

METROAIR

Corporate Technical White Paper

From Sky to Street: Metro 3D Mobility for All

A modular three-dimensional urban public transportation system combining synthetic urban air systems, modular autonomous mobility, AI swarm flight, and hybrid air transporters.

VERSION

2.0

EDITION

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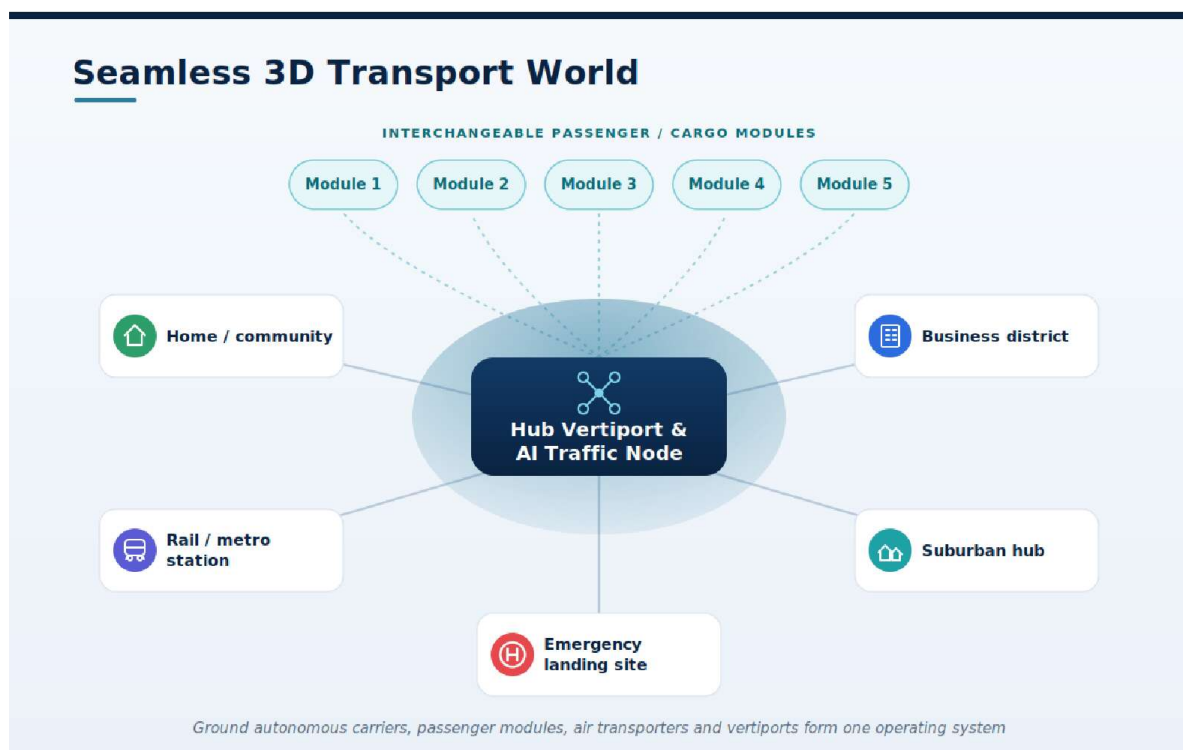
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From Sky to Street: Metro 3D Mobility for All

White Paper Version 2.0

A Modular Three-Dimensional Urban Public Transportation System Combining Synthetic Metro 3D Mobility, Modular Autonomous Vehicles, AI Swarm Flight, and Hybrid Air Transporters



Seamless 3D transport world: a hub Vertiport and AI traffic node connecting autonomous ground carriers, passenger modules, emergency sites, suburban hubs, and business districts.

MetroAir Inc. | 2026 Update | Official Version 2.0

This official Version 2.0 is a self-contained white paper that incorporates the complete MetroAir system concept and expands it with current technical, regulatory, industrial, and research evidence

Executive Summary

MetroAir Version 2.0 presents a complete three-dimensional metropolitan transport concept. The system is not an air-taxi service in the narrow sense. It is a synthetic urban air system in which a Multicruiser air transporter carries only the passenger module between Vertiports, while autonomous ground carriers handle the street-level segment. The passenger does not transfer from car to aircraft and then back to another car; rather, the passenger module itself moves between ground and air layers.

The MetroAir system concept argued that the dominant exposed-propeller eVTOL air-taxi model would face public acceptance, vertical-descent, power-settling, Vertiport-capacity, energy, and business-model constraints. Those assumptions have become more important as the AAM industry has moved from concept renderings toward certification, infrastructure design, and early operational planning. Regulatory activity around powered-lift aircraft, Vertiport design, BVLOS operations, UTM, and AAM implementation plans confirms that urban aviation is no longer only an aircraft-design problem. It is a system-of-systems problem.

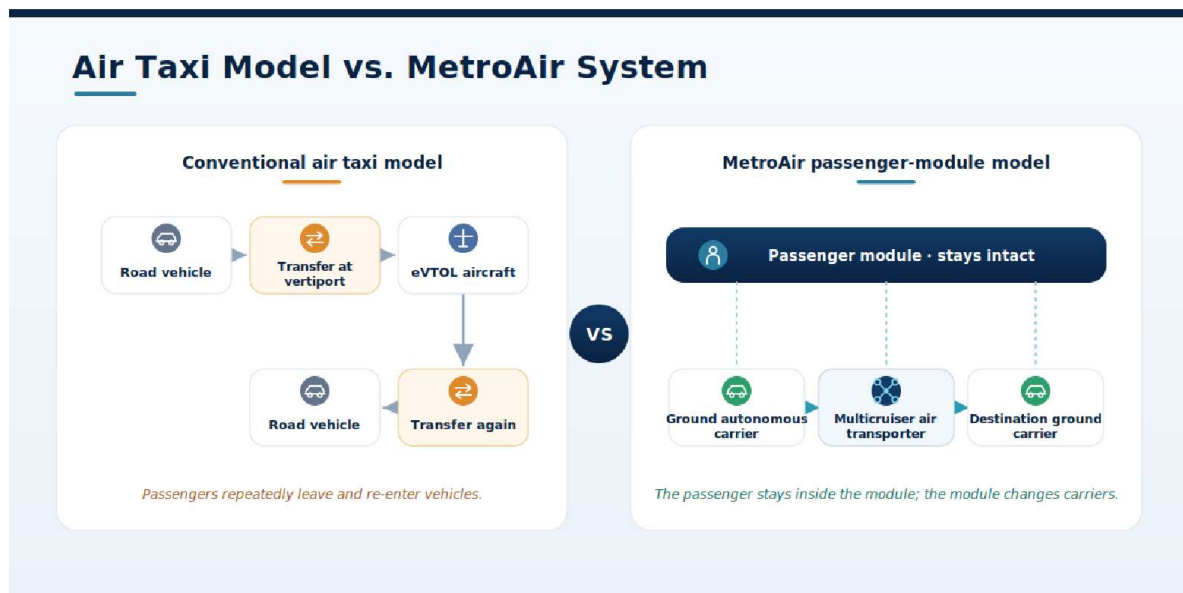
The essential idea of this Version 2.0 is that urban air mobility must be integrated with modular ground mobility. Recent PBV and modular electric vehicle developments show that the automobile industry is moving toward service-oriented platforms, modular upper bodies, and autonomous fleet operations. At the same time, robotaxi operations show that autonomous ground transport can work within defined operational design domains, while also demonstrating that a stand-alone robotaxi service does not by itself solve metropolitan congestion or regional access.

A second major update is artificial intelligence. AI is not treated here as a decorative add-on to the aircraft. It is the traffic intelligence of the system. The Multicruiser must be able to recognize its environment, avoid other vehicles, perform precise approach to the catcher, manage energy, select emergency landing sites, and fly as part of a connected swarm. The system also requires a central AI that generates a dynamic three-dimensional corridor web, a Vertiport AI that manages launcher/catcher, docking, passenger modules, energy and turnaround, and an aircraft edge AI that guarantees immediate collision avoidance when network conditions degrade.

A third update is energy. The battery-only eVTOL model has demonstrated short-range feasibility, but battery energy density, high-power vertical lift, thermal stress, reserve requirements, repeated fast charging, and battery degradation remain central constraints on economic operation. Version 2.0 therefore strengthens the Multicruiser as a modular air transporter that may use a hybrid turbo-generator electric architecture. Batteries provide peak lift power, emergency reserve, and low-noise local operation, while a turbo-generator supplies cruise power and maintains state of charge. This architecture is consistent with the

growing industrial interest in hybrid-electric flight for advanced air mobility and longer-range VTOL aircraft.

The final claim is that the air-taxi debate has been too narrow. A pilot-operated eVTOL that moves passengers between Vertiports is a transitional model. A truly public 3D transportation system requires modular passenger capsules, autonomous ground carriers, AI-managed swarm flight, rapid launcher/catcher Vertiports, and a scalable energy strategy. The resulting system is a seamless transport world: ground and air are not separate modes but layers of the same metropolitan mobility network.



Conventional air-taxi transfer model compared with the MetroAir passenger-module model.

Version 2.0 organizing principle

The MetroAir system concept is retained as the foundation. New research and industry developments are integrated directly into the Version 2.0 body as technical evidence that strengthens the system logic.

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1. Introduction: From Air Taxi to Modular 3D Urban Public Transportation

Recently, as the technological possibilities for air taxis have emerged, many designers and companies are working on developing air taxis. Air taxis have not only gained favor with many people due to expectations that they can alleviate traffic congestion in the city, but have also created a cash rush with investment funds flowing into some of the leading eVTOL aircraft development companies, but various technical problems have arisen. With this being raised, it appears that the peak point of the Gartner cycle has been surpassed.

Here, we point out the problems with the air taxi concept and suggest ways to realize urban aviation more efficiently.

Version 2.0 expands the same problem statement. The air-taxi market has matured from enthusiasm to a more sober assessment of certification, infrastructure, battery performance, public acceptance, pilot supply, and operating economics. The industry has learned that an eVTOL aircraft alone does not create a public transportation system. It only creates a flying vehicle. A public system requires coordinated ground access, automated Vertiport processing, energy management, fleet balancing, traffic separation, emergency response, and digital trust.

The MetroAir concept therefore moves beyond the air-taxi frame. A Multicruiser is not primarily a taxi cabin. It is an air transporter for a passenger module. The passenger module can be privately owned, shared, or public. The ground carrier may be autonomous and shared. The air transporter may be publicly managed for safety and availability. The Vertiport is an automated machine for module handling, launch, capture, inspection, charging or fueling, and fleet dispatch. This is the distinction between an air-taxi service and a modular 3D transport system.

Recent regulatory and industry developments reinforce this direction. FAA activity around powered-lift aircraft and Vertiport guidance shows that the aircraft category is being formalized, while BVLOS and UTM activity shows that unmanned traffic management and third-party services are becoming part of the low-altitude aviation infrastructure. NASA's AAM work likewise treats AAM as an integrated ecosystem rather than only as an aircraft market. (1, 3, 4, 5, 37)

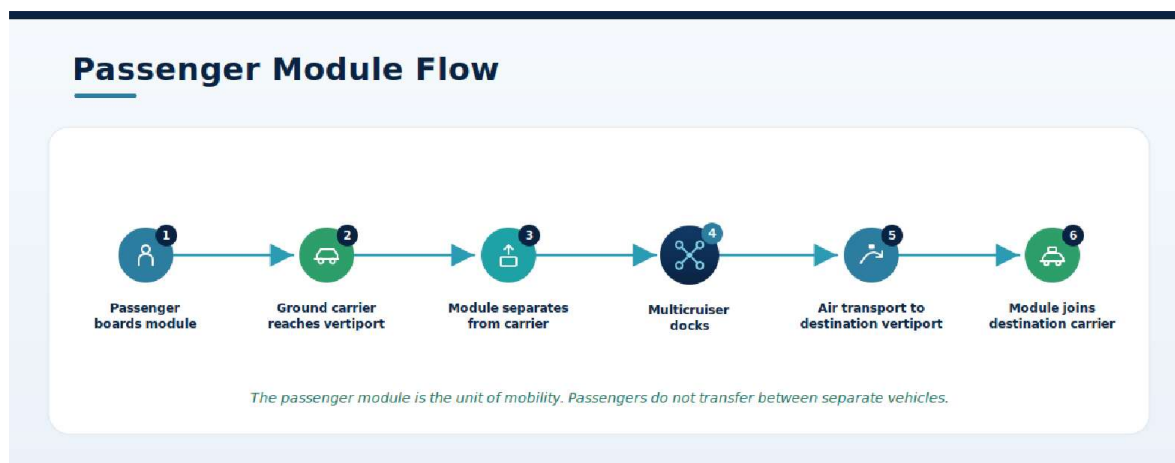


Figure 3. Passenger module flow in a seamless transport world.

2. Problems of Urban Flying

eVTOL aircraft currently being developed as air taxis, a wide variety of aircraft shapes are presented depending on the designer's design intent, and although some aircraft have advanced to the certification process, most of the shapes of the leading aircraft are distributed electric vehicles. By applying distributed electric propulsion, a design with multiple propellers exposed to the outside is adopted.

This design can be said to be a design that does not consider public acceptance when applied to the concept of urban aviation. There would be no problem if such an aircraft took the form of flying from the outskirts of the city to the suburbs, as in the current flight environment, but if frequent takeoffs and landings were performed in overcrowded areas within the city, even though the aircraft was very safe (e.g., a fatality rate similar to that of an airliner, there would be no problem.) Even if it is designed and manufactured, the threat of the shape caused by flying very close to people and buildings around the takeoff and landing site cannot be overlooked.

Quantify these threats and believe that urban flight will be possible if crash safety is at least as good as that of a passenger plane, but if the public refuses to allow such aircraft to fly close overhead, urban aviation will never be successful.

Since it is an aircraft capable of vertical takeoff and landing, it may be judged that the threat to the surroundings can be minimized by vertically descending tens of meters above the landing site and landing. However, this overlooks the power settling phenomenon of the helicopter that occurs during vertical descent flight. This phenomenon is also called a vortex ring state (VRS) in academic terms. It is a phenomenon in which the rotor loses thrust and controllability at a certain descent speed. This phenomenon was known early in the history of helicopter operation, when helicopters usually perform this type of flight. Thus a landing that approaches the landing pad with a constant descent angle was established.

This phenomenon of power settling also occurs in Multicopters. Of course, there are some design techniques to avoid power settling, but the airplane to which those techniques are applied is even if the aircraft manufacturer claims that it is very robust against power settling, it is expected that it will be difficult to allow a vertical descent type landing.

This is the biggest problem that arises when operating an aircraft in the city. If an eVTOL aircraft enters the landing zone with a certain descent angle, it will be too close to obstacles and too close to people's heads in most urban environments.



Figure 4. Urban problem statement: dense urban environments intensify public acceptance and operating-safety challenges for air taxis.

2.1 Public acceptance is not the same as statistical crash safety

A central argument of the system is that engineering safety and perceived safety are related but not identical. A vehicle may be designed to meet demanding certification requirements but still be rejected if the public experiences it as visually threatening, noisy, intrusive, or uncontrolled. This is particularly important for exposed-propeller distributed-electric aircraft because the threat is not only a statistical risk of crash. It is also the everyday impression of multiple rotors passing close to buildings, terraces, schools, and public spaces.

Public-acceptance research confirms that safety, noise, security, privacy, and environmental effects influence acceptance of urban air mobility. European citizen studies found openness to socially useful UAM missions, but also strong concerns about safety, noise, security, and visual impact. These findings support the original design direction of shielding the propulsive system and keeping normal operations above the immediate human environment. (8, 46, 47, 48)

For this reason, the Multicruiser architecture does not simply minimize crash probability. It attempts to reduce the visual and psychological threat of the aircraft itself. The Rimfoil concept protects the propeller, contributes to aerodynamic lift, creates a more integrated visual form, and supports mechanical handling inside a Vertiport. The same form factor that improves public acceptance also supports storage, docking, capture, and automated maintenance.

2.2 Vertical descent, VRS, and the misconception of simple rooftop landing

The intuitive public image of an eVTOL is that it rises vertically, flies across the city, descends vertically, and lands on a rooftop pad. The system rejects that assumption. Vertical takeoff capability does not mean that repeated steep vertical descents into dense urban Vertiports are operationally desirable. Helicopter operations have long recognized vortex ring state and power-settling risks, and eVTOL aircraft with different disk loadings and rotor arrangements may have their own VRS vulnerabilities.

Recent landing-trajectory research for eVTOL aircraft explicitly treats VRS as a critical factor in approach design. This strengthens the original white paper's argument that the urban aircraft must be designed together with its approach path, Vertiport geometry, and takeoff/landing assistance devices. (25)

In a dense city, a shallow or angled approach creates another problem: the vehicle must move close to buildings and people before reaching the landing point. A pure vertical descent can increase rotor-state risk, while a conventional approach path increases urban exposure. The launcher/catcher system and elevated hub Vertiport are a way to escape this contradiction by shortening the low-altitude transition near the Vertiport and moving the vehicle rapidly into a planned corridor.

Table 1. Urban flight problem areas and system-level responses

Risk area	Conventional air-taxi problem	MetroAir design response
Public perception	Exposed rotors and repeated low-altitude passes can be perceived as threatening.	Rimfoil-protected rotors, elevated Vertiports, and limited low-altitude exposure.
VRS / power settling	Assuming direct vertical descent may ignore rotor-state hazards.	Approach paths, catcher, and launcher are treated as system design variables.
Urban obstacles	Angled approach paths may pass close to buildings and pedestrians.	Hub Vertiports rise above local obstacles and connect to dynamic 3D corridors.
Noise and downwash	Frequent rooftop operations concentrate nuisance near residences.	AI scheduling, elevated nodes, and corridor planning distribute and control exposure.

3. Correlation Between Urban Air Operations and Vertiport Throughput

Vertiport started from the concept of creating a dedicated take-off and landing field, and many conceptual diagrams have been presented, but the take-off and landing form at this dedicated take-off and landing field that overlooks the characteristics of the aircraft also contains various problems that are difficult to solve.

Aircraft turnover rate is the first issue that arises. If an aircraft uses batteries as an energy source, battery charging and replacement will act as the biggest obstacle limiting the aircraft takeoff and landing turnover rate. It is expected that this will not secure the feasibility of the project in terms of cost effectiveness considering the cost of constructing a dedicated take-off and landing pad in the city center. The shape of multiple exposed wings and propellers also causes problems with containment within a cramped landing pad.

These problems were comprehensively reflected in the design to provide a comprehensive design including the shape and flight characteristics of the aircraft, aerodynamic efficiency, navigation methods in the city, the shape and internal structure of the Vertiport, and devices that can assist takeoff and landing from the Vertiport. We propose a synthetic urban aviation system and an integrated three-dimensional transportation system that extends this to modular mobility.

02
WHY METROAIR REDEFINES URBAN AIR MOBILITY
MetroAir White Paper Summary

Design logic behind a safer and more practical urban air system

01
Public Acceptance
Exposed propellers and intimidating aircraft shapes reduce urban acceptance.

02
Operational Safety
Dense urban landing requires safer low-speed maneuvering and reduced perceived threat.

03
Power-Settling Risk
Vertical descent challenges require new takeoff and landing methods.

04
Turnaround Efficiency
Urban service needs rapid loading, handling, and high-throughput vertiports.

05
Integrated Solution
MetroAir combines aircraft design, vertiport design, and control systems into one architecture.

Conventional eVTOL Approach


- Exposed, high-speed propellers increase noise, perceived danger, and public concern.
- Downwash and complex control make low-speed urban landings more difficult.
- Narrow utility and slower turnarounds limit real-world urban operations.

MetroAir Rimfoil Hexa Approach


MetroAir Response

- Enclosed rimfoil propulsion
- High-throughput vertiports
- Six-rimfoil Multi-Cruiser air transporter
- Integrated modular air-ground mobility

Acceptance

Safety

Efficiency

Scalability

Figure 5. Vertiport assumptions and the question of whether a Vertiport is merely a landing matter.

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3.1 Turnaround is the economic center of urban aviation

The economics of an urban aviation system are not determined only by aircraft cruise efficiency. They are determined by the number of safe departures and arrivals that can be processed per unit time, the time needed for docking and passenger-module handling, the energy replenishment cycle, the ability to recover from local failures, and the allocation of vehicles across the network. A Vertiport with beautiful architecture but low throughput is not a transport node; it is a symbolic landing deck.

NASA throughput analysis and Vertiport capacity studies show that UAM capacity is constrained by more than pad count. Passenger flow, fleet availability, separation rules, weather, scheduling, charging, and ground handling all shape actual throughput. This reinforces the original claim that the Vertiport, aircraft, energy system, and control system must be co-designed. (6, 26, 27)

MetroAir's use of launcher/catcher mechanisms should therefore be understood as a capacity architecture. The goal is not mechanical spectacle. The goal is to reduce the time during which the vehicle occupies the landing interface, rapidly transfer it to internal handling systems, and keep the top deck available for the next arrival or departure. In this sense, the Vertiport is closer to an automated logistics node than to a small rooftop airport.

3.2 Why the passenger module changes throughput logic

In a conventional air taxi, the aircraft is also the passenger cabin. Every boarding, cleaning, safety check, and cabin reset is part of the aircraft turnaround. In a passenger-module system, these processes can be partially decoupled. Passenger modules can be prepared, cleaned, secured, assigned, and queued separately from air transporters. Air transporters can be inspected, fueled, charged, or repositioned without carrying the passenger environment.

This separation is similar to the way containers changed freight logistics. The value lies not merely in the vehicle but in the standardized interface. For MetroAir, the interface includes mechanical docking, electrical connection, data authentication, weight and balance verification, emergency release logic, and passenger safety interlocks. Once these interfaces are standardized, the air transporter can become a fleet asset and the passenger module can become the personal or public mobility unit.

Recent PBV and modular vehicle developments show that the ground industry is already moving toward standardized service-oriented platforms. MetroAir extends this logic vertically. It asks why a passenger module should remain trapped in two-dimensional traffic when a standardized air transporter can move it across the metropolitan region. (20, 21, 22, 31, 32)

4. Vertiports as Synthetic Urban Air System Nodes

First, the synthetic urban aviation system is explained.

This is based on the premise that it would be more cost-effective to consider operating urban aviation as a large-scale system rather than operating it at the level of an air taxi.

Vertiport is in terminology, it can be said to be an urban airport built vertically. If constructed vertically, the problem of expensive construction land can be avoided, but the problem remains as to how to use the vertically constructed Vertiport. Passengers also have problems using Vertiport. To comprehensively solve this problem, a hub Vertiport will be built in the area where traffic volume is expected to be the highest.

This is to ensure smooth takeoff and landing of aircraft. In general, the height of buildings and traffic volume in downtown areas are proportional, so tall buildings are located near the center of overcrowded downtown areas, lower buildings are located on the outskirts of the city center, and lower buildings are located on the outskirts of the city center, and traffic volume is generated accordingly, so the heights vary in each region. A Vertiport will be built over the road.

Facilities that perform key functions performed at the hub airport are installed inside the hub Vertiport. For example, maintenance, traffic control, boarding process, cargo handling, security, etc. At a hub airport, the runway is the core takeoff and landing facility, but at Vertiport, a takeoff and landing pad and takeoff and landing assist devices for vertical takeoff and landing are installed at the top.

The takeoff and landing assist device is to quickly and safely take off and land an aircraft. It includes an ejection device for takeoff and a catcher device to safely hold it immediately after landing.



Figure 6. Hub Vertiport vision: a vertical node built above the road network.

