircraft.

Density Altitude calculations are beginning to find out the value of air density, first considering ideal gas low ((Rd = J / (kg X deg K) = 287.05 for dry air)), using the standard ISA sea level parameters expressed as;

P = 1013.25 Pa, T = 15 deg C (deg K = deg C + 273.15), and the air density at sea level, D = 1.2250 kg/m3.

Applying the given steps below, density altitude can be calculated by known weather parameters:

a) Ambient Temperature (Degree of Fahrenheit (F) or Celsius (C))

b) Dew Point (Deg of F or C)

c) Altimeter Setting (Pressure, mb)

d) Absolute Pressure (mb), and

e) Air Density (kg/m3), using the dew point temperature according to (Eq 11);

$$\rho = \left(\frac{P_d}{R_d T}\right) + \left(\frac{P_v}{R_v T}\right) \tag{11}$$

f) Water Vapor Pressure (WVP).

Water vapor pressure is a calculation that comes across saturation vapor pressure as a polynomial developed by Herman Wobus according to (Eq 12);

$$E_S = \frac{e_{so}}{p^8} \tag{12}$$

However, following the curve fitting equation, often called Tetens' Formula, which WVP gives accurate results by applying (Eq 13);

$$E_S = c_0\, 10^{\frac{c_1 T_c}{c_2 T_c}} \tag{13}$$

particularly at higher outside air temperature, when saturation pressure becomes significant for the DA calculations.

The equations and proposed steps for density altitude calculation introduced by Shelquist (2024), are similarly demonstrated in Appendix 1 (airdensityonline, 2024) by comparing the recent (30.08.2021) and current (01.01.2024) available data weather conditions for Baku city, which indicate a variety of values in different seasonal periods which is important to consider upon implementation of UAM operations, especially altitude density.

Determination of density altitude is important to clarify prescriptive aircraft performance at a given flight level and monitor the parameters during vertical climb and descent. The measurement of the density altitude for a particular location is carried out by affecting three key atmospheric factors; air pressure, temperature, and humidity. High ambient air temperatures are less dense, therefore, by increasing altitude, the air density (according to Equation 11) is reduced accordingly. In spite of the fact that humidity does not significantly impact density altitude, the volume of water vapor in the air determines the precise calculation of density altitude according to Equation 13. High density altitude has a negative effect on aircraft aerodynamic performance, particularly during take-off and climb rates influenced by temperature; humidity mainly reduces engine thrust power as well as rotors and propeller efficiency (FAA, 2008). Density altitude is highest during the summer due to the higher temperature inherent to Azerbaijan, and in the winter weather density altitude is significantly lower in all Baku urban areas.

(B). Impact of wind speed and gust on e-VTOL aircraft operations are primary weather parameters in areas such as Baku, where wind speed and direction can be changed at any time of the day and hours. The definition of wind/gust limitation for each particular urban proposed air vehicle contributes to the selection of aircraft types for its future operations in unstable weather conditions. Requirements for wind velocity and gust are under standard rules, but analysis of the impact of turbulence, tailwind, and crosswind requires detailed investigations for aircraft with low-speed approaches and hovering landing and take-off features. Key principles and flight rules of UAM aircraft operations in the near-term are assumed using Visual flight Rules (VFR) and instrument flight rules (IFR), and mid-term ConOps will be applied to published Radio Navigation Performance (RNP) routes and instrument procedures (Boeing, 2023). The VFR operation rule in snow conditions requires visibility of 0.5 miles (800 meters), with an ambient temperature of -4˚C and initial take-off and final approach phases at relative steady wind condition have been considered at 17 kts (31.5 km/h), (EASA, 2019). Due to its location on the Absheron Peninsula, Baku and its surroundings are opened by the coast of the Caspian Sea from three directions, while the North wind is mostly prevailing, followed by other directions. Maximum wind speed reaches 40 kmph (21.6 knots), and average speed consists of between 15 and 25 kmph (8 and 13.5 knots). Average wind gusts fluctuated between 25 kmph and up to 40 kmph (13.5-21.6 knots),

Indeed, wind characteristics are an influential factor in the design configuration and aerodynamics of the aircraft, moving air over the surface and transforming it into pressure. Measure of the force exerted on a surface by the wind, expressed as a force or wind load on the whole surface, which in the International System of Units (SI) is Newtons or Pascals (Johnson, 2020). Wu et al. (2019) conducted a detailed overview of gust loads on aircraft and concluded that the induced force influences the detrimental effect on aerodynamic performance and structural damage under increased loads. Pradeep et al. (2020), investigated optimal trajectories at wind conditions for multicopter type of e-VTOL aircraft and found that it restricts flight endurance due to the low specific energy of Lithium-ion batteries. Schweiger et al. (2023) examined the impact of wind/gust speed conditions on UAM air vehicles in the Hamburg and Munich areas and recommended considering decisions for vertiport locations and traffic flow performance.

Consequently, the determination of specific power rotor/propeller and batteries need to add the loads extracted by wind speed and gusts to the existing design performance. This can be expressed as an error coefficient or factor of wind/qusts load $(F_{(w/g)l} = W_{l})$, deemed for recalculation of e-VTOL design parameters to obtain an accurate result considering the wind load on rotor/propeller dynamic characteristic as per (Eq 14).

$$F_{(w/g)l} = \frac{1}{2}\rho V^2 A \tag{14}$$

As far as the square surface area of particular air vehicles is unknown, the precise power of rotors/propellers will remain unpredictable. Wind force will reduce the power efficiency of rotors/propellers, while reducing the battery energy density to an equivalent value. The value of equations (2-9) from the constant value will be shifted to the real value, accompanied by wind load factors.

The evaluation of the weather barriers for UAM operations introduced by Reiche et al. (2021) demonstrated the impact of wind speeds, dividing them into four categories: slow between 0 and 15 knots, and median average is 15-20 knots, high scale is 15-20 knots, and the value more than 25 knots is critical. The result found that vertical wind shear (gusts) over 35 knots will be dangerous for e-VTOL aircraft operations over megacities. Furthermore, NASA in collaboration with AvMet Applications Inc., set up a wind threshold for UAM air vehicles (Ng, 2022), classifying horizontal wind speed limitations as <15 ± 5 kts (green), <20 ± 10 kts (yellow), >25 kts, or gusts >35 kts (red).

The use of comprehensive weather conditions, including air temperature, rain, wind, cloud, icing, and precipitation is accompanied by operational restrictions on the overall air transportation system, and under these circumstances, UAM operation is not excluded as a new transportation mode. Taking into account the limitations associated with periodic variation in ambient air parameters, uncertainty remains a main challenge because of the regulatory framework, and standard procedures laid out based on actual data of e-VTOL aircraft performance as well as air navigation route characteristics at low altitude.

The smaller size e-VTOL aircrafts are more vulnerable and sensitive to weather conditions such as wind shear and gusts, air pressure and density altitude, visibility range, low altitude icing conditions and overall temperature changes. Indeed, UAM vertiport is capable of getting up-to-date weather information through sensors and transferring it to the relative operational station, ensuring reliability and safety at each stage of air vehicle flights. Recognizing the potential weather challenges, meteorological analysis is a serious matter for providing substantial UAM aircraft operations. Available historical weather data obtained from the World Weather Application Programming Interface (WWAPI, 2024) allows an assessment of the meteorological status of Baku city, in order to examine the future challenges and advantages of UAM operations, and applying advanced preventive actions.

