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Urban Air Mobility (UAM) Flight Path: Literature Review and Conceptual Design of UAM Corridor Virtual Lane System using “Tracks”

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Abstract

As the Urban Air Mobility (UAM) industry grows and becomes more popular, most of the conversations in the public domain are focused on the (electric Vertical Take-off and Landing) eVTOL aircraft and the physical infrastructure that will support these eVTOL aircraft. However, there is a lack of research on UAM traffic management and flight paths taken by aircraft between locations.

The United States (U.S.) Federal Aviation Administration has proposed the use of corridors to minimize the interaction between UAM operations and traditional air traffic as eVTOL aircraft perform flight activities. The government also acknowledges the need for additional structures (such as “tracks”) to aid traffic management within corridors as UAM attains increased levels of operation density. A review of literature showed that there is no published work addressing the design of additional structures such as “tracks” within corridors. This paper aims to add to the existing body of literature by proposing a conceptual design for eVTOL aircraft tracks that can improve order and safety within corridors. More specifically, this paper presents two iterations for the flight tracks; a horizontal track system that can be implemented in corridors with large dimensions and a vertically staggered track system that can be implemented in corridors with more space constraints.

Keywords: UAM, eVTOL, flight corridors, FAA, AAM, tracks

1.0 Introduction

Globalization, urbanization, and buoyant economies have led to an increase in rural-urban migration, increased traffic congestion in many big cities, and increased levels of Carbon dioxide (CO_2) emissions. A concept that has the potential to address both traffic congestion and CO2 emissions is Urban Air Mobility (UAM).

According to the National Aeronautics and Space Administration (NASA), UAM is a means of expanding transportation networks using short flights that will transport people and goods around metropolitan areas. Urban Air Mobility is a subset of the Advanced Air Mobility (AAM) concept, which also includes Unmanned Aircraft Systems (UAS) that deals with drone transportation (NASA, 2020). It is anticipated that individuals will hail air-taxi rides to commute between destinations using electric Vertical Take-off and Land (eVTOL) aircraft, but like any industry, the success of UAM is dependent on its acceptance by society (its users). To aid public acceptance, people need to see and experience the benefits of the UAM services, be reassured that their safety is not compromised, privacy is not intruded, and that aircraft noise will not interrupt daily activities.

Most of the conversation about UAM in the public domain today is focused on the aircraft (i.e., eVTOL/VTOL) and the aerodromes (i.e., vertiports) where aircraft operations will occur, but little publicity is directed towards the path that the eVTOL/VTOL aircraft will take when completing flights. Commencement of UAM services will increase airspace congestion and the pressure on the existing Air Traffic Management (ATM) system, thus, a traffic system for UAM operations that does not rely on the current ATC system is needed. Aviation regulatory bodies around the world are working with industry experts and the academic community to develop suitable traffic management solution ideas.

The Federal Aviation Authority (FAA), in the first version of its Concept of Operation for UAM, proposed the creation of corridors in the airspace exclusively for UAM operations (FAA, 2020). At the onset of UAM operations, it is expected that aircraft separation/strategic de-confliction between aircraft within corridors will be maintained by “flight intent sharing” i.e., the operator communicates its intent to initiate a flight and the Provider of Service to UAM (PSU) checks for conflicts with other intended operations (NASA, 2020). At this nominal phase of operation, it is anticipated that operators will plot shortest/most efficient paths between destinations using available flight corridors, but, as UAM operations increase and its demand approaches corridor capacity, the FAA acknowledges the need for corridor capacity expansion and proposed the creation of "additional structure within corridors e.g., tracks" Tracks are expected to support the growth of operations within UAM corridors.

Majority of the accessible research on UAM flight path and UAM traffic management concentrate on optimizing the nominal UAM operational framework for increased UAM aircraft traffic/operations, but no published proposition has been made for a design of UAM corridor tracks that may help increase operational capacity within UAM corridors (as suggested by the FAA) when UAM operation reach full maturity. This paper aims to provide a conceptual design proposal for a track system within UAM corridors that will help maintain order of operations while addressing security and noise concerns.

The first section of the paper provides a survey of literature with respect to UAM flight path and traffic management. The second section presents two iterations of a conceptual design for "tracks" within UAM corridors that will enhance safety and efficiency during dense UAM operations. Finally, implications of the concept are explored and discussed; conclusions are presented. The Appendix contains additional noteworthy information gathered.

2.0 UAM Flight Path Literature Survey

2.1 Definition of "Point- to-Point"

In transportation, "Point to Point" network is defined as a route that directly connects locations without interruption (I.e., without a change of aircraft and/or passengers). It is important to note that the route taken may not be the shortest straight-line path between the origin and destination (Zgodavová, 2018).

According to the FAA UAM ConOps v1.0, a point-to-point UAM operation is defined as the transportation between two known aerodrome (vertiport) locations (FAA, 2020). For this paper, "point-to-point" transportation/ flight path/route will be defined as the uninterrupted movement between **two** defined vertiport/aerodrome locations regardless of the path taken between the vertiport locations (i.e., direct path with shortest distance or predefined long route).

2.2 Flight Path Design Considerations

From a review of UAM flight path literature and discussions with subject matter experts, three main approaches to UAM flight path emerged:

1. An open urban airspace in which eVTOL aircraft can fly freely. This approach is presented as "Unconfined point-to-point travel in urban airspace" in this paper.

2. Flight paths routed along/above existing (road) freeways, railways, rivers and creeks.
3. Flights restricted to a specific and defined volume of airspace called “corridors” such that nominal UAM flight operations will be carried out within these corridors.

The section below presents summaries of research work and industry projects on the three flight path approaches listed above.

2.2.1 Unconfined point to point travel in urban airspace

NASA proposes the use of Urban Air Mobility Operational Environment (UOE) which is a “flexible airspace area encompassing the areas of high UAM flight activity”. The UOE is expected to be static and flexible depending on activity of controlled airspace nearby, the needs of the metropolitan area it encompasses, and height of buildings in the area (NASA, 2020).

Figure 1: NASA idea of UAM operations (NASA, 2020)

Skyroads is a German company developing a decentralized, integrated, automated vehicle guidance and airspace management system to manage air traffic safely and efficiently. Skyroads believes that a unified method of commanding vehicles will be required to maintain dense and complex UAM airspace operations.

Skyroads argues that most metropolitan areas in western countries are not protected by special airspaces and flight limitations in these metropolitan areas are mostly defined by minimum safe altitudes, thus, a move to protect these airspaces for exclusive eVTOL operations could displace current users, require them to carry additional equipment, or require them to adhere to additional rules which may lead to political opposition. Skyroads is currently using “aseptic” airspaces (i.e., an airspace in which only one type of aerial operation is allowed and legal and/or policing approaches are used to maintain the sanitary condition of that airspace) to develop and test the application of its solution. The pictures below (obtained from the Skyroads website) show what I believe to be Skyroads' flight path concept using low altitude virtual lane networks to connect vertiports (Skyroads, 2022).

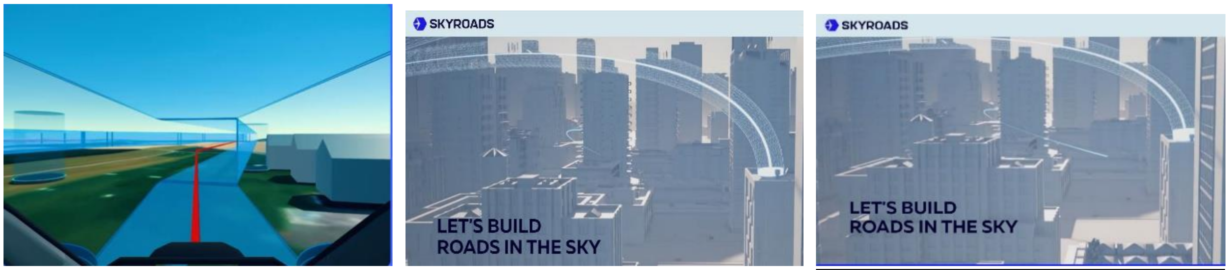


Figure 2: Skyroads flight path concept (Skyroads, 2022)

EHang is the leading UAM Company in Asia working on a smart city system for Autonomous Aerial Vehicles (AAV) operations. EHang argues that it is difficult to guarantee the safety of an autonomous UAM system if vehicles are allowed to fly freely in suburban airspace, as such, EHang is currently testing the use of a "command-and-control" centralized system. This system ensures that all aerial vehicles are registered and remotely controlled to fly pre-registered and pre-determined point-to-point routes between defined vertiports. The point-to-point routes are set by computer programs and cluster management techniques. The EHang white paper does not specify the use of corridors since all aircraft and flight will be controlled from its command-and-control center (EHang, 2020).