4.1 The Vertiport as an automated urban machine

The system treats the Vertiport not as real estate for aircraft parking but as a machine for processing modules and aircraft. A hub Vertiport contains boarding, security, maintenance, control, energy service, vertical movement, docking, launcher, capture, and emergency management. Its physical form is defined by flow: the flow of passengers, passenger modules, aircraft, energy, data, maintenance events, and emergency contingencies.

FAA Engineering Brief 105A provides a performance-based reference for Vertiport design, but it also highlights the evolving nature of VTOL operations and the need for operational data. MetroAir's launcher/catcher and module-handling Vertiport is more specialized than conventional pad-based designs, so it requires its own simulation, ground test, scaled flight test, and operational envelope development. (3, 6, 26)

The road-over-Vertiport concept remains important because urban land is the scarcest infrastructure input. Placing a vertical node over a road or intersection can reduce land acquisition problems and connect directly to pedestrian, transit, and autonomous ground layers. The issue is not whether every city will adopt the exact same structure. The issue is that the Vertiport must be located where transport demand exists, not only where aviation land is available.

4.2 Functional layers inside a hub Vertiport

Table 2. Hub Vertiport functional layers

Layer	Primary function	System implication
Street / access layer	Pedestrian, transit, autonomous ground carrier, service vehicle access.	The Vertiport becomes a multimodal mobility node rather than a remote aviation site.
Passenger module layer	Boarding, security, assignment, cabin readiness, cleaning, module inspection.	Passenger-flow management can be decoupled from aircraft turnaround.
Aircraft handling layer	Air transporter inspection, docking, energy service, storage rack movement.	Fleet assets are processed like high-value automated vehicles.
Launcher/capture deck	Catcher, launcher, wind alignment, top-deck safety and automated recovery.	The top deck becomes a high-throughput interface, not a waiting area.
Control layer	Vertiport AI, local traffic sequencing, emergency routing, and communication links.	Local AI is a safety-critical part of the system architecture.

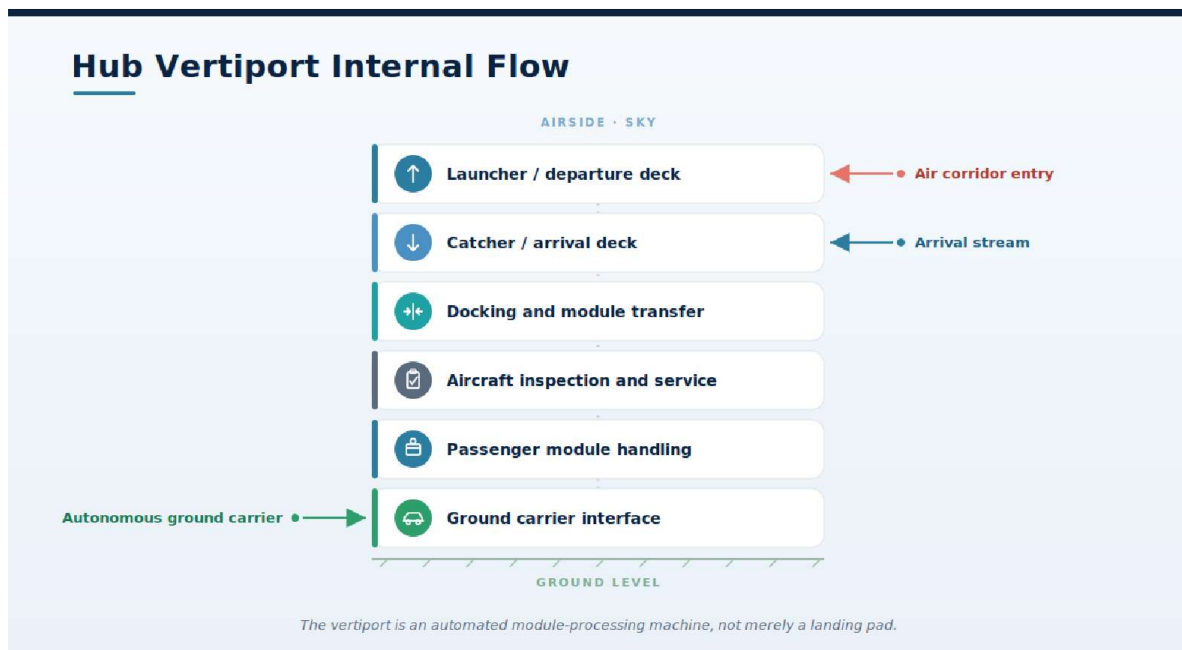


Figure 7. Hub Vertiport internal flow with launcher, catcher, module handling, aircraft inspection, and ground access.

5. Multicruiser Air Transporter Design Concept

Aircraft is designed according to the design concept to enable the operation of a synthetic urban aviation system. It is an aircraft designed to specialize in urban aviation operation requirements.

Urban aviation operations are: First, in order to operate in the city, the propeller must not be exposed, and this means that aircraft that approach close to people must not pose a threat to people. Public acceptance is a difficult item to quantify, but it will play a decisive role in the realization of urban aviation.

The second condition is that the aircraft must have the maneuverability and safety of a Multicopter at low speeds, and low-speed maneuverability is very important to have the ability to quickly separate from other aircraft and obstacles in crowded urban spaces.

The third condition is high-speed cruising performance, which is the performance that a winged aircraft can achieve. In order to quickly move to the outskirts of an overcrowded city with many aircraft and obstacles, a flying vehicle with wings that is faster and more efficient than a Multicopter is required.

The fourth condition is landing at the Vertiport. It must have a structure that allows rapid internal movement and loading by auxiliary devices, and this means that it must have a structure and shape that makes it easy to handle the aircraft.

The fifth condition is the modular concept, which is related to the energy storage device, i.e. battery output density. Aircraft and vehicles, it must be a modular structure that can be combined and separated, and an energy storage device must be mounted separately on the aircraft and ground vehicle to exchange energy.

The aircraft must be able to transport payload to and from the city center and the outskirts of the city, as well as fly independently to where it is needed, so in this case, the aircraft must be able to use its own built-in energy source while saving energy, must be completely electronically connected and maintain swarm flight status. The Multicruiser invented for this system is designed to satisfy the five requirements mentioned above and is operated while electronically connected to other aircraft of the same standard.

The core structure of the aircraft is the Rimfoil, which is a shape that protects the propeller and provides visual stability (the first requirement), and the hexa- shaped Multicopter shape is maintained as is to demonstrate the functional advantages of the Multicopter (two and the third requirement), and when the forward flight speed is increased by the propeller, the Rimfoil along with the short wing generates lift to achieve the efficiency of a fixed-wing airplane (the third requirement and the short wing acts as a two dimensional wing), a take-off and landing assist device inside the Vertiport and that it has a shape that is easy to handle (graspable and easy to store) in handling facilities (e.g., aircraft elevators and storage racks, the fourth requirement), and that the long central fuselage and short wings are suitable for

battery packs. Alternatively, the design takes into account the provision of sufficient space to store various devices such as fuel cells, flight control computers, mission computers, and docking systems (the fifth requirement).

In order to demonstrate sufficient maneuverability in the city, the aircraft must have a compact structure by reducing its moment of inertia, and the shape of this aircraft is designed to be suitable in that respect.

This aircraft is designed to improve the shortcomings (increased weight and equipment) of the lift cruise type design, in which the vertical takeoff propeller is used only for takeoff and landing, and the wing control surface is used for control during forward flight. In other words, the vertical takeoff propeller is responsible for 100% of the takeoff and landing thrust during vertical takeoff and landing, but during forward flight using separate forward thrust. When the amount of thrust is gradually reduced and the lift share of the fixed wings (stub wing and Rimfoil) is gradually increased, the vertical takeoff propeller is designed to play a control role and control the flow of the Rimfoil, and this has a simple structural shape. It is the core of the aircraft design that allows it to demonstrate maximum aerodynamic performance. It should be noted that the shape of the vehicle shown in the picture is a replica of the shape of a typical car-shaped fuselage and that the vehicle does not necessarily have this shape. In other words, the aircraft was designed to accommodate various design requirements for operating the aircraft in the city, as described above, but the vehicle may have any type of structure. As you can see, it has a car-shaped fuselage, so it can be operated similar to a helicopter along with an aircraft, and it can be used as a modular type as described later. It should be noted that it can be used by docking with an aircraft in the form of a boarding vehicle.

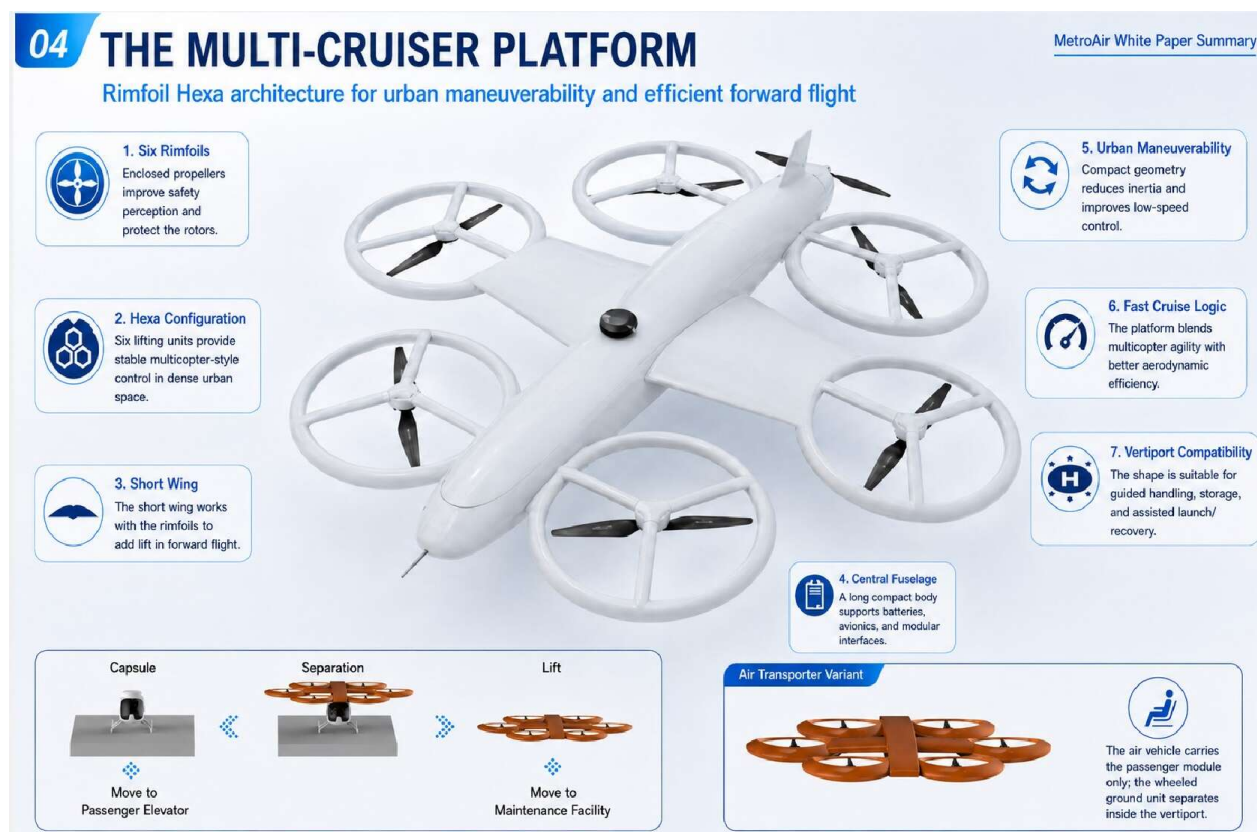


Figure 8. Multicruiser concept visualization with Rimfoil-protected rotors and a separable passenger module.

5.1 The Multicruiser as an air transporter, not a flying taxi cabin

The Multicruiser is deliberately defined as an air transporter. Its value is not that it carries its own fixed passenger cabin. Its value is that it can connect to a standardized passenger module, move it through the air layer, and detach it at the destination Vertipoint. This distinction changes the design priorities. A conventional air taxi prioritizes cabin integration, passenger comfort, aircraft certification, and short trips. The Multicruiser prioritizes docking, handling, modular payload compatibility, energy flexibility, swarm connectivity, Vertipoint processing, and fleet-level operations.

The Rimfoil concept has several simultaneous roles. It shields the rotor to reduce visual threat, helps shape airflow, and provides a structure that can be mechanically held by aircraft holders, contributes to lift in forward flight, and creates a compact perimeter for storage and capture. Unlike a simple duct that may add drag in cruise, the Rimfoil is conceived as an aerodynamic element that participates in the transition between Multicopter-like maneuverability and wing-supported cruising.

The original design requirements remain valid: protected propulsion, low-speed maneuverability, higher-speed cruise efficiency, mechanical compatibility with Vertipoint handling systems, and modular energy architecture. Version 2.0 adds three further requirements: AI-ready sensing and computing, swarm communication interfaces, and

hybrid-electric powertrain integration. These are not secondary additions. They are necessary if the vehicle is to operate without a pilot at metropolitan scale.

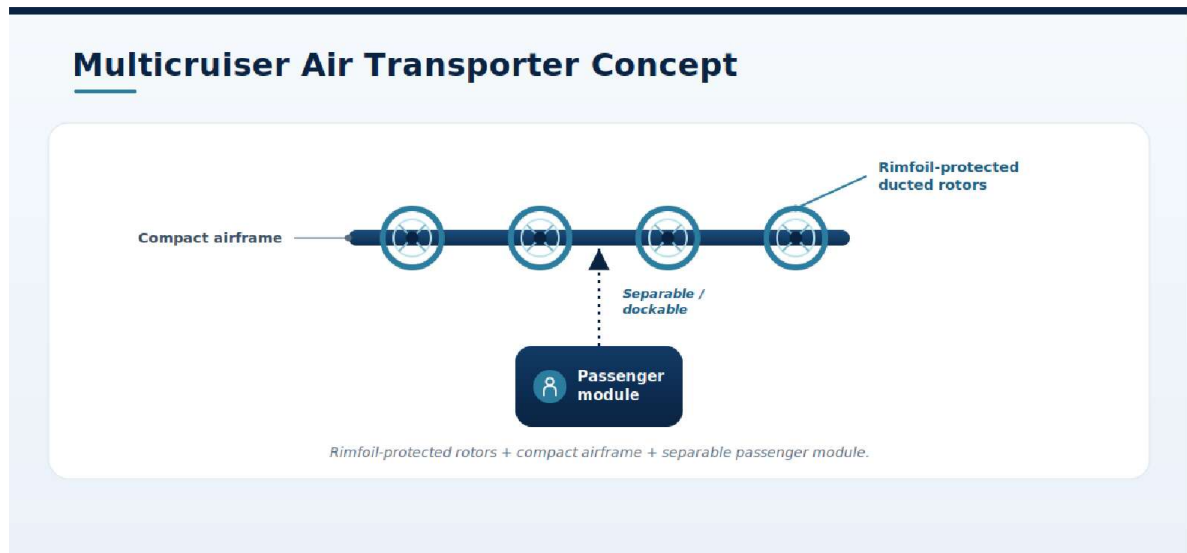


Figure 9. Multicruiser air transporter concept: a compact airframe carrying a separable passenger module.

5.2 Comparison with lift-cruise and vectored-thrust eVTOLs

Table 3. Multicruiser transporter logic compared with conventional eVTOL logic

Design dimension	Conventional lift-cruise / vectored-thrust eVTOL	Multicruiser transporter logic
Passenger cabin	Integrated aircraft cabin.	Passenger module is separable and can be processed independently.
Urban perception	Often exposes multiple rotors or complex tilting mechanisms.	Rimfoil-protected rotor geometry reduces visual threat.
Vertiport handling	Aircraft is handled as a complete passenger vehicle.	Air transporter can be stored, inspected, and dispatched as a fleet asset.
Energy architecture	Primarily battery-electric in leading air-taxi models.	Hybrid-electric turbo-generator strategy can extend range and turnaround.
Autonomy path	May begin as pilot-operated AAM.	Designed from the beginning for AI swarm operation.

6. Hub Vertiport Operating Concept

Herb Vertiport is explained for the operating concept.

A hub Vertiport is a core Vertiport built in an appropriate location, for example in the center of the most overcrowded city center. The operating concept is as follows.

Vertiports are built perpendicular to the road, making it easy for riders to access the ports via sidewalks. These Vertiports can also be designed in conjunction with the subway so that the exit of the subway is directly connected to the entrance of the Vertiport.

Passengers are required to make reservations in advance before using the city flight system, and this is because all flights must be calculated in advance on the integrated control central computer and the passenger's schedules must be reflected in all flight schedules. This is because this aviation system is premised on complete control, calculation, real-time control, and aircraft control.

Therefore, a comprehensive control and integrated computer facility is located at a safe point located in the center of the hub Vertiport, and is linked with all urban aviation systems and the control systems of other Vertiports.

A reserved passenger goes to the boarding area and goes through simple procedures (simple procedures at the subway level are required), they go to the boarding area, board a vehicle that moves along the rails (an operation similar to a gondola), and the vehicle moves to the takeoff area at the top. During the flight, various precautions and information are broadcast to passengers and they are asked to prepare for takeoff.

Aircraft that was waiting in advance near the take-off catapult is connected to the vehicle and docked aircraft and module. The device used for docking may utilize any mechanical method already in use.

The takeoff method is similar to the way an aircraft takes off from an aircraft carrier. The aircraft reaches maximum power and then the ejection device, the method is applied by grabbing a specific part of the vehicle, and throwing it into the air. This is the fastest and safest way to enter an aircraft into a corridor, and by applying this method, an aircraft can quickly escape to the outskirts around Vertiport, which is expected to be overcrowded with aircrafts. After entering a certain altitude, the aircraft operates the forward prop to quickly increase speed. Due to the characteristics described above (it is called a Multicruiser), the aircraft is neither lift cruise or vectored thrust vehicle. It should be noted that since there is no transition flight (the process of switching between Multicopter control and control surface control) like the thrust method, it is possible to quickly maneuver into a corridor calculated and determined in real time.

A landing aircraft is immediately hooked by the landing assist device installed on the landing pad. The hooking device installed on the pad is usually a mechanical device used to

hang an object, so it is not specifically discussed here. The hooks installed in the landing assist device also come in various forms and methods, so they will not be specifically discussed here. It is assumed that the aircraft makes a precise landing at the location where the hook is, which is usually the case for drones. Since it refers to a precision landing method, one of the methods developed to date can be applied.

The landing pad is designed to be interlocked with the aircraft elevator. As soon as the aircraft is hooked from the landing pad, the hooking landing pad moves to the elevator and the next new landing pad is formed to catch the next aircraft, hooks the aircraft, separates the aircraft from the top of the elevator. For this purpose, a device to catch the flying object must be designed, but its forms and methods may vary, so they will not be discussed. However, the aircraft must have a structure that makes it easy to separate and combine the aircraft and the vehicle, and the shape of the aircraft mentioned above (the Rimfoil of the aircraft registered as a patent) is such that it can be easily held by a device that catches the aircraft called an aircraft holder. It should be noted that it is a structure.

After being captured, the aircraft and payload are separated or the process is performed for the transporter and boarding module. It should be noted that the operation of the docking system device can all be automated by a series of automatic signaling devices.

The vehicle is moved to the aircraft elevator because the aircraft must be inspected and prepared for restart, such as battery replacement and resupply (if necessary). Therefore, the aircraft elevator penetrates the maintenance room in the process of descending vertically and is stored in the aircraft rack after completing preparations for the next aircraft. Please note that although the specific method and form of the aircraft rack cannot be specified here, it can be designed by applying normal mechanical methods.

As mentioned earlier in the takeoff method, the prepared aircraft must dock with the aircraft at some point when the module with passengers on board ascends the takeoff elevator, so the path of the elevator along which the prepared aircraft moves must be connected to the specific docking position of the takeoff stand.

The separated vehicle (with passengers on board) moves downward by the vehicle elevator, connects to the boarding area and goes through the process of passengers getting off at the boarding area. Since the gondola moves sequentially to the gondola boarding and disembarking point, the normal design method can be applied to this design.

The vehicle that passengers disembark passes through the maintenance room along other elevator lines to undergo a series of processes such as inspection, exchange, supply, and cabin cleaning. Meanwhile, another aircraft ready for takeoff waits at the aircraft rack and moves to the takeoff deck in order.

The series of passenger boarding, disembarkation, and takeoff processes described above and the landing process is all operated in conjunction with the city flight and control system, passenger reservation system, Vertiport Passenger Processing system, and Reservation

Management System, and is calculated and processed in real time by the integrated AI computer that manages the individual systems.

For example, if a specific elevator malfunctions at Vertiport, this not only affects the aircraft moving along the elevator for takeoff, but also affects passengers who have booked a ride, and also affects the corridor set at a specific time in the city space, affects all moving aircraft. Therefore, it should be noted that the operation of Vertiport is inseparable from the concept of urban navigation.

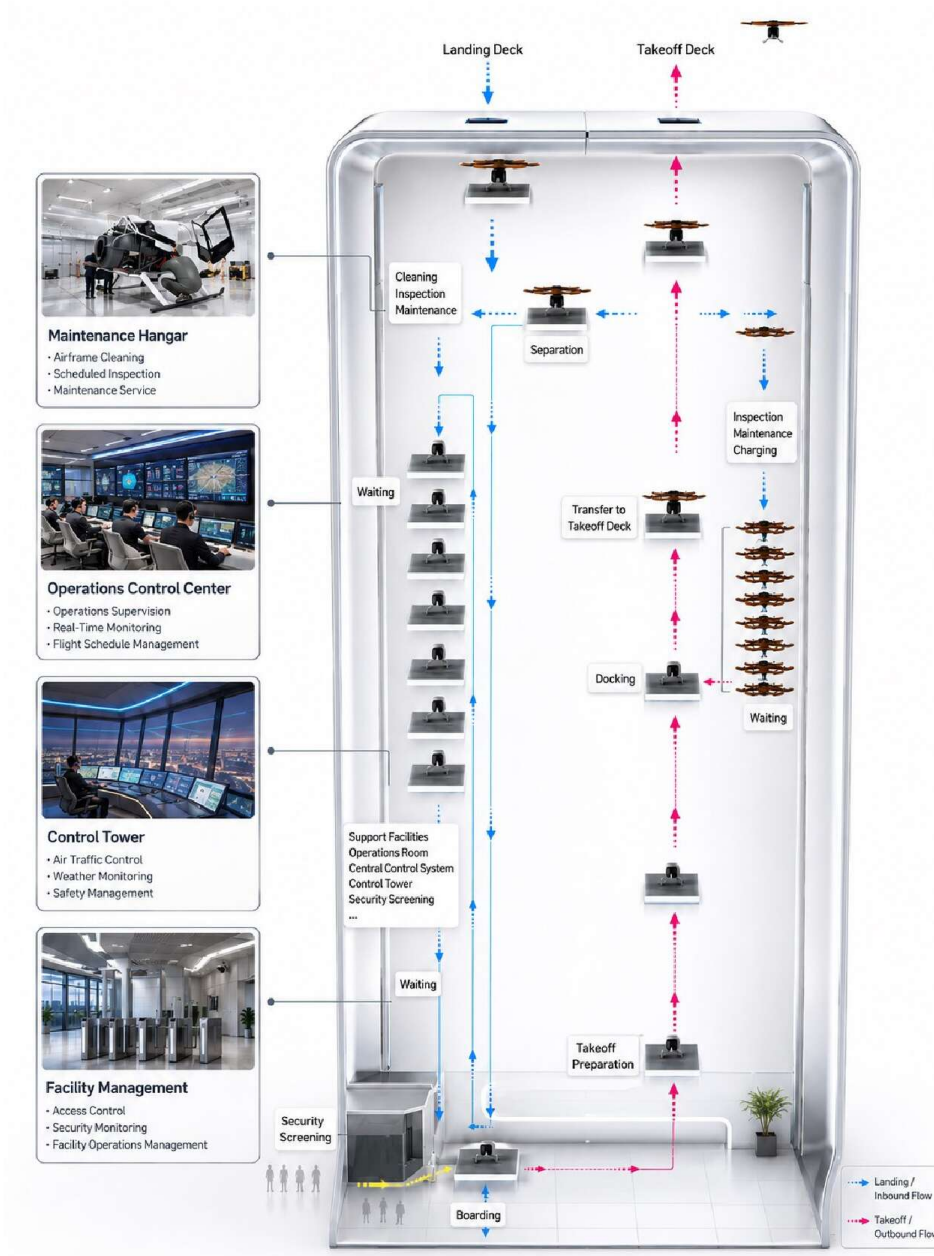


Figure 10. Vertical hub Vertiport concept showing internal aircraft and module movement.