6. Results and Discussion

To establish a successful UAM operation, efficient infrastructure with suitable characteristics is essential. The elements and relevant performance of UAM ground infrastructure and airspace management have to provide passenger and aircraft throughput at a satisfactory level in all stages of flight operations. Therefore, a properly managed relationship among the involved infrastructures contributes to setting up useful urban mobility network options. For UAM operators and flight planning management, one of the crucial approaches may be a close collaboration among stakeholders, across the widened urban air mobility ecosystem (Kamargianni and Matyas, 2017; Pons-Prats et al., 2022). The basic on ground physical infrastructure for UAM operations is vertihubs, vertiports, and vertistops that have a relatively small footprint, allowing them to build it near urban and suburban accessible zones. In addition, requirements for communication, navigation, and surveillance (CNS) need to be developed applying highly sustainable 5G/6G wireless devices. The combination of reliable ground structures helps define the right air traffic routes for e-VTOL aircraft integrating the Air Traffic Management system as well as interoperability between air vehicles (Holden and Goel, 2016). The modeling of the UAM network applicable to the Baku metropolitan area was analyzed by considering initial determinant factors such as the urban flight destinations, vertiport placement, validity of the proposed business model, applicability of weather conditions, suitability of e-VTOL aircraft types, with the best safety features and maneuverability, as well as existing and developed rules in state regulation frameworks.

6.1 UAM Airspace Classification and Operation

Urban airspace management at low altitude driven by e-VTOL aircraft is associated with various complexities that need to be addressed across the implementation of the UAM concept in the future. The variety of air vehicle design specifications, forecasted high air traffic density, and determination of airspace class usage for particular aircraft are the reasons to develop air traffic rules and procedures (Qu et al., 2023). The designated UAM airspace operations are allowed above 400 ft, generally covering heights between 1500 and 4000 ft Above Ground Level (AGL), meanwhile the landing and take-off area comes below 400 ft (Collins et al, 2018). However, integration of UAM air vehicles into existing airspace classified within uncontrolled class G and flight operations will be performed using B, C, D, and E classes as well. UAM operators are responsible for advice on situational and weather awareness to ensure an optimized flight plan at selected classes while avoiding flights in hazardous conditions, associated with high dynamic wind variability and changes in ambient air parameters important for flights at low-altitude environments. (Boeing, 2023). The various e-VTOL air vehicles, such as multicopters, tiltwings tiltrotors, and lift+cruise vehicles designed for different ranges of flights in urban environments, require detailed knowledge of weather aspects affecting safety operations, including visibility, wind speed and gust, ice conditions at low and density altitudes. In order to provide reliability of the network schedules and to identify operational capability, real-time weather monitoring and advanced forecasting are important for air operators and fleet planning management (Schweiger et al., 2023). In the case of the necessity of adjustment mission plans, prior to the flight, it should be indicated all available information concerning that flight. This information could be contained according to FAA-CFR 14. 91.103 (FAA, 2021); aircraft performances, allowable payload, flight restrictions, ATC delay, charging problem, last minute weather changes, and most importantly density altitude, wind gust, and charging challenges. Requirements of accurate weather data necessary for UAM operations contribute to aircraft safe flights at the arranged route networks. In this context, an analysis of altitude density and wind characteristics is considered in this study, referring to previously conducted studies by Patterson et al. (2018).

6.2 Vertiport Installation and Energy Management

Designing of UAM operational networks based on business models as a passenger function transport system requires similar vertiport networks within ground infrastructure to provide landing/take-off pads, and also charging device facility capabilities. Placement of a vertiport is the primary factor, with its proximity to existing urban infrastructure (education and business centers, parks, ground and underground transportation stations) defines the efficiency of the action as having a mutually affordable connection (Choen, 1996).

Currently, modern vertiport developments are presented as a particular case (Thiemer, 2020) and in the model of conceptual design (Dezeen, 2020) introduced by several researchers however, the ground operational infrastructure should be far away from high-voltage electrical stations, or wind turbines causing airflow disturbance, which may hinder flight operations impacting electronic communication waves (Mulinazzi and Zheng, 2014). Moreover, safety assurance is the most important since the e-VTOL aircraft performs the mission in urban airspace. The definition of landing pads in often cases uses as vertistops, vertiports, and vertihubs (MVRDV, 2018; Krylova, 2020), In addition Skyports and Rooftops can be considered potential landing areas within city centers due to a lack of land spaces to ensure UAM operation (Vascik, 2019). Concerning vertiport dimensions and technical requirements, it is still an open-ended question, yet either the ICAO (2020) Annex 14, Volume II, "Heliport Planning and Design" or the EASA (2019) document CS-HPT-DSN, can be adapted, adding new standards to existing regulations. Unlike heliport planning developed for helicopters, considering ground handling services and maintenance, for the e-VTOL aircraft is necessary charging stations to meet demand of energy sources. Charging stations for full electric air vehicles at vertiports must be equipped with a powerful electrical grid system able to serve several aircraft within each interconnected parking zone, at the time. The power grid system is a new and smart central energy generation unit having various subsystems such as controllable solid-state and local transformers, as well as stationary batteries, to ensure a stable energy supply for UAM vehicles.

A high-level electrical grid structure, consisting of electricity generated from power plants, then transferred the available energy to local distribution systems using regional transmission lines. The regional distribution center then transmits the necessary energy capacity to vertiport customers (Thipphavong, 2022). A smart distributed control unit monitors the overall energy system to balancing power fluctuations and adjust energy supply, in order to transfer the required energy demand to consumers. This provides an adequate energy demand for e-VTOL batteries, avoiding physical damage of components and increases the efficiency.

e-VTOL aircrafts, designed exclusively for electrical propulsion and energy storage systems derived special take-off and landing space requirements depending on construction dimensions. Parking places equipped with charging stations at vertiport facilities are considered a safety requirement. Methodical approach for selection of current networking and vertiport placement in this paper is based on own estimations without referring to literature or expert consensus (albeit, literature and expert opinion are absent or not available at all). However, according to the study conducted by Fadhil (2018), the vertiport placement is preferable due to its proximity and accessibility to main ground transport hubs, underground lines, and train stations. Rath and Chow (2019), argue that the location of vertiports for UAM operation is necessary close to airport access based on air travel data, although the airport itself may be most suitable area for vertihubs assignment.

Vertiports are represented as a smaller prototype of commercial airport terminals with take-off and landing areas, instead of runways, while differing by configuration. There are several studies dealing with vertiport placement and related facilities (Antcliff et al., 2016; Fadhil, 2018; Rath and Chow, 2019), as well as the definition of its various configurations (MVRDV, 2018; Krylova, 2020; Boeing, 2023), but none of them is based on practical experience (Pons-Prats et al., 2022). At the present, without analyzing society's demands and intended e-VTOL aircraft seat capacity, determining the vertiport throughput, number of take-off and landing pads (TLP), and parking areas for the assumed urban network, these are most probably restricted because of the initial applicable data sets. The mentioned factors become actual, being the commencement of UAM operations however, identification regarding vertiport size and configuration is approximately possible, referring to the current assumptions of standards and criteria as well as foreseen future perspectives, Table 3.