Figure 3: EHang flight path and traffic management concept (EHang, 2020)

The advantages and disadvantages of the unconfined point-to-point travel in urban airspace include:

Advantages

- Aircraft can fly battery optimized routes i.e., routes that will use the least amount of battery charge

- Quicker/shorter flight times

Disadvantages

- Visual and auditory concerns of the public
- High level of interaction with urban area obstructions e.g., buildings, construction sites etc.
- As operations increase, the Pilot in Charge (POCs) may be overwhelmed with traffic patterns i.e., having to keep track of aircraft in multiple directions within the airspace
- Difficulty identifying rogue aircraft and aircraft with malicious intent

2.2.2 Flight paths above existing freeways, rail lines and rivers/creeks

Youngjae (2021) identified the potential need for holding patterns when UAM operations reach full maturity and vertiport congestion starts affecting traffic patterns. Three holding pattern designs, with predefined dimensions and different complexity levels applicable to different airspace structures were proposed.

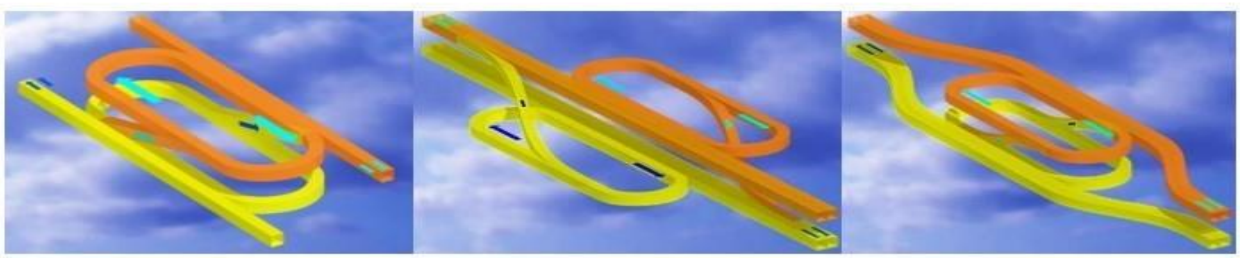


Figure 4: Holding pattern concept (Youngjae, 2021 Vol. 11, Iss. 22)

For this study, live simulations and design simulations were performed on VFR flight routes designed along rivers and major roads in the Seoul-GyungIn area (in Korea) to avoid noise sensitive areas and obstacles. For this case study, the first holding pattern was simulated with a fixed wing aircraft (high speeds and low turn rates). The dimensions of the holding pattern were dictated by the width of the Han River and the first holding pattern concept was situated at three different locations along the Han River (Youngjae, 2021). (Youngjae, 2021 Vol. 11, Iss. 22)

Figure 5: Holding pattern simulation (Youngjae, 2021 Vol. 11, Iss. 22)

The advantages and disadvantages of flight paths above existing freeways, rail lines and rivers/creeks include:

Advantages

- Avoidance of noise sensitive areas

Disadvantages

- Having (low altitude) routes over roads could distract road drivers and lead to road accidents.
- Routes may not be optimized for eVTOL aircraft battery i.e., more battery power will be consumed compared to shortest path routes.

2.2.3 Point to point travel within corridors

For UAM flight operations in the U.S, the FAA proposes the use of corridors. UAM corridors will be "performance-based airspace structures with defined dimensions governed by rules that prescribe access and operations known to all airspace users" (FAA, 2020).

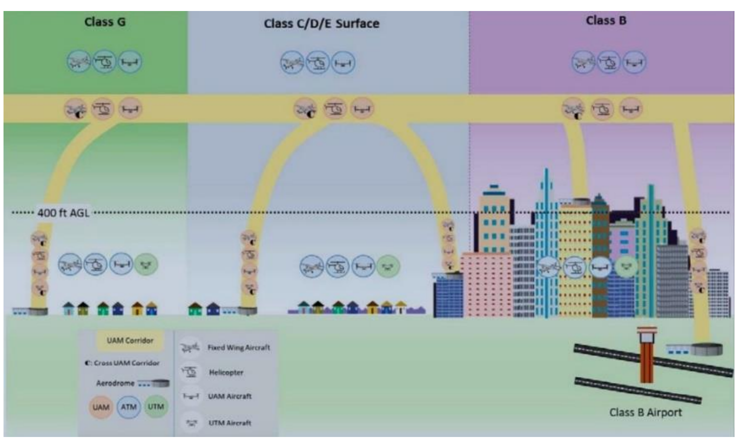


Figure 6: UAM Corridor concept (FAA, 2020)

UAM corridors will serve as a primary means of separation between UAM operations, and all other forms of airspace operations. As UAM operations increase, additional UAM corridors may be required, and the FAA anticipates the creation of corridor networks to optimize paths between vertiports. The FAA will provide UAM corridor guidelines while the design and development of the UAM corridors will be left to collaborative efforts by industry stakeholders (FAA, 2020).

Varon Vehicles is an American company working on the implementation of UAM in Colombia. Varon vehicles is working on an airspace integration architecture that connects the vertiports through low altitude virtual lanes within corridors (Varon, 2022).

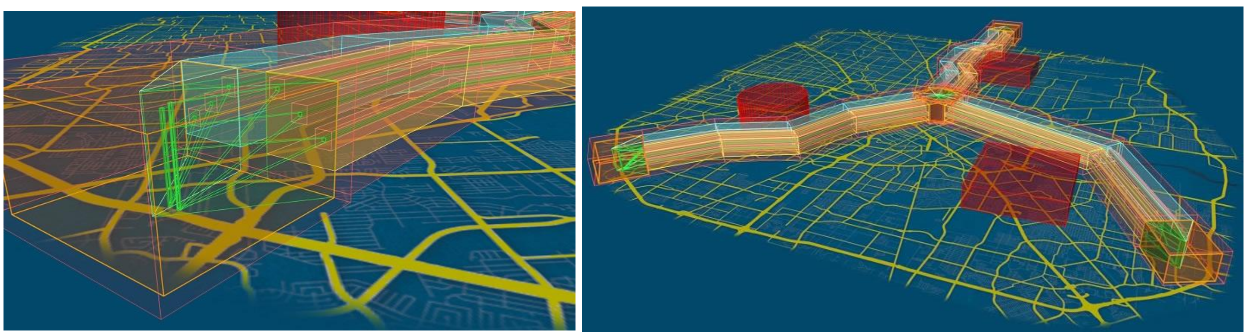
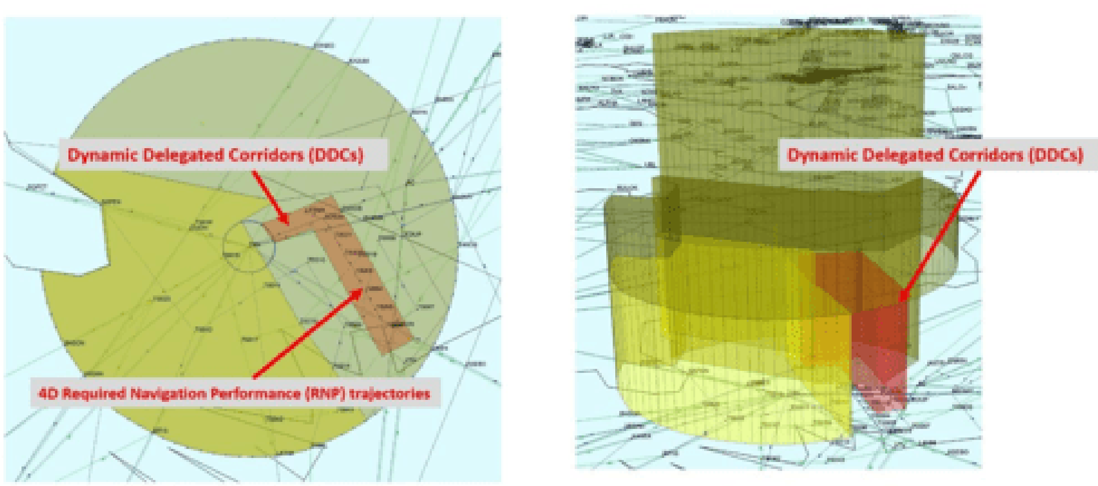


