EXPLORING DETROIT METROPOLITAN WAYNE COUNTY AIRPORT AS A TESTBED FOR RESOLVING INTEGRATION CHALLENGES FOR AIR TAXI OPERATIONS

Sinan Abdulhak[1], Ben Donaldson[2], Armaan Kamat[2], Karis Hu[2], Zerong Huang[2] & Max Z. Li[1,2,3]

[1]Industrial and Operations Engineering, University of Michigan
[2]Aerospace Engineering, University of Michigan
[3]Civil and Environmental Engineering, University of Michigan

Keywords: Airport Shuttle, Air Taxi Operations, Electric Vertical Take-off and Landing (eVTOL) Aircraft, Extended Reality

1. Introduction

The U.S. National Airspace System (NAS) is a unique demonstration of the current scale of and demand for air transportation operations. Not only does it encompass the world's largest region of airspace—representing 29 million square miles—but it also safely delivers 50,000 daily flights [1]. This represents a remarkably complex operating environment for Air Traffic Managers (TMs) who manage the regional flows of aircraft across U.S. airspace, working alongside Air Traffic Controllers (ATCOs) who guide aircraft into and out of space-constrained airports. The strengthening demand for air travel—which is projected to rise from 5 billion to 8 billion passengers annually by 2040 [2]—has motivated R&D efforts to increase passenger connectivity to airports. Electric vertical take-off and landing (eVTOL) aircraft have emerged as a compelling approach for this "air taxi" use case, reducing travel times between cities and airports by up to 90%, and come with a small carbon footprint [3]. Preliminary market studies show that demand for air taxi operations could reach 11 million daily trips by 2030, showcasing the robust demand for this use case [4], with passengers exhibiting a higher willingness to pay for this "airport shuttle" use case [5].

Although air taxis offer significant potential for bolstering airport connectivity, they could greatly increase the complexity of an already challenging operating environment. In addition to increasing the number of aircraft operating in space-constrained airports, eVTOLs will introduce perceptual challenges for ATCOs due to their small size [6], and crucially, must operate without disrupting existing departure and arrival procedures at airports. This highlights the need to (1) visualize the existing state of aircraft operations at airports to identify viable departure and arrival pathways for eVTOLs, (2) propose trajectories for eVTOLs that minimize conflicts with existing operating procedures at hub airports, and (3), explore novel intelligent human-computer interfaces to support the decision-making of ATCOs in a future operating environment with greater complexity. We especially see value in accomplishing (3) using extended reality (XR) to construct a digital representation of an airspace operating environment with air taxi service in a more ecologically valid way, enabling higher fidelity assessments of spatial constraints at the airport and evaluations of candidate eVTOL trajectories. This also enables vital human-in-the-loop studies to evaluate, e.g., how AI-based agents could be best integrated to offload tasks from ATCOs when they are overburdened.

While it is important to propose solutions to the aforementioned operational and human-systems integration challenges, perhaps an even greater undertaking is evaluating their effectiveness in a representative operating environment. Ideally, this would be at an airport that (1) serves a major city, (2) has space to test various trajectories to / from the airport and candidate vertiports for enplanement/deplanement, and (3) has established air taxi procedures and infrastructure to the major city it

https://doi.org/10.71945/icas2026_0682

serves. This is what makes Detroit Wayne County Airport (DTW) a compelling hub to address these integration challenges before expanding eVTOL operations to highly space-constrained hub airports (e.g., New York's JFK). DTW has an established air taxi corridor connecting two major population and economic centers in the U.S. state of Michigan: Detroit and Ann Arbor. Detroit, with a population of approximately 650,000 [7] and a metropolitan population of approximately 4.4 million [8], is Michigan's largest city and the center of a major U.S. metropolitan economy, with a gross metropolitan product of approximately $200 billion [9]. Ann Arbor, with a population of approximately 120,000 [10], is home to the University of Michigan, a leading public research university and a major hub for education, research, and technology innovation [11]. This air taxi corridor supports beyond visual line of sight (BVLOS) operations [12, 13], has an underutilized concourse which could serve as a vertiport for eVTOLs, and has extra tarmac space suitable for eVTOL operations. This test environment, which has received support from state and local governments and solicited proposals to test AAM integration [14], marks an excellent opportunity to evaluate various candidate eVTOL trajectories to / from DTW without impacting regularly scheduled airline operations [13, 15].

To our knowledge, no eVTOL air taxi operations currently exist between a major city and a hub airport, positioning our research as a key step in supporting the first test flights and regularly scheduled operations for such a use case. To this end, our major contributions include:

1. investigating the market viability (e.g., demand projections) and economic impact of air taxi operations between a major city and hub airport on both air taxi operators and other stakeholders (e.g., cities)
2. analyzing the operational feasibility of eVTOL operations from two major cities, Detroit and Ann Arbor, to DTW, a major hub airport, by visualizing approach paths of existing aircraft operations and proposing eVTOL trajectories between DTW and Detroit/Ann Arbor.
3. building an interactive graphical user interface (GUI) to enable stakeholders (air navigation service providers, airlines, researchers) to design kinematically feasible eVTOL trajectories and visualize them in a 3D map viewer with airspace features (e.g., arrival/departure corridors and Class B layers)

These contributions lay the groundwork for future extensions, including building a high-fidelity representation of an out-of-the-tower view for a major U.S. airport in a 3D XR environment to evaluate both proposed eVTOL trajectories and agentic AI systems to address unique operational challenges that will arise from air taxi operations.

The remainder of this manuscript is structured as follows: Section 2 briefly surveys existing works that examine integration challenges with air taxi operations, Section 3 discusses the methods used to conduct our economic analyses, visualize current aircraft procedures at a major hub airport, and model eVTOL trajectories, Section 4 highlights results from economic forecasts and visualizations of eVTOL trajectories, and Section 5 discusses opportunities for future work and concludes our manuscript.

2. Literature Review

The promise of UAM enabling greater access within dense urban environments has garnered significant interest in the transportation and mobility sector [16]. The travel time reductions (e.g., Blade's service from Manhattan to JFK in 5 minutes vs 1 hour 40 minutes by car) and economics enabled by multi-passenger eVTOLs—which in theory, could halve travel costs on a per-seat basis compared to cars [16]—make the airport shuttle use case especially compelling. These advantages have spurred R&D efforts and public-private partnerships to estimate the market viability of airport shuttles and conceptualize how such operations could manifest. Indeed, various studies have estimated the demand for UAM-enabled service between urban areas and hub airports, including for Los Angeles International Airport (LAX) [17], Incheon International Airport (ICN) [18], and the San Francisco Bay Area using simulation-based methods [19]. Notably, one NASA study highlights customers' greater willingness to pay for UAM airport shuttles [5], emphasizing that the greatest financial stability lies within this use case. However, to our knowledge, few studies explore the economic viability of eVTOL airport shuttles by utilizing county-level population growth regressions to estimate demand for the airport's "catchment" area, or the geographic region the airport serves. While existing literature forecasts demand using, e.g., behavior-based choice models (e.g., multinomial logit for Munich [20]), we develop a framework to calculate passenger demand, trip costs, projected ticket revenue, and economic impacts on secondary stakeholders beyond eVTOL operators (e.g., county, business activity, etc).

Studies investigating the operational viability of airport shuttles include a joint Joby and NASA effort to explore eVTOL service for the Dallas Fort Worth Airport (DFW) area [6], a partnership between Airbus and the French civil aviation authority (DGAC) for Paris airport (CDG) [21], among others. However, one significant challenge with eVTOL operations is space. As highlighted by [5, 16, 22], one of the key drivers of attractiveness for eVTOL airport shuttle operations is the significant time savings it can offer. The time advantages of eVTOLs can only be realized if vertiports are placed close to the passengers embarkment and dis-embarkment locations, which corresponds to highly space constrained areas (e.g., either dense urban areas or airport locations). To our knowledge, most conceptual efforts propose placing vertiports landside or offsite from the airport, requiring last mile transport efforts that reduce the time savings advantage of eVTOLs. In contrast, we propose making use of extra concourse space at a hub airport (DTW) that enables passengers to egress directly into the terminal building. To this end, we investigate the operational implications associated with this underexplored concept, including spatial constraints that eVTOLs must navigate when approaching the terminal and proposing trajectories that minimize conflicts with existing aircraft operations.

Given the novelty of eVTOL operations, one could look to helicopter operations as a preliminary framework for operational integration, as helicopters operate at major airports with defined approach paths constrained by IFR separation standards and terminal airspace geometry [23]. While eVTOLs share the VTOL operational concept, they differ fundamentally in propulsion system, noise profile, and speed envelope [24], necessitating purpose-designed approach corridors rather than direct adoption of existing helicopter procedures.

To model the physical behavior of eVTOL aircraft along complex terminal pathways, existing literature spans a spectrum from high-fidelity flight dynamics simulations to abstracted geometric routing. Advanced flight dynamics frameworks, such as the NASA Generic Urban Air Mobility (GUAM) simulation tool, utilize full non-linear, six-degree-of-freedom rigid-body formulations to capture complex aero-propulsive interactions and transition mechanics during takeoff and landing phases [25]. Similarly, trajectory optimization techniques for tilt-wing and multi-rotor eVTOL configurations frequently employ gradient-based optimal control to minimize energy consumption or transition time while strictly enforcing aerodynamic stall limits and acceleration constraints for passenger comfort [26]. While highly accurate for individual vehicle control envelope prediction, these high-fidelity formulations introduce significant computational overhead, rendering them less practical for macroscopic air traffic management simulations or interactive multi-variant route planning applications [27].

To bridge the gap between computational efficiency and physical realizability within BVLOS flight corridors, researchers widely adopt point-mass kinematic models [28]. By reducing the aircraft to a point mass and isolating essential macroscopic state kinematics while neglecting high-frequency actuator and rotor-blade aeroelastic dynamics, the kinematic formulation strips away unnecessary numerical stiffness [29]. This simplified mathematical structure allows for deterministic trajectory generation and immediate validation of critical flight constraints, such as ensuring waypoint spacing accommodates the vehicle's minimum coordinated turn radius. Consequently, a point-mass kinematic approach serves as an ideal compromise, providing sufficient physical realism to guarantee route safety margins while remaining computationally lightweight enough to support real-time trajectory visualization, iterative route planning, and interactive backend auto-validation frameworks [27].

Beyond geometric obstacle avoidance, the operational deployment of eVTOL trajectories demands strict integration with ground-based infrastructure, vertiport zoning, and regional communication networks. Evolving regulatory foundations, such as the FAA Advanced Air Mobility Integration Pilot Program [14], dictate the localized physical and safety perimeters that anchor terminal approach paths. Furthermore, route selection within high-density environments is fundamentally constrained by the continuous coverage of BVLOS tracking infrastructure, as exemplified by the regional air mobility corridors linking municipal centers to major hubs [13]. Consequently, macro-scale trajectory planning cannot treat urban airspace as an open free-flight zone; routing frameworks must co-optimize three-dimensional geometric profiles with localized network availability and strict separation envelopes from conventional traffic flows.

3. Methods

To explore the viability of air shuttle operations between major urban centers (Ann Arbor, Detroit) and a hub airport (DTW), we investigate both the economic and operational viability of this use case. The economic analysis provides insight to the demand that is present for air shuttle service. This not only conveys whether such a service is sustainable from a market perspective (e.g., profitability, economic benefits for the counties/cities receiving air taxi service), but also has operational implications by providing insight to the number of operations that can be expected. This feeds into an operational analysis of eVTOL operations, where we investigate the spatial constraints at DTW by visualizing existing aircraft operations at the airport, and propose trajectories that minimize conflict with existing operations. Lastly, we outline initial steps that were taken to visualize these operational considerations in an XR environment, which provides a foundation for future explorations on the integration of eVTOLs at the hub airport and evaluations of human-AI decision aids to alleviate the added complexity associated with the introduction of eVTOLs in dense, Class B airspace.