Taking relevant time-consuming processes in UAM operations, which will be taken into account, like passenger boarding time, charging electric UAM vehicles or swapping batteries, aircraft cleaning and maintenance, as well as passenger boarding. When the demand increases and the operation is close to the saturation point, the changes in vertiport configuration can be modified according to the document issued by ICAO (2023).

The integration of the UAM network with the existing transportation system in the near perspectives reaches to create a multi-modal global urban network service, while increasing vertiport sizing and enhancing the effectiveness. Baku City, Sumgait, and Airport Shuttle could have an extra-large structure forming a hub and spoke model. While suburban vertiports could serve as spoke nodes, vertiport clusters in densely populated urban areas could function as hubs (Wu and Zhang, 2021). Synergy of airport shuttle UAM service with existing airport infrastructures can increase capacity using a minimum investment of funds (Choi and Hampton, 2020).

6.3 Battery Specifications of e-VTOL Aircraft

In order to increase the motor efficiencies of e-VTOL aircrafts, the battery specification and size need to be suited the payload required UAM mission. At the stage development of various design concept, the lithium–ion batteries are having a better technical characteristic, specified in faster rechargeability, higher energy power and density. Moreover, the sizing of an electrical battery with storage capacity for powering aircraft systems, should be configured to deliver up to 400 Wh/kg of specific energy density. Actual battery weight with a fully

Table 3. Network configurations and relevant functions

Network Locations	**Nardaran, Novkhani, Pirallahi**	**Mardakan, Hovsan, Khirdalan, Zigh**	**Airport-GYD, Baku, Sumgait, Lokbatan**
Configuration	Vertistop	Vertiport	Vertihub
Number of e-VTOL pad	1	2	3+
Parking area	1	2+	5+
Charging station	1	2+	5+
Management support	✓	✓	✓
e-VTOL servicing	✓	✓	✓
Gate infrastructure		✓	✓
Line maintenance	✓	✓	✓
Base maintenance			✓
Hangar facility			✓

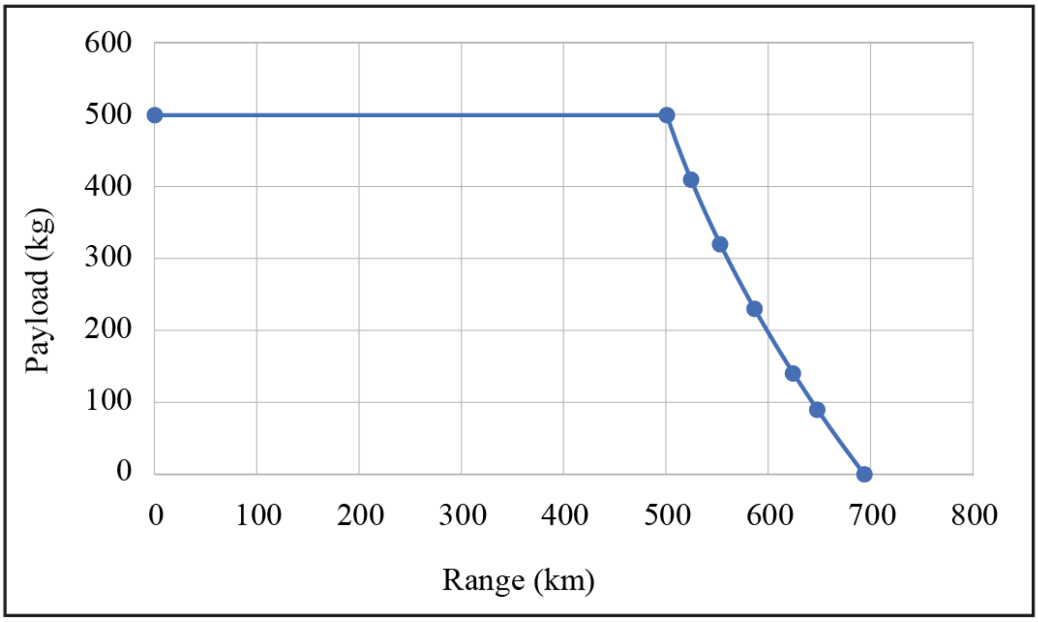

Fig. 2. The relation between payload and flight ranges (Akash et al., 2021)

occupied seat capacities per aircraft use a total energy of 741 MJ, by adding the energy required for each mission phase. Figure 2 is indicating the variation of the range, depending on the payload - number of passengers carried in the aircraft (Akash et al., 2021).

Taking into account that the battery weight is the part of the total aircraft weight, each value of specific energy density increasing by lowering battery mass, which solved using the Lithium–Sulphur battery with highest energy density equal to 600 Wh/kg (Figure 3).

The safety of electric aircraft depends on a reliability of powerplant and more important performance of an inline energy storage system providing functional link to rotor/propulsion. However, the connection between energy storage system and power capability are interrelated within the battery itself (Figure 4).

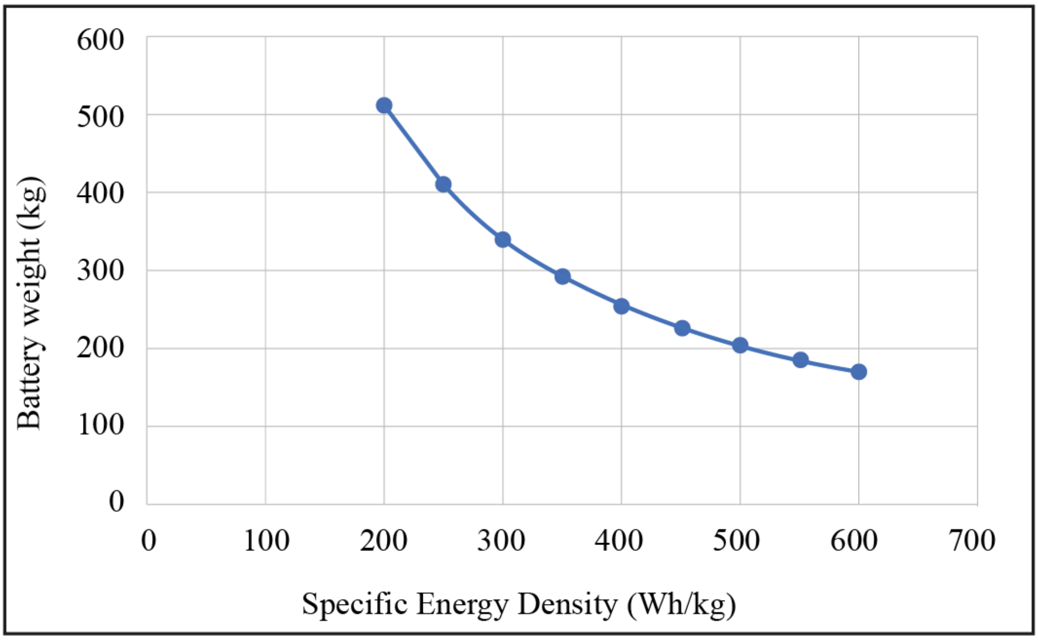

Fig. 3. The relation between battery weight and specific energy density (Akash et al., 2021)

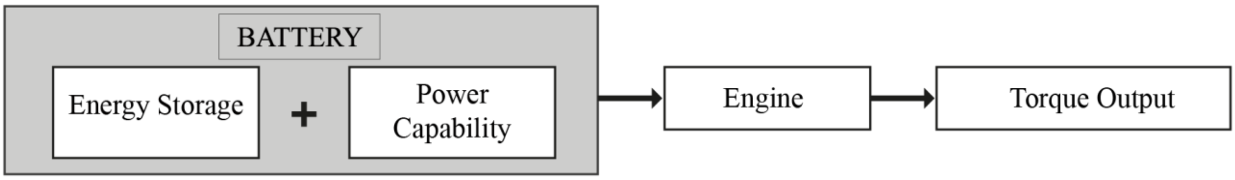

Fig.4. Schematic pathway from battery storage energy system to powertrain.