Figure 7: Varon vehicles concept (Varon, 2022)

Nguyen (2020) proposed the combination of Dynamic Delegated Corridors (DDC) and full four-dimensional Required Navigation Performance (4D RNP) to create a dedicated UAM section of the airspace and provide a high level of navigation precision (through latitude, longitude, altitude, and time information) for aircraft. This is expected to reduce the need for large separation buffers between aircraft laterally and longitudinally (Nguyen, 2020).



Dynamic Delegated Corridors (DDCs) & 4D RNP Trajectory in plan view

Dynamic Delegated Corridors (DDCs) & 4D RNP Trajectory in side view

Figure 8: DDC and 4D RNP concept within corridor (Nguyen, 2020)

The FAA is currently working on defining / providing corridors for UAM traffic to enter and exit class B & C airspaces (airspaces with active commercial aircraft traffic, especially around airports) to prevent interaction with conventional aircraft traffic. These corridor discussions are currently focusing on areas where interaction with conventional commercial traffic is expected to be high e.g., around airports. Outside these areas (i.e., in-between corridors), operators and pilots are expected to adhere to urban airspace flight rules (Sheth, 2022). In the figure above, Nguyen (2020) shows a corridor defined within a specific airspace. In between corridors, operations essentially become "unconfined travel in urban airspace" and flight rules are determined by urban airspace rules.

Wang (2021) approached UAM traffic assignment from a macroscopic perspective by developing a model that shows optimal traffic flow paths from origin to destination through predefined waypoints to aid UAM operations planning and air traffic assignment during high-density operations. In this solution, the author proposes a "complexity-optimal air traffic assignment model" that shows traffic flow distribution within UAM corridor networks that minimizes congestion and air traffic complexity (Wang, 2021).

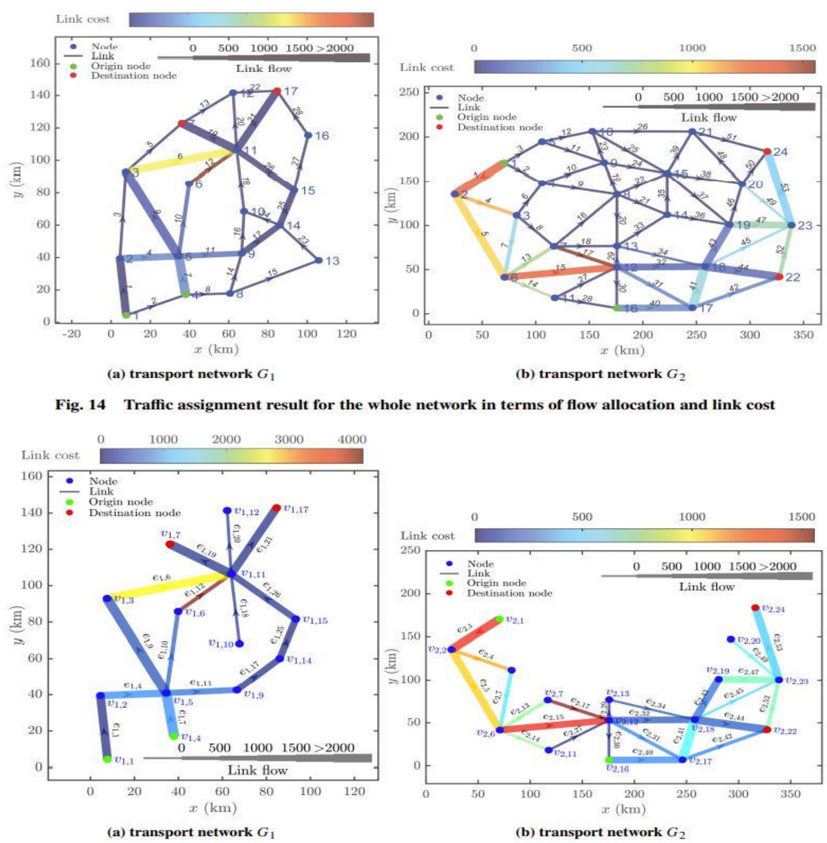


Figure 9: Optimal traffic flow path design (Wang, 2021)

The assumptions, advantages and disadvantages of travel within corridors include:

Assumptions:

- Corridors will be defined for the entire NAS and not just commercial aircraft traffic interaction areas

Advantages

- Based on the assumption above, this flight path structure will give communities more control of their airspace by giving them the ability to decide UAM traffic routes with the use of corridors
- This may aid the public acceptance of UAM
- This will minimize the interaction with other airspace users, thereby reducing the possibility of accidents
- Air traffic within corridors will aid in the identification of rogue aircraft

Disadvantages

- Corridor routes may not be the most efficient for aircraft battery charge depletion.
- Additional structures may be required within corridors to support dense UAM operations

Table 1 below provides a summary of the three approaches listed above.

Flight Path Approaches	Summary
Unconfined Point to point travel in urban airspace	• The uninterrupted transit between two defined vertiport locations in urban airspace without confinement to a defined volume of the airspace (i.e. corridor) • Proposed by NASA in its Concept of Operations (ConOps) document (NASA, 2020). This appears to be the direction that Skyroads is taking.Seems like the direction Skyroads is taking
Flight paths above existing freeways, rail lines and rivers/creeks	• The creation of flight paths above/along current road highways, rail lines, rivers, and creeks

Point to point travel within corridors 1. ***With predefined traffic system/flight path*** 2. ***With waypoints (point of reference that can be used for location and navigation)***	• The uninterrupted transit between two defined vertiport locations through corridors created in the airspace. • Proposed by the FAA in its Concept of Operations (ConOps) for UAM operations in the U.S. • Current proposition features the establishment of corridors in areas with commercial air traffic, e.g., around airports and restricted flight areas. • Anticipated implementation may include definition of corridors between multiple vertiport locations. • The use of tracks will create a traffic structure within defined corridors that could help address the auditory, visual and safety requirements of the public.

Table 1: Summary of flight path approaches from literature review

3.0 Conceptual Proposal

3.1 Point to point travel using tracks within corridors

As UAM operations increase, the FAA anticipates the need for an increase in the internal structure and complexity of UAM corridors and UAM corridor networks. To address the increased capacity demands on the UAM corridors, the FAA suggests the use of "tracks" within UAM corridors (refer to Figure 10 below). It is anticipated that Air Traffic Control (ATC) will be responsible for setting UAM corridor availability (I.e., open or closed), and communicating availability status to operators through Providers of Service to UAM (PSUs) (NASA, 2020). Depending on the size of these corridors and traffic density, there could be predefined routes or tracks within the corridors.