3.1. Economic Assessment for Air Taxi Operations at DTW

In assessing eVTOL operations within the DTW service area, it is critical to determine the economic validity of conducting established eVTOL operations at DTW over time. To this effect, we first estimate the Wayne, Washtenaw, and Windsor census populations [30] and project their population growth. We calculate a least-squares linear regression of population growth in each county from 2020-2024 and assume population growth continues according to the regression through the year 2035. We then divide population values against the DTW catchment area to estimate a fraction of passengers native to the DTW service area [31]. Results are coupled with the number of enplanements year-over-year [32] and the percentage of individuals native to the DTW service area to establish O&D trends over time [31].

We then use ground transportation models of the Seattle-Tacoma and Denver airports to approximate transportation delineation for DTW [33] and a hypothetical demand for air taxi flights across the split [33]. Among the other modes of transport, M-Air associated air taxi flights begin with a share of 0% which is assumed to grow linearly to 2% in 2035. The shifts in modal split over time are depicted in Figure 1.

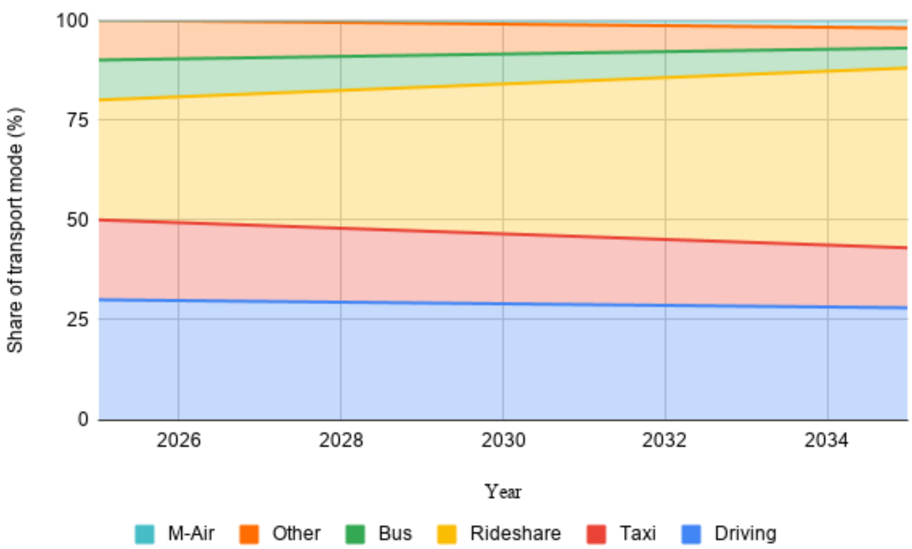


Figure 1 – Expected change in modal split of transportation to/from DTW airport over 10 year period from 2025-2035.

Multiplying the modal split against the resultant O&D enplanements estimates an annual number of passengers by transportation mode. Using the number of passengers opting for air taxi transportation, we assess a mile average of 22 miles between MCity/Michigan Central and DTW (assuming both locations are equally popular), an average number of six passengers per flight, and a cost per mile average of $3 [34]. Assuming passengers leave their vehicles at a given location, whether at Michigan Central or in Ann Arbor, when taking an eVTOL, passengers are thus unable to utilize their vehicle upon returning from the airport. This logistical limitation, compounded with the difficulty of surveying modes of egress prior to travelers' trips, thus drives the assumption that travelers may opt to utilize the same eVTOL transport upon their return to their origin airport [35]. We thus base our ultimate projection upon a return-trip utilizing an eVTOL. We then establish an average cost per person for a round trip to DTW. Finally, we divide our passenger demand by the average number of spots on an air taxi for a total number of flights. We additionally multiply passenger demand against round-trip ticket fares to calculate our final estimate of ticket revenue over time. The complete process for forecasting baseline number of air taxi flights and total ticket revenue is shown in Figure 2.

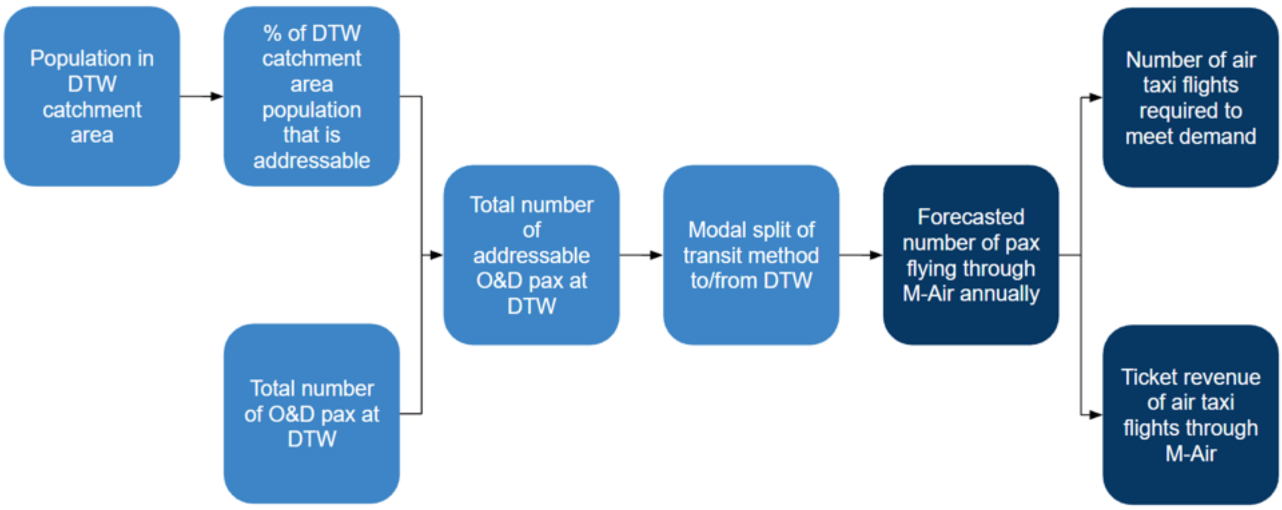


Figure 2 – High-level flow of steps for baseline forecast of M-air related air taxi flights and ticket revenue.

3.2. Economic Assessment of Operational Value Added Per Industry

To assess the economic impact of eVTOL operations on industries within the DTW service area, we opt for inter-industry analysis — or input-output (I-O) analysis. The model's utility in assessing impacts of change within a given region is bolstered by its measurement of interdependent relationships between industries, making it ideal for assessing the potential ramifications of change associated with long-term eVTOL operations [36, 37]. Notably, eVTOL operational data is fairly limited in scale as commercial eVTOLs remain in the proof-of-concept stage [38]. As such, survey data related to average eVTOL operation spending remains relatively broad, necessitating an Industry Output Event [39]. With this in mind, we identify 3 industries of note: Air Transportation (NAICS 481), Transit and Ground Passenger Transportation (NAICS 485), Other Transportation and Support Activities (NAICS 487OS). The remaining industries were compiled into a singular category labeled "Other Categories", subtracting each row output (commodity output for the make table and industry output for the use table) across the 3 industries from a total commodity output value. This acts as an aggregate summary of the effects of non-eVTOL-related economic activity within the system.

To model economic ramifications of eVTOL operations, we thus capture the direct and indirect production generated by a given industry per dollar of delivery to the final use of a resultant industry. We do so specifically through the incorporation of national "Make" and "Use" tables, in which "Make" tables track commodity production through industries, and "Use" tables establish commodity usage by intermediate and final industries. The use table additionally captures value added through gross operating surplus, taxes on production and imports, less subsidies, and employee compensation [37]. In accordance with the procedures laid out in the BEA Input-Output Handbook, we thus adopt the

Leontief model, linking a final demand, y, to the total industry output, x:

$$x = (I - A)^{-1} y. \tag{1}$$

Here, $(I - A)^{-1}$ is characterized as the total requirements matrix. For an Industry Output event, we utilize the industry-by-industry total requirements matrix:

$$(I - WB)^{-1}, \tag{2}$$

where W is the transformation matrix, or an industry-by-commodity matrix proportionally mapping a particular commodity output as it is produced in each industry. Notably, W accounts for scrap (p, transformed into a diagonal matrix $\hat{p}$) in industrial production, differentiating the matrix from the market share matrix, D, which is in turn a function of the make table, V. Specifically,

$$(I - \hat{p})^{-1} D = W. \tag{3}$$

For this model, as a simplifying assumption, we opt to neglect the influence of scrap ($\hat{p} = 0$). In doing so, we shift our economic focus to industries producing primary commodities, as there are no industries listing scrap as a primary product [40]. Doing so further reflects the operational reality of eVTOLs, as current lifecycle analyses of eVTOLs neglect scrappage and recycling processes altogether due to a lack of data [41, 42].

$$D = W. \tag{4}$$

We further restrict our analysis to model domestic production; thus, we neglect the influence of noncomparable imports and rest-of-the-world adjustment, as they bear no domestic equivalent [43].
B, in contrast, is a commodity-by-industry direct input coefficients matrix acting as a function of the intermediate components within the use table, U. Thus, the matrix tracks the use of commodities by a given industry per dollar of output.
Substituting the industry-by-industry total requirements matrix into Equation (1), which critically operates using the Industry-Technology Assumption (ITA) [44], and taking into account the simplification of Equation (4) yields:

$$x = (I - DB)^{-1} y. \tag{5}$$

From this adjusted equation, D and B are broken down into their representative equations. As D is a function of the make table, D is thus characterized as:

$$D = V\hat{q}^{-1}, \tag{6}$$

where $\hat{q}$ compiles the total commodities of the make table as a diagonalized square matrix.
Similarly, as a function of the use table, B is characterized as:

$$B = U\hat{g}^{-1}, \tag{7}$$

where $\hat{g}$ specifically depicts the total output for each selected industry as a diagonalized matrix. It is of note that $\hat{g}$ includes scrap production in its output; as mentioned before, however, we neglect the influence of both scrap and noncomparable imports and thus negate their inclusion [37].
We then characterize the final demand, y, using the previously specified industries of Air Transportation, Transit and Ground Passenger Transportation, Other Transportation and Support Activities, and Other Categories.
Using direct operating costs for Advanced Air Mobility, as published by Roland Berger, we establish a percentage breakdown of operating costs in terms of flying (18%), vertiport (20%), maintenance (37%), and general aircraft costs (26%) [45]. Note that the percentages are rounded and thus do not equal 100%. We then sort flying and general aircraft cost percentages as Air Transport demand. Maintenance and vertiport cost percentages are listed under the Support category [46, 47]. The resultant aggregated percentages are then multiplied across two-way ticket revenue for a final demand shock.
For this model, we determine the transit and ground passenger transportation demand shock to be 0. The modal split in Section 3.1 assumes the passenger demand growth for M-Air associated taxi flights

is exclusively derived from the passenger demand for driving. A 2% decrease in driving demand by 2035 thus translates to a 2% increase in the M-Air Share. As other forms of ground transportation are unaffected by the introduction of M-Air in our model, the net demand for this industry is omitted from the final demand vector.

To gauge an appropriate opportunity cost for the adoption of M-Air as opposed to driving, we calculate the approximate change in parking revenue by multiplying M-Air passenger demand over time against average parking lot fees. As airport parking revenue provides critical support for airport operations, its impact is non-negligible and must be taken into account when establishing overall demand for M-Air flights [48]. Here, assuming all parking lots have equally distributed demand, we establish an average of $25 per day and an average trip length of 4.3 days, culminating in an average parking cost of $107.50 [49, 50]. Although the percentage breakdown of operating costs does not include a relevant term for Other Categories, parking lots are under NAICS 812930 and reflect opportunity costs in the final demand vector [51]. As such, we subtract the associated parking revenue to establish a negative demand shock for the Other Categories input.

Combining the demand shocks of Air Transportation, Transit and Ground Passenger Transportation, Other Transportation and Support Activities, and Other Categories thus yields the final demand vector y.