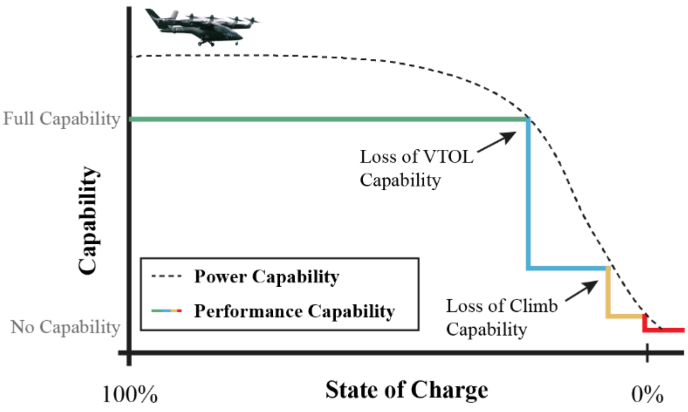

Fig.5. Energy storage system performance capability vs energy state of charge e-VTOL ((General Aviation Manufacturers Association (GAMA), 2023))

Consequently, the power capability is a function of the High Voltage Energy Storage System which include the energy state of the battery. As a battery deliver high power to powertrain system, the electric aircraft will lose some performance capability of battery by reducing power as the state of charge (SOC), Figure 5.

The State of Charge (SOC) is a metric value for estimation the remaining level of energy in the battery packs compared with the fully charged cycle, while providing the needs to be recharged. In addition, the battery is an electrochemical structure, which below 20% of discharge rate can damage its internal parts impacting on operational life cycle (Cunha et al., 2023).

Referring to study by Bills et al. (2023) generation of the EVTOL data set has developed the power profile to define the baseline battery characteristic for each mission examining charging and discharge cycle parameters as per Table 4.

During Take-off and Landing the cell is discharged at a high constant power, however landing cycle checked bit a for long time than take-off. In Cruise level the cell discharged at a lower constant power for a slightly for long duration. According to charging protocol at Charging cycles the cells are charged applying a constant current-constant voltage (CC-CV) method.

Table 4. Baseline Mission Parameters (Charge) Bills et al. (2023)

Flight mission	**Parameter Definition**	**Results**
Take-off (Hover)	54W	t=75 s
Cruise	16W	t=800 s
Landing	54W	t=105 s
Rest 1	0A	T < 27˚C
CC Charge	1C	V > 4.2
CV Charge	V=4.2	I < C/30
Rest 2	I=0	T < 35˚C

At the Rest 1 mode the cell is allowed to rest until it has cooled to a temperature below 27 °C or for at least 15 minutes and at the Rest 2 mode the cell is allowed to rest until cell temperature reaches 35 °C, then allowed to rest 15 minutes before starts to the next cycle.

6.4 UAM Service Segmentation and Business Model Application

Reviewing the UAM missions, an outcome dictates inherently to establishing suitable operational models offered by individual operators or decision makers to manage the infrastructure, taking into account the characteristics of studied area. Initially, the formation of service segmentation, in the future enables to determination of the business model, depending on the vehicle's operator capabilities. In fact, the service segment is still unchanged, while the business model can include single use or more operation functions upon owner-carrier selection.

Referring to the project "NASA Urban Air Mobility Sub-Project, " Mogford et.al. (2019) argues that air vehicle operator roles are not defined at the present however, operators are key drivers of UAM organizational processes among involved infrastructure stakeholders and, at the same time responsible persons for the airworthiness of the aircraft. Li et al., (2020) offered that future operators would be named Fleet Managers, aiming to arrange operational business models. To improve the UAM operation concept, service providers need to establish an effective partnership structure (Nneji et al., 2017), albeit according to the study by Al-Haddaet et al. (2020) the UAM operational model is still uncertain. At the first stage of operations, there are three proposed main customer segments for the future UAM market in urban environments, which are necessary to consider. Passenger carrying UAM missions will be the prevailing segment of urban transportation, next is cargo segmentation, providing door-to-door or last-minute delivery services, because of the low payload volume of e-VTOL vehicles. An emergency mission is particular, considering several use cases, including fire, search-rescue, and health care. Notably, all proposed mission operators need to perform necessary periodic maintenance services to ensure the continued airworthiness of their air vehicles. The proposed characteristics of the various actual operational models for this paper are presented in Figure 6.

Conceptual approaches for meaningful operational models with regard to passenger UAM are demonstrated in the studies Kluge et al. (2018) and Straubinger et al. (2020a). Although the interpretation of customer segmentation and business model stated differently, they have a similar aim in describing UAM operation activities in several business models.

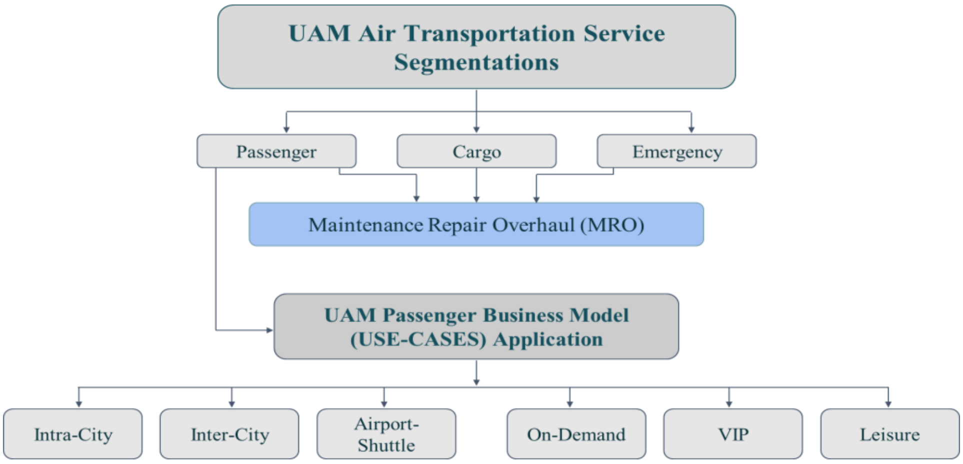

Fig.6. The proposed UAM Operation Service Segments and Business Models

In spite of many different urban air mobility missions having been proposed altogether, this emphasizes a broader definition of business models that have a strong focus on trip purposes.

The offered modes of UAM transportation vary by the purposes performed by flight destinations, classified according to business models, however the concept is still in the same meaning as air-taxi service for society (Baur et al., 2018; Dannenberger et al., 2020). The public UAM mission is intended to provide travel to and from work or on demand bases around a city, so called intra city transportation (Syed et al., 2017), rapid round-trip connectivity with the airport as an airport shuttle (Fu et al., 2019; Straubinger et al., 2021), as well as intercity operation connecting the city center to suburban and rural areas. This mode also includes regional transportation between nearby big cities using e-VTOL aircraft with long range flight capabilities (Syed et al., 2017; Volocopter, 2019). There is expectation that these flights can be set up on a scheduled basis and regularly along the same routes as an urban transportation system for optimizing air travel within an urban environment. The on-demand service model is significantly widened, where multiple individual customers are able to use a single vehicle for flights (Holden and Goel, 2016) either as an air taxi or airport shuttle as well as for emergency purposes. VIP-model is focused for customers' high income and rendered for government employees offering luxurious air transportation service in the mode of charter flights. However, leisure is not much discussed, although it is offered to leisure and tourist travelers to provide sightseeing around the region with a bird's eye view of the natural beauty and urban landscape.