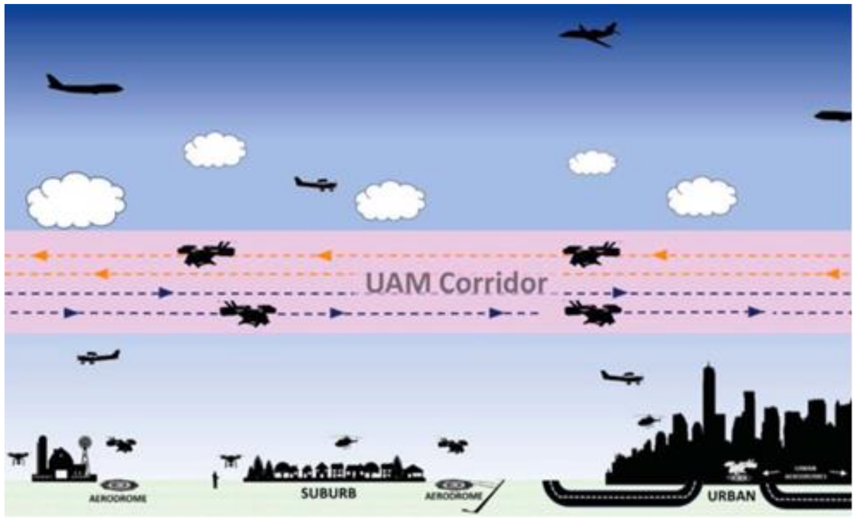


Figure 10: UAM Corridor Tracks concept (NASA, 2020)

The advantages and disadvantages of using tracks within corridors include:

Advantages

- Gives communities more control of their airspace as they have an input in deciding the route/path for corridors.
- Addresses visual and auditory concerns of the public which may aid public acceptance
- Ease of identifying rogue aircraft
- High level of traffic and aircraft order within the urban airspace

Disadvantages

- Routes may not be aircraft battery optimized
- Flights may be longer as they will not follow the shortest possible path

3.2 Virtual Lane Concept

The inspiration behind this flight path concept was taken from map applications and the FedEx sorting center in Memphis. The FedEx sorting center provided inspiration for a traffic management system that features an orderly, timely and controlled movement of aircraft through predefined paths while the map applications provided inspiration for the flight paths around urban areas. Figure 11 below shows examples of urban area navigation obtained from a map application while figure 12 shows the anticipated application of the concept.

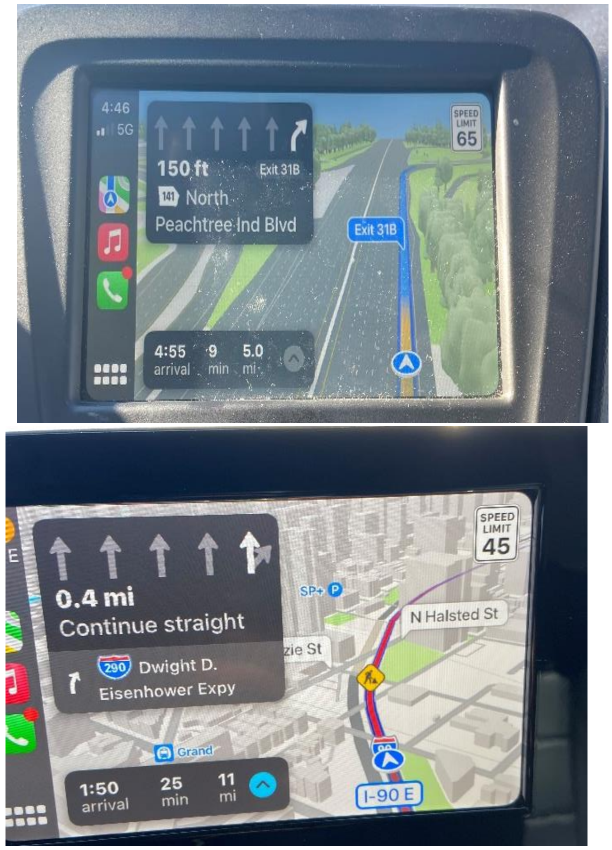


Figure 11: Map application use for automobile vehicles

Figure 12: Envisioned application of virtual lane concept

The virtual lanes designed in this project can be used for both scheduled and on-demand service. On-demand services will cater to real time passenger demand i.e., transporting passengers between vertiport destinations shorty after a request is made, while scheduled services will feature preplanned flight flown by aircraft with seats available for purchase.

For the virtual lane concept in this, the scheduled and on-demand use cases considered include:

- Airport shuttle/transport:
    - Transit from suburban/residential areas to airport
    - Transit from downtown areas to airport
    - Transit from rural areas to airport
- Suburban/residential area transit to/from downtown area
- Suburban/residential area transit to/from other suburban/residential areas

For this conceptual design, the following assumptions were made

- Nominal UAM operations
- For horizontal concept iteration: The width of the Corridor is sufficient to accommodate 6 eVTOL aircraft (with the widest wing spans) flying next to one another (side-by-side) with adequate wing-tip separation gaps on either side of the aircraft, and the height of corridor is sufficient to accommodate the tallest eVTOL aircraft.
- For Staggered concept iteration: The width of Corridor is sufficient to accommodate up to 4 eVTOL aircraft (with the widest wing spans) flying next to one another (side-by-side), and the height of the corridor is sufficient to accommodate three of the tallest eVTOL aircraft including a 50ft vertical separation gap between each aircraft.

In Figure 13 below, the two virtual lane concept iterations are presented.

Iteration 1: Horizontal lanes/tracks that use overhead turn loops to change traffic direction. Presented on the right side of Figure 13.

Iteration 2: A staggered virtual lane system with low-speed lanes located at the lowest lane altitude and high-speed lane located at the highest lane altitude. Shown on the left side of Figure 13.

Both iterations have "activity regions" in which flight maneuvers occur and all these activities occur in the outermost lanes. These activities include:

1. ***Exit***: There are the sections in which aircraft will leave the virtual lane, typically to a vertiport or landing site.
2. ***Join***: Aircraft will join the virtual lane in these sections. This occurs in the outermost lanes, after the exit section.

3. ***Turn***: These are the sections of the virtual lane system provided for aircraft to complete "go-arounds" or "U-turns" i.e., change their direction of travel. In the horizontal lane iteration, aircraft complete the turns above the lane system while in the staggered lane iteration, the aircraft complete the turns below the lane system.