Upon calculating y, we next establish B, D, $\hat{g}$, and $\hat{q}$ for domestic requirements. We thus obtain summary make and use tables after redefinitions using the BEA Input-Output Accounts Data tool [52]. For this model, we opt for a use table compiled in producers' prices. Although the BEA also offers a use table incorporating purchasers' prices, it was last updated in 2017 and the producers' prices table was last updated in 2024 [52]. We therefore opted to make use of more recent economic values in this study. As such, however, we deflate all monetary values to a 2024 baseline. Utilizing the Comparative Statics method in light of this 2024 data [53], we further promote the 2024 baseline as part of an operational equilibrium, analyzing the changes to this equilibrium from the adoption of eVTOL technologies over time.

Per the definition supplied by the BEA, purchasers' prices include domestic transportation costs and trade margins added to the producers' prices [54]. In contrast, producers' prices exclude trade margins and transportation costs but include sales and excise taxes by producers [55]. Within the demand vector, assuming nonzero final demand shocks, flying and aircraft depreciation, transit and ground passenger transportation, vertiport upkeep, maintenance, and parking are classified within the services category. In this framework, the transportation and trade matrices are reallocated as particular industries. We thus adopt the producers' prices framework, taking into account relevant transportation costs and trade margins appear as independent columns within the table.

The use table compiling producers' prices does not include trade margins and domestic transportation costs and instead incorporates these activities according to industry. As such, we are able to aggregate the remaining industries into an Other Categories section without providing additional financial adjustments. In contrast, combining industry data using the purchasers' prices table could potentially cause double-counting in the data set owing to the built-in trade margins and transportation costs [54].

Upon obtaining the relevant make (V) and intermediate use tables (U) from the BEA and neglecting scrap and noncomparable imports, we calculate D and B and incorporate the final demand vector y to calculate a national total output matrix.

To better denote industrial impact on DTW, national data sets are regionalized to Wayne County, despite including the Windsor and Washtenaw populations in the catchment area. Simple location quotients (SLQs) are constructed using industry-based earnings for specific industry incomes and total earnings by place of work for the all-industry denominator, as per the BEA industry estimate methodology [56, 57]. The SLQs act as a proxy for regional specialization across different industries; in the case of income-based outputs, the SLQ is defined as follows:

$$SLQ_i^r = \left(\frac{\text{Local Concentration}}{\text{National Concentration}} \right), \tag{8}$$

where:

$$\text{Local Concentration} = \left(\frac{\text{Local Industry Income}}{\text{All Industry Summation of Local Earnings}} \right), \tag{9}$$

and:

$$\text{National Concentration} = \left(\frac{\text{National Industry Income}}{\text{All Industry Summation of National Earnings}} \right), \tag{10}$$

wherein r is the defined region and i the relevant industry [37, 58, 59]. An SLQ in excess of 1 indicates a higher share of local area income when compared to a national baseline, where an excess in industry is assumed to be exported from the given region [44]; conversely, an SLQ below 1 indicates a lower share of local area income compared to a national area baseline, requiring imports to compensate for the county's demand with respect to a given industry. Thus, to regionalize the data, for each producing industry i and each purchasing industry j, the following calculation applies:

$$a_{ij}^{rr} = \begin{cases} (SLQ_i^r)a_{ij}^n, & \text{if } SLQ_i^r < 1 \\ a_{ij}^n, & \text{if } SLQ_i^r \geq 1 \end{cases} \tag{11}$$

where the national coefficients are denoted as a_{ij}^n and a_{ij}^{rr} represents the intraregional coefficients [44]. Normalizing each industry by the SLQ thus results in an approximate producing-side scaling for the regionalization of the technical coefficients matrix A^{rr}, or, as established prior, DB [58].

We finally calculate the Total Regional Industry Output upon substitution of the regional technical coefficients matrix and the final demand vector. The resultant output matrix is representative of the regional economic output per specific industry over time, with final demand vectors growing over time in accordance with projected eVTOL operational growth. Additionally, a summation of the elements of the output vector yields an Aggregated Regional Industry Output that characterizes the production necessary to sate the demand requirements [44].

3.3. Visualizing Departure and Arrival Procedures at DTW

Before modeling candidate trajectories for eVTOLs flying into / out of DTW, it is important to understand the current state of aircraft operations at the airport. For this, we develop a Python program to parse DTW's approach procedures from the Federal Aviation Administration's (FAA) National Airspace System Resources (NASR) dataset [60], which extracts the location (e.g., coordinates) and attributes (e.g., heights, widths) necessary for constructing the geometry of the approach procedures. We then convert the latitude / longitude of the waypoints to a local XY coordinate space using an equirectangular projection, and build the corridor edges, which define the volume of airspace the aircraft is expected to be in when following a given approach procedure. Lastly, we convert back to the geographic coordinate system and output a file in Keyhole Markup Language (KML), which is used to visualize geographic data. Our output file is designed to be viewed in Google Earth, allowing stakeholders to gain a 3D perspective on airspace utilization at the airport, which supports the design of candidate eVTOL trajectories for various runway configurations.

To complement our visualizations of approach corridors with how this airspace is used in practice, we overlay historical traffic tracks extracted from the NASA Sherlock data warehouse onto the same Google Earth scene (Figure 3). Scheduled traffic funnels into the runways along the published corridors and occupies the upper Class B shelves, while the low-altitude band beneath these streams stays largely unused. This indicates that an eVTOL arrival is best kept below the existing flow of commercial air traffic rather than merging eVTOLs into it. These approach corridors are vital for constraining the space available for eVTOL operations, and are therefore overlaid in the GUI for eVTOL trajectory planning and visualization (Section 3.5).

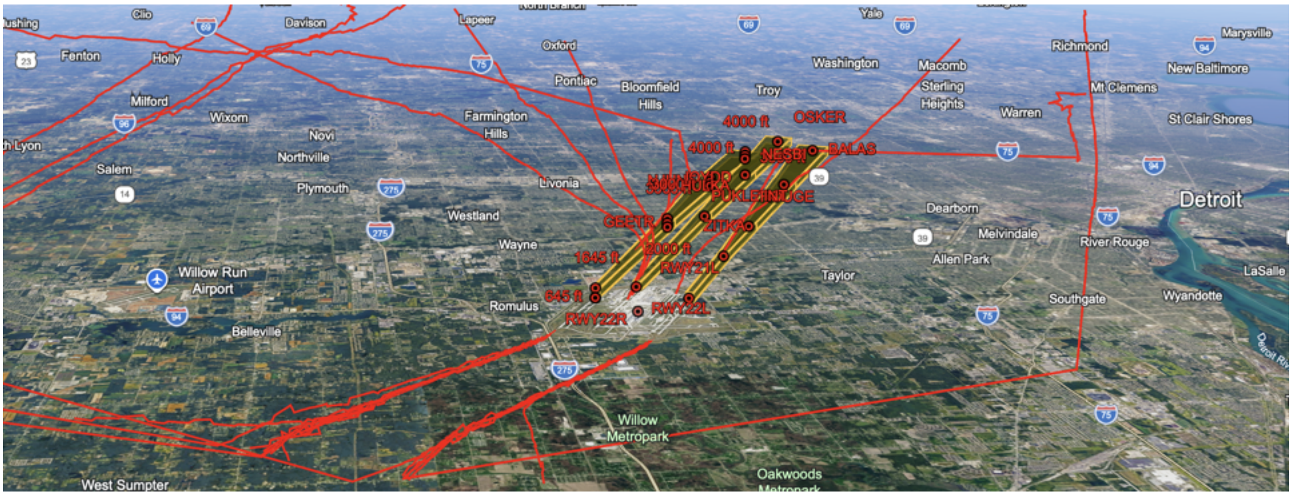


Figure 3 – DTW arrival corridors reconstructed from the FAA NASR dataset, shown in Google Earth with historical commercial flight trajectories (red) from NASA Sherlock. Scheduled traffic concentrates along the corridors and on the upper Class B shelves, leaving the low-altitude band open for eVTOL arrivals.

Finally, the proposed trajectories are imported, processed, and viewed in a web-based 3D application built on CesiumJS. The web app supports several viewing modes, including (1) free camera, which enables the viewer to freely pan, tilt, and move while viewing the eVTOL follow a trajectory, (2) onboard chase cameras, which follows the eVTOL, and (3) a tower view, which fixes the camera roughly at the location of the DTW control tower to replicate what a controller would see (Figure 14). The range of viewing perspectives enables various stakeholders to analyze eVTOL trajectories and assess a wide range of eVTOL integration challenges. For example, the free view could enable an FAA airspace specialist to analyze whether an eVTOL trajectory provides sufficient seperation from existing arrival corridors, while the tower view could enable human factors researchers to identify approach paths that present the greatest perceptual challenges.

3.4. Modeling eVTOL Trajectories for Operations at DTW

3.4.1. Spatial and Regulatory Considerations for Trajectory Modeling

Integrating eVTOL terminal approach routing into the NAS introduces severe spatial constraints, which are driven by the complex geometry and segmentation of U.S. airspace [61]. Airport shuttle operations to a hub airport within Class B introduces unique challenges, as the FAA Aeronautical Information Manual [62] restricts unauthorized low altitude penetration near major hubs. More critically, Instrument Flight Rules (IFR) arrival corridors designed under the United States Standard for Terminal Instrument Procedures (TERPS) [63] establish expansive obstacle clearance surfaces. These constraints provide virtual corridors with guaranteed separation minimums that protect commercial traffic, but they act as rigid spatial boundaries that any eVTOL route near the hub must respect.

Managing these arrival trajectories is further complicated by the radar separation minimums and wake turbulence buffers enforced under FAA Order JO 7110.65 [64], which compress the operational volume available around congested airports. These minimums require both horizontal and vertical separation and dedicated areas where aircraft can hold to absorb fluctuations in the traffic flow. To route new entrants without disrupting existing flows, recent frameworks use the concept of interstitial airspace. Formalized in the NASA Urban Air Mobility Concept of Operations [65], interstitial airspace refers to the underutilized spatial gaps beneath the floors of Class B airspace and between active IFR flows. Although these gaps offer potential approach paths for eVTOLs in theory, the combination of regulatory separation requirements and the spatial demands of hub airport operations makes eVTOL trajectory modeling challenging.

3.4.2. Developing Airport Shuttle Trajectories for DTW

To develop viable air taxi routes, we identify two key transit nodes, Ann Arbor (MCity) and Michigan Central Station in Detroit, and design trajectories that minimize interference with existing terminal procedures at DTW. Working within the spatial constraints set by the existing aircraft arrival corridors (Section 3.3), we manually designed eVTOL trajectories using these 3 criteria:

1. *Lateral and vertical separation*: maintaining a safety buffer from the precision runway monitor (PRM) approach volumes.
2. *Infrastructure alignment*: following existing ground transport corridors such as railroad tracks where possible, to limit noise impact over populated areas and to leverage existing BVLOS infrastructure.
3. *Variable approach altitudes*: designing arrival profiles that remain below or between the primary fingers of the DTW approach corridors and possible below the bypass airport(eg. KYIP) pattern altitude.