6.1 Reservation-based system control

The original system assumed that passengers reserve the service before use because every flight must be computed with the state of the wider network. Version 2.0 strengthens this assumption. In a high-density autonomous 3D transport system, reservation is not only a business convenience; it is a safety function. A reservation creates a demand signal, assigns a passenger module, predicts a ground arrival time, reserves a launcher/capture slot, assigns an air corridor, and ensures that destination capacity and emergency alternatives are available.

This is different from hailing a taxi. A street taxi can wait in a lane or circle a block. An air transporter must have a defined time, trajectory, energy margin, separation context, and destination slot. The passenger may experience the system as seamless, but behind that interface the system must continuously solve a coupled scheduling problem across ground carriers, passenger modules, air transporters, Vertiports, and dynamic corridors.

Simulation work on UAM networks and Vertiport throughput supports this network-level view. Bottlenecks appear when vehicle availability, charging or energy service, pad availability, passenger processing, and route capacity are treated separately. MetroAir avoids that fragmentation by treating the Vertiport as a node in a single digital operating system. (6, 27)

6.2 Failure propagation and local autonomy

A hub Vertiport is a powerful node precisely because it concentrates flows. That concentration also creates failure propagation. A malfunction in a module elevator, docking latch, launcher, catcher, energy service bay, or communication link can affect inbound aircraft, outbound modules, passengers, and corridors. This is why the Vertiport must have local AI and deterministic safety states. It must be able to slow arrivals, redirect flights, hold passenger modules, transfer modules to alternate lines, and communicate local capacity changes to the central traffic AI.

The system should be designed with degradation modes rather than binary success/failure assumptions. For example, a launcher may operate at reduced cadence; a catcher may switch to a backup capture lane; a passenger module line may be bypassed; an aircraft inspection bay may be isolated. Each state must have a defined impact on network capacity and emergency margins. This is where digital twins and real-time simulation become operational tools rather than planning accessories.

7. Rapid Takeoff and Landing: Launcher and Catcher

The take-off and landing assist device is a structure that is linked to the exit of the aircraft and has a device that allows the aircraft raised by the elevator from below to be ejected when the exit opens. This device is called a launcher, and its role is to provide energy to the aircraft so that it can enter the airspace safely and quickly.

In order for aircraft operation in the city to have the meaning of public transportation, the turnover rate and transfer volume of the aircraft must be considered. The takeoff interval of a passenger plane at an airport cannot be directly applied to the takeoff interval of an aircraft at a city Vertiport. This is because the concept of mass transportation cannot be applied in urban areas.

For example, at LAX the average number of passengers per day exceeds about 200,000. Based on this, when considering the operation method of the Vertiport to realize the concept of mass transportation, the number of passengers on board and the method of takeoff and landing of the aircraft are important issues.

The first issue to be addressed is how quickly the aircraft can take off and land, and for this purpose, the performance characteristics of the aircraft are determined. These design requirements were reflected in the vehicle shape design. The aircraft must have the ability to mix three operating methods to handle rapid takeoff and landing at the Vertiport.

Aircraft that take off and land on a takeoff and landing pad, such as an aircraft taking off and landing on an aircraft carrier, have a rapid approach, a sure stop, and a force-energized catapult takeoff. Not only does it provide more stable takeoff and landing than the helicopter takeoff and landing method, but in reality, it also results in, this is a way to avoid aerodynamic phenomena such as power settling.

It is desirable for the aircraft to have a landing method similar to the method in which a light helicopter flies to a landing site at high speed and lands using rotor air brakes. The aircraft designed for this system is in the form of a Hexacopter using a Rimfoil. This aircraft has a structure that can use rotor air brakes and at the same time, the Rimfoil can generate high lift at a high angle of attack, making it suitable for a quick approach landing. It is designed to perform its function and is based on the premise that all aircraft are fully connected electronically and fly in a swarm flight. The swarm flight technology will be applied to the flights of these air metro systems in the future.

Since the real-time calculation is assumed to be applied to all swarming aircraft, the aircraft approach the landing pad while maintaining a constant distance, which can be compared to a gondola system operated at constant intervals. The rotary take-off and landing system plays the role of catching a landing aircraft and delivering it down to the Vertiport's aircraft

escalator. The time for this function will affect the separation distance of the aircraft. In the proposed concept, if the takeoff and landing system handles landing aircraft within 10 seconds, it will be possible to catch aircraft at 10-second intervals. If a two-seater aircraft is handled in this way, it can transport 720 passengers per hour, and if operated for 20 hours a day, it can handle 14,400 passengers, which is a level that can be called a public air transportation system.

The number of seats per aircraft is not something to be simply compared to an airliner that transports hundreds of people at a time. Rather, when flying in an urban area, the movement performance that the aircraft can have and the aircraft handling method are more important factors to consider, and in the proposed synthetic urban aviation system, at least 2 seats are required. It will be possible to seat up to 4 people. The size of the aircraft will rather depend on Vertiport's standardized vehicle handling capabilities.

The rotary takeoff and landing assistance system installed at the top of the Vertiport is an important device that assists quick takeoff and landing, and is designed to allow rotation. The first reason is the direction of the wind. For the safe landing of an aircraft, straight wind take-off and landing are important. Since the wind direction varies by season and changes frequently depending on the weather, it is necessary to receive weather information in real time and rotate the device, called the aircraft catcher and launcher, at a specific angle so that it can point in the wind direction such a mechanism that it can do.

The specific position control of the rotary takeoff and landing system is based on real-time wind information, but what is important is that this wind information is also distributed in real time to all aircraft using the Vertiport. It must be transmitted and linked with the aircraft's automatic flight control system.

For example, an aircraft lands by UAM catcher and lands on the Vertiport. After induction, the wind direction is recalculated and the information is transmitted to the rotary takeoff and landing system and the aircraft approaching for landing. Then, the rotary takeoff and landing system not only rotates in a specific wind direction, but the approach path is instantly calculated and used for control by the aircraft on its way to landing. It is important to note that all signaling systems are real-time. The development of integrated control s/w to enable such a system is a task that needs to be developed in the future.

The UAM launcher is located opposite (or near) the UAM catcher and has the function of quickly ejecting the aircraft. It is desirable to apply a method similar to ejecting aircraft from an aircraft carrier. Consider taking off by grabbing a specific part of the aircraft and throwing it into the air, like shooting a slingshot. When an aircraft is ready for takeoff, the takeoff propeller accelerates to maximum speed, and then the ejection device accelerates and throws the aircraft forward and upward. The expression 'throw' means a large acceleration, and since this can cause discomfort to passengers, the ejection strength and take-off prop of the aircraft are adjusted appropriately to achieve optimal acceleration. This method, above all, is intended to ensure that the aircraft is controlled by quickly obtaining the optimal speed, and to quickly move to a designated corridor and quickly escape from the Vertiport.

Rapid takeoff and landing of aircraft at Vertiport, if auxiliary devices are activated and an aircraft with flight performance capable of interoperating with such auxiliary devices is operated and operated systematically in the above-mentioned manner, the hub Vertiport can handle more than 10,000 passengers per day. If there five are built in the metropolitan area, it will be able to have the capacity of one transportation system. In the city center depending on the overcrowding, Vertiports of various sizes can be built and various navigation methods can be added.



Figure 11. Top-deck rotary takeoff and landing system concept.

7.1 Why assisted takeoff and capture matter

The launcher and catcher are central to the MetroAir concept because they address three problems simultaneously: VRS avoidance, Vertiport throughput, and rapid entry into the planned corridor. A vehicle that hovers slowly above a Vertiport consumes energy, occupies a critical deck, exposes nearby residents to noise and downwash, and remains in the most congested part of the airspace. Assisted launch reduces the time spent in that vulnerable zone.

The catcher serves the opposite function. It converts a precision approach into an immediate mechanical recovery event. Once captured, the air transporter can be pulled away from the top deck and moved into internal processing. This makes the top deck a throughput interface. It also allows the aircraft design to include mechanical holding points and docking

interfaces that would be unnecessary in a conventional air taxi but valuable in a high-frequency public system.

The concept requires rigorous validation. Passenger comfort limits acceleration, wind variability affects launch direction, and capture tolerance must be verified under sensor error, gusts, emergency states, and partial system faults. Version 2.0 therefore frames the launcher/catcher not as a finished device but as a core research and development program connected to CFD, dynamics simulation, hardware-in-the-loop testing, and scaled flight trials.

7.2 Wind alignment and the rotating deck

A rotating launch/capture system allows the Vertiport to align operations with wind rather than forcing the aircraft to absorb all wind variability. The original white paper emphasized real-time wind information shared with the aircraft and the deck. Version 2.0 extends this into an AI-controlled local weather and flow management system. Wind, gusts, temperature, rooftop turbulence, wake interactions, and approach demand should be integrated into launch and capture sequencing.

The rotating deck also makes the Vertiport more adaptable to seasonal wind patterns and local building geometries. In a dense city, the wind at the top of a tower is not always the same as the wind at street level or at corridor altitude. A Vertiport AI should therefore maintain a local micrometeorological model and share a continuously updated approach envelope with incoming eVTOLs.

8. Operational Concept of the Synthetic Urban Air System

There is a high possibility that installing a corridor in a specific location above a major city center will be an unreasonable problem. Public acceptance is not an aspect of rationality but an aspect of emotion, and this is an important factor to consider in urban aviation. No one who lives in the city likes to have airplanes flying close to their heads all the time. Aircraft will be cautious in choosing the vertical descent landing method due to the problem of power settling, and it is unlikely that the vertical descent landing method will become a routine landing method.

Therefore, it would be desirable for the Vertiport to be built at least higher than the surrounding buildings. The structure of the downtown area is generally proportional to the overcrowding, so the height of the building is from the central part of the city center to the outskirts. The Vertiports will be built in a form of sequentially decreasing height, and aircraft that take off and land quickly from these Vertiports will have minimal impact on residents around the Vertiports.

The vehicle and vehicle capacity of each Vertiport is calculated in real time along with all flight systems. The number of aircraft flying in the city center, flight path, destination, departure point, number of nearby Vertiports, capacity at Vertiports, processing capacity, etc. are all calculated in real time and all systems are operated within the range that can be sufficiently processed. The ability to respond to emergency situations must also be considered.

If one Vertiport becomes disabled, the entire system is inevitably affected, so the emergency landing site must always be on standby and memorized in the system and the aircraft's automatic control computer.

Helipads constructed on the rooftops of buildings in downtown areas will be very useful as emergency landing sites. In addition to these helipads, emergency landing sites should be installed throughout the city in advance in preparation for emergency situations, taking into account the number and operation of aircraft to be handled by the urban aviation system. It is impossible to fly numerous aircraft over urban areas without these measures.

When an emergency situation occurs, the information is delivered to all aircraft in real time, and each aircraft has the ability to make an emergency landing in each situation. The helipad or emergency landing site is determined and you land there, so this flight concept possibly must be developed.

The basic form of the aircraft will be one in which the propeller, which poses a visual threat to people, is not exposed, and even for such an aircraft, flying down under a building will only be permitted in the case of an emergency landing. Since the Vertiport is said to be built

at least higher than the surrounding buildings, it is important to ensure that people around the aircraft are not significantly aware of the aircraft's flight under normal circumstances. In an emergency situation, an aircraft may fly into the roof of a low building or a helipad on the ground, but even in such cases, it is desirable for the aircraft to have a shape that does not pose a visual threat.

Vertiports are distributed from large to small sizes from the city center to the city outskirts and suburban areas, and single-family homes that have minimal impact on residents of surrounding houses when aircraft take off and land may have private takeoff and landing pads. These private airfields are also part of a large system and must be informationized on a comprehensive computer, and publicity must be ensured and institutionalized so that they can be used as emergency airfields.

The huge system is fully controlled, all flying vehicles must fly while sharing information in real time, and so all corridors will be in a state of flexible change in real time. For example, when a new aircraft enters the flight system, a new corridor is formed and it affects the currently established so-called corridor web, so the three-dimensional corridor web covering the sky above the city (virtually and electronically) fluctuates. This will be a shape and means that each corridor affects the path and speed of all aircraft flying through the web. It is for this reason that all aircraft in the proposed system must have a swarm flight configuration.



Figure 12. City-scale synthetic urban aviation concept with multiple Vertiport nodes.

8.1 Dynamic corridors instead of fixed aerial roads

The original system described a dynamic three-dimensional corridor web that changes as vehicles enter and leave the network. This is one of the most important ideas in the white paper. Fixed corridors may be useful in early, low-density operations, but a mature metropolitan system must adapt to changing demand, weather, emergency closures, energy states, Vertiport capacity, and the distribution of aircraft.

NASA and FAA work on AAM, UTM, BVLOS, and collaborative traffic management points in the same general direction: the future low-altitude airspace will rely on digital coordination, data exchange, performance-based separation, and service suppliers rather than only traditional voice-based air traffic control. (4, 5, 37)

MetroAir therefore treats every Multicruiser as a connected node. Each aircraft shares position, velocity, destination, energy state, passenger-module status, emergency capability, and intent. The corridor web is not painted in the sky. It is generated by the traffic AI and continuously revised as the system changes. The public sees a safe and quiet service; the system sees a real-time optimization problem.

8.2 Emergency landing and network resilience

A dense urban air system cannot depend on a single destination Vertiport remaining available. Emergency landing sites, existing helipads, designated rooftops, ground emergency pads, and private or community landing points must be mapped, certified, and digitally integrated. Each Multicruiser must know its feasible alternatives at all times.

The emergency system should be hierarchical. Immediate collision avoidance is handled by aircraft edge AI. Local Vertiport failures are handled by Vertiport AI. Metropolitan network re-dispatch is handled by central traffic AI. Human supervision remains essential in early deployment, but the primary safety response must be machine-speed, verified, and deterministic enough to support certification.

This resilience architecture is also relevant to public acceptance. Citizens are more likely to accept urban aviation if emergency behavior is predictable, audible warnings are controlled, landing sites are known, and the system avoids improvisation over populated areas.

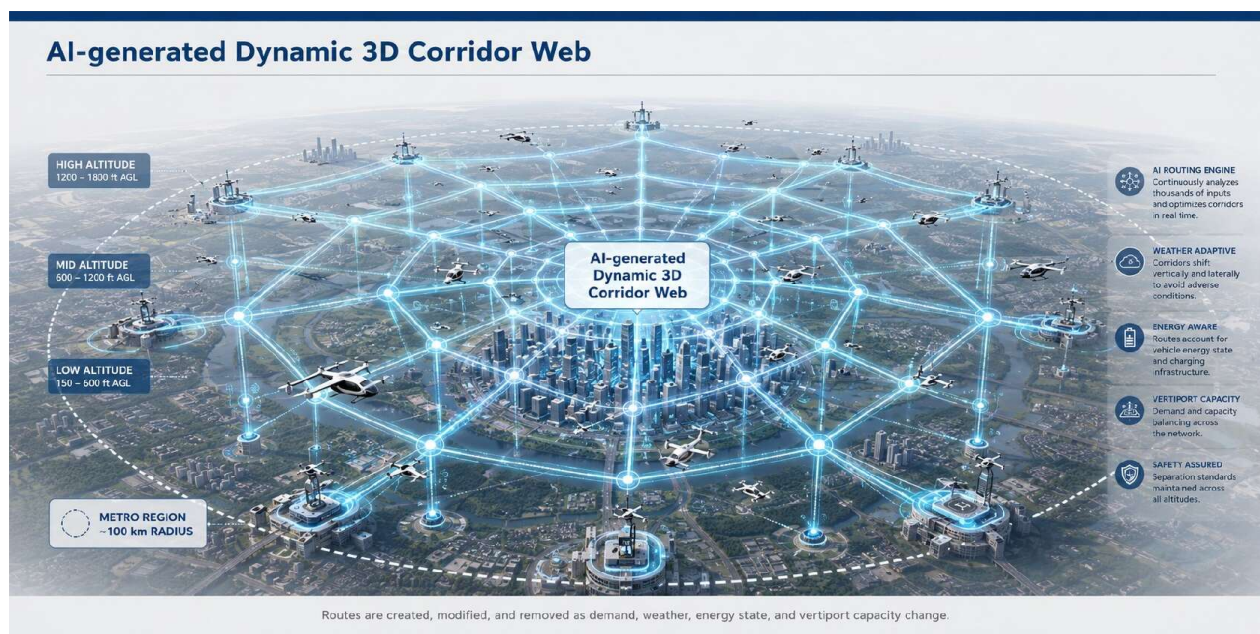


Figure 13. AI-generated dynamic 3D corridor web. Routes are created, modified, and removed as demand, weather, energy state, and Vertiport capacity change.

9. Modular Mobility and the Passenger-Module Transport Model

If a synthetic urban aviation system is built, it will be modular. When combined with a mobility system, it becomes possible to build a 3D urban public transportation system.

Modular Mobility is a concept that was previously announced by Airbus and Ital Design, and is designed to separate and combine the aircraft, passenger module, and ground vehicle, so that the flight vehicle docks with the passenger module, moves it to a specific point in the air, and then travels on the ground at that point. The idea is to hand over the passenger module, and this has received attention as a way to solve the problems of low energy density and low output ratio of the power source of Multicopter, which are the biggest weaknesses of electric propulsion aircraft.

In other words, energy can be distributed and stored between the aircraft, passenger module, and ground vehicle when necessary, and the aircraft has the advantage of saving energy when flying without a passenger module and ground vehicle.

However, in order to realize this concept, the aircraft there was no clear measure as to how much it could fly while combined. If it is assumed to be an aircraft of the presented shape (pop up), a ducted structure surrounds the propeller in order for the aircraft to come down

close to the ground, it is acknowledged that a prop was adopted, but the design of covering the Multicopter's propeller with a duct generates excessive drag from the duct during flight, so it has a worse cruising power ratio than the Multicopter with the highest cruising power ratio (cruising power / hovering power). Considering that a Multicopter-type vehicle can fly few kilometers in a fully charged state, it can be estimated that a ducted prop- shaped Multicopter vehicle will show less than half of that performance (the exact performance is not disclosed: no data available).

However, if the duct surrounding the Multicopter's propeller is replaced with a Rimfoil that acts like a wing (Multi-cruiser Named flying vehicle) of the duct, as the lift-to-drag ratio increases significantly, it is expected that a flight distance of more than three times kilometers will be secured. If a Multi-cruiser aircraft docked with a vehicle can fly at a speed of more than 200 kilometers per hour for more than 100 kilometers and carry a passenger module, it will be possible to operate it in conjunction with a synthetic urban aviation system in a metropolitan area with a radius of at least 250 kilometers.

If a large urban area can be moved such kilometers in the air within 60 minutes and the passenger module can be delivered to another ground vehicle, a modular mobility has sufficient validity. Moreover, for aircraft, passenger module and the ground vehicle, an auxiliary device is required when separating and assembling the vehicles. Airbus and Ital Design later presented the concept of a docking station, but it is questionable how quickly the modules can be processed with the docking station of the proposed type, remains. However, these modular mobility is combined with a synthetic urban mobility system, a new three-dimensional transportation system can be built. We call this '3D Urban Public Transportation System'.

In this system, consumers mainly purchase passenger module and privatize them, and the aircraft is integrated and managed by the government, which is responsible for safety, by applying the public concept. Additionally, a system that allows the ground vehicle to be borrowed and lent based on the concept of sharing, is applied. Of course, the passenger module can be provided as a service that transports passengers like an air taxi in the synthetic urban aviation system, but Vertiport handles public capsules and aircraft while also providing a service for personal and public modules, the system can be designed as a facility that can handle it. In that case, the following scenario is possible.

An individual named 'A' purchases a passenger module and then rents a ground vehicle to use vehicles as a car and use it on a regular car basis. It is operated like a car in the form of a combined running body.

When driving a long distance from a large city to the outskirts, avoid ground traffic congestion and go to the outskirts of the city center. When an individual want to travel in the air, he or she uses a smartphone to make a reservation for aircraft service, using the Vertiport near his residence as the departure point and the Vertiport installed at a specific point in the suburbs as the destination. The individual then drives into the departure Vertiport, where an automated system launches the vehicle. After separating from the ground vehicle,

docking with the eVTOL vehicle, ejecting, and flying to the destination Vertiport. The passenger module that arrives at the destination Vertiport is separated from the aircraft, and the module is combined with another ground vehicle waiting there, and then the occupants drive to another destination in a car-like driving mode.

Autonomous driving and flying vehicles are needed mainly at night when ground transportation is not crowded to meet reservations. They will move in autonomous driving and flight mode.

If a 3D public transportation system is built, the flight range will increase due to technological developments such as batteries or fuel cells, which will expand the current metropolitan area and create a world where smooth movement is possible anywhere within that area.



Figure 14. Three-dimensional seamless transportation system using a MultiCruiser and modular passenger vehicle.

9.1 The missing link between automotive modularity and AAM

The automotive sector is moving toward modular electric platforms, PBVs, and autonomous service fleets. The aviation sector is moving toward eVTOL aircraft, Vertiports, and AAM traffic management. The weakness of many current AAM proposals is that these

two movements are joined only superficially: a passenger rides a car to a Vertiport, transfers into an aircraft, lands, and then rides another car. That is not seamless mobility. It is an expensive multimodal transfer chain.

MetroAir's core proposal is the missing link. The passenger module itself becomes the unit of mobility. It can connect to a ground carrier for street movement, detach at a Vertiport, attach to a Multicruiser air transporter, fly to another Vertiport, and then attach to another ground carrier. The user remains inside the module. The system handles the mode shift.

This architecture also clarifies ownership and governance. Passenger modules may be private, shared, or public. Ground carriers may be shared autonomous vehicles. Multicruiser air transporters should be managed as a public-safety-critical fleet because airspace safety, maintenance standards, and energy management require centralized governance. This combination preserves personal convenience while treating flight as a regulated public layer.

9.2 Modular mobility is now an industrial direction

Kia's PV5 and E-GMP.S platform illustrate the industrial move toward purpose-built electric vehicles with modular bodies and standardized underbody systems. Toyota's e-Palette similarly treats the vehicle as a multi-purpose mobility and service platform. These vehicles are not MetroAir passenger modules, but they show that the automotive industry is already leaving the single-purpose passenger car behind. (20, 21, 22)

Academic work on autonomous modular public transit and modular autonomous vehicles also supports the idea that pod-based systems can adapt capacity to demand, reduce unnecessary vehicle mass, support platooning, and improve operational flexibility. MetroAir extends this research vertically by asking how the passenger pod can be transferred through air when road congestion or metropolitan distance makes the ground layer inefficient. (31, 32)

The practical challenge is interface standardization. A MetroAir passenger module must define structural load paths, crashworthiness, cabin safety, HVAC, power transfer, data authentication, door interlocks, emergency release, fire containment, and weight/balance sensing. These standards are not accessories. They are the core technology that allows the system to scale beyond a prototype.