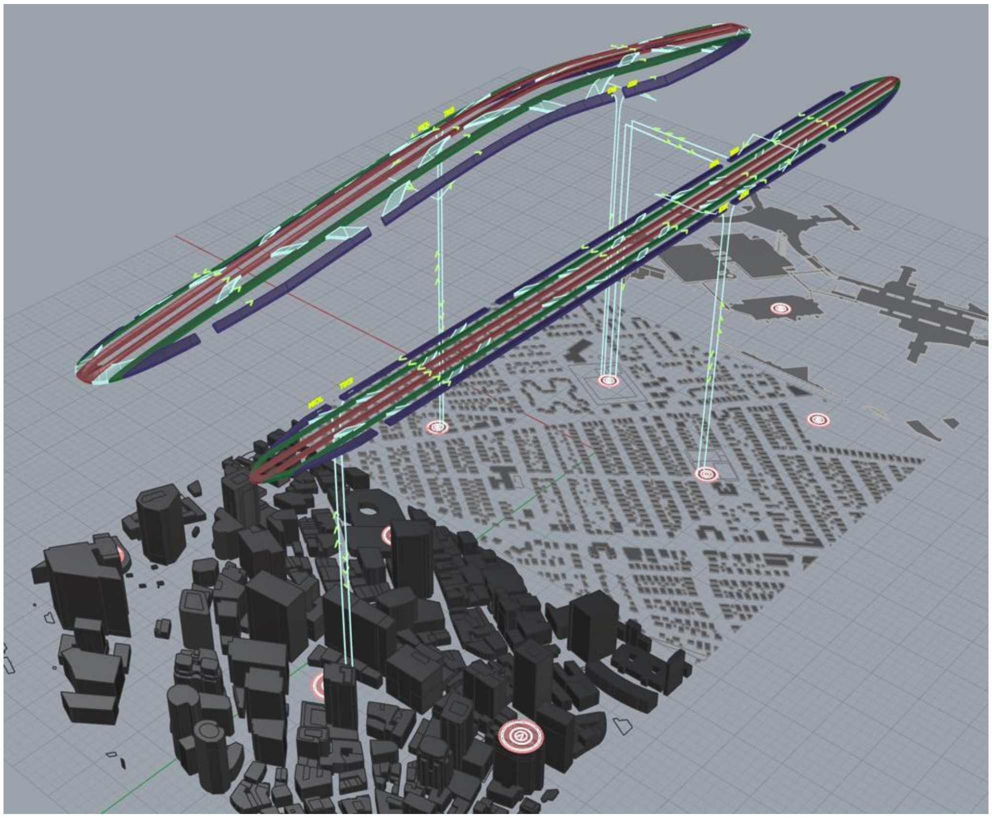


Figure 13: Virtual Lane concept iterations

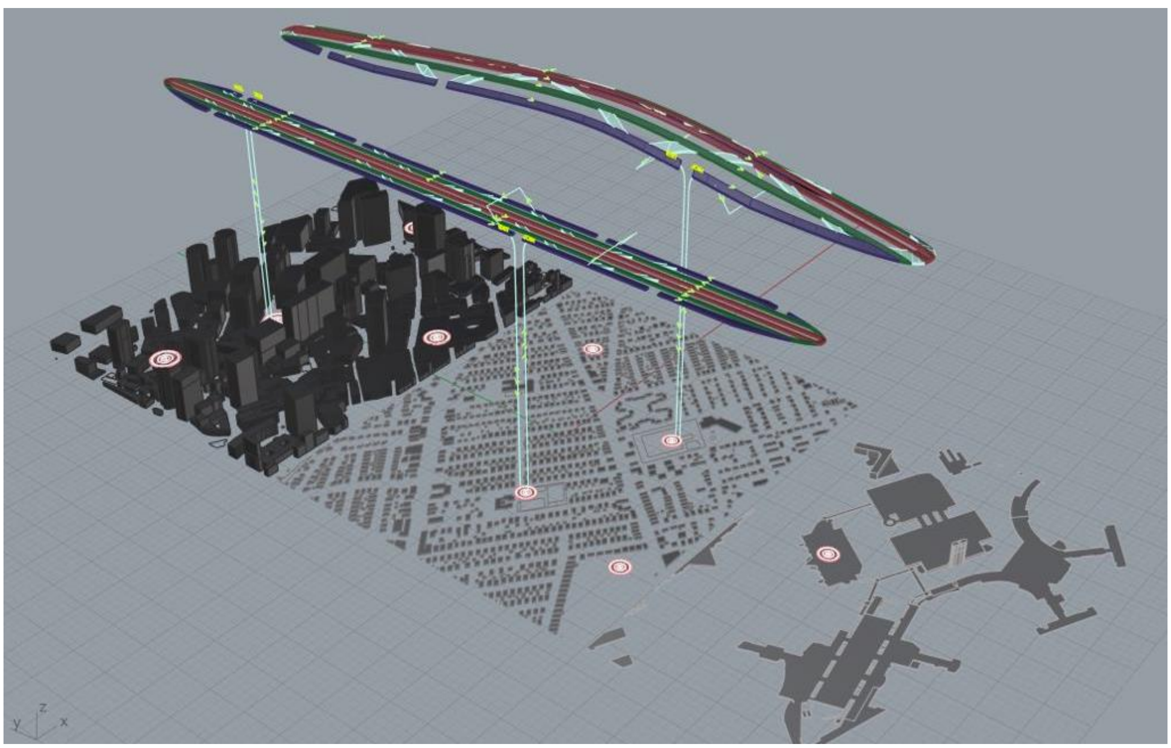


Figure 14:Virtual Lane concept iterations

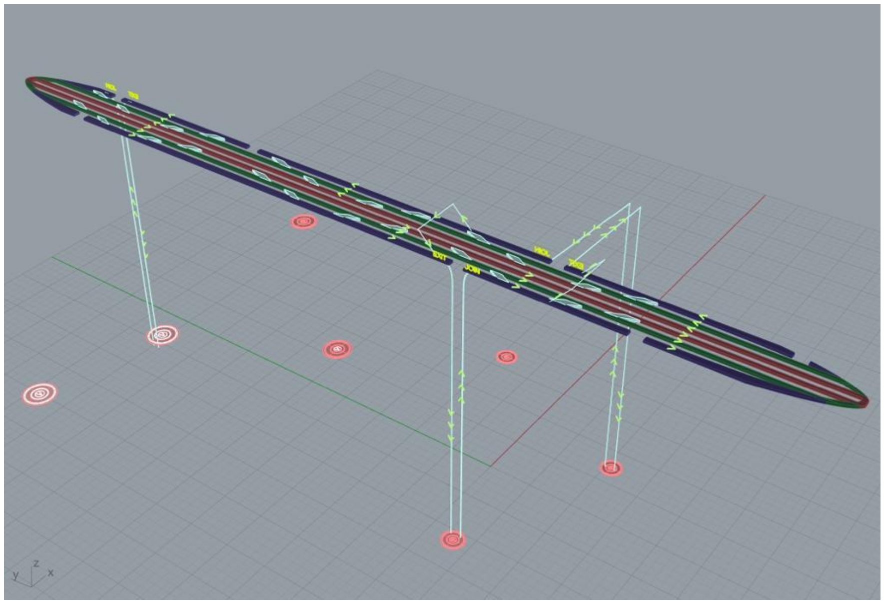


Figure 15: Horizontal Lane concept

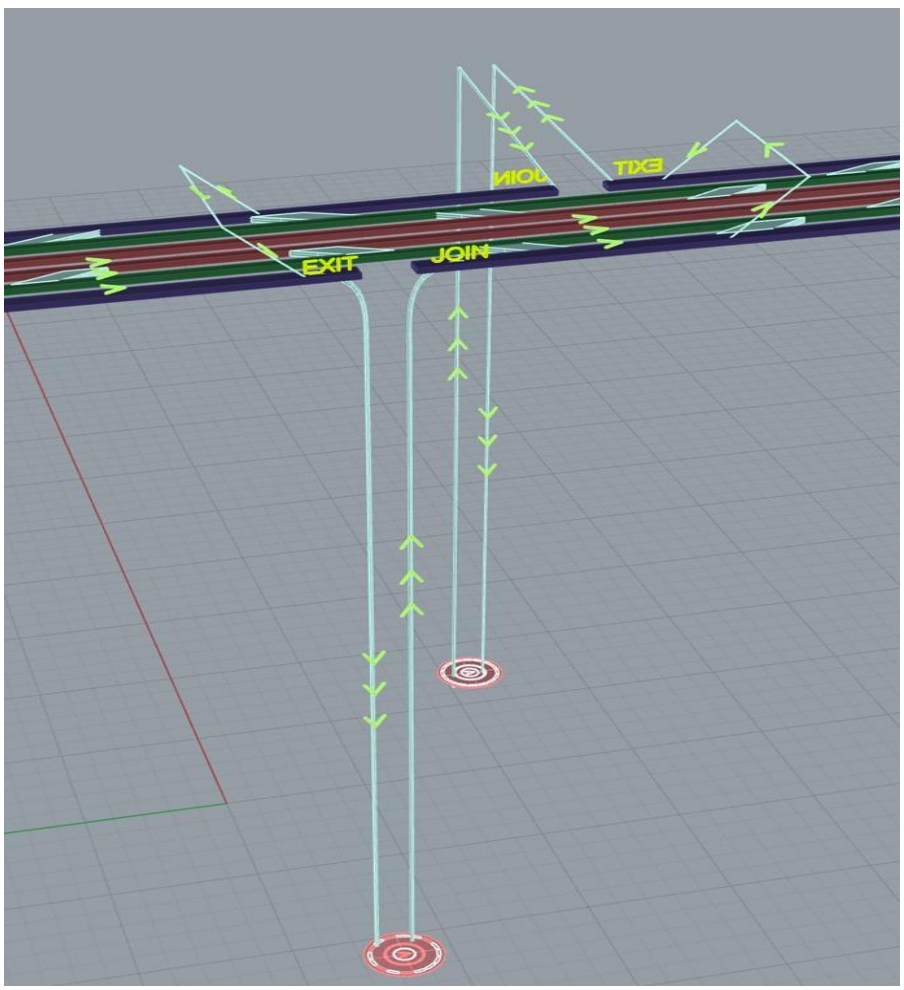


Figure 16: Horizontal Lane concept detail

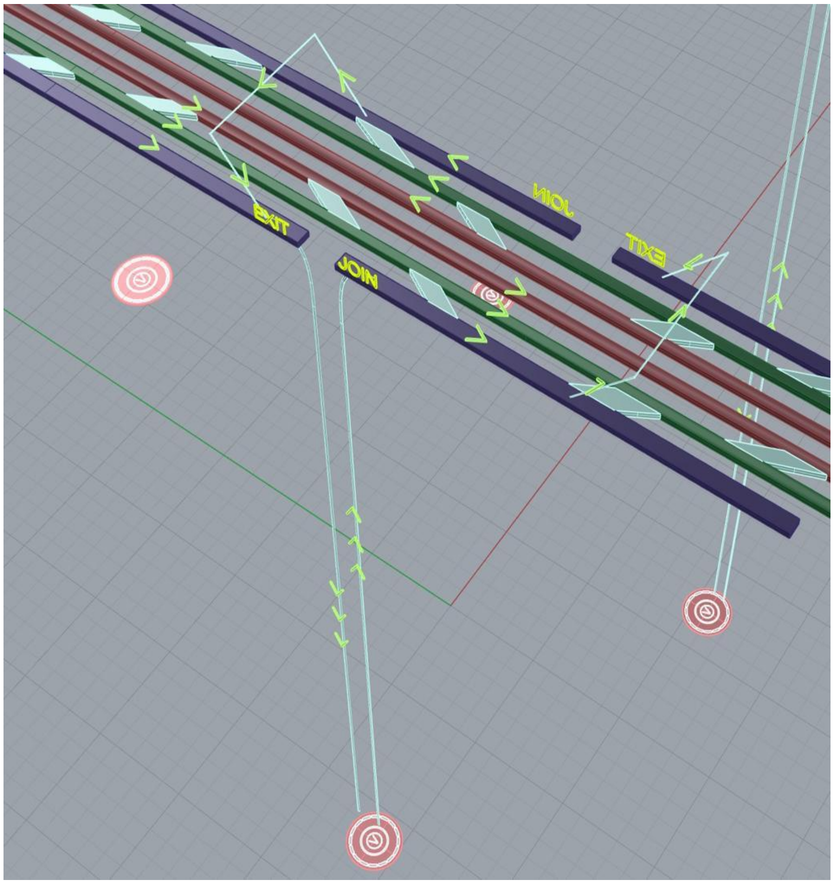


Figure 17: Horizontal Lane concept detail

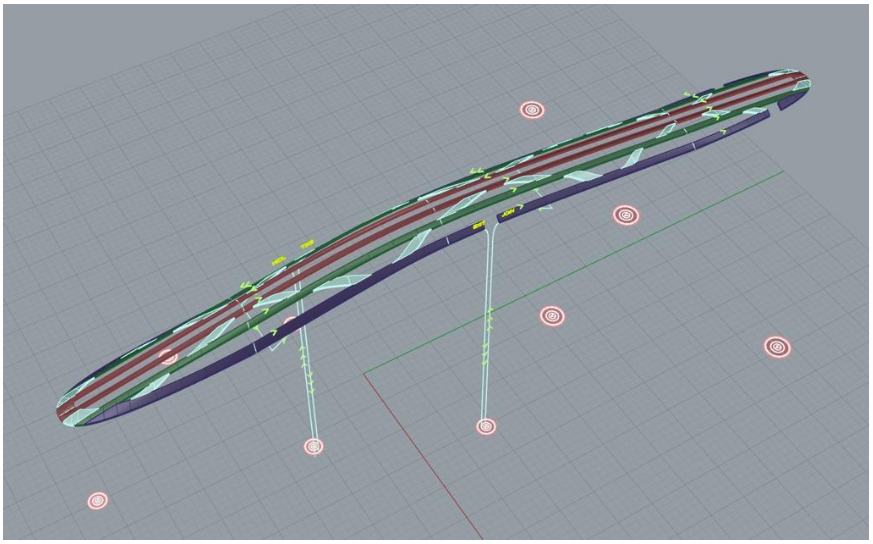


Figure 18: Staggered Lane concept

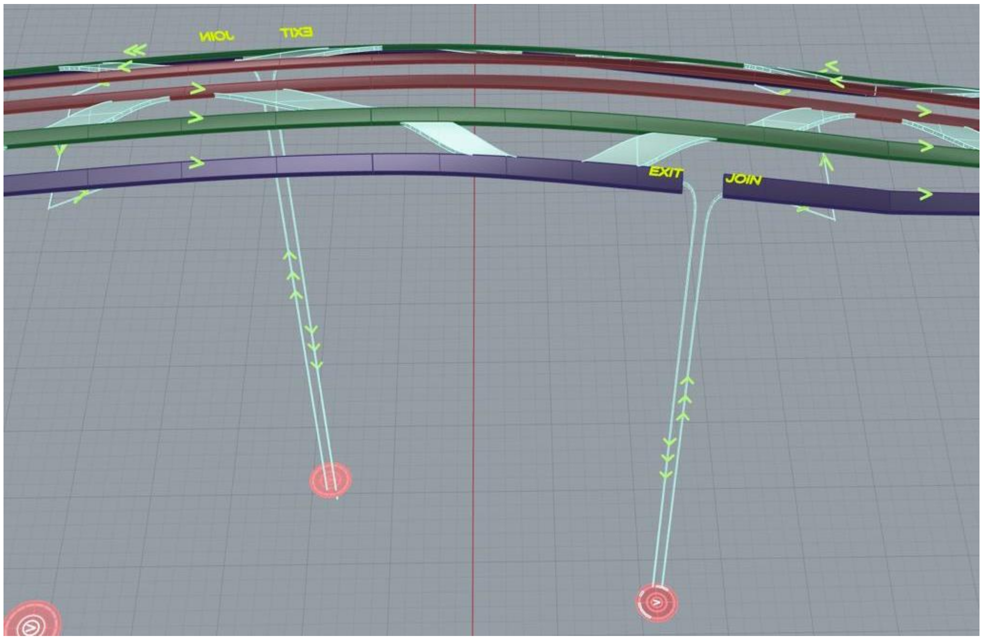


Figure 19: Staggered Lane concept detail

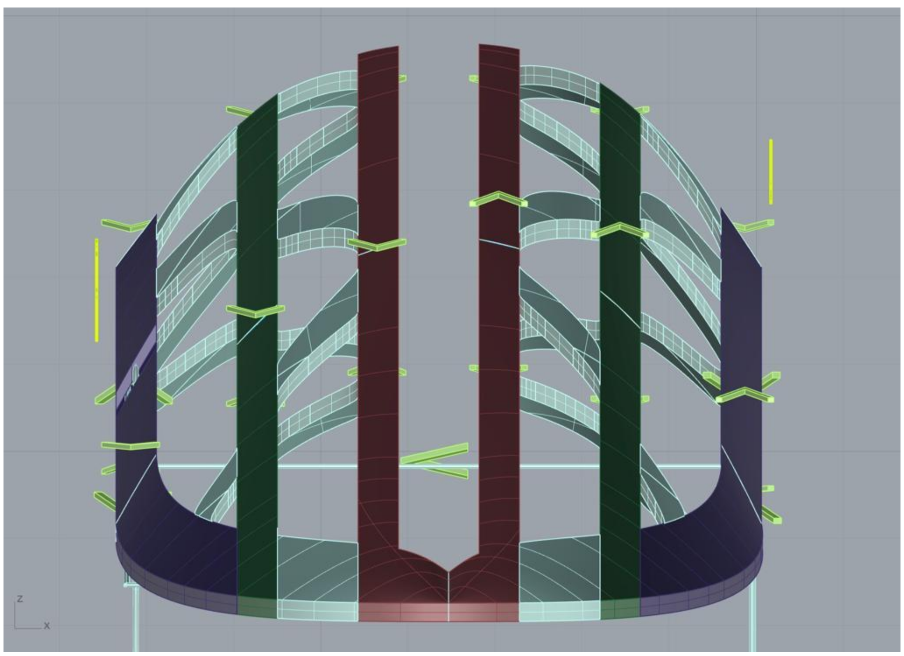


Figure 20: Staggered Lane concept cross section detail

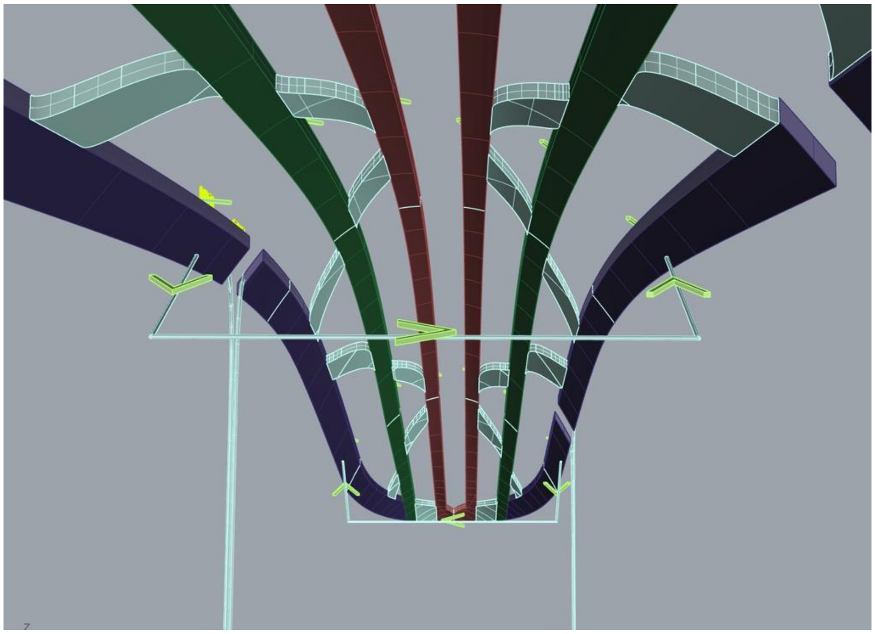


Figure 21: Staggered Lane concept detail

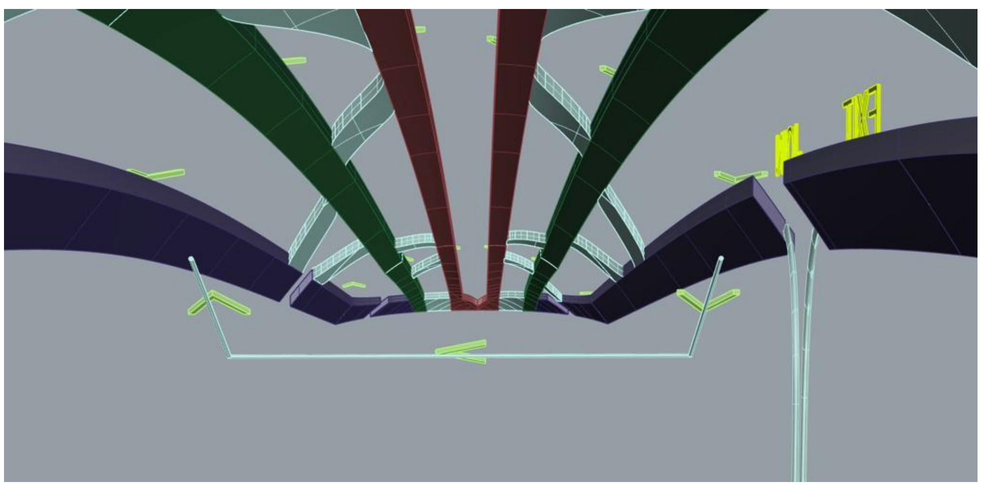


Figure 22: Staggered Lane concept detail

The vertically staggered iteration of the virtual lane track concept can be implemented in areas with limited horizontal space within the corridors. Also, the “exit” and “turn” sections in each activity region can also be used as holding patterns.

<u>3.3 Design considerations for UAM operations using “Tracks”</u>

Safety, security, noise, and public acceptance form the foundation of the Corridor track designs are presented in this paper. This section provides a brief explanation of how these concepts were included in the design of the virtual lane track concepts presented in this paper.

3.3.1 Safety