Together these criteria keep eVTOL entry and exit deconflicted from existing aircraft operations.
To confirm that these routes are kinematically deasible, we incorporate a low-fidelity, point-mass model that characterizes the basic eVTOL maneuvers of turning, climbing, and braking, smoothing the discrete reference waypoints into time-resolved trajectories. The input is an ordered list of waypoints, each given by latitude, longitude, altitude above ground level (AGL), and a holding flag. The output is a state time series: three-dimensional position, groundspeed, heading, vertical rate, roll, and load factor at each step. The equations are integrated in a local North-East-Down (NED) tangent plane anchored at the first waypoint. The Ann Arbor to Detroit corridor spans about 40 km over nearly uniform terrain near 650 ft MSL, so this flat-earth approximation introduces negligible projection error at the fidelity required for terminal routing. Integration uses a fixed step of $\Delta t = 0.1$ s with a 3000 s timeout.
Longitudinal motion follows a five-phase state machine:

$$\text{TAKEOFF} \rightarrow \text{FORWARD} \rightarrow \text{HOLD} \rightarrow \text{LANDING} \rightarrow \text{TAXI}. \tag{12}$$

In cruise (FORWARD) the speed command enforces a stopping-distance rule so the aircraft decelerates in time to stop at the next waypoint, fix, or pad without overshoot:

$$v_{\text{target}} = \min\left(v_{\text{cruise}}, \sqrt{2\, a_{\text{decel}}\, d_{\text{stop}}}\right), \tag{13}$$

where d_{stop} is the remaining distance to the active waypoint. Performance limits use a representative eVTOL platform (Joby S4): cruise speed 90 kt, climb rate 492 fpm, maximum acceleration $0.15g$, and service deceleration $0.10g$ (Table 1).
Lateral motion uses a rate-limited turn capped at a standard 3 deg/s. For coordinated flight the required bank angle is

$$\phi = \arctan\left(\frac{v\,\dot{\psi}}{g}\right). \tag{14}$$

At 90 kt, this 3 deg/s limit sets a minimum turn radius of about 884 m. Waypoints spaced too closely or joined at large turn angles yield an infeasible trajectory that violates the turn rate limit and causes the integration to diverge, so the limit constrains path design directly. Vertically, the aircraft climbs at the climb at its vertical speed of 492 fpm (2.5 m/s) to cruise altitude, holds a low-altitude level deceleration into the capture point, then descends vertically in the LANDING phase. Longitudinal and vertical load factors are tracked as cabin comfort metrics.

3.5. Trajectory Planning and Visualization Tool

We package visualizations of airspace procedures (Section 3.3) and the kinematic model (Section 3.4.2) into an open-source web tool[1] that enables stakeholders to identify spatial constraints at DTW, propose trajectories, and visualize them.

[1] https://github.com/jasonr2020/airtaxi-trajectory-visualization

Table 1 – Kinematic model parameters (Joby S4 defaults).

Parameter	Symbol	Value
Cruise speed	v_{cruise}	90 kt
Climb rate	v_{climb}	492 fpm
Max acceleration	a_{accel}	$0.15g$
Service deceleration	a_{decel}	$0.10g$
Max turn rate	$\dot{\psi}$	3 deg/s
Min turn radius @ 90 kt	$R_{\min}$	884 m
Time step	Δt	0.1 s

The application's frontend is a React application. A Leaflet map provides the 2D planning canvas, where the user places, drags, and edits waypoints over the arrival corridors and Class B overlays (Figure 10). A CesiumJS globe replays the resulting trajectory in 3D with free, onboard, and tower cameras (Figure 14). Altitude and groundspeed profiles of the eVTOL are rendered with Plotly.
The backend is a FastAPI service that hosts the kinematic engine of Section 3.4.2, implemented with NumPy and Pandas. It exposes two functions over a JSON interface: a full simulation that returns the state time series for replay and analysis, and an online feasibility check that re-runs the model whenever the route changes and flags any waypoint that makes the route infeasible. The frontend and backend communicate over HTTP, and the system is containerized with Docker for local or server deployment.

3.6. Groundwork for Developing an XR Environment to Visualize eVTOL Operations

Our main goals with the XR environment are (1) to develop an immersive representation of the tower environment under eVTOL operations and (2) enable future HITL studies to evaluate the effectiveness of AI-based decision support systems in reducing the aforementioned perceptual and workload challenges that come with air taxi operations. We choose the Apple Vision Pro (AVP) XR headset for its excellent eye-tracking capabilities and reduced incidence of motion sickness [66]. Although the focus of this paper is not to build a complete XR environment, we take initial steps to build an out-of-the-tower view at DTW, which serves as the first step for constructing this future airspace environment in XR. To build this view, we use the Unity engine, which natively supports AVP and Cesium, a library for importing 3D photogrammetry tiles from Google Earth. Unity's development environment—with the ability to execute code in c#—enables future efforts to, e.g., model eVTOLs following a custom trajectory. We note that due to compatibility issues between Cesium and AVP, we have been unable to deploy the virtual environment to the headset. We elaborate on opportunities for future work in developing the XR environment in Section 5.

4. Results

4.1. Ticket Revenue and Passenger Demand Economic Analysis

We begin by presenting the market demand and economic impact for an eVTOL airport shuttle between Detroit / Ann Arbor and DTW. Using the methodology described in Section 3.1, we compute the expected number of passengers and resultant ticket revenue from 2025-2035. We assume that M-Air accounts for 0% share in 2025 and grows linearly to 2% in 2035. While the demand grows year-over-year, for this model, we assume the demand to be fixed regardless of price. The growth to 2% is significantly lower than the modal share of more widely used transportation methods to and from the airport, such as driving, taxi, and rideshare services (i.e., >20%) [67, Appendix E]. Our forecast predicts that the annual revenue generated by airport shuttle ticket sales will reach approximately $22 million by 2035 prior to the incorporation of regional economic multipliers (Figure 4). This revenue is assumed to continue growing over the 11 year period. Our calculations assume a ticket cost of approximately $3/mile [34], which corresponds to a one-way cost of $75 for service between MCity and DTW and $57 between Michigan Central and DTW based on the distance to each destination. This culminates in a total round-trip cost of $150 for service between MCity and DTW and $114 between Michigan Central and DTW. We intend for the revenue estimates to be conservative compared to a likely higher ticket price charged for a much more urban area. Both routes are assumed to be equally utilized by passengers on air taxis with six passenger seats, and air taxis are assumed to be at maximum capacity for each trip.

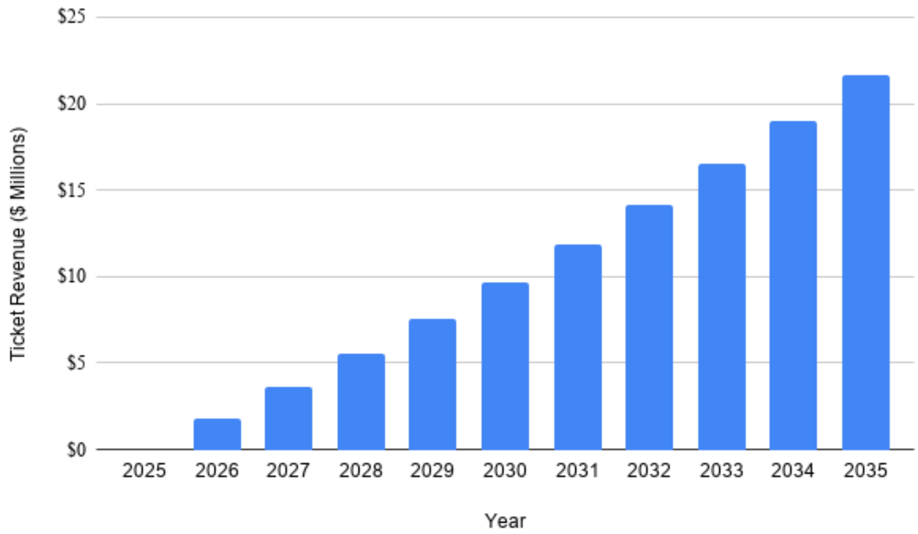


Figure 4 – Forecasted ticket revenue associated with M-Air air taxi flights to DTW airport.

4.2. Economic Analysis of Regional Industry Impacts

Upon calculating the total regional economic output per industry over time using the methodology provided in Section 3.2, we find that with a $3 per mile charge, as defined as a typical eVTOL fare [34], the opportunity cost of reducing parking revenue and an increased number of diverted passengers yields an Other Categories sector that contracts over time (Figure 5). In contrast, the Air Transport and Other Transportation and Support Activities sectors trend upward over time. Transit and Ground Transportation, owing to the absence of a demand shock, remains roughly at zero over time. As eVTOLs are an emerging technology, we assume a baseline environment does not support eVTOL operations and thus define the baseline output of eVTOL-supporting industries to be 0. The forecasted Aggregated Regional Industry Output shown in Figure 6 thus depicts the sudden adoption of eVTOLs within the region. Any changes as a result of the Aggregated Regional Industry Output for the highlighted industries correspond to the expansion and contraction of industry output needed to satisfy final demand. By 2035, the Aggregated Regional Industry Output reaches approximately $7.02 million, indicating an expansion of the regional industry output by $7.02 million to fulfill the final demand.

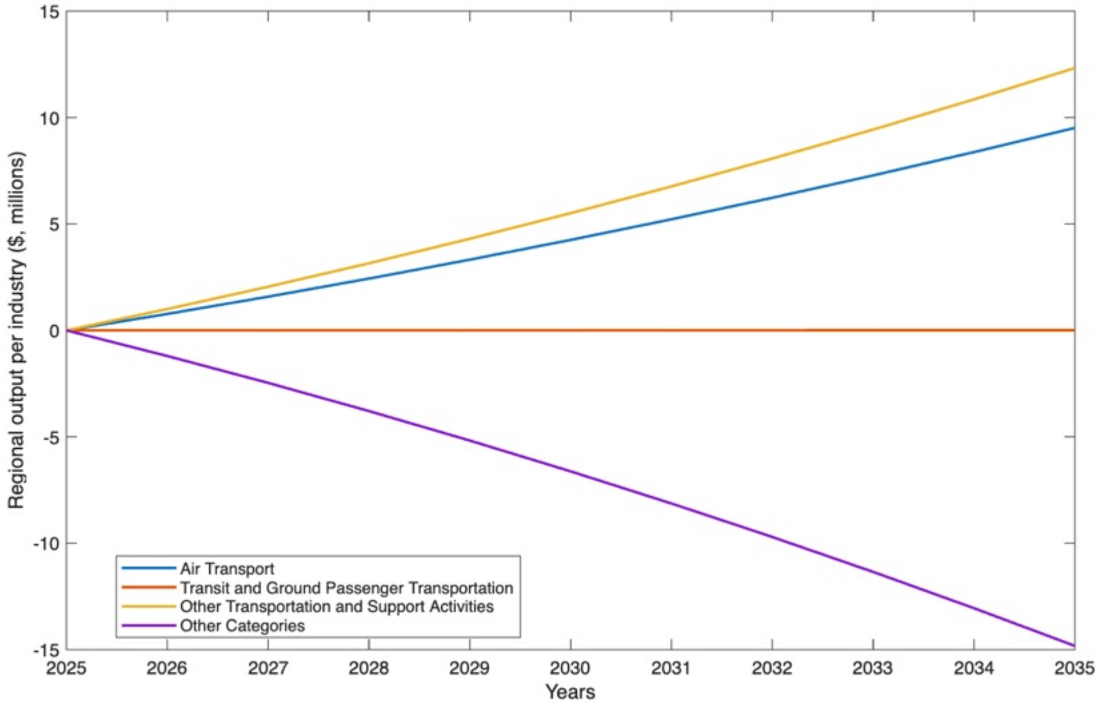


Figure 5 – Forecasted regional output per industry under current literature-derived conditions ($3.00 per mile charge).