10. Autonomous Ground Mobility and the Robotaxi / PBV Layer

Autonomous ground mobility is a required layer of the MetroAir system. It performs at least five functions: first-mile and last-mile passenger movement, passenger-module movement into and out of Vertiports, night-time fleet balancing, distribution of ground carriers across demand zones, and emergency ground recovery when air service is temporarily degraded.

Robotaxi operations demonstrate that autonomous driving can become a real commercial service within bounded operational design domains. Waymo's public safety materials and expanding ride-hailing service show that driverless ride service is not merely a laboratory concept. At the same time, the retreat of GM from Cruise robotaxi funding shows that autonomous driving is technically promising but economically difficult when treated as a stand-alone ride service. (23, 24)

This dual lesson is critical for MetroAir. The goal is not simply to add an air taxi to a robotaxi. The goal is to use autonomous ground carriers as part of a higher-level mobility architecture. The ground carrier may be simple compared with a private automobile because it does not need to be owned, stored, or configured by one individual. It can be optimized for docking, passenger-module transfer, fleet cleaning, charging, and standardized service.

The PBV movement is therefore not merely a trend in vans. It is a sign that ground vehicles are becoming modular service machines. In a MetroAir network, these ground machines connect directly to a vertical air layer. The result is a mobility system where the physical unit of user experience is the passenger module, not the car and not the aircraft.

Table 4. Autonomous ground mobility as the street layer of MetroAir

Ground layer function	Technology source	MetroAir implication
Autonomous access	Robotaxi operations in defined ODDs	Ground carriers can move passenger modules to and from Vertiports.
Service modularity	PBV and skateboard EV platforms	Upper-body modularity can evolve toward detachable passenger modules.
Fleet balancing	Robotaxi dispatch and charging algorithms	Ground carriers and air transporters can be redistributed at night or off-peak.
Public accessibility	Shared autonomous service models	The system can serve users who do not own a car or module.

11. AI-Based Autonomous Flight and Swarm Safety

The future of high-density urban air mobility cannot be based on one pilot in every aircraft. Pilot-operated eVTOL service may be a necessary transitional stage for certification, public trust, and early market formation. It is not the final form of a public 3D transport system. The economics of pilot cost, training, seat loss, dispatch complexity, and high-frequency operations push the industry toward autonomy.

Wisk's autonomous eVTOL program and sky grid integration show that autonomy and airspace integration are already central industrial directions. The significant point is not simply that one aircraft can fly without a pilot. It is that autonomous aircraft must be embedded in a digital traffic-management environment. (10, 11, 12)

MetroAir's AI architecture includes three levels. The central traffic AI forecasts demand, generates corridors, assigns Vertiport slots, and manages fleet distribution. The Vertiport AI manages local sequencing, launcher/catcher timing, wind alignment, passenger module handling, and energy service. The aircraft edge AI handles perception, immediate collision avoidance, emergency landing, degraded communication, and precise approach.

Recent UAV swarm research supports this multi-agent direction. Graph-based multi-agent reinforcement learning and edge-AI swarm control research show how multiple agents can coordinate trajectories, avoid obstacles, and maintain group behavior in dynamic environments. These research trends do not by themselves certify passenger transport; however, they provide the technical evidence that swarm-level autonomy is a serious research frontier rather than a speculative phrase. (28, 29, 30)

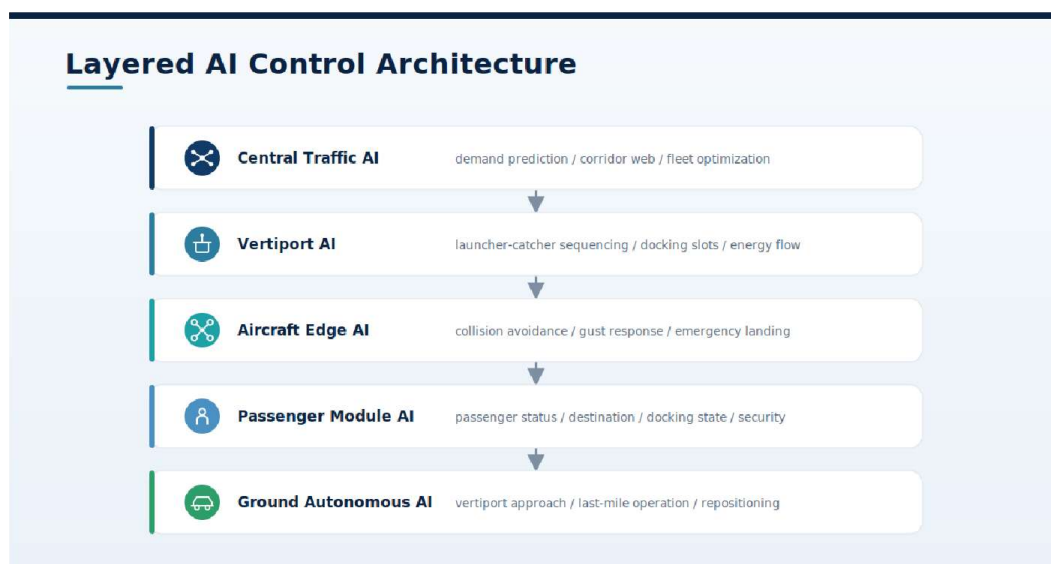


Figure 16. Layered AI control architecture connecting central traffic AI, Vertiport AI, aircraft edge AI, passenger module AI, and ground autonomous AI.

11.1 AI functions on the Multicruiser

Table 5. Core AI functions for autonomous Multicruiser operations

AI function	Operational purpose	Certification issue
Sensor fusion	Recognize buildings, aircraft, birds, weather, Vertiport markers, and catcher position.	Training data, sensor redundancy, and explainability of critical decisions.
Detect and avoid	Maintain separation from drones, aircraft, and other Multicruisers.	Performance envelope under degraded sensors and communication.
Precision approach	Align with rotating catcher and dock safely.	Verified tolerance under gusts, GPS errors, and optical occlusion.
Energy-aware navigation	Select routes based on battery SOC, fuel, weight, and alternate landing sites.	Reserve requirements and deterministic emergency policy.
Swarm coordination	Share intent and adapt to corridor web changes.	Validation of multi-agent behavior and fail-safe priority rules.

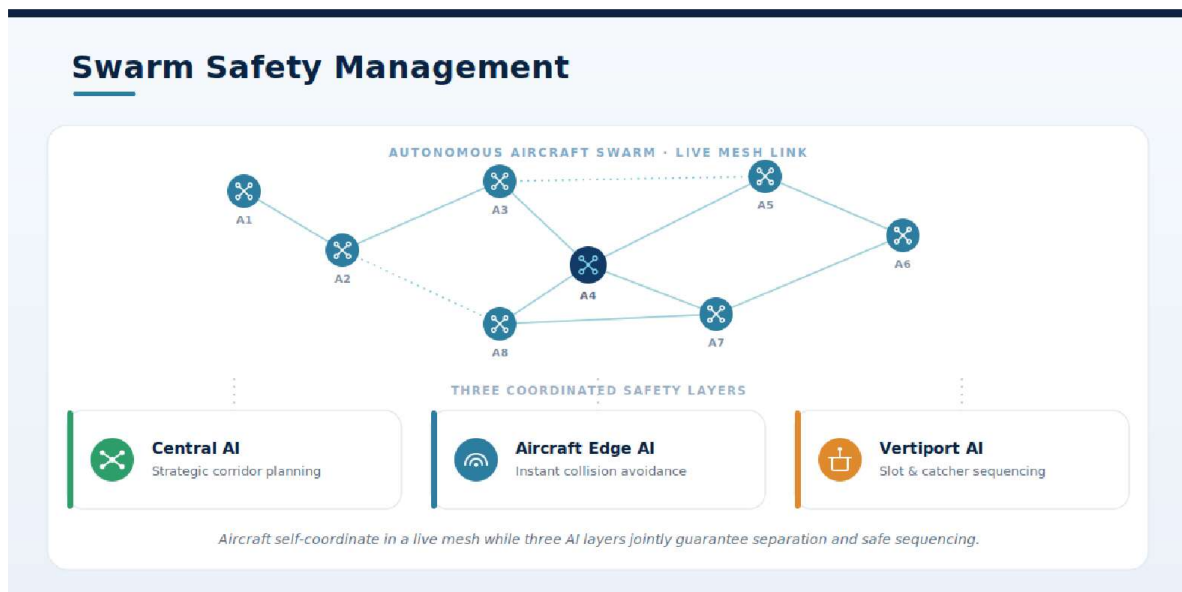


Figure 17. Swarm safety management: central strategic control, aircraft edge collision avoidance, and Vertiport slot/catcher sequencing.

12. AI-Generated Dynamic 3D Corridor Web

The corridor web is the operational brain of the system. In low-density demonstrations, fixed routes and fixed Vertiports may be sufficient. In metropolitan operation, the network must dynamically adapt. A new aircraft entering the system affects other aircraft, Vertiport queues, energy reserves, emergency landing options, and even ground autonomous vehicle allocation. This is why the original white paper described the corridor web as a moving, elastic structure.

Version 2.0 formalizes that concept as an AI-generated dynamic 3D corridor web. The web is generated from demand forecasts, reservations, current weather, local wind fields, Vertiport capacity, and aircraft energy states, emergency closures, noise constraints, and ground traffic conditions. It is not a single path for each aircraft. It is a managed flow field with priority rules, separation buffers, alternate routes, and emergency gates.

A corridor web must also support public policy. Cities may define quiet zones, schools, hospitals, government buildings, and sensitive cultural areas as keep-out or keep-high areas. The AI must respect those zones while still maintaining efficient routes. This makes urban air mobility an urban planning system as much as an aviation system.

The corridor web concept also connects to UTM and BVLOS rulemaking. Low-altitude airspace will increasingly rely on digital services, data exchange, and performance-based capabilities. MetroAir can use this direction by making the Multicruiser fleet, Vertiports, and ground carriers digitally native from the beginning. (4, 5, 37)

13. Energy Bottleneck and Hybrid Turbo-generator Strategy

The strongest technical constraint on battery-only urban air mobility is not that battery aircraft cannot fly. They can. The problem is whether the range, reserve, charging time, battery lifetime, thermal management, payload, and turnaround economics can support a public metropolitan network. Leading eVTOL concepts often focus on relatively short trips and rapid recharging. That may be suitable for premium airport transfers or early services, but it does not by itself create a low-cost 3D public transportation system. (13, 14, 15)

The Multicruiser transporter model is better suited to a hybrid-electric architecture. Batteries provide high-power vertical lift, emergency reserve, and quiet local operations. A turbo-generator provides sustained cruise power and maintains battery state of charge. The electric propulsion architecture can still drive distributed motors, but the energy source is not limited to battery mass. This is particularly valuable for a vehicle that may need to reposition without a passenger module, fly between Vertiports, or serve longer metropolitan routes.

GE Aerospace and BETA Technologies' hybrid-electric partnership and Rolls-Royce's turbo-generator testing show that hybrid-electric propulsion for AAM and smaller aircraft is an active industrial direction. These developments support the MetroAir argument that a pure battery air-taxi model is not the only path. (16, 17)

The system does not reject batteries. It assigns batteries the role for which they are most valuable: high power, responsiveness, redundancy, emergency reserve, and low-noise operation near people. It assigns chemical fuel or future hydrogen carriers the role for which they are most valuable: energy density and range extension. This division of labor is more realistic than expecting a single battery pack to solve all aircraft missions.

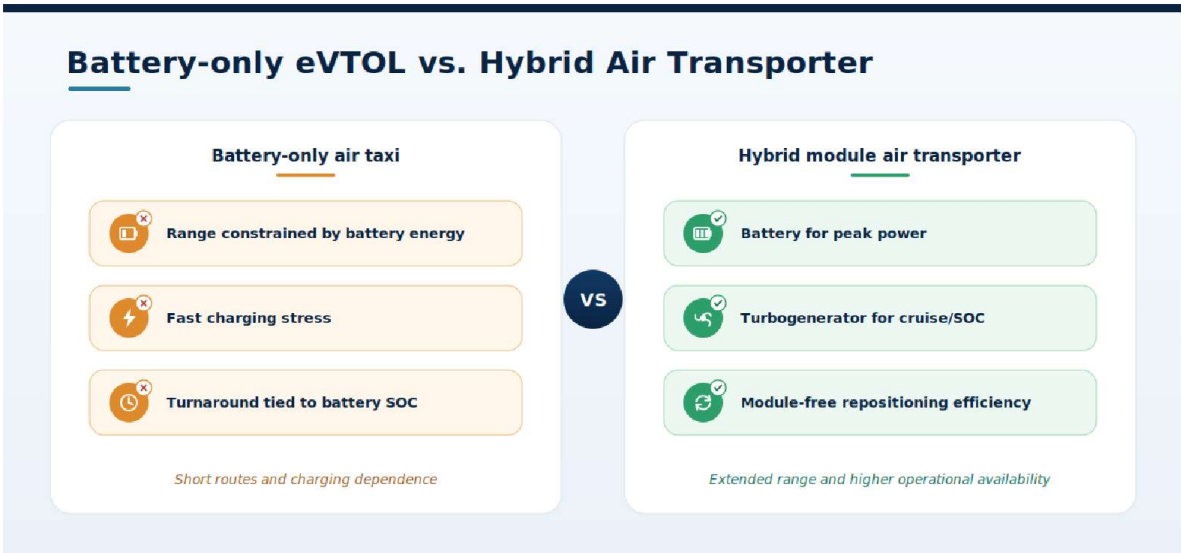


Figure 19. Battery-only eVTOL compared with the hybrid Multicruiser air transporter energy strategy.

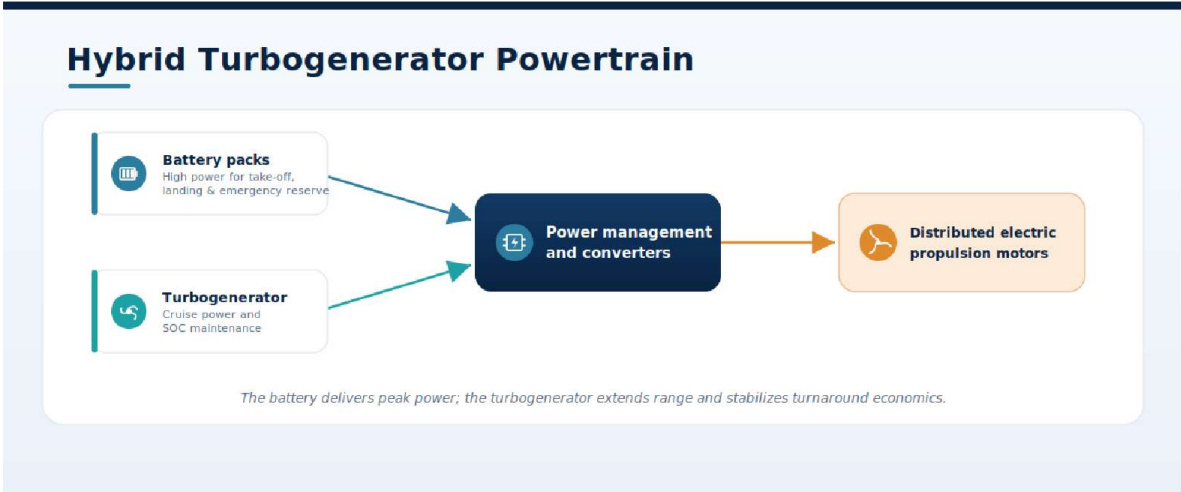


Figure 20. Hybrid turbo-generator powertrain architecture for the Multicruiser air transporter.

Table 6. Energy logic of battery-only and hybrid air transporter systems

Energy issue	Battery-only air taxi	Hybrid Multicruiser air transporter
Range	Limited by battery energy density and reserve requirements.	Extended by turbo-generator cruise power and SOC management.
Turnaround	Depends on fast charging or battery swap infrastructure.	Can combine fuel service, SOC maintenance, and battery reserve management.
Peak power	High lift power stresses batteries thermally and chemically.	Battery handles peak lift with generator support where appropriate.
Fleet repositioning	Empty aircraft still carries full integrated cabin.	Transporter can reposition without passenger module, reducing mass.
Future fuel path	Mostly tied to battery chemistry progress.	Can migrate from SAF/Jet-A to hydrogen, synthetic fuels, or ammonia-cracked hydrogen.

14. Low-Carbon Fuel Roadmap and Ammonia-Cracking Possibilities

A hybrid turbo-generator strategy must be honest about emissions. In the near term, the most practical fuel path may include existing aviation fuels and sustainable aviation fuel blends. That does not make the system permanently fossil-dependent. It creates a staged transition path: use mature turbo-generator technology to solve operational range and turnaround, then migrate fuel sources as low-carbon aviation fuels, hydrogen systems, and carrier technologies mature.

Hydrogen has high gravimetric energy potential but difficult storage and infrastructure constraints. Ammonia is attractive as a hydrogen carrier because it can store hydrogen without carbon and can be cracked to produce hydrogen. Industrial-scale ammonia-to-hydrogen conversion is advancing, and this makes ammonia relevant to long-term energy planning. (18)

However, ammonia is not a simple aircraft fuel solution. It is toxic, requires careful storage and handling, and ammonia/hydrogen combustion in gas turbines raises NOx and ammonia-slip issues. Any reference to ammonia in MetroAir should therefore be framed as a long-term fuel-chain possibility rather than an immediate aircraft integration. (19)

The practical roadmap is staged. First, validate the hybrid-electric aircraft architecture with conventional or approved sustainable fuels. Second, establish fuel service and safety procedures at Vertiports. Third, introduce lower-carbon fuels as they become certifiable. Fourth, evaluate hydrogen or ammonia-cracked hydrogen systems only after weight, safety, emissions, and certification constraints are understood. This staged approach is more credible than claiming immediate zero-emission metropolitan aviation.

Table 7. Staged fuel transition strategy

Stage	Fuel / energy source	Main work required
Near term	Approved aviation fuel or SAF blends in a compact turbo-generator.	Certification, noise, emissions, fire safety, Vertiport fueling procedures.
Mid term	Higher SAF blend, synthetic fuel, or hydrogen demonstration.	Supply chain, storage, combustion behavior, maintenance procedures.
Long term	Ammonia-cracked hydrogen or other hydrogen carriers.	Cracker mass, thermal integration, toxicity management, NOx control, ammonia slip prevention.

15. Metropolitan Network, Public Access, and Economic Logic

The purpose of the MetroAir system is not to create a premium aircraft ride for a small group of users. The purpose is to expand the functional metropolitan area. If a passenger module can move from a suburban or regional node to a central hub in minutes, the geography of work, housing, healthcare, and education changes. The system can reduce the penalty of distance without forcing all development into already congested city centers.

The economic logic depends on standardization and fleet utilization. Passenger modules, ground carriers, Multicruiser air transporters, docking interfaces, Vertiport handlers, and AI traffic services must become standardized enough to benefit from production scale. An air transporter does not need to be produced in automobile volumes to become economical; it needs to be produced as a repeatable fleet platform with standardized maintenance, common parts, and predictable operating cycles.

The ownership model can combine private and public elements. A passenger module may be personally owned by users who want continuity of cabin environment. Public modules can serve ordinary transit riders. Ground carriers can be shared. Air transporters should be operated as a regulated public or concession fleet. This creates a pathway to public accessibility rather than a luxury-only system.

The system also creates new industries: modular passenger-module manufacturing, automated docking systems, Vertiport construction, launcher/catcher mechanisms, AI traffic management software, maintenance robotics, hybrid-electric powertrain service, and low-carbon fuel logistics. The white paper's industrial claim is therefore not only about one aircraft. It is about a complete mobility ecosystem.

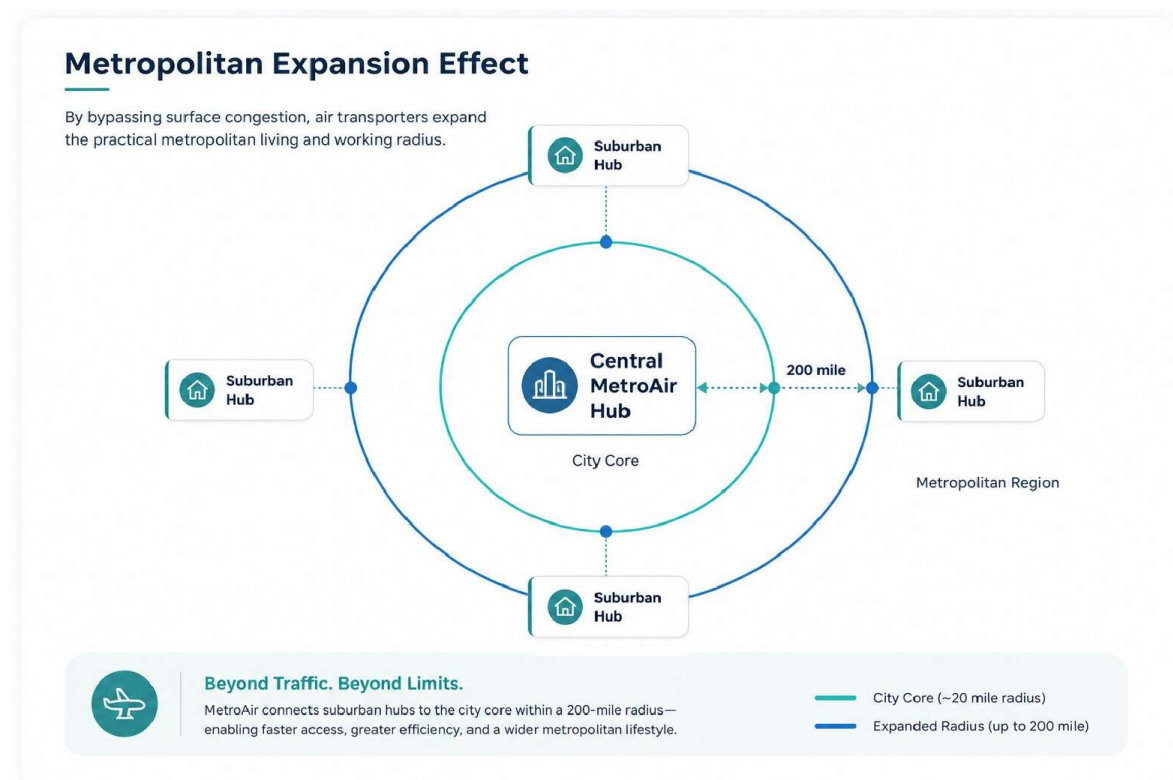


Figure 21. Metropolitan expansion effect: bypassing surface congestion extends the practical metropolitan region.