Herein, the represented six business models are initially proposed for considerations of their realization upon the maturity stage of the UAM operation. There are numerous research articles attempting to establish various service model scenarios. All UAM missions can be performed under any of six business models and utilize air vehicles (air taxi), depending on destinations. A scheduled commuter intra-city or airport shuttle and an air taxi performing intercity missions are separate use cases, where each use case has the same base mission but is performed under a different business model (Patterson et al., 2018).

Ecosystem UAM involves a large number of government subjects and private stakeholders, which need mutual collaboration and agreement to develop the business. Therefore, UAM development in the near future will open a way by offering multiple business models, even if confronted with authority requirements, financial structures, and marketing problems (Pons-Prats et al., 2022). The business model, operational concept, market structures and their integration into the upcoming urban air transportation system have been proposed by several researchers, to ensure a successful UAM operation.

According to Moore (2010), the essential attractiveness of business models for users will be easy access to arrival and departure facility locations, door-to-door service, and the introduction of the on-demand mobility concept. On-demand and scheduled service concepts by Nneji et al. (2017) are considered the best solutions for commercial, private, and personal users, adding ideas to those offered by Hansman and Vascik (2016), who identified intercity and intracity use cases. Although the final functional organizational structure is not yet defined, the authors of both studies focused on the relationship between e-VTOL owners (fleet operators) and service providers as an important and dominant actor. Meanwhile, the study by Cizreliogullari et al. (2022) demonstrated that UAM operations are an air transportation ramification with a separate, equal structure consisting of four operational divisions, excluding MRO.

Reiche et al. (2018) have proposed three commercial "use cases" named, air metro, air-taxi and last-mile delivery, and the study by Baur et al. (2018) has concluded that

UAM can be valuable depending on air vehicle characteristics. Regarding UAM service segmentation, Cohen and Shaheen (2021), integrating the results of various analyses, proposed three segments and five business models of the UAM market, while emphasizing that the passenger segment will prevail over others in intensity. Similar segmentation is defined in the study conducted by Imanov (2023), while offering six business models. Furthermore, according to the findings of Al Haddad et al. (2020), the distribution and implementation of UAM are still uncertain, and the development of business models is mostly differentiated. In fact, Ernest et al. (2023) clearly describes the three most feasible use cases for passenger UAM air transportation segmentation over the near to mid-term perspectives, which are analyzed within the current paper considering only three use-cases at the initial stage appearance.

The proposed three models are applicable for the Baku metropolitan area, including intra city, suburban/district, and airport shuttle operations. Intracity service is within downtown and around, with destinations up to 50 km, meanwhile, the airport shuttle covers the same ranges and can be extended up to 150 km depending on the readiness of regional infrastructure. Inter-city assumes the journey between big cities as well as regional ones by utilizing the flight destination up to 300 km. Business model assignations and main trip characteristics are outlined in Table 5.

The purpose of all models with different functions aims to safe transportation of peoples between well-arranged networks, using a giving advantage to reduce trip times, especially in the most congested parts of the cities. e-VTOLs will become a part of multimodal transport, performing air taxi functions as a time-efficient alternative to current transportation modes, carrying a high volume of passengers on daily basis.

Table 5. UAM trip characteristics and business models

Trip characteristics	**Intra-City UAM**	**Airport Shuttle**	**Inter-City UAM**
Routes	Intracity, districts and suburban	Town Centers	City to City, Regional
Range	Up to 50 km	Up to 150 km	50-300 km
Average Speed	80-100 km/h	100-150 km/h	200-300 km/h
Frequency	Daily	24 hours	Daily
Network Type	Hub and Spoke	Hub and Spoke	Point-to-Point
Demand Estimation	High	High	Medium
Payload (PAX)	2-5 + Personal items	4-7 + Hand baggage	4-5 + Hand baggage

6.5 Selection of e-VTOL Aircraft Type for UAM Network Operations

Approach to aircraft selection, Stocker and Shaheen (2017) emphasized mainly, the nexus between level of automation of e-VTOL and use-cases, Bridgelall et al. (2023a), argue that, the successful deployment of eVTOL aircraft for public urban airspace prefers to use four-seat configuration battery powered air vehicles capable of autonomous operation. Straubinger et al. (2020b) demonstrated several design requirements drivers for e-VTOL aircraft that significantly impact UAM operation, however, seat capacity, flight range, and cruise speed are expressed as important top level configuration concepts. Because both systems are designed as distributed electric propulsion (DEP) concepts, which are interconnected in all electric vehicles, the current energy density and power features of e-VTOL aircraft are based on formulas; for rotors/propellers (Equations 1-6) and batteries (Equations 7-10) inherent to each flight step.

The most recent comprehensive analysis performed by Bridgelall et al. (2023b) defined the propulsion efficiency index (PEX), which serves to choose appropriate e-VTOL types. Applying three independent variables, consisting of a set of flight range, coefficient of payload, and aspect, using a linear regression model, the result found more than 90 percent of the PEX distribution level in aircraft design processes. Considering that propulsion power demand is directly proportional to battery utility consumption, this analysis also concerns changes in battery efficiency, including energy density and power. Adequately, apart from the range capability, unfavorable weather conditions, and high wind/gusts would also impact on operational performance of any e-VTOL aircraft (Bridgelall et al., 2023a).

The aircraft selection criteria depend on the established UAM flight network and operating distance. Relying on Figure 1, there are four main design concepts of UAM air vehicles: lift and cruise, multicopter, tilted wing, and rotor, with different configurations as per Table 2. According to the initially proposed networking stated in the current study, the e-VTOL aircraft within the lowest range up to 100 km capabilities are most suitable for the Baku region, as are City Airbus, EHang, Volocopter, and Cora. Usually, most big cities with suburbs cover the range within 35-50 km, including the nearest local airports. Hence, multicopters are the best inner-city air vehicles with short-distance applications enabling air taxi functions.

6.6 Designing of Urban Network Destinations For Baku Metropolitan Area

The multimodal nature of UAM operation requires integration of multiple aspects to design network mobility, involving available land surface for vertiport placement, air navigation management, charging, communication, and service facilities, as well as affordable ground transportation to vertiports. The relationship between supply and demand in particular regions determines the optimal location of vertiports, which contribute to the modeling of air networks (NASA, 2018; Wu and Zhang, 2021). The determinants for the UAM modeling structure depicted in Figure 7, which are based on three initial input data points, as a primary component. The first includes the most congested entry gates (green pins), the second is predicted cities (red map pin), considering the identification availability of land surfaces for vertiport construction and the number of populations, the third are proposed air network connections for intracity (blue line) and airport shuttle (red line) operations using a three-dimensional (3D) Google Earth, Data Visualization Application (DVA). It should be mentioned that identification of landing pads is not considered near public-owned, commercial, and industrial areas, the top roofs of residential buildings in the downtown area, or secured zones due to land use restrictions and aircraft operational requirements, as well as to avoid negative influence on communities. Relying on regular statistical information, the most congested ground transportation occurs from four entry gate directions leading to Baku city or crossing over the center to travel to the outskirts, suburban, airport, or rural destinations.