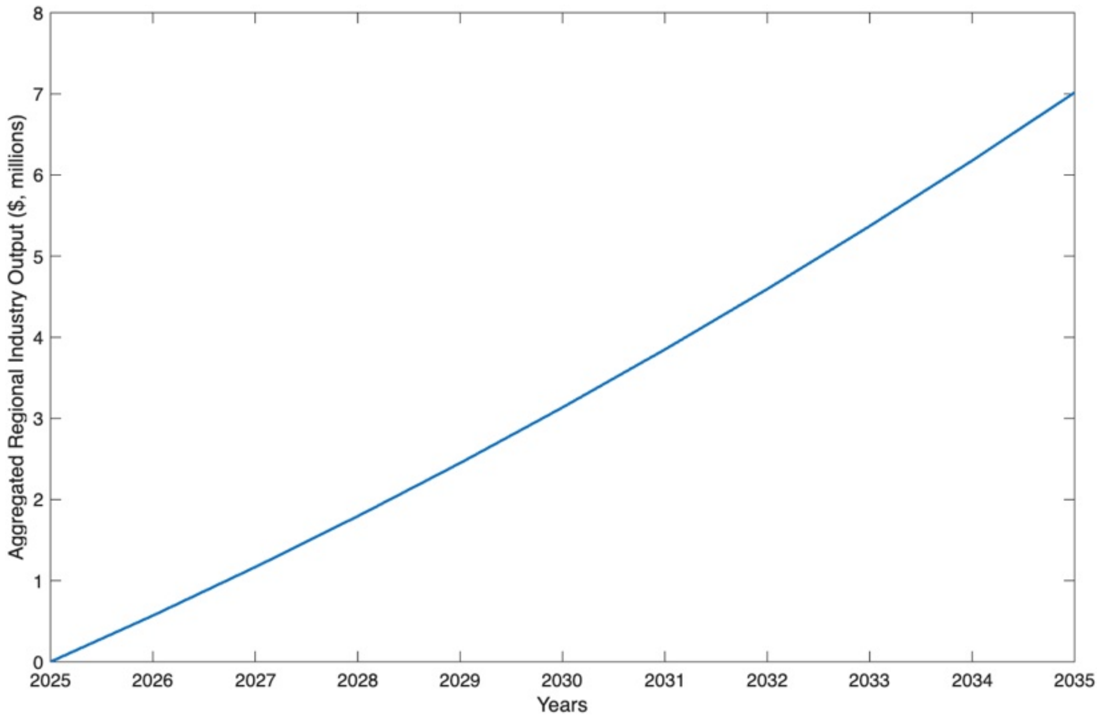


Figure 6 – Forecasted Aggregated Regional Industry Output over time utilizing a $3.00 per mile charge.

Following the establishment of the positive Aggregated Regional Industry Output at $3.00 per mile, we then move to establish a cost per mile that nets a positive forecasted regional output across all industries upon adoption. Figure 7 thus depicts a positive, if marginal, regional output for the Transit and Ground Transportation and the Other Categories sectors at $6.04 per mile. Thus, the adoption of a ticket fare at $6.04 per mile acts as an approximate threshold for non-negative output across all sectors within the region. By 2035, with this rate of increase, the Aggregated Regional Industry Output ultimately yields an approximate value of $44.13 million to meet the values of the final demand vectors over time, as shown in Figure 8. While this appears significantly larger than the output values as a result of the initial $3.00 per mile baseline, the increase is attributable to an increase in ticket revenue leading to subsequent spikes in Air Transport and Other Transportation and Support Activities. The rapid growth in passenger demand and subsequent ticket revenue allows both sectors to grow without experiencing negative net output. Through inter-industry relationships, the growth of these sectors instigates positive output effects in the other industries, outpacing the negative growing impact of parking as a result of diverted passengers. The resultant Aggregated Regional Industry Output thereby provides a significantly higher regional contribution, leading to the expansion of producing industries within the region by $44.13 million to address final demand.

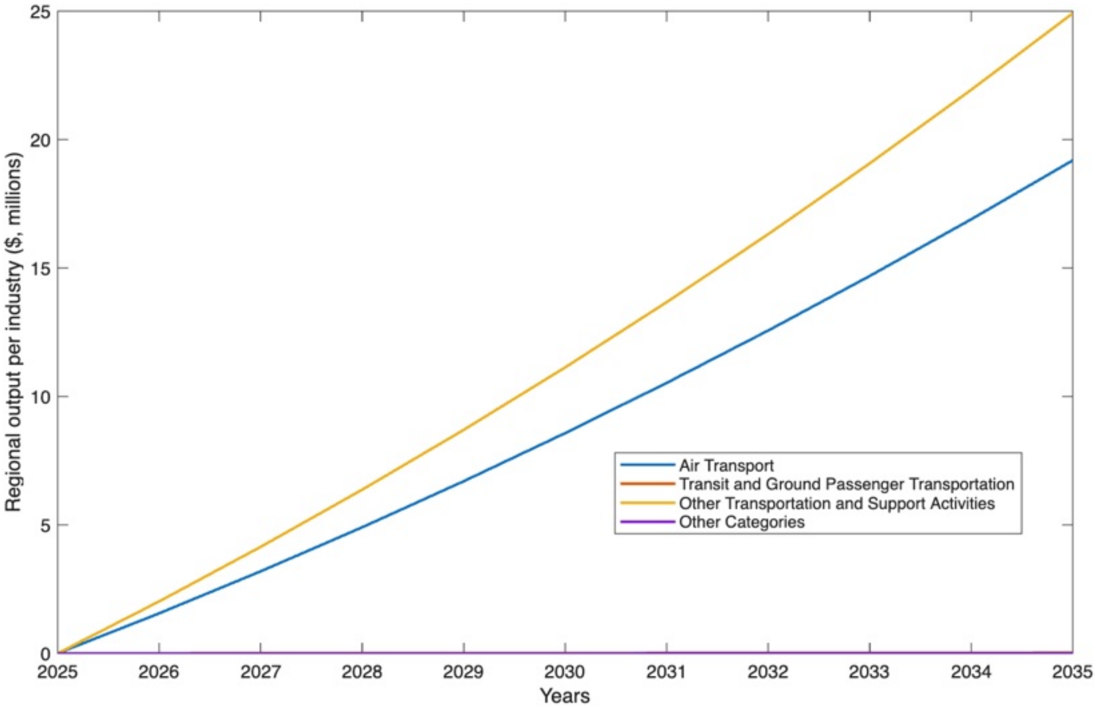


Figure 7 – Forecasted regional output per industry under positive growth conditions across all industries ($6.04 per mile charge).

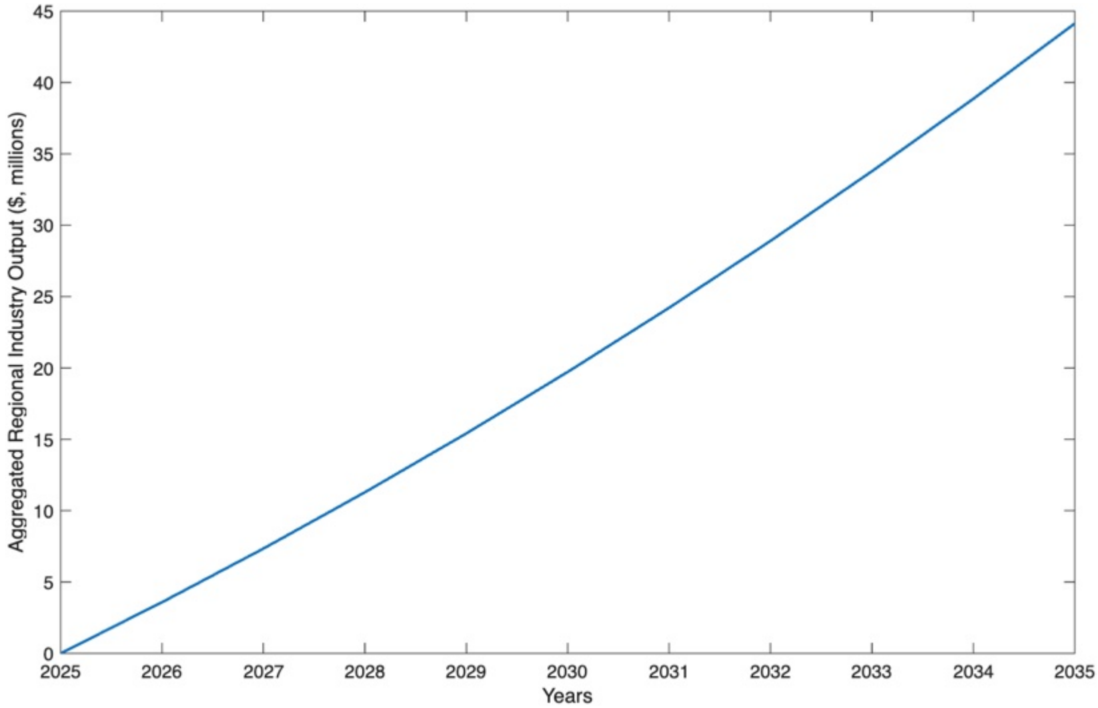


Figure 8 – Forecasted Aggregated Regional Industry Output netting a positive output in all industries ($6.04 per mile charge).

4.3. Visualization of DTW Approach Corridors

We execute the Python program described in Section 3.3 and use Google Earth to visualize the runway approach procedures at DTW for the three main configurations: south flow (Runways 22R, 22L, and 21R) shown in Figure 9, north flow (Runways 4L, 4R, and 3R), and west flow (Runways 27L and 27R). The eVTOL trajectories we propose next are for the south flow configuration at DTW.

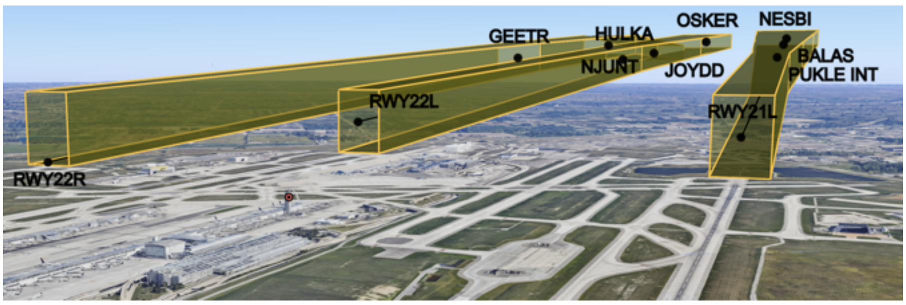


Figure 9 – Perspective view of current approach corridors for (from left to right) runways 22R, 22L, and 21R at DTW.

To visualize the most space-constrained scenario, we choose the non-parallel runway operations (PRM) IFR approach, whose looser separation minimums expand the volume of the approach corridor and therefore give a conservative bound on the airspace occupied by commercial traffic. The reconstructed corridors are then overlaid on both the 2D Leaflet planner (Figure 10) and the 3D trajectory viewer, so that candidate routes can be designed directly against the corridor and Class B boundaries.

4.4. Candidate eVTOL Trajectories for South Flow Operations at DTW

The first step in trajectory design is visualizing the space available for eVTOL operations, which are constrained by existing air traffic (arrival corridors) and Class B airspace. To this end, we overlay these visualizations onto an interactive trajectory planning canvas (Figure 10).