16. Development, Verification, and Certification Roadmap

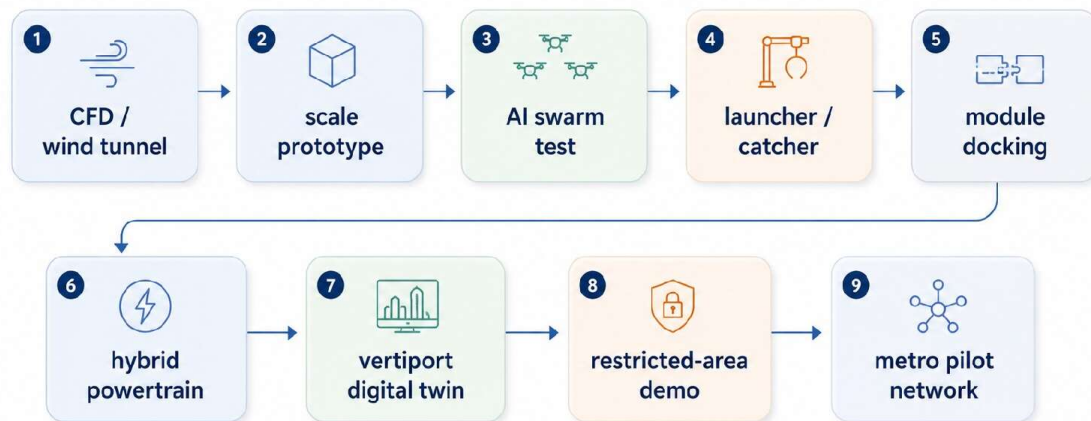
The system must be developed in stages. A full metropolitan network cannot be certified or deployed at once. Version 2.0 proposes a staged roadmap that separates aircraft physics, docking mechanics, AI behavior, powertrain integration, Vertiport automation, and network operations before combining them.

Stage 1 is aerodynamic and powertrain validation. Rimfoil lift, drag, rotor interaction, noise, gust response, and transition behavior must be studied through CFD, wind tunnel models, and scaled flight tests. Stage 2 is docking and mechanical handling. The aircraft holder, passenger-module latch, emergency release, center-of-gravity sensing, and vertical handling equipment must be validated before passenger carriage.

Stage 3 is autonomy and swarm behavior. The aircraft should first demonstrate basic autonomous flight, then detect-and-avoid, then precision approach, then multi-aircraft sequencing, then degraded communication safety. Stage 4 is launcher/catcher testing using unmanned scaled vehicles and ground rigs. Stage 5 is Vertiport digital twin testing, where passenger, aircraft, energy, and emergency flows are simulated as a single system.

Stage 6 is limited-area integrated demonstration. This should not begin in dense public airspace. It should begin in a controlled test range, then an industrial site, then a limited urban corridor with emergency alternatives. Stage 7 is public service under defined operating limits. Each stage should produce data for certification, public communication, insurance, and policy development.

MetroAir Development Roadmap



A staged roadmap is required: component validation must precede integrated passenger-network trials.

Figure 22. MetroAir development roadmap from CFD and scaled prototypes to Vertiport digital twin, restricted-area demonstration, and metropolitan network.

Table 8. Verification roadmap

Roadmap step	Primary output	Evidence produced
CFD and wind-tunnel tests	Rimfoil aerodynamics, rotor interaction, noise map.	Aerodynamic database and design envelope.
Scaled prototype flight	Low-speed control, transition behavior, failure response.	Flight-test data and control-law validation.
AI and swarm test	Detect-and-avoid, corridor following, emergency rerouting.	Autonomy performance metrics.
Launcher/catcher rig	Mechanical acceleration/capture and tolerance.	Safety envelope and passenger comfort limits.
Module docking test	Latch, release, power/data connection, CG verification.	Interface standard and emergency behavior.
Hybrid powertrain test	SOC management, generator response, thermal behavior.	Energy model and maintenance procedures.
Vertiport digital twin	Integrated flow of aircraft, modules, passengers, and energy.	Capacity and resilience model.
Restricted-area demo	End-to-end unmanned system operation.	Certification package and public acceptance evidence.

17. MetroAir Vision and Industrial Ecosystem

We proposed the most reasonable 3D public transportation system that can be implemented with current technology. Modular mobility and this system combined with the air metro system is possible if the aircraft is reasonably designed. The aircraft not only has a shape suitable for handling in a Vertiport, but also has aerodynamic characteristics that combine the advantages of a Multicopter and a fixed-wing airplane, making it the most suitable design for urban aviation in terms of public acceptance. Airbus's pop-up concept is modular if the flying car was a great inspiration, the new aircraft presented would serve as the missing link that would enable the design of all proposed systems. This heralds not only research and development to build a system, but also the birth of a new huge industry. New modular cars will be developed, running systems will be developed, industries that service them will emerge, public air mobility services will emerge, and the design and construction of Vertiports will emerge as a large industry. There will be a device industry that must be supported in building such a system. All of this will ensure equality of movement in and around the metropolis, ensuring a more comfortable life for people and increasing the utilization of land in the metropolitan area.

17.1 Mission and business vision

1. The Multi-Cruiser is the company's eVTOL aircraft product and the core vehicle for the 3D transport concept.
2. The main research area is the aerodynamic characteristics and performance of Multicruisers and the construction of a three-dimensional transportation system through modularization.
3. The short-term strategy is to develop Multicruiser drones and derivatives; the long-term strategy is to shape an urban air vehicle system.
4. Derivatives of the Multicruiser will be developed and business models will be established in aircraft segments with profitable weight and size.
5. By size class, MetroAir will continue researching flight characteristics and enter markets with high added value where complete R&D capability can be demonstrated.
6. The urban aviation system using Multicruisers will be strengthened through cooperation with companies and organizations in relevant technology fields.
7. For the long-term goal, MetroAir will create reasonable standards, expand assets, attract investment, and distribute resulting value through joint ventures with participating individuals, institutions, and companies.

Version 2.0 strengthens this vision by adding three strategic pillars. First, the Multicruiser must evolve from a distinctive aircraft concept into a standardized air-transporter platform. Second, the passenger-module interface must become an industrial standard that connects PBV, robotaxi, Vertiport, and air transport ecosystems. Third, the AI corridor web must

become the software infrastructure that transforms individual vehicles into a safe public network.

The business opportunity therefore includes both hardware and system infrastructure. Hardware includes the Multicruiser, passenger modules, ground carriers, docking mechanisms, launch/capture devices, and hybrid-electric powertrain components. Infrastructure includes Vertiports, energy service, digital twins, AI traffic management, and safety monitoring. Services include passenger transport, module leasing, maintenance, inspection, emergency response, data services, and public concession operations.

The most important social promise is mobility equality. If the system is built only as a premium airport-transfer service, it will not justify the complexity of urban air mobility. If it is built as a public 3D layer that extends metropolitan access and reduces dependence on congested roads, it can change the geography of opportunity. That is why the document uses the phrase 'From Sky to Street.' The sky layer is valuable only when it is integrated with the street layer.

17.2 Contact and corporate information

MetroAir Inc. is a Korean corporation focused on Multicruiser aircraft and the system architecture required for modular three-dimensional urban transportation. Its work connects aircraft design, modular mobility, Vertiport systems, and future urban air operations.

Table 9. MetroAir corporate information

Office	Information
Head office S. Korea	1206 GLmetrocityHyangdong Hyangdong-ro 201, Deokyang-gu, Goyang-si, South Korea. Tel. +82 70 8983 6260.
Head office US	251 Little Falls Drive, Wilmington, New Castle County, Delaware 19808
CEO	Hagyoon Kim. E-mail: ceo@metroair.kr / enfnal62@gmail.com
Marketing	Jisu Kim. E-mail: jisukim@metroair.kr / metroair.marketing@gmail.com.

18. Passenger Module Interface and Safety Standards

The passenger module is the central object of the MetroAir system. In a conventional air-taxi model, the aircraft is the cabin, the propulsion system, the avionics platform, and the certified vehicle all at once. In the MetroAir model, the passenger module becomes a standardized mobility capsule that interfaces with two different vehicle layers: the autonomous ground carrier and the Multicruiser air transporter. This creates the possibility of seamless movement, but it also creates a new certification problem: the module interface must be treated as a safety-critical standard.

A passenger module standard must define structural loads, crashworthiness, fire protection, egress, cabin pressure and ventilation assumptions, electrical safety, electromagnetic compatibility, cybersecurity, identity management, and emergency release logic. The module must be strong enough to be lifted, accelerated, captured, and handled by automated equipment. It must also be light enough that the air transporter remains efficient. The structural interface must therefore be designed with aircraft loads, road-vehicle loads, Vertiport handling loads, and passenger comfort loads in a single load case family.

The module also requires an electrical and data standard. When attached to a ground carrier, it may receive power for HVAC, infotainment, lighting, communications, and doors. When attached to a Multicruiser, it may exchange data on passenger count, payload mass, center of gravity, door status, battery contribution, cabin environment, emergency equipment, and destination. When in the Vertiport, it may be inspected, cleaned, charged, secured, and assigned to a route. A single module interface must support all of these states without requiring the passenger to understand the mode transition.

The most important safety principle is positive confirmation. The system must not assume that docking has occurred. It must verify mechanical latch engagement, electrical continuity, data authentication, door and hatch status, fire isolation, passenger seat occupancy, restraint status, module weight, center of gravity, and emergency release readiness. A failed check should automatically remove the module from the flight queue. These interlocks are part of the transportation system, not optional user-interface features.

The passenger module must also be designed for evacuation. If a module is on a ground carrier, evacuation can resemble a road-vehicle procedure. If it is inside a Vertiport, evacuation may require station platforms, safe corridors, or fire-isolated holding bays. If it is attached to a Multicruiser, the aircraft safety case must consider emergency landing, post-landing egress, and rescue access. The module must therefore include signage, lighting, communication, and emergency release functions that work across all modes.

Standardization also determines the business model. If every aircraft or ground carrier uses a proprietary module, the system cannot become public infrastructure. The interface should

be open enough to allow multiple module manufacturers and service providers, but controlled enough to preserve safety. This is analogous to container standards, aircraft ground-service interfaces, rail coupling systems, and EV charging standards. Standardization is what transforms a product into a network.

Version 2.0 therefore treats the passenger module interface as a first development priority. Early prototypes should not attempt to solve every comfort feature. They should validate the mechanical, electrical, digital, and safety interfaces. Once the interface is stable, cabin variants can follow: commuter modules, accessible modules, medical modules, cargo modules, premium modules, and public-transit modules. The same air transporter can then serve different public purposes without redesigning the aircraft.

This modularity also improves resilience. If a passenger module requires cleaning, repair, battery service, or security inspection, it can be removed from the operating pool while the air transporter continues to serve another module. If an aircraft requires maintenance, the module can be transferred to another aircraft or returned to a ground carrier. The passenger experience remains continuous because the network handles the mode substitution behind the scenes.

The interface standard should ultimately include digital identity. Each module must be known to the central system, its maintenance history, configuration, weight category, energy state, fire-safety status, ownership status, and operational limitations. Without digital identity, module interchange becomes unsafe. With it, the system can make automatic decisions about which module can be attached to which air transporter under which weather, route, and load conditions.

Table 10. Passenger module interface requirements

Interface area	Required standard	Reason
Mechanical latch	Positive locking, redundant sensors, emergency release, tolerance envelope.	Prevents unsafe launch, capture, or ground movement.
Electrical power	Mode-specific power transfer, isolation, overcurrent protection.	Allows HVAC, module systems, and energy sharing without unsafe coupling.
Data authentication	Module ID, maintenance status, payload, door state, CG, route authorization.	Allows AI dispatch and Vertiport control to trust the module state.
Fire and thermal safety	Compartment isolation, smoke detection, battery safety if module has storage.	Protects passengers and automated handling systems.
Human factors	Accessible entry, restraints, emergency signage, cabin monitoring.	Makes the module usable as public transport, not a luxury capsule.

The interface is therefore the hidden foundation of the entire system. The Multicruiser can only scale if it can trust the module. The Vertiport can only process traffic if it can trust the docking state. The AI corridor web can only allocate flight paths if it knows the actual payload

and energy margins. In MetroAir Version 2.0, module standardization is not a later accessory. It is the engineering heart of seamless 3D transport.

19. AI Safety Case and Certification Evidence

AI in the MetroAir system must be divided into certifiable functions. A general statement that the system uses artificial intelligence is not sufficient for aviation safety. The safety case must identify which AI functions are advisory, which are operational, which are safety-critical, and which are prohibited from making irreversible decisions without deterministic guardrails. This distinction is essential because aviation certification requires evidence, not optimism.

The central traffic AI may use predictive and optimization methods for demand forecasting, slot allocation, corridor generation, and fleet distribution. These functions affect efficiency and capacity, but they can be bounded by conservative safety envelopes. The aircraft edge AI, by contrast, handles immediate collision avoidance, landing-site selection, degraded sensor response, and emergency maneuvering. These functions require much stronger assurance because reaction time is short and human intervention may not be available.

A layered AI safety case should include independent monitors. Even if a learned planner proposes a route, a deterministic safety monitor should verify that the route respects geofences, separation limits, energy reserves, weather constraints, and emergency landing options. This is similar to the idea of using AI for optimization while keeping certified safety constraints in a separate, verifiable layer. The AI may suggest; the safety envelope permits or rejects.

Training data must be controlled. Urban aviation data will be highly variable: buildings, cranes, birds, drones, helicopters, emergency vehicles, weather, smoke, rain, and optical reflections. The system must therefore include synthetic data, real test data, edge-case simulation, and continuous monitoring of model drift. Data from one city cannot automatically be assumed valid in another city because skyline, weather, regulatory rules, and public constraints differ.

The AI certification path should begin with functions that are easier to verify. Visual recognition of Vertiport markers, module state classification, maintenance anomaly detection, and traffic-flow prediction can be validated before full autonomous passenger operation. Detect-and-avoid and emergency landing selection should then be demonstrated in unmanned flights under controlled conditions. Full passenger service should arrive only after the system has accumulated evidence across weather, failure, and traffic scenarios.

Human supervision remains part of the early system. However, human supervision must not be confused with remote piloting of every vehicle. A remote supervisor can monitor fleets,

approve contingency modes, and intervene in rare cases, but the aircraft must remain safe if communication is delayed or lost. This is why edge AI and deterministic fallback modes are essential. The vehicle must be able to continue, hold, divert, or land safely without waiting for a remote human to fly it.

Cybersecurity is part of the AI safety case. A malicious command to a passenger module, a false GPS signal, a corrupted wind report, a spoofed Vertiport slot, or a compromised module ID can create physical risk. The system must use authentication, encrypted communication, anomaly detection, and safe-state logic. AI can help detect anomalies, but the security architecture must not depend solely on a learned model.

The certification evidence should include simulation logs, hardware-in-the-loop tests, flight-test data, failure injection, adversarial scenario testing, and operational monitoring. The system should maintain a safety data lake, but access to that data must respect privacy and cybersecurity. Over time, operational data can improve performance, but any learning update that affects safety-critical functions should pass a controlled validation pipeline before deployment.

EASA's AI roadmap and FAA's ongoing work around AAM, BVLOS, and UTM show that regulators are preparing for increasing automation but still require structured assurance. MetroAir should therefore position its AI architecture as certifiable-by-design: layered, bounded, monitored, and supported by progressive evidence. (4, 9, 37)

The core message is that AI makes the system possible only if it is disciplined. Unconstrained AI would reduce trust. Layered AI with deterministic safety monitors can increase trust by making complex, high-density operation manageable without turning every aircraft into a remotely piloted vehicle.

20. Vertiport Digital Twin and Throughput Simulation

Before a hub Vertiport is built, it should exist as a digital twin. The digital twin is not a marketing animation. It is an operational model that includes passenger arrival, module assignment, security check, vertical movement, aircraft docking, launcher timing, catcher timing, maintenance inspection, energy service, weather, emergency events, and network constraints. Only such an integrated model can answer whether a proposed Vertiport can handle public-transport demand.

Throughput must be measured at several levels. The top-deck throughput measures how frequently a vehicle can be launched or captured. The internal handling throughput measures how quickly aircraft and modules move through elevators, racks, inspection bays, cleaning bays, and docking interfaces. The energy throughput measures charging, fueling, SOC recovery, thermal cool down, and safety checks. The passenger throughput measures boarding, disembarkation, accessibility, security, and wayfinding. The network throughput measures whether destination Vertiports and air corridors can receive the traffic.

A common mistake is to calculate Vertiport capacity from the number of pads. MetroAir's system uses launcher/catcher logic precisely because pad count is not enough. A pad-based system may have aircraft waiting, hovering, charging, or being cleaned while occupying critical real estate. A module-handling system transfers the vehicle away from the critical deck as soon as possible. The digital twin must therefore model time in each state rather than simply count landing spots.

The digital twin should run both scheduled and stochastic scenarios. Scheduled scenarios test planned commuter peaks, airport-transfer peaks, event traffic, and night-time repositioning. Stochastic scenarios test elevator failure, catcher fault, unexpected weather, passenger no-shows, module security holds, emergency diversions, and temporary corridor closures. The design is not mature until it can explain how capacity degrades and recovers.

NASA throughput work, VertiSim-style simulation, and Vertiport capacity research all support this system-level method. They show that the relationship between vehicles, pads, routes, passengers, and energy is nonlinear. Adding more aircraft can reduce performance if Vertiport capacity or charging capacity is insufficient. Adding more Vertiports can reduce delays if network routing is balanced, but can also increase complexity if traffic management is weak. (6, 26, 27, 38)

The MetroAir digital twin should eventually be connected to live operations. During service, it can forecast queue lengths, identify emerging bottlenecks, recommend slot changes, pre-position modules, and adjust ground-carrier dispatch. It can also support maintenance by detecting unusual aircraft turnaround times or energy consumption. The digital twin becomes a living operational tool.

Digital twins are also valuable for public communication. Citizens and regulators can understand expected noise exposure, emergency routes, visual corridors, and service reliability before deployment. Public acceptance is easier to build when the system can show how it behaves under stress rather than merely promise safety.

Table 11. Vertiport digital twin model components

Digital twin component	Modeled variables	Output
Passenger flow	Arrivals, accessibility, boarding, security, no-shows, module assignment.	Queue time, dwell time, passenger throughput.
Aircraft handling	Capture, docking, inspection, rack storage, launch sequencing.	Aircraft cycle time and deck occupancy.
Energy service	Battery SOC, turbogenerator fuel, thermal cool down, fueling safety.	Energy bottleneck and reserve margin.
Airspace network	Corridor capacity, weather, separation, emergency alternatives.	Delay, reroutes, and safety buffers.
Failure scenarios	Elevator fault, catcher fault, weather closure, communication degradation.	Degraded-mode capacity and recovery plan.

21. Noise, Public Acceptance, and Urban Policy

Noise is not a minor detail in urban aviation. It is a system acceptance variable. The public may tolerate occasional emergency helicopters, but it will not automatically accept frequent scheduled aircraft operations near homes, schools, parks, and offices. A public 3D transport system must therefore manage acoustic exposure as a design requirement from the beginning.

Noise is shaped by rotor design, tip speed, blade loading, operating mode, altitude, approach path, building reflections, weather, and flight frequency. A quiet aircraft can still become unacceptable if it repeats often enough over the same neighborhood. A louder event may be acceptable if it is rare or occurs over an industrial corridor. This means that AI corridor planning should include cumulative noise exposure, not only instantaneous decibels.

The launcher/catcher system has an acoustic logic. Reducing hover time near the Vertiport can reduce the duration of high-power noise in the most sensitive zone. Elevated Vertiports can also separate operations from street-level listeners, although building reflections must be modeled. The rotating deck may help align flight paths with preferred wind and noise directions.

Public acceptance also includes visual impact, privacy, perceived control, and fairness. If citizens believe that air mobility serves only wealthy passengers while imposing noise on everyone else, acceptance will fall. MetroAir's public-transport framing is therefore important. A system that supports ordinary commuting, medical access, emergency logistics, and regional connectivity has a stronger public-interest justification than a luxury air-taxi service.

Urban policy should define where Vertiports may be located, how emergency landing sites are designated, which areas are keep-out zones, how noise exposure is measured, how public complaints are processed, and how data is shared. The AI corridor web must comply with these policies. The city should not be treated merely as an obstacle map; it is a political and social environment.

Public engagement should start before construction. The system can use digital twins and simulations to show residents expected routes, altitudes, noise envelopes, emergency behavior, and service benefits. Community feedback can then inform corridor placement, operating hours, and station access. This is not only public relations. It is risk reduction.

Studies on public acceptance and UAM policy indicate that perceived safety, noise, privacy, environmental benefit, and trust in regulation all matter. MetroAir's protected rotor design, modular public-transport model, and elevated Vertiport strategy are intended to respond directly to these concerns. (8, 46, 47, 48, 49)

22. Modular Vehicle Integration and PBV Implementation

The PBV trend gives MetroAir a practical ground-side pathway. Modern electric platforms increasingly separate the lower platform from the service body. This is not yet the same as a detachable passenger module, but it moves the industry toward standardized interfaces, software-defined operation, and purpose-specific vehicle bodies. The gap between PBV and MetroAir is a development challenge, not a conceptual impossibility.

In the first implementation stage, MetroAir modules may be handled only within controlled facilities. A passenger boards a module at a Vertiport, the module attaches to an air transporter, and the destination Vertiport places it on a local ground carrier. In a later stage, modules can be picked up at homes, offices, or community nodes by autonomous carriers. The system can mature from station-to-station service to door-to-door module continuity.

Ground carriers do not need to be private automobiles. A carrier can be a low-speed autonomous platform designed to move a passenger module safely through city streets. It can be smaller and simpler than a car because the module provides the passenger environment. It can also operate at night to reposition empty modules or carriers, reducing peak-hour inefficiency.

The PBV/PAV boundary should be defined by regulation. A passenger module on a road must satisfy road-safety requirements when attached to a ground carrier. The same module in the air must satisfy aviation-related structural and fire-safety requirements. This dual-mode certification problem is challenging, but it can be solved by defining the module as a certified transport container with mode-specific carriers.

Kia's PV5 and Toyota's e-Palette show that manufacturers are willing to create mobility platforms for diverse services rather than only traditional passenger cars. A MetroAir module can be positioned as the next step: a certified module that participates in both ground and air service networks. (20, 21, 22)

The city implementation plan should include curb management. Autonomous carriers cannot block sidewalks or intersections while waiting for modules. Vertiports should have controlled module exchange lanes, underground or elevated interfaces, and integration with rail and bus stations. The purpose is to avoid transferring congestion from roads to Vertiport access points.

Standardized module logistics can also support freight and emergency services. A cargo module can move medical supplies, critical parts, or time-sensitive goods. A medical module can support regional hospital access. A public-service module can move rescue equipment. This flexibility increases utilization and strengthens the economic case for the infrastructure.

23. Fleet Operations, Maintenance, and Energy Management

A public 3D transport system is a fleet operation. The individual aircraft is important, but fleet availability is more important. The system must know how many Multicruisers are available, where they are, which modules they can carry, what their maintenance status is, how much energy they have, which Vertiports can service them, and what demand is expected in the next several hours.

Fleet operations should use predictive maintenance. Every flight produces data: vibration, rotor performance, generator behavior, battery temperature, motor current, structural loads, docking forces, latch cycles, and capture events. These data can identify components that should be inspected before failure. Predictive maintenance is especially valuable because one aircraft failure can affect Vertiport queues and corridor capacity.

Energy management is a network problem. A battery-only air taxi must recharge or swap batteries between flights. A hybrid Multicruiser must manage battery state of charge, generator fuel, thermal state, emissions limits, noise-sensitive electric-only segments, and reserve requirements. The optimal decision may vary by route, weather, payload, and destination capacity.

The AI energy manager should assign vehicles to missions based on actual energy state and expected recovery time. A vehicle with high battery SOC and low fuel may be assigned to a short mission ending at a fueling-capable Vertiport. A vehicle with strong fuel reserve and moderate battery SOC may be assigned to a longer cruise with low-noise electric operation near departure and arrival. A vehicle with unusual thermal behavior may be routed to inspection.