The safety of passengers, goods and the aircraft are extremely important in the design of any UAM virtual lane system. To ensure safety, the virtual lane system will ensure adequate vertical, lateral, and horizontal separation between all aircraft at all times. The virtual lane system will also be capable of accommodating non-nominal flight conditions and contingency plans as required. The next few paragraphs explain how the separation/collision avoidance and non-nominal conditions will be addressed within the virtual lane track system.

3.3.1.1 Nominal Flight Conditions: Separation &Collision Avoidance

In the *Horizontal virtual lane track iteration*, the main forms of separation required are lateral and horizontal. Lateral separation is ensured by designing the tracks/lanes to accommodate the eVTOL aircraft with the widest wingspan and adequate wingtip-to-wingtip spacing. Horizontal separation is ensured by anti-collision software on aircraft and prescribing speed limits that will be followed by pilots/autonomous systems.

In the *Staggered virtual lane track iteration*, the main forms of separation required are horizontal and vertical. Vertical separation is ensured by a 50ft spacing between the top of the aircraft in the lower altitude/lane and the bottom of the aircraft in the higher lane/altitude. Horizontal separation is ensured by anti-collision software on aircraft and prescribing speed limits that will be followed by pilots/autonomous systems.

3.3.1.2 Non-Nominal Flight Conditions & Contingency Plans

Non-nominal flight conditions include aircraft system failure, passenger emergency, and the inability of an aircraft to continue/complete a flight plan, while contingency plans are made to ensure the safety of the passengers and aircraft.

In the *Horizontal virtual lane track iteration,* in the event of an emergency, the aircraft can immediately descend out of the virtual lane/track while the operators work with the pilot and ATC to assess the problem and reroute the aircraft to the closest landing location.