In order to discharge the traffic, the proposed UAM network is able to significantly impact the delays on the roads, partially solving the exciting problem of residents. Lack of intensive domestic flights and train lines from South and Northern, the Enters 1 and 2 (green pin) are overloaded due to regional cargo and private transportation, with suburban and intracity travelers. The train line to the West is operational, however it's not affected by the decreasing traffic solution in two directions, because the western highway has a in both directions. Meanwhile, the ground transportation infrastructure remains complicated on the ways from the Eastern side of nearby districts and suburbs, uniting all destinations at entries 3 and 4 (green pin). The average radius of the Baku metropolitan area consists of approximately 30 km from the city center within maximum distance to Sumgait (35.6 km) and Pirallahi district (39.8km), and with a minimum distance to Zigh (7.4 km) and the central stadium (9.5 km) near Enter 3. Three geographic locations from the West of Baku covered Sumgait, Khirdalan, and Lokbatan providing an excellent opportunity to enable the significant contribution of the establishment of regional networking UAM operations for middle and long-ranges, including Eastern Zangezur economic territory. Taking into account proposed urban network destinations, the installation of vertiports will differ depending on daily operational capabilities, interest and the number of populations willing to use the offered intracity air transportation service by applying brand new technological achievements.

In recent years, there have been numerous publications to study the advancement of the new UAM concept based on e-VTOL aircraft. The prediction from industry stakeholders is relatively positive, as these air vehicles are able to provide safer, noiseless, and more efficient air transportation service in low altitude airspace (Xu, 2020). Both organizations, NASA, and FAA, emphasize studying UAM aircraft characteristics, network design, and market feasibility continuously (Gibson, 2017) in order to update situations in current progress.

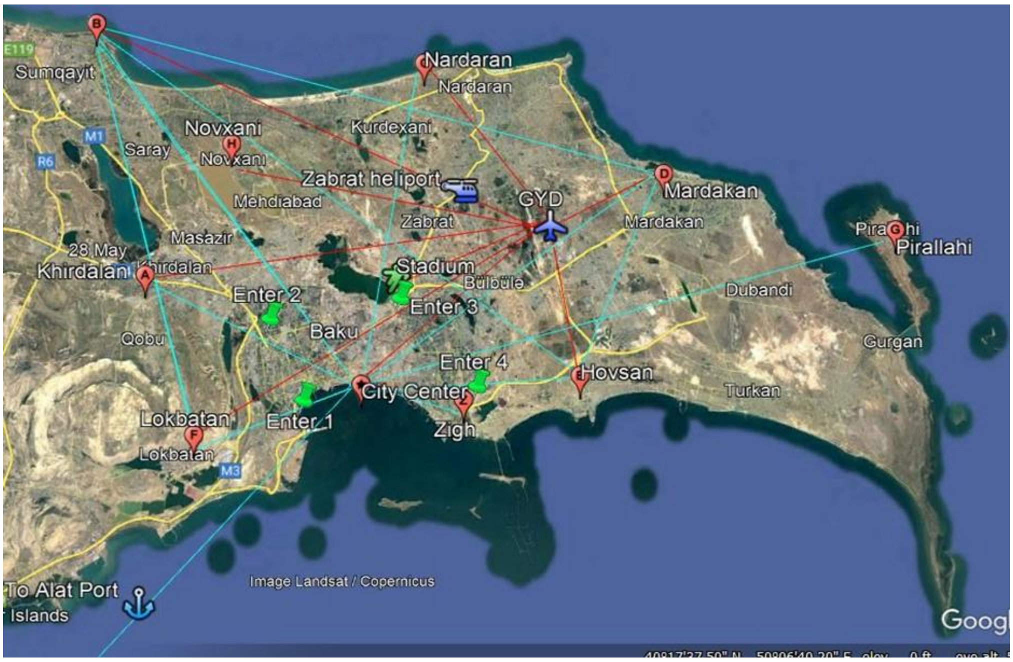

Fig.7. Proposed UAM networking for Baku metropolitan area

6.7 Regulatory Framework Necessary to Establish with Administrative Authorities

The intended project to deploy UAM services requires the definition of applicable standards and regulations to ensure safety operation, and sustainable integration within the overall transportation system of big cities. To provide common knowledge and skills concerning UAM air transportation within and between urban areas relevant regulatory frameworks are necessary for each infrastructure activity. The regulatory framework is different across countries and significantly varies depending on the specific regional conditions. To the author knowledge, there are not any documents yet, concerning the UAM concept issued by Azerbaijan authorities. However, public service representatives should consider adapting necessary regulatory documents, referring to previous or basic recommendations issued by international aviation organizations. Effective integration of UAM operations in the Baku metropolitan area and urban environment through the coordination and engagement of civil aviation representatives as an organization developing regulations and standards.

7. Conclusion

Urban Air Mobility e-VTOL aircraft manufacturers, involved organizations, and stakeholders are attempting to deploy the concept beginning in 2025 and in 2026 expected to be globally (urbanairmobilitynews, 2023). However, many experts assume that in 2030 UAM air transportation will become more widespread (Chomsky, 2023) other than following years. There are signs from different countries as the USA, Japan, Germany, France, China, Korea and Singapore enforcing to the initial preparatory stage of implementation and certification. As a new mode of urban air transportation, eVTOL aircraft will provide mitigation of traffic congestion on the roads, safe and noiseless operation, as well as zero-emission, because of full electric powertrains with a distributed propulsion system.This study presents a comprehensive scenario for improving intra-city mobility criteria, and the use of eVTOL aircraft in the public airspace of the Baku metropolitan area, considering passenger segmentation use cases, network planning, vertiport and navigation infrastructure requirements, weather conditions, and suitable aircraft selection. Despite the analysis, there are still significant limitations to finding detailed references to published data, associated lack of regulatory framework issued on behalf of aviation authorities. The challenges that need to be overcome, rely on government policy requirements, introducing changes in urban planning for vertiport installations, rules of air traffic management over urban airspace, providing reliable wireless equipment to ensure communication, navigation, surveillance (CNS), and society acceptance.

Notwithstanding the limitations and challenges, this paper has practical and theoretical implications for policy decision makers. The findings provide a practical perspective for urban planners and involved single companies, which may be useful guidelines at the initial stages of UAM services and obtaining significant information about e-VTOL aircraft and its design configurations to overcome arising barriers in the implementation processes. The study not consider financial evaluations regarding infrastructure management, the establishment of regulatory documents and the air vehicle prices. The theoretical contribution of this paper is that the industry needs more research to fully capture the initial and future implications for Azerbaijan and all regions. Therefore, it enables local scientists to explore different relevant topics concerning the overall UAM operational concept, infrastructure management, and financial analysis. Consequently, it can motivate aviation stakeholders to investigate a UAM market, conduct a safety assessment, and to consider the feasibility of the potential investment opportunity, cost estimation for insurance and maintenance, as well as be used to explore in future work. Furthermore, this study supposes that e-VTOL aircraft to be reliable in autonomous operation mode over urban environments, performing air mobility missions, and will see higher demand for expansion in this sphere of application. Particularly, short-range multicopters largely suit air taxi functions around residential areas of big cities and nearby suburbs.