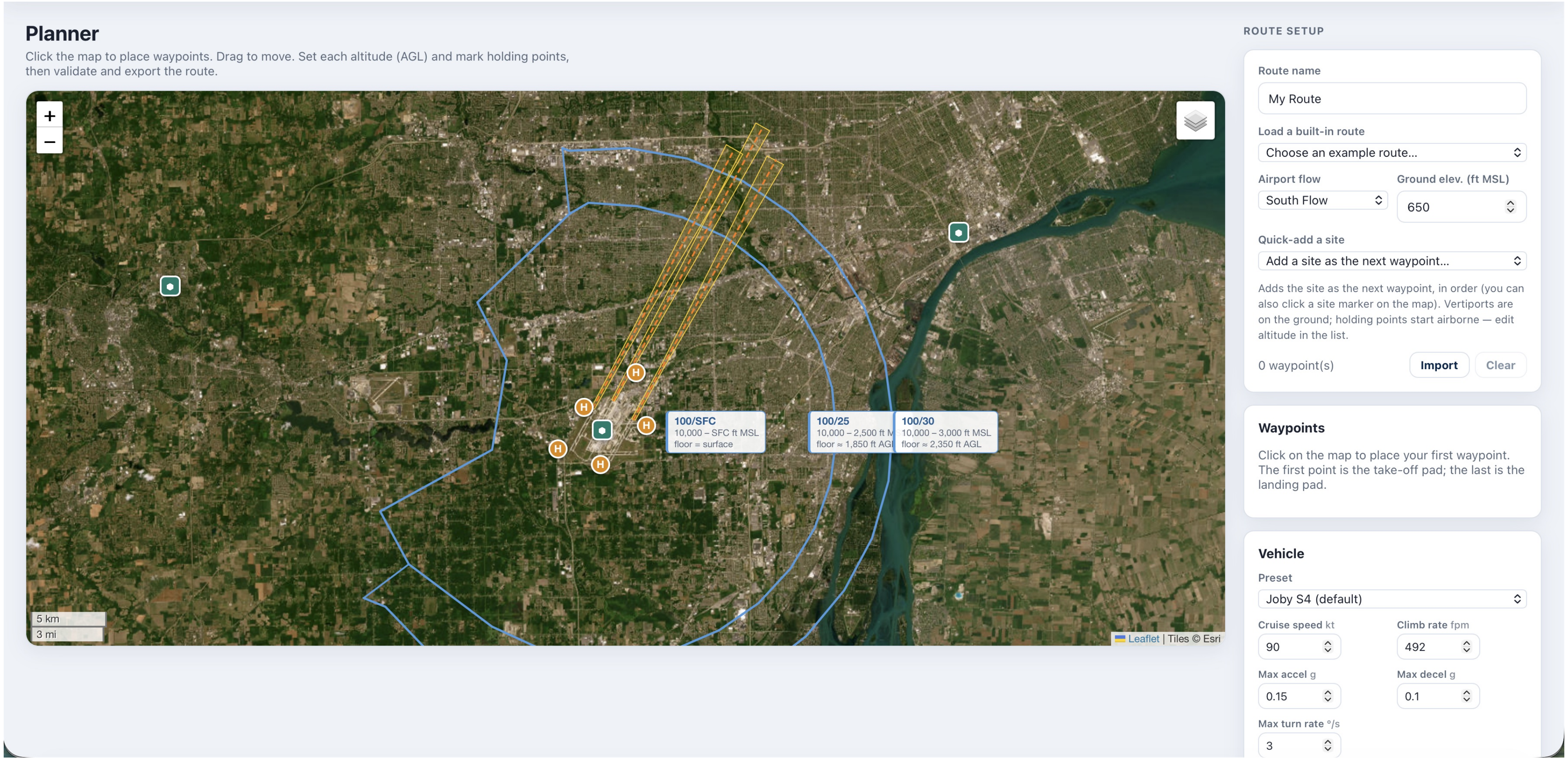
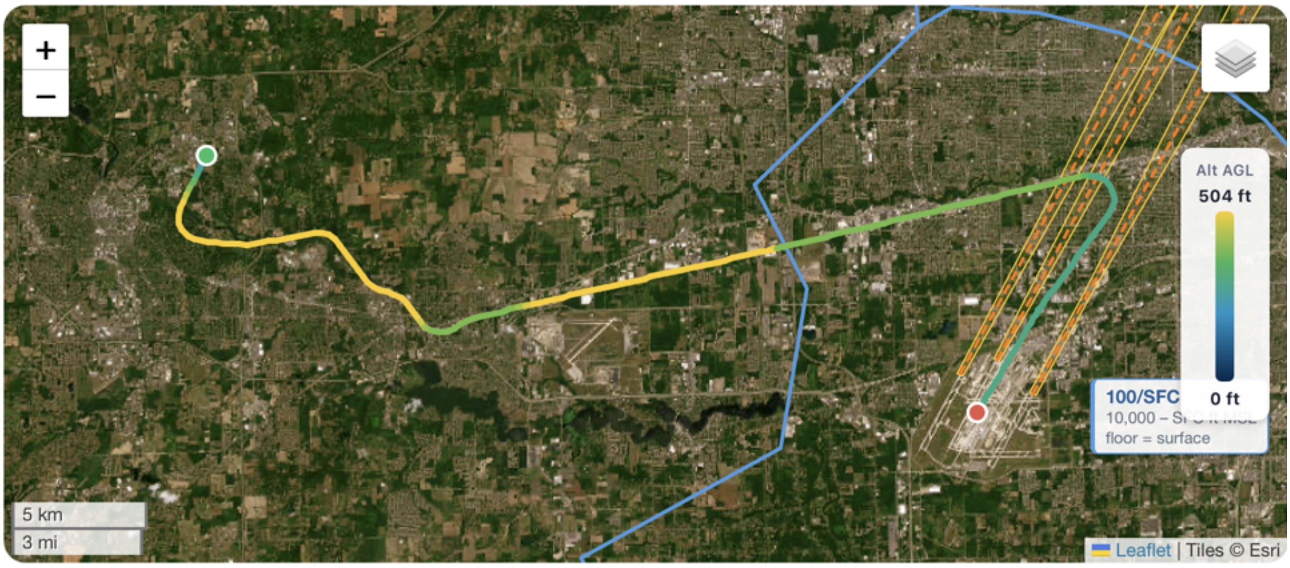


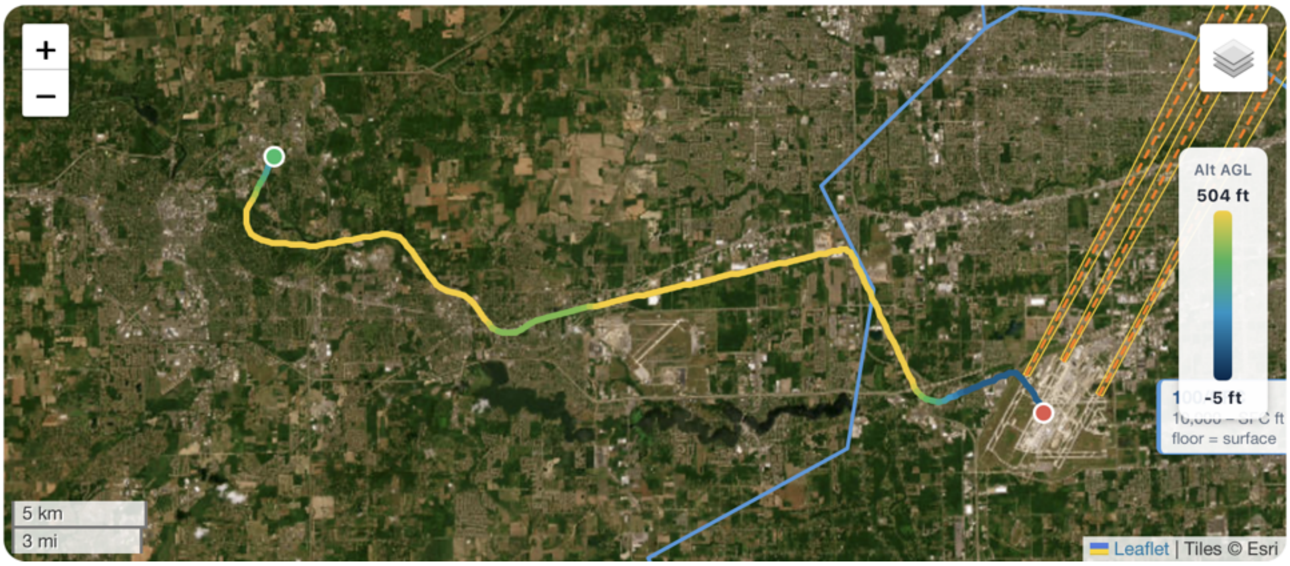
Figure 10 – Leaflet planner: arrival corridors and the two innermost DTW Class B shelves (8 NM surface core and 10 NM 2,500 ft shelf) are overlaid so the user can place waypoints in the low-altitude gaps and route to the Concourse C vertiport.

The user can choose to display North, South, and West flow configurations at DTW. The Class B airspace surrounding DTW consists of several stacked shelves; we render the two innermost shelves, which are also the most important to consider for eVTOL operations: a surface core out to 8 NM (floor at the surface, ceiling 10,000 ft MSL) and the first outer shelf out to 10 NM (floor 2,500 ft MSL, ceiling 10,000 ft MSL). Overlaying reconstructed commercial arrival corridors with the Class B geometry reveals the low-altitude airspace volumes that remain outside the high-occupancy PRM zones used by Part 121 traffic. These interstitial volumes represent potential entry and exit corridors for eVTOL operations.

Using this constraint map, we design two reference passenger routes that follow the proposed BVLOS air taxi corridors to connect the vertiport at DTW's Concourse C apron with two urban vertiports: MCity in Ann Arbor and Michigan Central Station in Detroit. The Ann Arbor route approaches from the west and remains laterally offset from the Runway 22R arrival corridor (Figure 11), while the Detroit route approaches from the northeast through lower-altitude sectors that are seldom occupied by current arrival traffic (Figure 12).



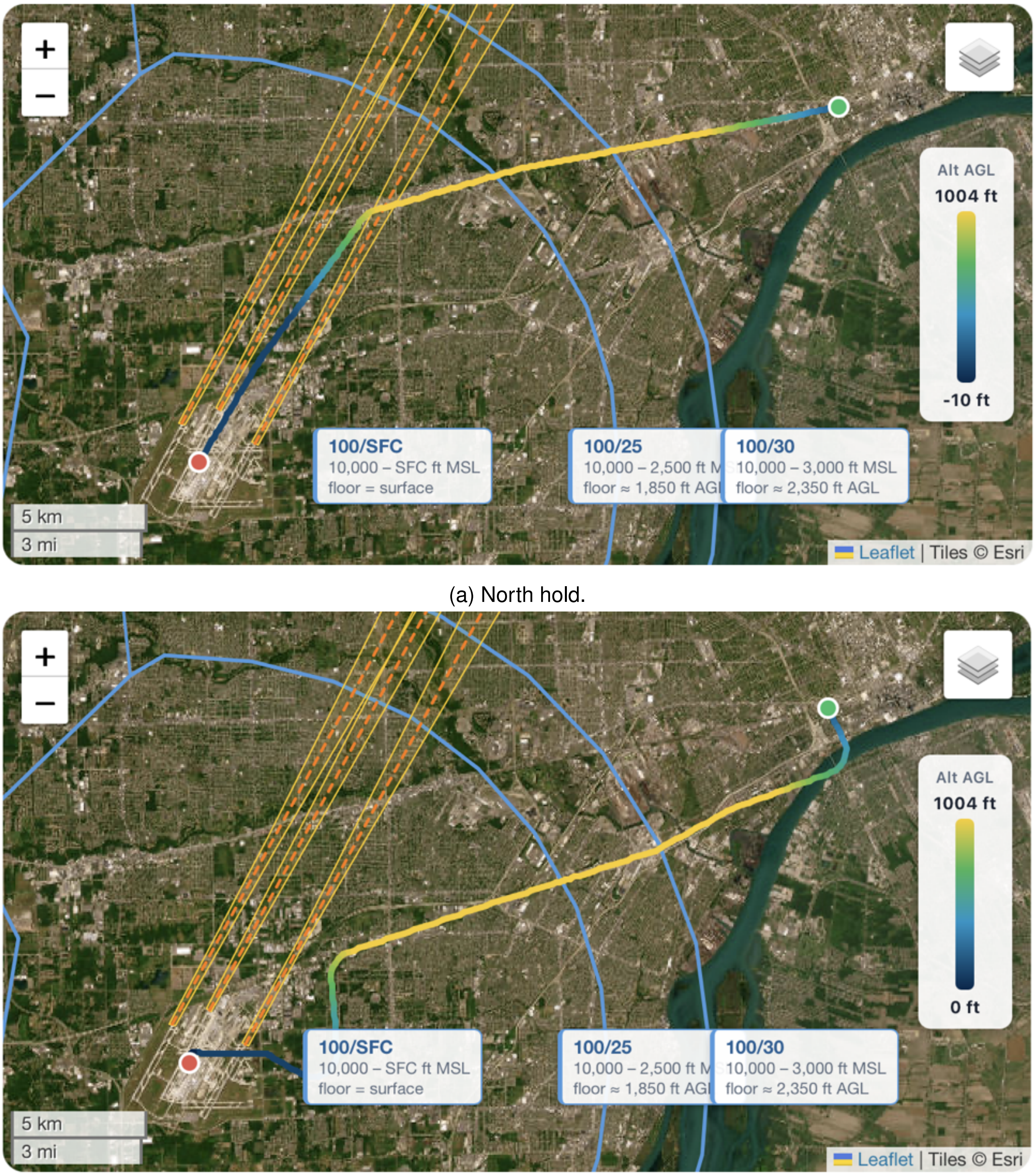
(a) North hold.