In the *Staggered virtual lane track iteration,* in the event of an emergency, aircraft can immediately make right turns to leave the virtual lane while the operators work with the pilot to assess the problem and ATC to reroute the aircraft to the closest landing location.

3.3.2 Noise

In noise tests performed by Joby aviation and NASA (Boyer, 2022), at 1640ft and a cruise speed of 100knots, Joby aviation's' aircraft registered the equivalent of 45.2 dBA. Although this is a low noise level, the virtual lane concepts presented in this paper feature a track system that will be used by multiple aircraft simultaneously and at possibly lower altitudes than 1640ft. It is expected that the cumulative/combined noise effect generated by multiple aircraft flying in the same tracks will be significant. To address this noise concern, the following altitude and airspace segregation recommendations (Table 2) were made.

Table 2: Altitude and Airspace Segregation Recommendations

Altitude	Operations
0 - 400ft	UAS operations
0 - 500ft	Emergency services (police/fire/ambulance)
600 ft. – 2500ft	UAM operations. • Horizontal lane iteration: Altitude of lanes should be 330 - 350ft above the average height of the tallest buildings. • Vertically staggered iteration: The lowest lanes in the stager should be 330 - 350ft above the average height of the tallest buildings in the area. The height of subsequent lanes above should be equivalent to the sum of 50ft + the height of the tallest eVTOL aircraft (to be determined as aircraft complete the certification process).