Maintenance scheduling should be coordinated with demand. Public transport demand peaks in morning and evening. Aircraft and modules can be inspected and repositioned during off-peak periods. Autonomous ground carriers can move modules at night when roads are less congested. The entire system should behave like a coordinated mobility utility, not a set of independent vehicles.

Fuel and charging infrastructure should be redundant. A Vertiport may provide electrical charging, battery conditioning, SAF or fuel service, future hydrogen service, and module battery service. Safety procedures must isolate passenger areas from energy-service areas. The digital twin should model energy bottlenecks just as carefully as launcher/capture bottlenecks.

24. Hybrid Powertrain Engineering Considerations

The hybrid turbo-generator architecture proposed for the Multicruiser is a series-hybrid concept. The propulsion motors remain electric. The turbo-generator produces electrical power, which is managed through converters and combined with battery output. This allows distributed electric propulsion to remain available while reducing dependence on battery energy density alone.

The architecture must solve several engineering questions. The generator must be lightweight, reliable, and responsive enough for aircraft operations. The battery must support high peak power, rapid load changes, emergency reserve, and safe thermal behavior. The power electronics must manage transients between generator output, battery discharge, motor demand, and regenerative or idle states. The control system must prevent unsafe oscillations or overloads.

Noise and emissions must also be considered. A turbo-generator may introduce a different noise profile from pure electric motors. It should therefore be operated in regimes that minimize acoustic impact near Vertiports and sensitive corridors. One possible strategy is battery-dominant operation during launch, capture, and low-altitude urban segments, with generator-dominant operation during cruise or higher-altitude segments where acoustics and emissions can be managed more effectively.

The hybrid system improves mission flexibility. A vehicle can maintain battery reserve for emergency landing. It can perform longer repositioning flights without long charging pauses. It can support seasonal demand and suburban links beyond the range of short-hop eVTOL service. It can also reduce battery cycling stress because the battery no longer supplies all mission energy.

The design must also address failure modes. Generator failure should leave enough battery reserve for safe landing. Battery failure should be isolated. Power electronics faults should not cascade across all motors. Fuel-system faults should trigger defined emergency routes. The certification basis will require clear allocation of hazards, redundancy, and maintenance intervals.

Industrial work by GE Aerospace, BETA Technologies, and Rolls-Royce indicates that hybrid-electric flight is a serious pathway for longer-range advanced air mobility and small aircraft. MetroAir's contribution is to connect that powertrain strategy to a modular transporter business model rather than to a conventional passenger cabin aircraft. (16, 17, 41)

25. Emergency Response and Resilience Architecture

The system must assume that failures will occur. The safety question is not whether every component can be made perfect. The question is whether the system can detect failures early, isolate them, maintain safe separation, protect passengers, and recover service without uncontrolled improvisation. Resilience must be designed into the air vehicle, the module, the Vertiport, the AI control system, and the metropolitan network.

Emergency landing sites are a core part of the architecture. Existing helipads may be useful, but they are not enough. The city should designate and digitally certify a network of emergency sites with known dimensions, obstacles, load capacity, access routes, rescue procedures, and communication interfaces. Each Multicruiser should continuously know which sites are reachable given its energy state, payload, wind, and system health.

Emergency behavior should be graded. A minor sensor disagreement may trigger reduced speed and additional separation. A Vertiport fault may trigger diversion to an alternate hub. A generator fault may trigger battery-reserve landing. A module fire warning may trigger immediate landing at the nearest certified emergency site. A communications failure may trigger a pre-defined lost-link procedure. These states must be understood before service begins.

The passenger module can improve emergency management. Because the passenger environment is standardized, rescue crews can be trained on one module architecture. Emergency release, fire suppression, communication, and evacuation can be standardized. Ground carriers can be dispatched to emergency sites to recover passengers or modules after a safe landing.

The AI system should broadcast state changes to all affected vehicles. If one Vertiport closes, the corridor web must re-route inbound vehicles and adjust departure demand. If weather deteriorates, routes may shift to lower-capacity safe corridors. If an aircraft declares emergency, nearby aircraft should automatically increase separation and yield priority.

Public trust depends on predictable emergency behavior. The system should publish emergency principles, not confidential technical details. Citizens should know that aircraft do not wander randomly, that emergency sites exist, that low-altitude emergency flight is planned, and that passenger modules can be recovered safely. Resilience is therefore a technical and social requirement.

26. Deployment Phasing and Business Model

MetroAir should not attempt to begin with a full citywide passenger network. The first phase should prove the aircraft and module interface in controlled unmanned operations. The second phase should prove Vertiport handling with empty passenger modules. The third phase should carry cargo or non-passenger modules. The fourth phase should conduct limited passenger demonstrations in controlled corridors. Only after these stages should high-frequency public service be considered.

A plausible early business case is time-sensitive cargo, medical logistics, and industrial-site transport. These operations can validate docking, route control, energy management, and Vertiport operations while reducing passenger risk. They also generate data for maintenance and throughput models. Passenger service should grow from evidence, not from marketing deadlines.

A second early case is regional campus transport: airport-to-industrial zone, university-to-research park, hospital-to-satellite facility, or island/coastal connections. These routes can have controlled infrastructure, known emergency sites, and predictable demand. They are more realistic than immediately entering the most complex downtown airspace.

Public-private partnership is likely required. Vertiports are urban infrastructure. Airspace safety is public. Passenger modules and ground carriers may be private or shared. Air transporters may be operated by a public concession. This combination resembles rail, airport, road, and mobility-service governance more than private automobile sales.

Pricing should be designed for access. Early service may be premium, but the long-term system must move toward public transport economics. Standardization, automation, fleet utilization, and mass production of air transporters can reduce cost. The passenger-module model helps because the air transporter does not need to be a complete luxury cabin and can serve many modules across the day.

The business model should include non-passenger revenue: cargo modules, maintenance services, Vertiport licensing, AI traffic management, module leasing, data analytics, and emergency logistics. These additional revenue streams help support the infrastructure during the transition from demonstration to public service.

27. End-to-End Operating Scenarios

Scenario 1 is a commuter module trip. A passenger reserves a journey from a suburban community to a central business district. The reservation system assigns a passenger module, a ground carrier, a departure Vertiport, an air transporter, a destination Vertiport, and a destination ground carrier. The passenger boards the module near home. The ground carrier delivers it to the local Vertiport. The module is verified, lifted, attached to a Multicruiser, launched into the corridor, captured at the destination hub, transferred to a ground carrier, and delivered to the final address.

Scenario 2 is a public capsule trip. A user without a private module books a seat in a public module at a transit-connected hub. The module is treated like an urban rail cabin but can be lifted into the air layer. Public modules can run on high-demand corridors at scheduled intervals. This allows the system to serve public transport goals rather than only personalized trips.

Scenario 3 is medical logistics. A hospital requests a sterile cargo module or medical passenger module. The system assigns priority, clears a corridor, and delivers the module between hospital Vertiports or emergency sites. Because the module is standardized, medical equipment can remain secured during mode transitions. This use case can justify early infrastructure because it serves public value.

Scenario 4 is fleet repositioning. After the evening peak, demand shifts from the central city to suburbs. Empty passenger modules, ground carriers, and Multicruisers reposition under autonomous operation. Air transporters without passenger modules fly lighter, using less energy. Ground carriers move at night when road congestion is low. The next morning, the system begins with the fleet already distributed.

Scenario 5 is degraded operation. A central hub loses one module elevator. The Vertiport AI reduces departure cadence, redirects some modules to a secondary line, informs central AI of reduced capacity, and triggers alternate destination assignments. Inbound aircraft are sequenced into lower-rate arrival windows. Passengers experience delay but not disorder. This is the difference between a designed public system and an ad hoc vehicle service.

Scenario 6 is emergency diversion. A Multicruiser detects abnormal generator behavior during cruise. The edge AI calculates that battery reserve is sufficient for an alternate Vertiport or certified emergency site. Central AI clears priority through the corridor web. Nearby aircraft increase separation. The destination system dispatches a ground carrier to recover the passenger module. The incident is logged for maintenance and regulatory review.

These scenarios demonstrate why the system must be designed as a whole. The aircraft, module, ground carrier, Vertiport, AI traffic system, energy infrastructure, and emergency network are not independent products. They are one transportation organism.

Conclusion: Seamless 3D Transport World

Version 2.0 confirms and expands the original MetroAir argument. The future of urban air mobility is not a collection of pilot-operated air taxis flying between rooftop pads. That model may appear first because it is easier to explain and closer to existing aviation categories, but it does not resolve the deeper system problems of access, throughput, cost, battery limitation, public acceptance, and metropolitan scale.

The MetroAir concept begins with a different unit of analysis: the passenger module. If the module can move from a ground carrier to an air transporter and back to a ground carrier, the passenger no longer experiences air and ground as disconnected modes. The city gains a third dimension without forcing citizens to perform multiple transfers. This is the practical meaning of seamless transport.

The Multicruiser is the enabling air transporter. Its Rimfoil-protected rotors respond to public acceptance and safety perception. Its compact form supports Vertiport handling. Its modular interface allows passenger modules to be carried without integrating every cabin function into the aircraft. It's AI and swarm-ready architecture allows future unmanned operation. Its hybrid-electric powertrain strategy addresses the battery bottleneck that constrains pure battery eVTOL economics.

The hub Vertiport is the enabling infrastructure. It is not a roof pad. It is a vertical automated node that moves modules, aircraft, energy, and data. Its launcher/catcher system reduces critical deck occupancy and supports rapid corridor entry. Its AI manages local safety and communicates with the central corridor web.

The AI-generated dynamic 3D corridor web is the enabling operating system. It converts many aircraft from a hazard into a coordinated flow. It responds to demand, weather, energy, Vertiport capacity, emergency states, and urban policy. It allows the system to be flexible rather than fixed and brittle.

The result is a new metropolitan mobility layer. It can expand the practical city, improve access to opportunity, connect suburbs and centers, support medical and cargo logistics, and create new industries in aircraft, modules, Vertiports, AI traffic management, hybrid powertrains, and low-carbon fuel infrastructure.

The final message is simple: air mobility becomes transformative only when it stops being a separate air-taxi product and becomes part of a modular, autonomous, AI-managed, three-dimensional public transport system. MetroAir Version 2.0 is the architecture for that transition.

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Appendix

A-1. Detailed System Requirements Catalogue

This catalogue converts the system vision into engineering requirements. It is included in the body of Version 2.0 because MetroAir is not merely proposing a design style; it is proposing a system architecture. Each requirement states what the system must do and why it is necessary for a safe, scalable, public three-dimensional transportation network. The catalogue should be treated as an initial requirements baseline that will later be converted into formal specifications, interface control documents, test procedures, and certification evidence.

Passenger module and interface

R-001. The passenger module shall have a certified mechanical interface that supports positive locking to both ground carriers and Multicruiser air transporters.

Without a certified common interface, modularity remains a concept rather than an operating system. The latch must indicate locked, unlocked, partial engagement, sensor disagreement, and emergency release states. The aircraft and Vertiport AI must not authorize movement unless the interface state is verified by redundant means.

R-002. The passenger module shall report payload mass, center of gravity, passenger count, restraint state, and door state before every transfer.

The air transporter cannot safely calculate control margin, energy reserve, or emergency landing options without accurate payload data. These values must be measured or verified automatically rather than entered manually, because a high-frequency system cannot rely on human paperwork at every launch.

R-003. The module shall provide mode-independent passenger protection, including lighting, communications, emergency instructions, and restraint confirmation.

A passenger remains in the same module while the carrier changes. The passenger interface must therefore remain stable during ground movement, Vertiport handling, air transport, capture, and recovery. Emergency communication must work in all modes.

R-004. The module electrical interface shall isolate high-voltage power, low-voltage service power, data, and emergency circuits.

Electrical faults should not propagate from a ground carrier to an air transporter or from an air transporter into the passenger module. Isolation protects passengers and allows a defective module or carrier to be removed without grounding the entire network.

R-005. The module shall be compatible with cleaning, inspection, and security processing while detached from both carriers.

Decoupling passenger service from aircraft turnaround is one of the main economic advantages of the system. If the cabin can only be cleaned or inspected while attached to an aircraft, the system loses its modular capacity benefit.

R-006. The module shall support accessible boarding and public-use variants, not only private premium variants.

A three-dimensional public transportation system must serve ordinary users, elderly passengers, wheelchair users, families, and public-service missions. The interface standard should allow multiple cabin designs without changing the air transporter.

R-007. The module shall include an emergency identification beacon and digital identity certificate.

After an emergency landing or degraded-state recovery, rescue teams and the traffic AI must know which module is involved, what passengers or cargo it contains, and what hazards are present. Digital identity is also essential for cybersecurity and maintenance tracking.

R-008. The module shall support safe storage and queuing inside a hub Vertiport without occupying aircraft handling capacity.

Passenger modules are inventory in the mobility network. They may wait, be cleaned, be assigned, or be transferred. They must therefore be compatible with racks, elevators, and safe waiting positions.

R-009. The module shall support multiple ownership models, including private ownership, public shared modules, and special-purpose service modules.

The architecture should not depend on one market model. Public service, private comfort, medical logistics, and cargo can all share the same air-transporter and Vertiport infrastructure if the module interface is standardized.

R-010. The module shall be designed for future energy sharing but shall not require module battery contribution for basic flight safety.

Energy exchange may improve efficiency, but the aircraft safety case should not depend on an unverified passenger module battery. Module energy should be supplementary unless certified as part of the aircraft power system.

Multicruiser air transporter

R-011. The Multicruiser shall be optimized as an air transporter for modules rather than as an integrated cabin aircraft.

This requirement preserves the main difference from conventional air taxis. The aircraft should prioritize docking, modular payload handling, Vertiport processing, protected propulsion, AI operation, and fleet utilization rather than cabin styling.

R-012. The propulsion system shall be shielded or integrated so that exposed propellers do not dominate the public visual impression.

Public acceptance is affected by perceived physical threat. A Rimfoil or comparable protected propulsion geometry reduces the visual hazard and provides a surface for aerodynamic, structural, and mechanical handling functions.

R-013. The vehicle shall maintain low-speed maneuverability suitable for precise approach, catcher alignment, and obstacle separation.

Urban operation requires precise control near Vertiports, emergency sites, and complex wind fields. The ability to maneuver at low speed is as important as cruise efficiency.

R-014. The vehicle shall use wing, Rimfoil, or other aerodynamic lift contribution during forward flight to reduce cruise power.

Pure Multicopter cruise is inefficient for metropolitan routes. The aircraft must exploit aerodynamic lift so that the air-transport layer can cover useful regional distances.

R-015. The airframe shall provide mechanical holding points for automated capture, storage, and maintenance.

A high-frequency Vertiport cannot handle aircraft manually. The vehicle must be designed for machines to hold, move, inspect, and store it. This should be a primary airframe design input.

R-016. The vehicle shall support autonomous flight with deterministic safety monitors independent of optimization AI.

AI can optimize routes and manage traffic, but final safety constraints must be verifiable. The aircraft should reject any AI command that violates certified limits.

R-017. The vehicle shall be able to reposition without a passenger module at reduced energy consumption.

This is a key advantage over integrated cabin air taxis. Lighter repositioning supports fleet balancing, maintenance movement, and recovery after demand peaks.

R-018. The vehicle shall support hybrid-electric power integration without compromising distributed electric propulsion benefits.

The motors can remain electric while the energy source includes batteries and a turbogenerator. The architecture should preserve controllability and redundancy.

R-019. The vehicle shall continuously report health, energy, payload, and mission status to the traffic AI and local Vertiport AI.

The corridor web and Vertiport scheduler require accurate state data. Silence or inconsistent state should trigger conservative behavior.

R-020. The vehicle shall include emergency landing logic that is valid with and without a passenger module attached.

A transporter may fail while empty, while carrying a public module, or while carrying a special-purpose module. The emergency behavior must account for each mass and configuration state.

Hub Vertiport and automated handling

R-021. The hub Vertiport shall be designed as an automated module-processing node rather than as a passive landing pad.

The economic value of the Vertiport is in passenger flow, module flow, aircraft flow, and energy flow. A passive pad cannot create public-transport throughput.

R-022. The top deck shall minimize occupancy time by transferring captured aircraft quickly to internal handling systems.

Deck occupancy is a scarce resource. The catcher should remove arrivals from the landing interface rapidly so that the next vehicle can be processed.

R-023. The launcher shall accelerate aircraft into a safe corridor entry profile within passenger comfort and structural limits.

The purpose of launch assistance is to reduce hover time and move the aircraft into controlled airspace. Acceleration limits must be defined for passenger comfort and module safety.

R-024. The catcher shall support precision recovery under wind, sensor error, and degraded-state envelopes.

A capture system that works only under ideal conditions cannot support public operations. Test cases must include gusts, optical errors, and system faults.

R-025. The Vertiport shall include redundant module movement paths or degraded-mode procedures.

A single elevator fault should reduce capacity rather than stop the entire node. Resilience must be designed into mechanical flows.

R-026. The Vertiport AI shall maintain a real-time local state model including queues, energy, wind, module inventory, aircraft state, and emergency capacity.

Local decisions must be based on local truth. The central AI cannot safely optimize the network if Vertiports report only coarse availability.

R-027. The Vertiport shall separate passenger areas from energy service, maintenance, and emergency isolation zones.

Hybrid energy and battery systems require fire and fuel safety. Passenger convenience cannot override physical separation requirements.

R-028. The Vertiport shall connect to walking, rail, bus, and autonomous ground-carrier access without creating street-level congestion.

A flying system can fail at the curb. Access design must be integrated with urban transportation planning.

R-029. The Vertiport shall include secure data interfaces for modules, air transporters, ground carriers, and traffic management services.

Cybersecurity is part of physical safety because incorrect state information can lead to unsafe dispatch or route allocation.

R-030. The Vertiport shall maintain emergency holding and evacuation procedures for modules in all internal positions.

Passengers may be in modules during transfer, queueing, or disruption. Emergency procedures must cover the entire building, not only the top deck.

AI corridor web and traffic management

R-031. The central traffic AI shall generate dynamic corridors based on demand, weather, Vertiport capacity, energy state, and emergency constraints.

Fixed routes can support initial operations but cannot optimize a dense metropolitan system. Dynamic corridors are required for public-scale service.

R-032. The corridor web shall include keep-out, keep-high, and noise-sensitive policy zones defined by the city.

Urban air mobility must respect civic constraints. The city is not an empty obstacle map; it contains social, legal, and environmental priorities.

R-033. The traffic system shall preserve certified separation minima even when optimization objectives conflict with safety limits.

Efficiency must never override separation. Deterministic monitors should enforce this rule.

R-034. Every Multicruiser shall share intent information sufficient for cooperative deconfliction.

Position alone is not enough. The system must know near-term trajectory, destination, energy state, emergency status, and planned Vertiport slot.

R-035. The traffic AI shall support emergency priority corridors that can temporarily reconfigure local flow.

Emergency landing or medical priority operations must be able to obtain safe passage without improvising through normal traffic.

R-036. The system shall operate in degraded communication modes with local edge safety preserved.

Loss of network connectivity must not produce loss of safety. Aircraft should continue, hold, divert, or land according to pre-certified lost-link procedures.

R-037. The AI system shall log all safety-relevant decisions and state transitions for audit and continuous improvement.

Aviation certification and public trust require traceability. Black-box operation is unacceptable for public transportation.

R-038. The central AI shall coordinate with ground autonomous fleet management so that air and ground capacity remain balanced.

A passenger module arriving by air is useful only if a ground carrier or local transit connection is available. The two layers must be optimized together.

R-039. The corridor web shall be tested in simulation before any city deployment using realistic demand and weather distributions.

A live city is not the place to discover network instability. Simulation is part of the safety case.

R-040. The AI architecture shall use role separation between optimization AI, safety monitors, and human supervisory interfaces.

This division makes certification more credible and prevents a single opaque model from controlling all risk.

Energy, maintenance, and environmental performance

R-041. The hybrid powertrain shall preserve sufficient battery reserve for emergency landing after generator failure.

The generator extends range but cannot be a single point of failure. Battery reserve is the emergency safety buffer.

R-042. Battery thermal state shall be included in dispatch decisions.

A battery that is charged but thermally stressed may not be suitable for immediate high-power lift. Energy management must consider health, not only SOC.

R-043. The turbogenerator operating mode shall be scheduled to minimize noise and emissions near sensitive areas.

Hybrid operation should not solve range by creating unacceptable local environmental impact. Route planning and power management must work together.

R-044. Fueling and charging shall be integrated into the Vertiport digital twin.

Energy service is a throughput constraint. It must be modeled alongside passenger and aircraft movement.

R-045. Maintenance data shall be collected from every docking, launch, capture, and flight cycle.

The high-cycle nature of public transport makes predictive maintenance essential. The system should learn from repeated mechanical events.

R-046. The system shall support low-carbon fuel transition without redesigning the entire aircraft architecture.

A staged energy roadmap requires compatibility with SAF, synthetic fuels, hydrogen-related systems, or future carriers as they mature.

R-047. Noise exposure shall be modeled cumulatively across routes and time of day.

Public acceptance is affected by repeated exposure. The AI corridor web should treat acoustic burden as a planning variable.

R-048. Energy efficiency shall be evaluated at fleet level, including empty repositioning, not only per passenger trip.

The passenger-module model creates unique efficiency advantages when air transporters reposition without modules. The metric must capture this.

R-049. The system shall include procedures for isolating a module, aircraft, or ground carrier with suspected battery or fuel hazards.

A single hazardous component must not contaminate the entire node. Isolation protects capacity and safety.

R-050. Environmental reporting shall include energy use, emissions, noise, and avoided ground congestion metrics.

Public infrastructure requires public accountability. Benefits and impacts should be measured transparently.

A-2. Verification and Test Program

The following test program converts the requirements catalogue into evidence. The tests are not exhaustive, but they identify the categories of proof that MetroAir must obtain before public passenger operation. The program begins with analysis and simulation, then component rigs, then scaled prototypes, then full-scale unmanned operations, then restricted passenger operations. Every test should produce data that can be reused in certification, insurance, public communication, and investor due diligence.

Aerodynamics and flight mechanics

T-001. Rimfoil lift and drag mapping

This test verifies a critical element of the aerodynamics and flight mechanics evidence chain. The test should define entry conditions, environmental conditions, success metrics, abort criteria, data to be recorded, and how the result changes the certified operating envelope. It should be repeated across nominal, degraded, and emergency states rather than demonstrated once under ideal conditions. The output should be a traceable test report connected to the requirements catalogue and the system safety assessment.

T-002. Rotor-Rimfoil interference under hover and forward flight

T-003. Gust response near urban building models

T-004. Transition from vertical lift to wing-assisted cruise

T-005. Low-speed precision maneuvering

T-006. Emergency descent envelope without vertical power settling

T-007. Noise map across thrust settings

T-008. Control authority under asymmetric rotor degradation

T-009. Payload CG sensitivity

T-010. Unmanned scaled prototype endurance test

Launcher and catcher

T-011. Launcher acceleration comfort test

This test verifies a critical element of the launcher and catcher evidence chain. The test should define entry conditions, environmental conditions, success metrics, abort criteria, data to be recorded, and how the result changes the certified operating envelope. It should be repeated across nominal, degraded, and emergency states rather than demonstrated once under ideal conditions. The output should be a traceable test report connected to the requirements catalogue and the system safety assessment.