Application of e-VTOL aircraft enabling UAM missions associated with new configuration architecture can have an added-value benefit of expanding higher speed and improved cruise efficiency, as well as reasonable operating and maintenance costs. The energy expenses will be much less than the fuel price, in addition electric propulsion components contain fewer moving parts and lubrication points, which are significant resource and cost savings (Patterson et al., 2018). The various design configurations of UAM vehicles, upgraded with electrical propulsion and reliable battery storage capabilities, contributed the exclusion of complex flight control actuators, mechanical transmission, the use of fossil fuels and many others in progress of effective use the urban air transportation mission in the largest megalopolises (Rezende and Barros, 2018). Successful largest companies such as; Boeing, Airbus, Volocopter, Wisk, Lilium, and others, after performing test flights, prepare their machines for certifications, which look forward to entry into service nearly in 2025-2026. Moreover, the presented UAM aircraft have many types, while keeping similarities in distributed electric propulsion systems in all-battery configurations. Ongoing upgrading processes in the development of

UAM air vehicles are expected to achieve the required reliability to meet future user demands, enable high safety performance, and obtain society's perceiving (Pons-Prats et al., 2022).

Nomenclature

BSP_{hover} : Battery Specific Power for hover
BSP_{cr} : Battery Specific Power for Cruise
R_{trip} : Distance for trip
SE_{trip} : Distance for trip
SP_{char} : Specific Power for charge
t_{char} : Time for charge
V_{cr} : Cruise speed
$^{L}/_{D}$: Lift to Drug ratio
ω_{bat} : Battery weight fraction
η_h : Hover efficiency
η_c : System efficiency
g : Gravitational constant
σ : Disk loading
ρ_{air} : Aircraft configuration (load factor)
P_d : Pressure of dry air (Pa)
P_v : Water vapor pressure (Pa)
R_d : Specific gas constant for dry air J/ (kg.K)
R_v : Specific gas constant for water vapor J/(kg. K)
A : Surface are (sg.m)
F : Force
T, T_c : Air temperature degree C
V : Wind speed
E_S : Saturation pressure of water vapor (mb)
P : Standard pressure at sea level 10.13 (Pa)
(w/g) : Wind/gusts
e_{so} : Constan equal to c_0 = 6.1078
c_1, c_2 : Lift coefficient
ρ : Air density (kg/m3)
ρA : Area density
W_l : Wind load (Newton, N)

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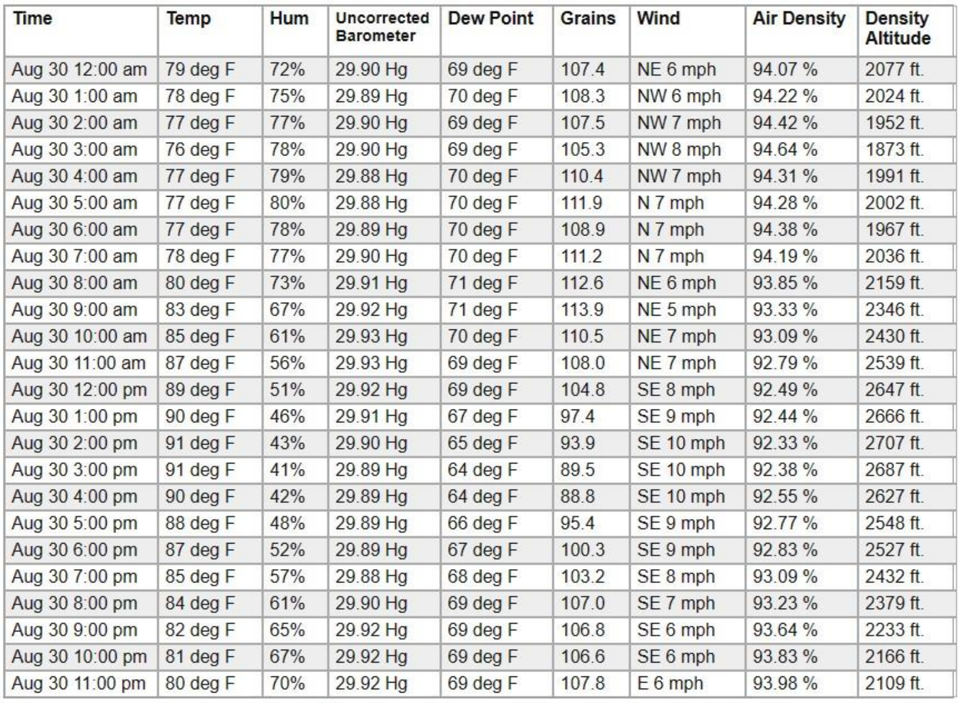
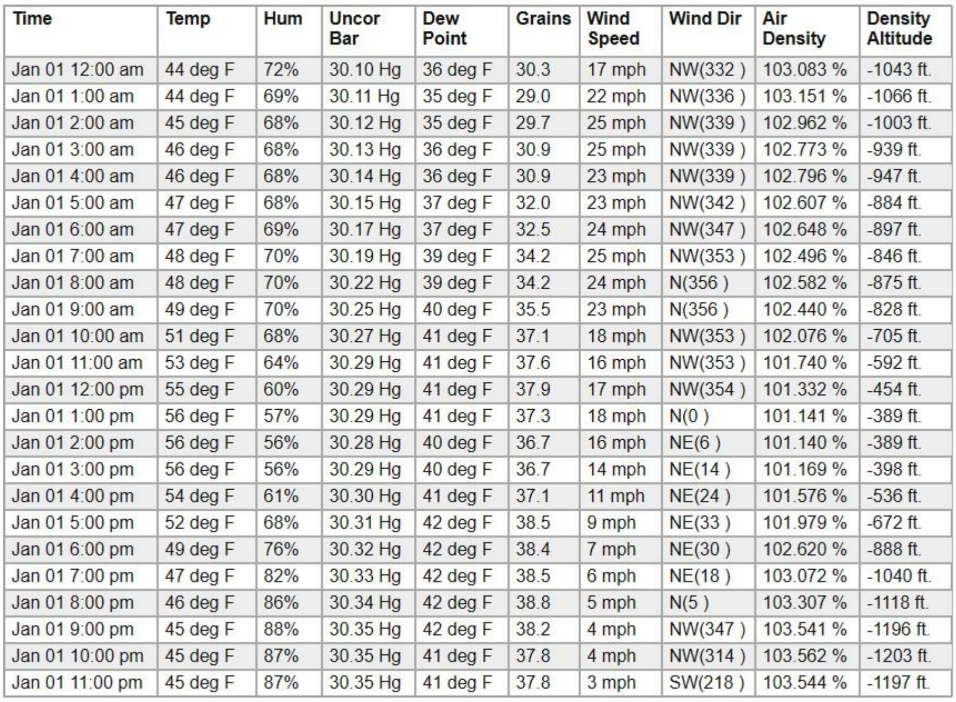
Appendix 1. Weather for Baku City Circuit (airdensityonline, 2024)