Based on the inverse square law that applies to sound and distance, at 330ft from the source, the intensity of sound should reduce by 20dB (Collman, 2015). The 330 - 350ft gap proposed between the virtual lane system and the tallest buildings will ensure that the noise/sound reaching the tall buildings is significantly less than the sound generated during a normal conversation (i.e., 60dB). This proposed gap also ensures that the sound generated within the virtual lanes are inaudible to homes in residential areas.

3.3.3 Security/Privacy

At full maturity, eVTOL aircraft will be performing autonomous operations. This will require the use of sensors and cameras. The use of cameras on aircraft flying in low altitude airspace may generate safety concerns for people that live and work along the flight path of aircraft. The use of a virtual lane system at a significant altitude above tall buildings will make it easy to identify rogue aircraft and/or aircraft in emergency situations. The altitude of the virtual lanes also provides sufficient space between aircraft and most residential communities at ground level.

3.3.4 Public acceptance & Giving cities control of their airspace

Involving communities in the design of routes for virtual lane system, and the significant height of the virtual lanes above tall buildings addressing auditory, visual and safety concerns, members of the public may be more receptive to the implementation of UAM. An expected advantage of this virtual lane system is the reduced workload to Operators and ATC. Anticipated operations of operators, PSUs and ATC is explained below.

Operators: Operators performing routine scheduled and on-demand flights will not need perform an extensive flight plan, instead, all that will be required by the virtual lane system is confirmation of intent to fly between two locations and operator will receive flight route information, corridor status, possible flight obstructions, incidents reported etc.

PSUs: Will be responsible for the maintenance of the corridors, monitoring the virtual lane system, and ensuring accurate/ up-to-date information is always available to airspace users.

ATC: ATC function will be taken up by PSUs such that communication between both parties will be limited to emergency cases and airspace information update exchange.

4.0 Conclusion

The operational concept of UAM entails the transportation of people and goods between aerodromes via one or more UAM corridors without the need for tactical ATC separation services and without disruption to other users of the airspace. The UAM community and stakeholders are expected to establish standards of operations with the FAA who will provide the necessary approvals required if the operational standards are deemed satisfactory and safe. The goal/aim of UAM is autonomous flight in which aircraft complete trips without human pilots on board. To achieve this, the flight path and traffic management system need to be robust while ensuring safety especially during dense operations. A search of literature revealed that no study has been done on additional structures that may be required within UAM corridors which the FAA envisions may be required during high density UAM operations. This study produced two different iterations for a track system within UAM corridors that will aid safety, separation, reduce workload of pilots at the initial phase and ease automation as operations advance. In this flight path concept, the corridors and tracks are positioned significantly above urban areas thereby minimizing noise and security concerns. The use of corridors and tracks will also make it easy to identify rogue and/or troubled aircraft.

With the virtual lane track system, Operators performing routine scheduled and on-demand flights will not need extensive flight plans, instead, PSUs will require a confirmation of intention to fly between two locations. The PSUs send flight route information, corridor status, possible flight obstructions, incidents reported etc. to the operators. The PSUs will be responsible for the maintenance of the corridors, monitoring the virtual lane system, and ensuring accurate/ up-to-date information is always available to airspace users. They will also be responsible for the routing of emergency service vehicles when required. This will ensure that ATCs are contacted during emergency situations where eVTOL aircraft may cross into other airspaces and to exchange airspace traffic updates.

Once more guidance is available on corridor dimensions, aircraft complete the certification process, and enter service, a more detailed and functional corridor / track concept can be designed, developed, and tested. Initiating UAM services with a corridor and track system will aid the development of the system and ensure that it scalable when increased operations demand.

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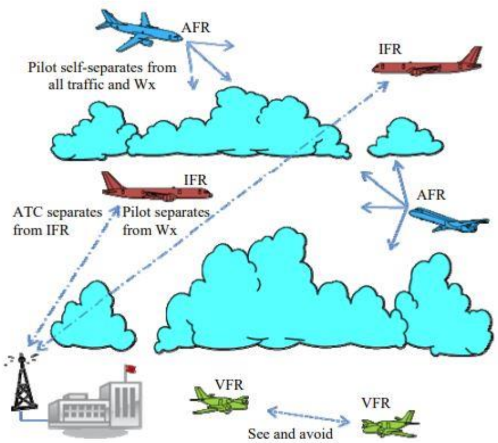
APPENDIX

Operational Gaps

UAM corridor dimensions	There currently are no defined and approved UAM corridor dimensions, to aid the design of a flight path concept
Aircraft design	Different aircraft manufacturers have different aircraft designs and dimensions. Flight path concept should be robust enough to accommodate all or almost all aircraft types
Separation standards	There are no defined separation standards for aircraft operating within urban airspace

The table below contains other noteworthy literature discoveries that will impact flight path design, traffic management, and implementation.

Other Noteworthy Research Discoveries	
Digital Flight Rules (DFR)	Digital Flight: “an operating mode in which flight operations are conducted by **reference to digital information**, with the operator ensuring flight-path safety through cooperative practices and self-separation enabled by connected digital technologies and automated information exchange” (NASA, 2022) Digital Flight Rules (DFR): “a set of regulations authorizing sustained Digital Flight as an alternative means of separation in VMC and IMC, in lieu of employing visual procedures or receiving ATC separation services (i.e. Visual Flight Rules (VFR) or Instrument Flight Rules (IFR)) (NASA, 2022) DFR is being proposed to augment Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) currently being used for NAS operations and is aimed at providing UAM vehicle operators with safe and unrestricted airspace access under all visibility conditions.

Autonomous Flight Rules (AFR)  	AFR uses the precise navigation provided by Global Navigation Satellite Systems (GNSS), Automatic Dependent Surveillance Broadcast (ADS-B) technology which gives aircraft the ability to share their satellite-derived position with other aircraft/ ground systems, and Required Navigational Performance (RNP) It provides route flexibility to the operators i.e. operators do not require approval to change flight trajectory. AFR essentially creates a traffic system in which operators initiate flight missions while all aircraft are constantly talking to one another and maintain separation based on the ADS-B and RNP information received by the avionics systems onboard the aircraft. (NASA, 2011) Additional equipment, training, and ATC will still be required for separating IFR flights and managing high volume terminal arrivals and departures
Required Navigation Performance (RNP)	Refers to navigation specification that allow the operation of aircraft along routes requiring high level of accuracy
Combination of proposed solutions	A combination of corridors and a traffic flow management system could help with UAM vehicle separation and operation predictability concerns (Mueller, 2017)
Weather and Operation Altitudes	Weather patterns within Urban areas where UAM operations will be deployed will have significant impact on operations, as such, viable altitudes with favorable weather patterns that will ensure safe operations are a necessity. Weather analysis showed that altitudes between 500 and 5,000ft are preferred for UAM operations due to strong winds above 5,000ft (Booz Allen Hamilton, 2018) . It is anticipated that initial UAM operations will commence in altitudes lower than 2,000ft while operational standards are established (William N. Chan, 2018)
Nominal operations	Flight operations within corridors which involve/include a planning, departure, enroute, arrival and post-operation phase. (FAA, 2020)

Non-nominal operations	Two types: 1. When an aircraft within a corridor deviates from the original flight path: operator is required to update subscribed PSU and other PSUs who will determine if the aircraft can continue operations within the corridor or the new airspace it entered. (FAA, 2020) 2. When an aircraft experiences failure requiring a forced landing: the PIC concentrates on flying and landing the aircraft, exits the corridor, turns on ADS-B transponder and notifies ATC while the operator works out contingency plans (with ATC) (FAA, 2020)
Public acceptance	To address visual and auditory acceptance concerns, routes should be planned at high altitudes (to aid visual acceptance) and around sparsely populated areas or noisy areas (e.g. rail ways & highways). Flight paths need to be routine and unsettling to the public. (Thipphavong, 2018)