T-012. Launcher structural load test

T-013. Catcher alignment tolerance test

T-014. Capture under crosswind

T-015. Capture after sensor degradation

T-016. Emergency abort before launch

T-017. Emergency release after capture

T-018. Rotating deck wind-alignment test

T-019. Repeated cycle mechanical fatigue test

T-020. Passenger module vibration during launch and capture

Passenger module interface

T-021. Latch positive-lock test

This test verifies a critical element of the passenger module interface evidence chain. The test should define entry conditions, environmental conditions, success metrics, abort criteria, data to be recorded, and how the result changes the certified operating envelope. It should be repeated across nominal, degraded, and emergency states rather than demonstrated once under ideal conditions. The output should be a traceable test report connected to the requirements catalogue and the system safety assessment.

T-022. Partial engagement detection

T-023. Electrical isolation test

T-024. Data authentication test

T-025. Door interlock test

T-026. Passenger restraint state test

T-027. Weight and CG sensing test

T-028. Emergency module release test

T-029. Fire isolation and smoke detection test

T-030. Accessible boarding and evacuation test

AI and traffic management

T-031. Single aircraft autonomous route following

This test verifies a critical element of the AI and traffic management evidence chain. The test should define entry conditions, environmental conditions, success metrics, abort criteria, data to be recorded, and how the result changes the certified operating envelope. It should be repeated across nominal, degraded, and emergency states rather than demonstrated once under ideal conditions. The output should be a traceable test report connected to the requirements catalogue and the system safety assessment.

T-032. Detect-and-avoid with cooperative traffic

T-033. Detect-and-avoid with non-cooperative drone

T-034. Lost-link procedure test

T-035. Dynamic corridor reallocation test

T-036. Vertiport closure reroute test

T-037. Swarm separation under demand surge

T-038. Edge AI emergency landing selection

T-039. Human supervisory override test

T-040. AI decision log audit test

Energy and maintenance

T-041. Battery peak power thermal test

T-042. Generator transient response test

T-043. Hybrid SOC management test

T-044. Generator failure with battery landing reserve

T-045. Fuel service turnaround test

T-046. Battery cool down scheduling test

T-047. Power electronics fault isolation

T-048. Predictive maintenance vibration correlation

T-049. Docking-cycle wear test

T-050. Fleet energy optimization simulation

Network and public operations

T-051. Morning peak simulation

This test verifies a critical element of the network and public operations evidence chain. The test should define entry conditions, environmental conditions, success metrics, abort criteria, data to be recorded, and how the result changes the certified operating envelope. It should be repeated across nominal, degraded, and emergency states rather than demonstrated once under ideal conditions. The output should be a traceable test report connected to the requirements catalogue and the system safety assessment.

T-052. Evening peak simulation

T-053. Special event surge simulation

T-054. Medical priority mission test

T-055. Cargo module mission test

T-056. Emergency site activation drill

T-057. Noise exposure simulation

T-058. Ground carrier dispatch coordination

T-059. Passenger delay recovery scenario

T-060. Regulatory demonstration package rehearsal

A-3. Research Evidence Integration Matrix

Version 2.0 integrates external research and industry developments into the system argument. The following evidence notes explain how categories of external work strengthen the original MetroAir logic. The notes are included in the main body because the purpose is not to list citations mechanically, but to connect each research trend to a design decision.

E-001. Powered-lift regulation

FAA powered-lift rules show that eVTOL and powered-lift aircraft are entering formal operating categories. This validates the need to design for certification rather than only for demonstration. For MetroAir, it means the Multicruiser must be framed within emerging powered-lift and autonomous-operation pathways. (1, 2)

E-002. Vertiport design guidance

FAA Vertiport guidance indicates that Vertiport geometry, safety areas, obstacle surfaces, and operational performance are becoming formal design issues. MetroAir extends this by proposing specialized automated Vertiports with launcher/catcher and module handling. (3)

E-003. BVLOS and UTM rulemaking

BVLOS and UTM developments support the idea that low-altitude airspace will depend on digital coordination, service suppliers, and performance-based requirements. This supports the AI corridor web concept. (4)

E-004. NASA AAM ecosystem work

NASA treats AAM as an ecosystem involving aircraft, airspace, infrastructure, and community acceptance. This reinforces the system-of-systems framing rather than a vehicle-only air-taxi view. (5)

E-005. Throughput research

NASA and academic throughput studies show that network performance depends on Vertiport capacity, vehicle availability, separation, weather, and energy cycles. This strengthens MetroAir's focus on automated processing and digital twin simulation. (6, 26, 27)

E-006. Noise research

NASA and UAM noise studies show that acoustic exposure, frequency, and urban reflections matter. MetroAir's elevated Vertiport, reduced hover time, and corridor planning are responses to this problem. (7, 39)

E-007. Public acceptance research

EASA and academic acceptance studies identify safety, noise, privacy, and trust as central concerns. This supports protected propulsion, public-service framing, and transparent emergency behavior. (8, 46, 47, 48)

E-008. AI certification roadmaps

EASA's AI roadmap shows that aviation AI must be treated through assurance, explainability, and progressive certification. MetroAir's layered AI architecture follows this discipline. (9)

E-009. Wisk autonomous AAM

Wisk's autonomous aircraft program demonstrates that pilotless AAM is not merely theoretical. It supports the argument that pilot-operated air taxis are transitional. (10, 11, 12)

E-010. Robotaxi operations

Waymo's service experience shows that autonomous driving can operate commercially within defined ODDs, while Cruise's retreat shows that autonomous mobility also needs a robust business model. MetroAir combines ground autonomy with air transport rather than treating each as a separate service. (23, 24)

E-011. PBV platforms

Kia and Toyota PBV developments show that vehicles are becoming modular service platforms. MetroAir converts this ground modularity into a passenger-module air transport system. (20, 21, 22)

E-012. VRS landing research

Recent eVTOL landing trajectory research supports the original claim that vertical descent should not be assumed as a simple urban landing solution. (25)

E-013. Battery stress research

ORNL and energy-storage reviews show that eVTOL batteries experience unique high-power demands. This supports the hybrid powertrain strategy. (15, 40)

E-014. Hybrid-electric propulsion

GE-BETA and Rolls-Royce hybrid-electric work shows industrial movement toward turbogenerator range-extension. MetroAir applies this to a modular air transporter. (16, 17)

E-015. Ammonia/hydrogen transition

Industrial ammonia cracking and gas-turbine emissions research support a cautious long-term fuel roadmap. MetroAir should frame ammonia as a future carrier possibility, not an immediate aircraft solution. (18, 19)

E-016. UAV swarm AI

Graph-based MARL and edge-AI swarm research provide technical support for multi-aircraft coordination, though certification will require deterministic safety layers. (28, 29, 30)

E-017. Autonomous modular transit

AMPT and MAV research show that modular pods can improve flexible public transit. MetroAir extends that logic into the air layer. (31, 32)

E-018. Airbus Pop Up precedent

Airbus/Italdesign Pop Up introduced a modular flying-car inspiration, but MetroAir differs by emphasizing public fleet air transporters and Vertiport systems rather than personal flying cars. (33)

E-019. ATM concepts for UAM

EmbraerX and related ATM concepts show that AAM requires future traffic-management architectures. MetroAir's dynamic corridor web is a vehicle-infrastructure implementation of the same broad need. (34)

E-020. K-UAM demonstrations

K-UAM Grand Challenge activities show that Korea is building operational experience in traffic management, communications, and Vertiport integration. MetroAir can position itself within this national direction. (35, 36)

A-4. Detailed Subsystem Architecture

A seamless 3D transport system requires subsystem interfaces that can be engineered, procured, tested, and certified independently before they are integrated. The following subsystem architecture translates the MetroAir vision into practical engineering domains. Each subsystem must have its own specification, but every specification must be compatible with the system-level safety case.

A-4.1 Aircraft structure and Rimfoil system

The Rimfoil is an aerodynamic and mechanical feature at the same time. It must protect the rotor, contribute to lift, maintain structural stiffness, provide mechanical holding geometry, and avoid excessive drag in forward flight. Its design should be studied with coupled CFD and structural analysis because local rotor flow, wing lift, and handling loads interact. The Rimfoil is also part of the public-facing visual identity of the aircraft. A protected and integrated form helps reduce the sense that rotating machinery is flying close to people.

The subsystem specification should include normal operating modes, degraded modes, maintenance procedures, required sensor data, cybersecurity assumptions, interface dependencies, and verification evidence. A subsystem that cannot clearly state its dependencies will create hidden integration risk. MetroAir should therefore develop interface control documents in parallel with prototype hardware, not after it.

A-4.2 Rotor and propulsion integration

Distributed propulsion gives redundancy and low-speed control, but it also creates acoustic, thermal, and maintenance complexity. Rotor speed scheduling should be coordinated with flight mode, noise limits, and battery/generator state. The system should define safe performance under one-motor degradation, partial power loss, and sensor disagreement. Propulsion integration must support both precision approach and efficient cruise.

A-4.3 Flight control computers and mission computers

The aircraft needs a separation between low-level flight stabilization, mission planning, detect-and-avoid, and network communication. Low-level control must remain deterministic and certifiable. Mission optimization can be more adaptive but must be bounded by certified envelopes. The computer architecture should allow safe software updates without changing certified safety kernels unexpectedly.

A-4.4 Passenger module mechanical latch

The latch is one of the most important physical interfaces. It must support aircraft loads, ground loads, vibration, launch acceleration, capture loads, and emergency release. The latch should be redundant and inspectable. A module should not be considered flight-ready until the latch state is verified by independent sensors and the control system confirms that the module is authorized for the assigned aircraft and mission.

A-4.5 Passenger module cabin systems

The cabin should be independent enough to preserve passenger comfort across ground, Vertiport, and air modes. HVAC, lighting, communication, monitoring, and emergency instructions should not reset during mode transition. The passenger should experience continuity, while the system handles complex vehicle changes invisibly. Cabin safety must include fire detection, restraint monitoring, and emergency communication.

A-4.6 Ground autonomous carrier

The ground carrier can be simpler than a private car because the passenger module provides the cabin. It can be optimized for docking accuracy, low-speed urban movement, fleet charging, and module handling. Its autonomy can begin in restricted ODDs such as Vertiport access roads, campuses, and controlled districts, then expand as validation accumulates.

A-4.7 Vertiport mechanical handling system

The handling system includes elevators, racks, docking stations, aircraft holders, module movers, inspection bays, and isolation bays. It should be designed like a high-reliability automated logistics system. Mechanical queues must have bypasses and degraded modes so that one failed component does not stop the node. Maintenance access must be designed from the beginning.

A-4.8 Launcher and catcher mechanisms

The launcher and catcher are not optional accessories. They are throughput and safety devices. The launcher helps the aircraft enter a controlled corridor quickly; the catcher removes arrivals from the deck quickly. Both mechanisms must be validated under repeated cycles, wind, misalignment, sensor errors, and emergency aborts. Passenger comfort limits must be defined experimentally.

A-4.9 Energy service infrastructure

Energy service must support batteries, turbogenerator fuel, thermal conditioning, safety isolation, and future low-carbon fuels. The Vertiport should treat energy as a flow with queues and constraints. Energy service bays should be physically separated from passenger areas and integrated into the digital twin. The system must know whether a vehicle is energy-ready, not merely parked.

A-4.10 Communications and navigation

The network must support high-integrity positioning, vehicle-to-infrastructure communication, vehicle-to-vehicle intent sharing, Vertiport state messages, lost-link procedures, and cybersecurity. Navigation should not depend on one source. GNSS, inertial, visual, radar, LIDAR, and infrastructure-based aids can be combined depending on cost and certification.

A-4.11 Central traffic AI

The central traffic AI plans corridors and capacity across the metropolitan region. It should not directly fly the aircraft moment by moment. Its role is strategic and tactical flow management: demand prediction, slot allocation, corridor generation, fleet balancing, and emergency reallocation. Safety constraints must be enforced by separate monitors.

A-4.12 Human supervisory operations center

Even a highly autonomous system needs human oversight. The operations center monitors fleet health, exceptional events, weather, cybersecurity alerts, public-service priorities, and regulatory reporting. The human role should be designed around supervisory control rather than continuous manual piloting. Training should focus on system state interpretation and exception management.

A-5. Operating Economics and Cost Drivers

The economic argument for MetroAir depends on moving beyond the premium air-taxi business model. The system must reduce cost through automation, standardization, high utilization, passenger-module decoupling, and fleet-level energy optimization. The following cost drivers should be modeled explicitly before major infrastructure investment.

A-5.1 Aircraft utilization

The air transporter should be used as many hours per day as maintenance and energy constraints allow. Passenger modules can queue independently, so aircraft should not wait for cleaning, passenger boarding, or cabin reset longer than necessary. Utilization is the first major cost lever.

A-5.2 Pilot removal pathway

Pilot-operated aircraft may be needed early, but the long-term public model requires autonomous operation. Removing the pilot improves seat efficiency, reduces labor cost, and enables higher frequency. However, autonomy shifts cost into certification, software assurance, remote supervision, and cybersecurity.

A-5.3 Module turnover

Passenger modules allow boarding, cleaning, security, and inspection to occur away from the aircraft. This can increase aircraft utilization and reduce top-deck occupancy. The module pool must be sized carefully: too few modules delay passengers; too many modules raise capital and storage cost.

A-5.4 Energy cost and cycle life

Battery-only economics are sensitive to battery degradation. Hybrid operation can reduce deep cycling, but it introduces fuel, generator maintenance, and emissions compliance. The economic model should compare total energy cost per passenger-kilometer, not only electricity price.

A-5.5 Vertiport capital cost

A hub Vertiport is expensive infrastructure. The cost is justified only if it processes enough modules and aircraft to act as public transport. The digital twin should estimate payback under realistic demand, downtime, and degraded capacity.

A-5.6 Maintenance labor and automation

High-frequency aircraft and module cycles require efficient inspection. Automated inspection, sensor diagnostics, and predictive maintenance reduce labor but require investment in data infrastructure and qualified maintenance procedures.

A-5.7 Fleet size and reserve vehicles

A reliable public system needs reserve vehicles. Too small a fleet collapses under failures; too large a fleet wastes capital. Simulation must determine optimal reserve ratios under weather and maintenance conditions.

A-5.8 Insurance and safety evidence

Insurance cost will depend on certified safety, operational data, emergency planning, and public acceptance. A system with clear emergency sites, data logs, and deterministic safety monitors should be more insurable than an opaque vehicle service.

A-5.9 Public service obligations

If the system receives public rights-of-way or Vertiport concessions, it may need service obligations, accessibility requirements, emergency availability, and fare controls. These obligations should be included in economic modeling.

A-5.10 Non-passenger revenue

Cargo, medical logistics, inspection, emergency transport, module leasing, Vertiport services, and AI traffic management can support the system before mass passenger volume arrives. These revenue streams should be planned rather than treated as afterthoughts.

A-5.11 Manufacturing scale

Air transporters will not reach automobile volumes immediately, but common design, modular parts, and fleet procurement can still reduce cost. The airframe should avoid unnecessary customization between operators.

A-5.12 Standardized maintenance parts

Rimfoils, rotors, motors, power electronics, latches, sensors, and module fittings should be standardized across the fleet. Spare-parts commonality is essential for cost and uptime.

A-5.13 Depreciation and upgrade path

Modules, ground carriers, air transporters, and AI software may have different depreciation cycles. The architecture should allow software and module upgrades without replacing the aircraft fleet prematurely.

A-5.14 Station economics

Small suburban nodes may not support full maintenance and fueling. The network should define which nodes are hubs, satellites, emergency sites, and community stops. Each node type has different capital and operating costs.

A-5.15 Demand smoothing

Reservations allow demand smoothing and capacity planning. Incentives can shift some travel to off-peak periods. Autonomous repositioning can prepare the network before peak demand begins.

A-6. City Network Design and Land-Use Scenarios

A 3D transport network changes urban geography only if nodes are placed where people actually need mobility. Vertiports should not be isolated aviation islands. They should be integrated with rail stations, bus terminals, high-density employment centers, regional hospitals, universities, airports, industrial zones, and suburban communities.

A-6.1 Central hub strategy

The central hub should be located where demand is highest and where ground congestion makes air transfer valuable. It may be above or adjacent to major road or rail infrastructure. The hub must process many modules and aircraft, but also manage noise, safety, and public access.

A-6.2 Suburban hub strategy

Suburban hubs connect lower-density communities to the metropolitan core. They may be smaller, lower, and less complex than central hubs. Their main function is to collect passenger modules from ground carriers and send them through the air layer during peak periods.

A-6.3 Airport connection

Airport routes may provide early premium demand, but the system should not be limited to airport transfer. Airport nodes can validate luggage modules, security procedures, and schedule reliability, but public value requires broader metropolitan service.

A-6.4 Hospital and medical network

Hospitals create strong use cases for priority modules, emergency logistics, and time-sensitive passenger transport. Medical modules can support public acceptance because they demonstrate social value beyond convenience.

A-6.5 University and research districts

Campus environments can support early testing because land ownership and access control are more manageable. They also generate predictable travel between campuses, labs, housing, and transit nodes.

A-6.6 Industrial and logistics zones

Industrial users can validate cargo modules and time-sensitive transport. These routes may operate with fewer public acceptance constraints than residential corridors and can generate early revenue.

A-6.7 Community landing sites

Small community sites can extend access but should not carry the complexity of hub Vertiports. They may support emergency landing, module pickup, or low-frequency service. Their certification should be simpler but still digitally integrated.

A-6.8 Emergency site network

Emergency sites must be mapped before regular service begins. They should include structural capacity, obstacle data, rescue access, lighting, communications, and ground recovery plans.

A-6.9 Noise-sensitive zoning

Schools, hospitals, historic districts, and dense residential areas may require keep-high or avoid zones. Corridor planning must respect city policy and cumulative exposure limits.

A-6.10 Land-value effect

By reducing the penalty of distance, the system can increase the value of land outside the current core. Policy should manage this effect to prevent unequal benefits or uncontrolled sprawl.

A-6.11 Transit integration

A Vertiport connected to subway, rail, and bus systems can serve more users than one connected only to car access. The system should be designed as a transit extension, not a competing luxury service.

A-6.12 Curb and street management

Autonomous ground carriers require pickup, drop-off, and module exchange zones. Without curb management, a Vertiport can create ground congestion even if it reduces regional travel time.

A-6.13 Weather geography

Different parts of a city may have different wind and microclimate patterns. Network design should account for seasonal wind, coastal fog, heat, and rooftop turbulence.

A-6.14 Equity planning

Public investment should require service to underserved communities, not only wealthy corridors. Passenger-module public service variants can help align the network with mobility equality.

A-6.15 Scalable node classes

The network should define node classes: main hub, satellite hub, community node, emergency site, maintenance base, and energy station. Each class should have different requirements and cost.

A-7. Human Factors and Public Service Design

A seamless transport system succeeds only if people understand it and trust it. The passenger should not be asked to manage the complexity of docking, flight corridors, energy state, or vehicle assignment. The passenger should experience the system as a clear and predictable journey.

A-7.1 Reservation interface

The reservation interface should explain time, price, module type, accessibility, baggage, and contingency options. It should not expose technical complexity unless the passenger requests details.

This human-factor requirement should be tested with mockups, passenger trials, simulation, and public engagement. Public acceptance is not obtained by telling people the system is safe. It is obtained by designing experiences that make safety visible, understandable, and reliable.

A-7.2 Boarding psychology

Passengers may feel anxiety when a module is lifted or attached to an aircraft. Cabin displays, lighting, sound design, and clear countdowns can reduce uncertainty. The system should communicate what is happening in simple terms.

A-7.3 Transfer without transfer

The main human-factor benefit is that the passenger does not leave the module. This reduces stress, protects luggage, supports accessibility, and makes air-ground mode change feel like an elevator ride rather than an airport process.

A-7.4 Accessibility

Modules should support wheelchair access, visual and auditory information, assistance calls, and safe boarding for elderly passengers. Accessibility should be part of the module standard, not a special afterthought.

A-7.5 Emergency communication

In an emergency, passengers need clear instructions from the module, not technical messages from the aircraft. The module should explain whether the journey is continuing, holding, diverting, or landing.

A-7.6 Motion comfort

Launcher acceleration, climb, turn, capture, and ground movement should remain within comfort envelopes. Technical throughput cannot be achieved by imposing unacceptable motion on passengers.

A-7.7 Privacy and security

The passenger module creates a private cabin but also generates data. The system should define what data is collected, who can access it, and how it is protected. Trust requires transparency.

A-7.8 Public module etiquette

Shared modules require rules for cleanliness, noise, seating, baggage, pets, and safety. These rules should be designed like public transit, not like private aviation.

A-7.9 Baggage and cargo

Baggage must remain secured through ground movement, lift, launch, cruise, capture, and ground delivery. Cargo modules may share standards with passenger modules but require different handling rules.

A-7.10 Service disruption

If a flight is delayed, the passenger should be offered ground continuation, alternate Vertiport, later air slot, or cancellation. Seamless service includes graceful failure.

A-7.11 Trust through visibility

Passengers may trust the system more if they can see high-level status: module verified, aircraft assigned, route cleared, weather checked, destination slot confirmed. These signals should be understandable.

A-7.12 Public affordability

The service cannot be framed only as a premium experience. Public modules, fare integration, and transit connections help make the system socially legitimate.

A-8. Governance, Data, and Cybersecurity

The MetroAir system is a cyber-physical public transportation network. Its safety depends on data integrity, communication reliability, identity management, and governance. The system must therefore be designed with cybersecurity and data policy as core requirements.

A-8.1 Operating authority

A public or concession-based authority should define who can operate air transporters, Vertiports, modules, and ground carriers. Fragmented private operation without common safety standards would undermine the system.

This governance item should be included in the system safety plan because organizational failure can become technical failure. A safe aircraft cannot compensate for unclear authority, weak cybersecurity, or unmanaged data dependencies.

A-8.2 Data ownership

Passenger data, module data, aircraft health data, and traffic data have different privacy and safety values. The system should define ownership, access, retention, and anonymization rules.

A-8.3 Cybersecurity baseline

Every module, aircraft, Vertiport, and ground carrier should authenticate itself before exchanging commands. Spoofed modules or false Vertiport slots could create physical risk.

A-8.4 Software update governance

AI and control software updates must pass validation before deployment. Safety-critical updates should not be pushed like consumer-app updates. Version control and rollback capability are required.

A-8.5 Incident reporting

The system should automatically log and report safety-relevant events. Regulators and operators need standardized categories for anomalies, degraded states, emergency landings, and cybersecurity events.

A-8.6 Third-party service providers

UTM, communications, weather, maintenance analytics, and module services may involve third parties. Contracts must define safety responsibilities and data-sharing obligations.

A-8.7 Public transparency

Cities and citizens should receive information about noise exposure, emergency planning, service reliability, and environmental performance. Transparency strengthens legitimacy.

A-8.8 Liability allocation

In a modular system, an incident may involve module manufacturer, ground carrier operator, air transporter operator, Vertiport operator, AI service provider, or maintenance provider. Liability must be allocated before service.

A-8.9 International standards

If MetroAir aims for global deployment, module and air-transporter standards should align with international aviation, automotive, cybersecurity, and accessibility standards where possible.

A-8.10 Ethical AI

AI scheduling may prioritize emergency services, disabled passengers, public routes, or paying premium users. These priority rules are ethical and policy decisions, not only software parameters.

A-8.11 Security of emergency sites

Emergency landing sites must be protected from obstruction, misuse, or false status reporting. Their digital availability must match physical availability.

A-8.12 Resilience against misinformation

Public perception can be damaged by misinformation after an incident. The system should maintain accurate logs and communication protocols that allow timely, factual explanation.

A-9. Standard Operating Procedures for Pilot Deployment

Pilot deployment should begin with standard operating procedures that are narrower than the final vision. A restricted pilot allows MetroAir to validate the system while protecting public safety and public trust. The procedures below should be understood as a starting framework for a controlled demonstration corridor, not as a finished operating manual.