Time	Temp	Hum	Uncorrected Barometer	Dew Point	Grains	Wind	Air Density	Density Altitude
Aug 30 12:00 am	79 deg F	72%	29.90 Hg	69 deg F	107.4	NE 6 mph	94.07 %	2077 ft.
Aug 30 1:00 am	78 deg F	75%	29.89 Hg	70 deg F	108.3	NW 6 mph	94.22 %	2024 ft.
Aug 30 2:00 am	77 deg F	77%	29.90 Hg	69 deg F	107.5	NW 7 mph	94.42 %	1952 ft.
Aug 30 3:00 am	76 deg F	78%	29.90 Hg	69 deg F	105.3	NW 8 mph	94.64 %	1873 ft.
Aug 30 4:00 am	77 deg F	79%	29.88 Hg	70 deg F	110.4	NW 7 mph	94.31 %	1991 ft.
Aug 30 5:00 am	77 deg F	80%	29.88 Hg	70 deg F	111.9	N 7 mph	94.28 %	2002 ft.
Aug 30 6:00 am	77 deg F	78%	29.89 Hg	70 deg F	108.9	N 7 mph	94.38 %	1967 ft.
Aug 30 7:00 am	78 deg F	77%	29.90 Hg	70 deg F	111.2	N 7 mph	94.19 %	2036 ft.
Aug 30 8:00 am	80 deg F	73%	29.91 Hg	71 deg F	112.6	NE 6 mph	93.85 %	2159 ft.
Aug 30 9:00 am	83 deg F	67%	29.92 Hg	71 deg F	113.9	NE 5 mph	93.33 %	2346 ft.
Aug 30 10:00 am	85 deg F	61%	29.93 Hg	70 deg F	110.5	NE 7 mph	93.09 %	2430 ft.
Aug 30 11:00 am	87 deg F	56%	29.93 Hg	69 deg F	108.0	NE 7 mph	92.79 %	2539 ft.
Aug 30 12:00 pm	89 deg F	51%	29.92 Hg	69 deg F	104.8	SE 8 mph	92.49 %	2647 ft.
Aug 30 1:00 pm	90 deg F	46%	29.91 Hg	67 deg F	97.4	SE 9 mph	92.44 %	2666 ft.
Aug 30 2:00 pm	91 deg F	43%	29.90 Hg	65 deg F	93.9	SE 10 mph	92.33 %	2707 ft.
Aug 30 3:00 pm	91 deg F	41%	29.89 Hg	64 deg F	89.5	SE 10 mph	92.38 %	2687 ft.
Aug 30 4:00 pm	90 deg F	42%	29.89 Hg	64 deg F	88.8	SE 10 mph	92.55 %	2627 ft.
Aug 30 5:00 pm	88 deg F	48%	29.89 Hg	66 deg F	95.4	SE 9 mph	92.77 %	2548 ft.
Aug 30 6:00 pm	87 deg F	52%	29.89 Hg	67 deg F	100.3	SE 9 mph	92.83 %	2527 ft.
Aug 30 7:00 pm	85 deg F	57%	29.88 Hg	68 deg F	103.2	SE 8 mph	93.09 %	2432 ft.
Aug 30 8:00 pm	84 deg F	61%	29.90 Hg	69 deg F	107.0	SE 7 mph	93.23 %	2379 ft.
Aug 30 9:00 pm	82 deg F	65%	29.92 Hg	69 deg F	106.8	SE 6 mph	93.64 %	2233 ft.
Aug 30 10:00 pm	81 deg F	67%	29.92 Hg	69 deg F	106.6	SE 6 mph	93.83 %	2166 ft.
Aug 30 11:00 pm	80 deg F	70%	29.92 Hg	69 deg F	107.8	E 6 mph	93.98 %	2109 ft.



Time	Temp	Hum	Uncor Bar	Dew Point	Grains	Wind Speed	Wind Dir	Air Density	Density Altitude
Jan 01 12:00 am	44 deg F	72%	30.10 Hg	36 deg F	30.3	17 mph	NW(332)	103.083 %	-1043 ft.
Jan 01 1:00 am	44 deg F	69%	30.11 Hg	35 deg F	29.0	22 mph	NW(336)	103.151 %	-1066 ft.
Jan 01 2:00 am	45 deg F	68%	30.12 Hg	35 deg F	29.7	25 mph	NW(339)	102.962 %	-1003 ft.
Jan 01 3:00 am	46 deg F	68%	30.13 Hg	36 deg F	30.9	25 mph	NW(339)	102.773 %	-939 ft.
Jan 01 4:00 am	46 deg F	68%	30.14 Hg	36 deg F	30.9	23 mph	NW(339)	102.796 %	-947 ft.
Jan 01 5:00 am	47 deg F	68%	30.15 Hg	37 deg F	32.0	23 mph	NW(342)	102.607 %	-884 ft.
Jan 01 6:00 am	47 deg F	69%	30.17 Hg	37 deg F	32.5	24 mph	NW(347)	102.648 %	-897 ft.
Jan 01 7:00 am	48 deg F	70%	30.19 Hg	39 deg F	34.2	25 mph	NW(353)	102.496 %	-846 ft.
Jan 01 8:00 am	48 deg F	70%	30.22 Hg	39 deg F	34.2	24 mph	N(356)	102.582 %	-875 ft.
Jan 01 9:00 am	49 deg F	70%	30.25 Hg	40 deg F	35.5	23 mph	N(356)	102.440 %	-828 ft.
Jan 01 10:00 am	51 deg F	68%	30.27 Hg	41 deg F	37.1	18 mph	NW(353)	102.076 %	-705 ft.
Jan 01 11:00 am	53 deg F	64%	30.29 Hg	41 deg F	37.6	16 mph	NW(353)	101.740 %	-592 ft.
Jan 01 12:00 pm	55 deg F	60%	30.29 Hg	41 deg F	37.9	17 mph	NW(354)	101.332 %	-454 ft.
Jan 01 1:00 pm	56 deg F	57%	30.29 Hg	41 deg F	37.3	18 mph	N(0)	101.141 %	-389 ft.
Jan 01 2:00 pm	56 deg F	56%	30.28 Hg	40 deg F	36.7	16 mph	NE(6)	101.140 %	-389 ft.
Jan 01 3:00 pm	56 deg F	56%	30.29 Hg	40 deg F	36.7	14 mph	NE(14)	101.169 %	-398 ft.
Jan 01 4:00 pm	54 deg F	61%	30.30 Hg	41 deg F	37.1	11 mph	NE(24)	101.576 %	-536 ft.
Jan 01 5:00 pm	52 deg F	68%	30.31 Hg	42 deg F	38.5	9 mph	NE(33)	101.979 %	-672 ft.
Jan 01 6:00 pm	49 deg F	76%	30.32 Hg	42 deg F	38.4	7 mph	NE(30)	102.620 %	-888 ft.
Jan 01 7:00 pm	47 deg F	82%	30.33 Hg	42 deg F	38.5	6 mph	NE(18)	103.072 %	-1040 ft.
Jan 01 8:00 pm	46 deg F	86%	30.34 Hg	42 deg F	38.8	5 mph	N(5)	103.307 %	-1118 ft.
Jan 01 9:00 pm	45 deg F	88%	30.35 Hg	42 deg F	38.2	4 mph	NW(347)	103.541 %	-1196 ft.
Jan 01 10:00 pm	45 deg F	87%	30.35 Hg	41 deg F	37.8	4 mph	NW(314)	103.562 %	-1203 ft.
Jan 01 11:00 pm	45 deg F	87%	30.35 Hg	41 deg F	37.8	3 mph	SW(218)	103.544 %	-1197 ft.