(b) West hold.

Figure 11 – Candidate eVTOL trajectories from Ann Arbor to the Concourse C vertiport at DTW. Routes are displayed in the GUI's "Plan" view and overlaid on DTW approach corridors (shaded yellow polygons) and Class B boundaries (blue lines).

Both routes are designed to remain beneath the commercial traffic operating within the Class B airspace. Overlaying the proposed trajectories with arrival corridors and Class B boundaries allows route designers to verify that adequate separation exists between eVTOL operations and existing commercial traffic.



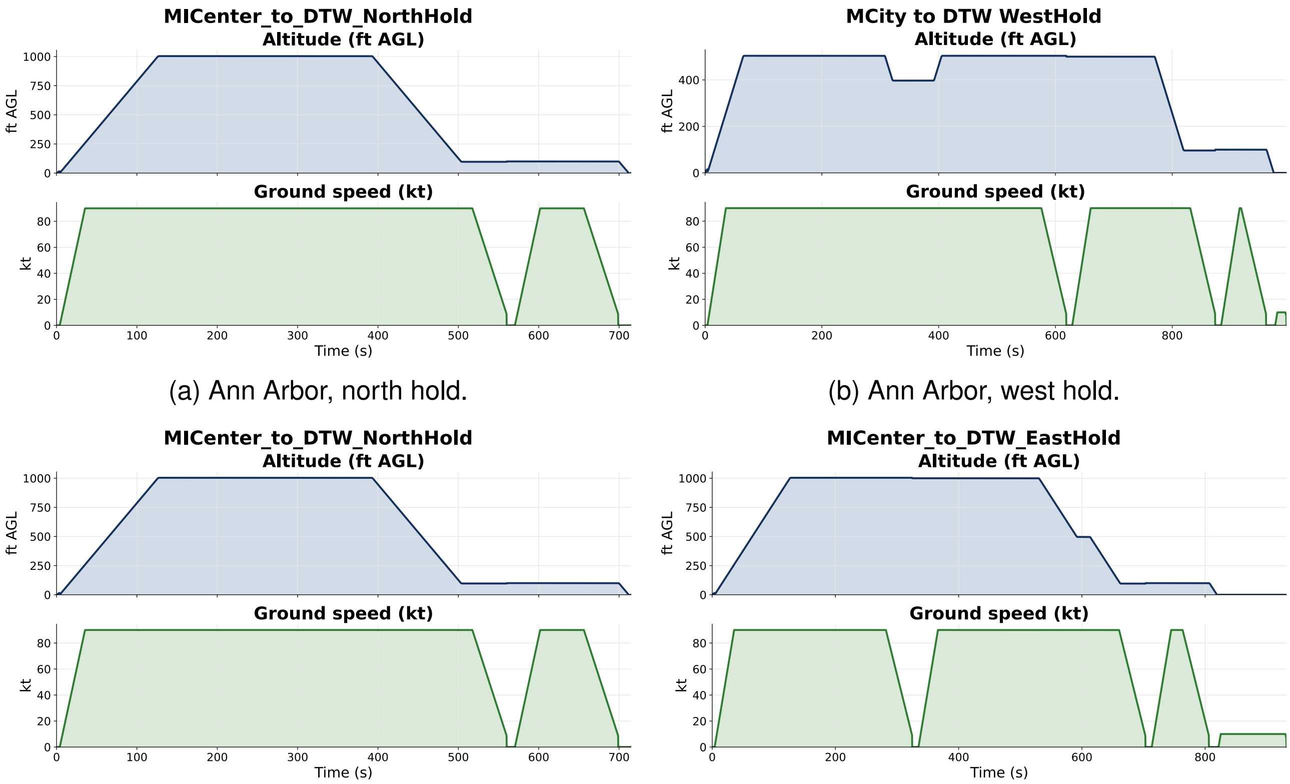
(a) North hold.

(b) East hold.

Figure 12 – Candidate eVTOL trajectories from Detroit to the Concourse C vertiport at DTW.

To provide temporal spacing before final approach, each route incorporates a holding fix located near the airport. The planner offers several candidate holding sites positioned north, west, or east of DTW. Candidate fixes are selected according to two operational criteria: (i) they are located above largely unpopulated green space, providing a contingency landing area should an aircraft be required to

hold beyond its planned energy reserve, and (ii) they remain sufficiently close to the airport to allow ATCOs to maintain visual awareness of the aircraft during the hold. For each origin, we evaluate two holding strategies: a north hold and a lateral hold (west for the Ann Arbor route and east for the Detroit route). Applying these holding strategies to the two baseline routes yields the four candidate trajectories summarized in Table 2 and shown in Figures 11 and 12.
All four trajectories remain within the Joby S4 performance envelope, cruising at 90 kt with peak altitudes between 1003 and 2005 ft AGL and transit times between 701 and 1200 s. The corresponding altitude and groundspeed profiles are shown in Figure 13. In each case, groundspeed decreases to zero at the holding fix before the aircraft proceeds to the Concourse C vertiport.



(a) Ann Arbor, north hold.

(b) Ann Arbor, west hold.

(c) Detroit, north hold.

(d) Detroit, east hold.

Figure 13 – Altitude (AGL) and groundspeed profiles for the four candidate routes. Groundspeed drops to zero at each holding fix.

Table 2 – Summary of the four candidate eVTOL routes to the Concourse C vertiport at DTW.

Origin	Hold	WP	Duration	Max alt (ft AGL)	Max GS (kt)
Ann Arbor (MCity)	North	13	20 min 24 sec	1153.7	90
Ann Arbor (MCity)	West	14	16 min 36 sec	1153.7	90
Detroit (MI Central)	North	8	11 min 55 sec	1653.9	90
Detroit (MI Central)	East	14	15 min 32 sec	1653.9	90

The four candidate routes show that feasible, deconflicted corridors exist within the interstitial low-altitude airspace at DTW, even under the conservative PRM corridor geometry. The two holding strategies expose a clear operational trade-off rather than a single best option, summarized in Table 3. Under a representative south-flow configuration, a north hold positions the eVTOL in trail of the primary arrival and departure streams, increasing exposure to wake turbulence generated by preceding heavy aircraft. In contrast, a lateral hold places the aircraft abeam the active runway and clear of the main traffic flow, functioning similarly to an airborne holding area adjacent to the runway. The aircraft remains in this position until a suitable gap appears in arrival and departure traffic, at which point it

Table 3 – Operational comparison of the north and lateral (west/east) holding strategies.

	North hold	West / East hold
Holding position	North of the field, in trail of the main flow	Abeam the runway, laterally clear of the active flow
Impact on eVTOL	Sequencing behind the primary stream	Airborne hold short of the runway in use
Wake turbulence	Higher exposure to wake of preceding heavy traffic	Lower exposure due to lateral offset
Advantages	No need to wait for a gap in arrivals/departures: eVTOL trajectory does not conflict with runway	Reduced exposure to wake turbulence
Disadvantages	Wake separation behind heavy traffic may add in-trail delay	Must wait for an adequate gap in runway traffic to cross to Concourse C

crosses toward Concourse C. This arrangement reduces wake-turbulence exposure but ties the timing of the final approach to runway traffic availability and requires more precise lateral spacing and sequencing near the runway. Route duration is influenced by both origin location and hold geometry. For the Ann Arbor route, the west hold produces a shorter transit time than the north hold (995.6 s versus 1234.2 s), whereas for the Detroit route the north hold is shorter than the east hold (714.6 s versus 932.0 s). However, the introduction of a runway crossing with the lateral hold introduces a significant drawback: a controller would likely need to issue a clearance to the eVTOL to cross an active runway. This is an especially significant drawback to consider, as increased controller workload is cited as one of the major concerns with eVTOL operations at Class B airports [6, 16]. In contrast, a north hold configuration directs the eVTOL in between active runways and only requires the crossing of an inactive crosswind runway to arrive at Concourse C. Because an active runway is avoided in this scenario, a preestablished coordination agreement—or letter of agreement (LOA)—could in theory be implemented to offload clearance and monitoring burden from the ATCO [6], similar to LOAs that enables certain operations staff at airports to cross runways without a clearance from ATC.

4.5. GUI for Airspace Visualization and Trajectory Planning for eVTOL Airport Shuttle

We design a GUI to enable stakeholders (e.g., FAA airspace planners, human factors researchers, etc) to visualize airspace relevant to eVTOL operations at a Class B airport and overlay proposed eVTOL trajectories alongside arrival corridors to explore the design space of possible trajectories and explore the spatial constraints associated with each trajectory. The end-to-end workflow begins with the user sketching a route between the city and airport on a map. The kinematic model validates this route and highlights infeasible waypoints. Next, the engine produces the smoothed trajectory, and passes it to the viewer, enabling the user to visualize the eVTOL following the trajectory in 2D and 3D perspectives alongside altitude and groundspeed profiles. This workflow supports both the development of kinematically feasible trajectories (e.g., conforming to the speed, acceleration, and turn limits outlined in Section 3.4.2) and an interactive/intuitive platform that visualizes trajectories in the geographical context in which they are proposed.

Beyond the trajectory planning canvas (where the user places, drags, and edits waypoints), several perspectives are provided, enabling the stakeholder to view trajectories from two operationally meaningful perspectives: the tower and onboard view. The tower view fixes the camera at the DTW control tower cab and tracks the eVTOL through its arrival (Figure 14), reproducing what a tower controller would see. The onboard view places the camera in a chase position behind the aircraft (Figure 15), giving a pilot or passenger perspective of the descent and final approach to the Concourse C pad. This also gives spatial clarity on the separation between the eVTOL and existing aircraft operations.

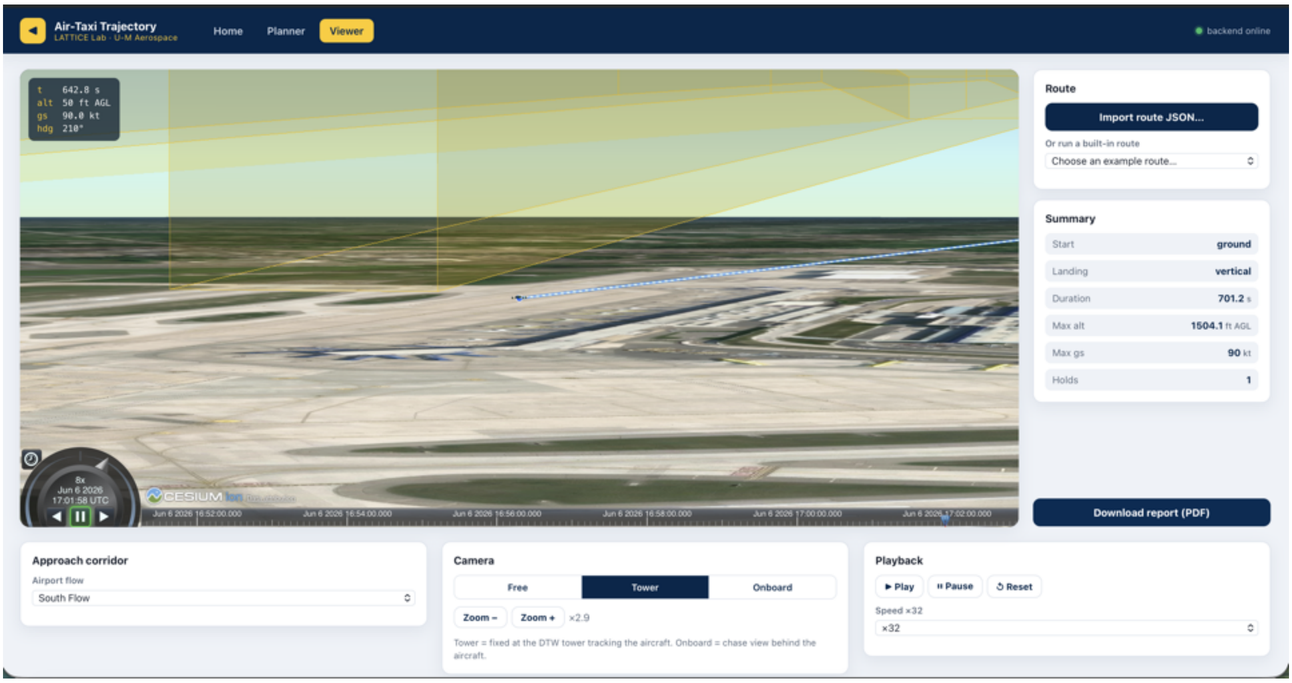


Figure 14 – CesiumJS viewer with the tower view fixed at the DTW control tower, tracking an eVTOL on final approach to Concourse C.