A-9.1 Passenger-module preparation

Before a module is released into the operating pool, the system should verify cabin cleanliness, restraint operation, door locks, communication, lighting, emergency signage, fire detection, module identity, and maintenance status. The procedure should be automated where possible, but a human or remote supervisor should be able to remove a module from service. Module preparation should be logged as a state transition. The module should not be assigned to a passenger until all required checks have passed.

A-9.2 Ground carrier dispatch

A ground carrier should receive a dispatch only after its battery state, route authority, sensor status, docking equipment, and traffic permissions are verified. The carrier should approach the passenger module at a controlled speed and stop within the docking tolerance. If the module is occupied, the carrier should provide passenger notifications before movement begins. The ground segment should be monitored for delay because late ground arrival can disrupt air slots and Vertiport capacity.

A-9.3 Vertiport intake

When a ground carrier arrives at the Vertiport, the module should be authenticated and transferred to the Vertiport handling system. The intake procedure should check passenger identity or public ticket state, module condition, payload, prohibited hazards, destination authorization, and assigned air transporter. If the module fails a check, it should be routed to a holding or inspection area without blocking the main flow.

A-9.4 Aircraft assignment

The Vertiport AI should assign a Multicruiser based on payload compatibility, energy state, maintenance status, destination, weather, and network slot availability. Assignment should not be first-come-first-served when energy or emergency margins differ. The assignment

procedure should verify that the aircraft can complete the mission and reach at least one alternate landing option with required reserves.

A-9.5 Docking and prelaunch

Docking should include mechanical latch verification, electrical and data handshake, module weight confirmation, CG calculation, passenger restraint confirmation, door status confirmation, route clearance, weather clearance, and emergency site availability. A single failed critical check should stop launch. Non-critical warnings should be categorized and either cleared or accepted under defined operating rules.

A-9.6 Launcher operation

The launcher procedure should include deck clearance, wind alignment, aircraft power readiness, passenger notification, acceleration profile selection, abort window definition, and post-launch state confirmation. The launcher should not operate if the corridor slot is uncertain. After launch, the system should confirm that the aircraft has entered the planned corridor and that the launcher has returned to safe state.

A-9.7 Cruise and corridor monitoring

During cruise, the aircraft edge AI should maintain stability, separation, energy management, and detect-and-avoid. The central traffic AI should monitor corridor flow and update intent data. The passenger module should provide cabin status but should not burden the passenger with technical details. If conditions change, the system should explain delays or diversions in passenger language.

A-9.8 Destination capture

Before capture, the destination Vertiport should verify catcher availability, wind alignment, module handling capacity, ground carrier availability, and emergency backup. The aircraft should approach through a verified envelope. After capture, mechanical hold state should be confirmed before module transfer. If capture is aborted, the aircraft should follow a predefined go-around or alternate plan.

A-9.9 Module release and ground continuation

After landing, the passenger module should detach from the aircraft only after mechanical, electrical, and safety conditions are confirmed. The module should be transferred to a ground carrier or station platform. The passenger should receive clear notice that the air

segment is complete and the ground segment is beginning. If the destination ground carrier is unavailable, the module should be routed to a safe waiting position.

A-9.10 Post-mission data and maintenance

After each mission, the system should record flight time, energy use, generator behavior, battery thermal state, latch loads, capture loads, passenger-module state, route deviations, communication quality, and any warnings. The data should feed maintenance, digital twin calibration, AI performance monitoring, and regulatory reporting. Post-mission data is one of the main assets of the pilot program.

A-10. Risk Register and Mitigation Strategy

A formal risk register is required because MetroAir combines aircraft, autonomous vehicles, passenger modules, Vertiports, AI, and hybrid energy systems. The following register identifies representative risks and mitigation directions. It should be expanded into a quantified safety assessment during engineering development.

RISK-01. Public rejection due to noise or visual threat

Mitigate through protected propulsion, route planning, elevated nodes, cumulative noise modeling, public engagement, and public-service use cases. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence. Risks that cannot be assigned to an owner tend to reappear as integration failures during demonstration.

RISK-02. Battery degradation reduces fleet availability

Mitigate through hybrid powertrain, thermal monitoring, battery health dispatch rules, and scheduled replacement. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-03. Generator failure during flight

Mitigate through battery reserve, emergency landing logic, generator health monitoring, and route selection with alternates. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-04. Passenger module latch misread

Mitigate through redundant sensors, mechanical indicators, independent verification, and no-launch logic under disagreement.

RISK-05. Vertiport elevator failure

Mitigate through redundant movement paths, degraded capacity procedures, module holding zones, and central AI capacity update. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence. Risks that cannot be assigned to an owner tend to reappear as integration failures during demonstration.

RISK-06. Catcher misalignment

Mitigate through wind sensing, precision approach aids, go-around procedures, tolerance testing, and backup capture states. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-07. Cyberattack on module identity

Mitigate through cryptographic authentication, anomaly detection, certificate revocation, and safe isolation of suspect modules. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-08. AI route optimization violates policy zone

Mitigate through deterministic geofence monitors that reject routes through keep-out or keep-high zones. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-09. Ground carrier blocks street access

Mitigate through curb management, scheduled module exchange, off-street interfaces, and traffic coordination. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-10. Emergency site unavailable despite digital availability

Mitigate through periodic inspection, real-time site status, physical access control, and alternative site planning. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-11. Weather microburst or rooftop turbulence

Mitigate through local wind sensing, conservative envelopes, rotating deck alignment, and corridor suspension rules. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-12. Passenger panic during launch or capture

Mitigate through motion comfort limits, cabin communication, gradual pilot trials, and clear passenger displays. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-13. Module fire or smoke event

Mitigate through detection, isolation bays, emergency landing priority, standardized rescue access, and fire-resistant materials. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-14. Fleet imbalance after demand surge

Mitigate through reservation management, night repositioning, demand incentives, and AI fleet balancing. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-15. Noise burden concentrated over one community

Mitigate through corridor rotation, exposure limits, public reporting, and policy constraints in AI planning. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-16. Maintenance data overload without actionable analytics

Mitigate through predictive-maintenance models, thresholds, and clear maintenance workflows. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-17. Regulatory delay for autonomous passenger flight

Mitigate through staged unmanned testing, cargo use cases, remote supervision, and early regulator engagement. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-18. Insufficient Vertiport throughput

Mitigate through digital twin simulation, launcher/catcher validation, module decoupling, and redesign before construction. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-19. Ammonia or hydrogen roadmap overpromising

Mitigate by treating these as long-term options while validating near-term SAF or conventional fuel hybrid systems. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-20. Fragmented supplier ecosystem

Mitigate through interface control documents, standardization, certification requirements, and supplier qualification. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-21. Public perception of elitism

Mitigate through public modules, transit integration, medical/cargo public-benefit use cases, and accessible fare policy. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-22. AI model drift after deployment

Mitigate through monitoring, validation gates, frozen safety kernels, and controlled update pipelines. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-23. Loss of communications in dense urban canyon

Mitigate through edge AI, inertial/visual navigation, lost-link procedures, and redundant networks. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-24. Inaccurate payload data

Mitigate through automated weighing, restraint sensors, CG calculation, and no-launch if data conflicts. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-25. Overcomplex passenger experience

Mitigate through simple interfaces, clear cabin status, seamless module continuity, and human support channels. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-26. Ground and air schedules desynchronize

Mitigate through integrated reservation, real-time slot management, and ground carrier dispatch tied to air capacity. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-27. Vertiport fire or fuel incident

Mitigate through separated energy zones, isolation, sensors, suppression, and emergency evacuation procedures. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-28. Economic underutilization of infrastructure

Mitigate through phased deployment, cargo/medical revenue, public-private partnership, and demand modeling. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-29. Unclear liability after modular incident

Mitigate through governance agreements assigning responsibility across module, carrier, aircraft, Vertiport, AI, and maintenance. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

RISK-30. Mismatch between aircraft certification and road-vehicle regulations

Mitigate through dual-mode module certification strategy and early engagement with aviation and automotive regulators. The risk owner should be identified before the pilot program begins, and the mitigation should be tied to measurable evidence.

A-11. Phase-by-Phase Implementation Plan

The implementation plan organizes development into phases that progressively increase complexity. Each phase has a defined purpose, success criteria, and evidence output. The plan deliberately avoids jumping directly to a citywide passenger service.

A-11.1 Phase 1: Analytical architecture

Define the system architecture, module interface, air-transporter requirements, Vertiport concept, AI roles, hybrid powertrain assumptions, and safety philosophy. Success means that the system can be described by requirements, interfaces, and preliminary hazard analysis rather than only by renderings.

The phase should end with a formal review gate. The gate should review safety evidence, technical performance, public acceptance, cost, regulatory readiness, and whether the next phase changes the hazard profile. The purpose of phasing is not to slow development; it is to prevent hidden complexity from accumulating until it becomes unmanageable.

A-11.2 Phase 2: Rimfoil and flight physics validation

Run CFD, wind-tunnel, and scaled rotor tests to validate the Rimfoil and propulsion interaction. Success means that the airframe concept has credible aerodynamic data, noise estimates, and control-envelope assumptions.

A-11.3 Phase 3: Module interface prototype

Build non-flying mechanical prototypes of the module, latch, ground carrier interface, and aircraft interface. Success means that docking, release, data handshake, and safety interlocks can be demonstrated repeatedly.

A-11.4 Phase 4: Vertiport handling rig

Build a ground rig for module movement, aircraft holding, launcher/catcher mockups, and degraded-flow scenarios. Success means that mechanical flow and failure response are understood before flight hardware is risked.

A-11.5 Phase 5: Unmanned scaled flight

Fly scaled Multicruiser prototypes without passenger modules to validate control laws, protected propulsion behavior, and precision approach. Success means stable autonomous flight and safe degraded-mode handling.

A-11.6 Phase 6: Unmanned module carriage

Carry instrumented dummy modules between controlled points. Success means that payload data, CG behavior, latch loads, and energy use are validated in flight.

A-11.7 Phase 7: Hybrid powertrain demonstrator

Test the battery-turbogenerator architecture on a ground rig and then on an unmanned flight demonstrator. Success means reliable power transitions, SOC management, thermal behavior, and emergency reserve logic.

A-11.8 Phase 8: AI corridor and digital twin integration

Connect vehicles, Vertiport model, ground carriers, and simulated demand in a digital twin. Success means that the system can schedule, re-route, degrade, and recover under simulated peak and fault scenarios.

A-11.9 Phase 9: Restricted-area end-to-end demonstration

Operate a closed or semi-controlled corridor with unmanned modules, ground carriers, launcher/catcher, and AI traffic management. Success means repeatable end-to-end service under defined limits.

A-11.10 Phase 10: Limited passenger trial

Carry invited passengers under restricted conditions with strong supervision and public reporting. Success means passenger acceptance, safety performance, and operational reliability sufficient to justify a broader public pilot.

A-11.11 Phase 11: Public pilot network

Deploy a small network of hubs and satellite nodes for public service, with defined operating hours, weather limits, and emergency sites. Success means sustained service reliability and transparent safety data.

A-11.12 Phase 12: Metropolitan expansion

Expand node classes, module variants, public fare integration, and low-carbon fuel transition. Success means the system begins to function as a metropolitan mobility layer rather than a demonstration corridor.

A-12. System Metrics and Key Performance Indicators

A public 3D transport system must be evaluated with metrics that connect aircraft performance, passenger experience, public acceptance, energy, safety, and network capacity. Aircraft range alone is not a sufficient measure. The following KPIs should be monitored during simulation, pilot operation, and public deployment.

KPI-01. Passenger door-to-door time

Measures the complete journey from requested origin to final destination, including ground carrier access, module processing, air travel, capture, and final ground segment. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses. A KPI that cannot be traced to an operational decision is useful for reporting but not for system improvement.

KPI-02. Module transfer time

Measures the time between ground-carrier arrival and air-transporter launch, or between aircraft capture and ground-carrier departure. This is a core seamlessness metric. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses

KPI-03. Top-deck occupancy time

Measures how long the launcher/catcher interface is occupied by each operation. Low top-deck occupancy is essential for high throughput. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-04. Aircraft utilization hours

Measures productive air-transporter hours per day, excluding maintenance, energy service, and waiting for modules. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-05. Passenger module utilization

Measures how many passenger trips each module serves per day and how long modules wait in queues or cleaning cycles. The metric should be tracked by city, node, time of day,

weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-06. Ground carrier utilization

Measures whether autonomous ground carriers are balanced across origins and destinations or stranded in low-demand areas. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-07. Energy per passenger-kilometer

Measures total energy used across ground and air layers, including empty repositioning and Vertiport energy consumption. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-08. Battery thermal margin

Measures how often batteries operate near thermal limits and whether dispatch decisions protect battery lifetime. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-09. Generator fuel efficiency

Measures hybrid turbogenerator energy conversion under cruise, climb, reserve, and repositioning missions. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-10. Reserve energy compliance

Measures whether every mission maintains required reserves for alternate landing and emergency behavior. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-11. Noise exposure per community

Measures cumulative exposure over neighborhoods, not only single-event aircraft noise. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-12. Public complaint rate

Measures social acceptance signals and should be interpreted with route, time, weather, and service-benefit context. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-13. Emergency site reachability

Measures the percentage of flight time during which each aircraft has at least one certified emergency site reachable with reserve. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-14. AI corridor stability

Measures whether dynamic corridor changes create unnecessary oscillation, delay, or complexity. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-15. Conflict-resolution latency

Measures how quickly the system detects and resolves predicted trajectory conflicts. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-16. Lost-link recovery success

Measures safe behavior under communications degradation or interruption. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-17. Vertiport degraded-mode capacity

Measures how much service remains after loss of an elevator, catcher, docking line, energy bay, or communication channel. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-18. Maintenance findings per cycle

Measures component health and can identify high-wear parts before failures occur. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-19. Unscheduled removal rate

Measures how often modules, aircraft, or ground carriers are removed from service unexpectedly. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-20. Passenger comfort index

Combines acceleration, vibration, cabin noise, waiting time, and perceived clarity of information. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-21. Accessibility service rate

Measures availability and reliability for passengers requiring accessible modules or additional assistance. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-22. Public module availability

Measures whether the system offers non-premium public service capacity rather than only private modules. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-23. Fare integration success

Measures whether trips can be combined with rail, bus, or other public transport without friction. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-24. Cybersecurity anomaly rate

Measures suspicious authentication, data, communication, or command events across the network. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-25. Software update stability

Measures post-update incident rates and regression-test success for AI and control software. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-26. Weather cancellation rate

Measures how often wind, rain, visibility, heat, or turbulence limits service. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-27. Route equity index

Measures whether service benefits are distributed across income, geography, and mobility-need categories. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-28. Cargo and public-service utilization

Measures non-passenger missions that strengthen public value and economic resilience. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-29. Carbon intensity per passenger-kilometer

Measures emissions under current fuel mix and tracks transition toward low-carbon fuels. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-30. Infrastructure availability

Measures uptime of Vertiports, energy service, communications, and emergency sites. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-31. Digital twin prediction error

Compares predicted queues, delays, energy use, and capacity against actual operations. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-32. Module cleanliness turnaround

Measures whether cabin cleaning and inspection can keep pace with passenger demand. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-33. Security processing time

Measures whether safety and security checks create unacceptable delays. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-34. Customer trust score

Measures whether users understand, trust, and are willing to reuse the system. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

KPI-35. Regulatory evidence completeness

Measures whether operational data are sufficient for certification expansion and authority review. The metric should be tracked by city, node, time of day, weather state, module type, aircraft type, and service class so that average performance does not hide local weaknesses.

Core Terminology and Definitions

This terminology section is integrated into the main body so that the Version 2.0 system can be read without a separate appendix. The definitions clarify how MetroAir uses terms that are often used loosely in the AAM industry.

Synthetic Urban Air System

An integrated urban aviation architecture in which aircraft design, Vertiports, traffic management, energy service, passenger modules, and ground mobility are designed as one system.

Multicruiser

A MetroAir air transporter concept using protected propulsion, Rimfoil aerodynamic features, Multicopter maneuverability, wing-supported cruise, modular docking, and AI-enabled operation.

Air transporter

An aircraft whose primary role is to transport passenger modules or other modules rather than to act as an integrated passenger cabin.

Passenger module

A detachable mobility capsule that can connect to a ground carrier, a Vertiport handling system, and a Multicruiser air transporter.

Ground carrier

An autonomous or manually controlled ground vehicle platform that moves passenger modules on roads or within controlled access zones.

Hub Vertiport

A high-capacity urban node that processes modules, aircraft, passengers, energy, maintenance, launch, capture, and traffic data.

Satellite Vertiport

A smaller node that connects communities, suburbs, or specific institutions to the hub network.

Launcher

A takeoff-assist mechanism that helps the air transporter enter the planned corridor quickly and safely.

Catcher

A landing-assist mechanism that captures or holds the air transporter after precision approach and transfers it to internal handling.

Rimfoil

A protected rotor and aerodynamic boundary structure intended to reduce visual threat, contribute to lift, and support mechanical handling.

Dynamic 3D corridor web

A continuously updated set of air corridors generated by AI based on demand, weather, energy state, Vertiport capacity, policy zones, and emergencies.

Central traffic AI

The system intelligence that performs demand forecasting, corridor generation, fleet distribution, slot allocation, and network-level emergency management.

Vertiport AI

Local AI that controls launcher/catcher timing, docking queues, module handling, local wind alignment, energy service, and degraded-mode operation.

Aircraft edge AI

Onboard AI that handles perception, detect-and-avoid, precision approach, lost-link behavior, energy-aware routing, and emergency landing selection.

Module AI

Software embedded in or associated with a passenger module for identity, cabin monitoring, destination, maintenance status, and docking authorization.

Swarm flight

Coordinated operation of multiple aircraft sharing intent and responding to each other within a network safety framework.

Detect and avoid

The aircraft function that detects cooperative and non-cooperative hazards and maintains safe separation.

Vortex ring state

A rotorcraft aerodynamic condition that can occur in certain descent regimes and may cause loss of thrust or controllability.

Power settling

A related operational hazard in which rotorcraft descent and power state can produce insufficient climb or recovery margin.

Hybrid turbogenerator

A power system in which a turbine-driven generator supplies electrical power to an electric propulsion architecture and supports battery state management.

Series hybrid propulsion

A hybrid architecture in which the propulsion motors are electric and the generator produces electricity rather than mechanically driving rotors.

Battery SOC

State of charge; the amount of remaining electrical energy in the battery, which must be interpreted together with thermal and health state.

SAF

Sustainable aviation fuel that can reduce lifecycle carbon intensity relative to conventional aviation fuel depending on feedstock and production pathway.

Ammonia cracking

A process that converts ammonia into hydrogen and nitrogen, considered as a possible long-term hydrogen carrier pathway.

Keep-out zone

An area where flight is prohibited for safety, security, noise, privacy, or policy reasons.

Keep-high zone

An area where aircraft may pass only above specified altitude or operating conditions.

Emergency landing site

A designated and digitally integrated site that an aircraft can use if a Vertiport or route becomes unavailable.

Digital twin

A dynamic simulation and data model of the Vertiport, fleet, energy, passenger, and airspace system used for design and operations.

Operational design domain

The set of conditions under which an autonomous system is permitted to operate.

Degraded mode

A predefined operating state that preserves safety and partial service after a component, subsystem, or external condition reduces capability.

Interface control document

A formal document defining mechanical, electrical, data, safety, and procedural interfaces between subsystems.

Public module

A passenger module operated as shared public transport rather than as a private cabin.

Private module

A passenger module owned or reserved by an individual or organization and moved by shared ground and air transporters.

Service module

A module configured for cargo, medical, maintenance, emergency, or other specialized missions.

Fleet balancing

The process of repositioning aircraft, modules, and ground carriers so that supply matches future demand.

Turnaround time

The time required to prepare a vehicle or module for its next mission after arrival.

Top-deck occupancy

The period during which the launch/capture deck is occupied and unavailable for another operation.

Public acceptance

The willingness of communities, passengers, regulators, and cities to allow regular operation based on perceived safety, benefit, fairness, and nuisance.

Seamless transport

A mobility experience in which the passenger does not manually transfer between vehicles even though the module changes carrier layers.

3D metropolitan transport

A transportation network that uses ground and air layers together to expand the practical reach of a metropolitan region.

Module inventory

The active pool of passenger, cargo, medical, and service modules available at a node or across the network.

Aircraft rack

An automated storage and staging structure inside a Vertiport that holds air transporters before or after service.

Energy service bay

A protected Vertiport area where battery conditioning, charging, fueling, inspection, or generator service occurs.

Isolation bay

A safe holding area for a module, ground carrier, or aircraft with suspected fire, battery, security, or mechanical issues.

Slot allocation

The process of assigning a vehicle a launch, corridor, arrival, capture, and module-transfer time.

Mission authorization

The digital approval that confirms a module, aircraft, route, energy state, weather envelope, and destination slot are all valid.

Remote supervision

Human monitoring and exception management for autonomous fleets without continuous manual piloting of each aircraft.

Deterministic safety monitor

A verified safety layer that rejects commands or routes violating certified limits regardless of optimization output.

Learning component

An AI component whose performance is derived from data-driven training and therefore requires monitoring and validation against drift.

Safety kernel

A minimal, highly assured control or decision layer responsible for preserving essential safety constraints.

Module state vector

The set of digital data describing module identity, latch state, payload, passenger status, maintenance condition, and route authorization.

Aircraft state vector

The set of digital data describing aircraft position, velocity, energy, health, payload, intent, and emergency capability.

Vertiport state vector

The set of digital data describing local capacity, queues, wind, energy service, equipment health, and emergency availability.

Corridor state

The operational status of an air corridor, including capacity, weather, noise limits, policy restrictions, traffic density, and emergencies.

Mobility utility

A public-oriented operating model in which the system is managed as infrastructure rather than as isolated vehicle sales.

Public concession fleet

A fleet operated under public authorization or concession, with service, safety, accessibility, and reporting obligations.

Accessible module

A passenger module configured for wheelchair access, assisted boarding, inclusive information, and safe restraint for users with mobility needs.

Medical module

A module configured for medical transport, equipment, staff access, or priority logistics.

Cargo module

A module configured for goods movement using the same docking and transport infrastructure as passenger modules.

Module-class certification

A certification approach in which a family of modules is approved for defined carriers, routes, and operating limits.

Node class

A category of Vertiport or landing site such as central hub, suburban hub, community node, maintenance base, energy station, or emergency site.

Degraded capacity

The reduced but still safe operating capacity of a node or network after a component or condition limits normal operation.

Operational envelope

The certified range of environmental, payload, energy, software, and traffic conditions under which a system may operate.

Public-benefit mission

A mission such as medical transport, emergency logistics, public transit service, or disaster response that supports social acceptance.

Metropolitan access radius

The practical area that can be reached within a target travel time when ground and air layers are integrated.

Fleet reserve ratio

The proportion of extra aircraft, modules, and ground carriers required to maintain service during failures, maintenance, and demand peaks.

Continuous assurance

The ongoing process of collecting operational data and confirming that safety, AI performance, maintenance, and cybersecurity remain within limits.

Mode transition

The change from ground carrier to Vertiport handling, air transporter, or back to ground carrier while the passenger remains in the module.

Separation assurance

The combined technical and procedural means of maintaining safe distance between aircraft and other hazards.

Public trust envelope

The social operating limit created by noise, safety perception, fairness, transparency, and benefit distribution.

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From Sky to Street: Metro 3D Mobility for All

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