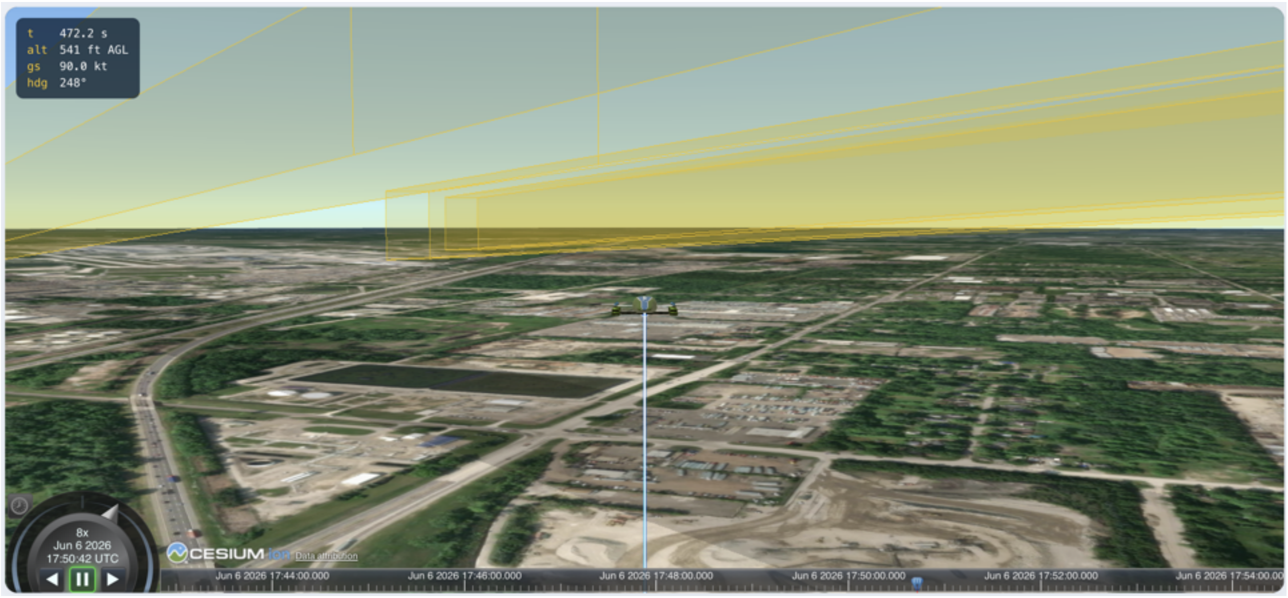


Figure 15 – Onboard chase view: pilot/passenger perspective of an eVTOL on final approach to the Concourse C pad at DTW.

These two screen-based perspectives are the foundation for a future extension to an immersive extended-reality (XR/VR) tower environment, which carries the same controller and pilot viewpoints into a headset for higher situational fidelity. This also supports future human-in-the-loop studies to address various considerations associated with eVTOL operations, including perceptual challenges with the aircraft type and evaluations of which AI-based decision aids reduce ATCO task complexity or workload.

5. Conclusion

In this manuscript, we examined some of the key integration challenges associated with introducing air taxi operations between major cities (Ann Arbor, Detroit) and a hub airport (DTW). More specifically, we constructed a 3D view of the current state of operations at the airport by visualizing aircraft arrival corridors and proposed kinematically feasible trajectories that minimize deconfliction with these existing operations. While designing these trajectories, we examined key operational and human factors tradeoffs, including exposure to wake turbulence, mitigating ATCO workload through avoidance of crossing active runways, and spacing requirements. An interactive GUI enables stakeholders to visualize these trajectories and associated tradeoffs in an accessible manner. Collectively, these contributions establish a foundation for future operational evaluations of eVTOL-based airport shuttles and provide a framework for assessing AAM integration at other major airports.

There are several promising directions for future work, which both address the limitations of our study and build upon our existing work. The eVTOL trajectories presented in this manuscript relied on point-mass kinematic models, which do not capture the complete flight dynamics of eVTOLs, and thus may affect which trajectories are indeed feasible. To this end, future work could model more complete flight dynamics by including an energy model that captures battery endurance during holds, so that all maneuvers stay within the operational limits of current eVTOL performance envelopes. Vertical airspace boundaries could also be enforced directly in the kinematics engine so that arrival and departure profiles maintain safe vertical buffers from the commercial glideslopes and Class B shelves, rather than being verified only against a horizontal overlay. Furthermore, because our work only modeled eVTOL trajectories in still-air performance, future work could introduce weather effects, including wind speed and direction, to better represent real-world operating conditions. To facilitate faster and less erroneous route creation under the 884 m minimum turn radius, future extensions could automatically insert intermediate waypoints where the current manual spacing would otherwise cause the path to diverge. Finally, the tool currently models a single aircraft at a time; extending support to multiple simultaneous flights would enable analysis of further operational and air traffic considerations, including the impact of trajectories on deconfliction, scheduling between concurrent eVTOL operations, and interactions with existing commercial air traffic.

Furthermore, the visualizations developed in this work provide a foundation for constructing a high-fidelity representation of this future airspace environment in XR. By transferring the existing tower and onboard perspectives into an immersive XR environment, researchers and stakeholders could evaluate proposed procedures in a more ecologically valid setting and gain greater insight into the spatial and perceptual challenges associated with eVTOL operations. Such an environment would also enable human-in-the-loop studies examining controller workload, situational awareness, and the detectability of eVTOL aircraft in complex traffic scenarios. Furthermore, it would provide a testbed for prototyping and evaluating AI-enabled decision-support tools that assist ATCOs with traffic monitoring, conflict detection, and workload management as airport operations become increasingly complex. Together, these capabilities would support the safe and scalable integration of eVTOL aircraft into future airport ecosystems and the broader National Airspace System.

Code and Data Availability

The trajectory planning and visualization tool developed in this work is openly available at `https://github.com/jasonr2020/airtaxi-trajectory-visualization`. The repository includes the FastAPI simulation backend, the React frontend, and the example routes used in this study.

Acknowledgments

We would like to acknowledge M-air for helpful discussions related to this project.

The web-based planning and visualization tool was developed with the assistance of an AI coding assistant (Anthropic Claude). All design decisions, validation, and results were carried out and verified by the authors.

The authors used a large language model (Gemini, Google) to assist with methodological brainstorming, code debugging, and fine-tuning for clarity of exposition pertaining to the economic input-output analysis. All methodological and design decisions, software development, validation, source selection and incorporation, and results were carried out and independently verified by the authors.

Contact Author Email Address

Corresponding author: smabdul@umich.edu

6. Copyright Statement

References

[1] FAA. Air Traffic By The Numbers, 2025.

[2] International Air Transport Association (IATA). Global Outlook for Air Transport. Technical report, International Air Transport Association (IATA), June 2023.

[3] Skip the traffic with an electric air taxi, 2025. Accessed: 2026-01-10.

[4] Rohit Goyal and others. Urban Air Mobility (UAM) Market Study. Technical report, NASA / Booz Allen Hamilton, November 2018.

[5] Pierluigi Coppola, Francesco De Fabiis, and Fulvio Silvestri. Urban air mobility (uam): Airport shuttles or city-taxis? *Transport Policy*, 150:24–34, 2024.

[6] Savvy Verma, Victoria Dulchinos, Richard Mogford, Robert D Wood, Amir Farrahi, Rania Ghatas, Eric Mueller, Tom Prevot, Karl Schulz, Kellen Mollahan, et al. Near term urban air mobility use cases in the dallas fort-worth area. 2022.

[7] U.S. Census Bureau. Quickfacts: Detroit city, michigan, 2025.

[8] U.S. Census Bureau. Metropolitan and micropolitan statistical areas population totals and components of change, 2024. Detroit–Warren–Dearborn, MI Metropolitan Statistical Area.

[9] Harvard Growth Lab. Metroverse: Economic composition, 2026.

[10] U.S. Census Bureau. Quickfacts: Ann arbor city, michigan, 2025.

[11] University of Michigan. Facts and figures, 2025.

[12] Executive Office of the Governor. Executive directive 2025-4: Establishing the michigan advanced air mobility initiative, July 2025. State of Michigan Executive Directive.

[13] Kate McAlpine. New Air Mobility Corridor to Advance eVTOLs and Beyond-Line-of-Sight UAVs. *Michigan Engineering News*, July 2025.

[14] Federal Aviation Administration, U.S. Department of Transportation. Electric Vertical Takeoff and Landing and Advanced Air Mobility Integration Pilot Program: Announcement of Establishment of Program and Request for Proposals, September 2025. Published: Federal Register, Vol. 90, No. 177, pp. 44751–44753.

[15] Federal Aviation Administration. Normalizing Unmanned Aircraft Systems Beyond Visual Line of Sight Operations: Notice of Proposed Rulemaking (BVLOS NPRM), 2025.

[16] Raja Sengupta, Vishwanath Bulusu, Chams Eddine Mballo, Emin Burak Onat, and Shangqing Cao. Urban air mobility research challenges and opportunities. *Annual Review of Control, Robotics, and Autonomous Systems*, 8(1):407–431, 2025.

[17] Mihir Rimjha, Susan Hotle, Antonio Trani, Nicholas Hinze, and Jerry C. Smith. Urban air mobility demand estimation for airport access: A los angeles international airport case study. In *2021 Integrated Communications Navigation and Surveillance Conference (ICNS)*, pages 1–15, 2021.

[18] Jong Hae Choi and Yonghwa Park. Exploring economic feasibility for airport shuttle service of urban air mobility (uam). *Transportation Research Part A: Policy and Practice*, 162:267–281, 2022.

[19] Pavan S Yedavalli, Emin Onat, Xin Peng, Raja Sengupta, Paul Waddell, Vishwanath Bulusu, and Min Xue. Assessing the value of urban air mobility through metropolitan-scale microsimulation: A case study of the san francisco bay area. In *AIAA Aviation 2021 Forum*, page 2338, 2021.

[20] Mengying Fu, Raoul Rothfeld, and Constantinos Antoniou. Exploring preferences for transportation modes in an urban air mobility environment: Munich case study. *Transportation Research Record*, 2673(10):427–442, 2019.

[21] Airbus, Groupe ADP, and RATP Group. Airbus, groupe adp and the ratp group sign a partnership to study the integration of flying vehicles into urban transport. Press Release, June 2019. Accessed: 2026-06-09.

[22] Zhiqiang Wu and Yu Zhang. Integrated network design and demand forecast for on-demand urban air mobility. *Engineering*, 7(4):473–487, 2021.

[23] David Hünemohr, Maximilian Bauer, Jan Kleikemper, and Markus Peukert. Analysis of helicopter flights in urban environments for uav traffic management. *Engineering Proceedings*, 28(1), 2022.

[24] Chananya Charnsethikul, Jose M. Silva, Wim J. C. Verhagen, and Raj Das. Urban air mobility aircraft operations in urban environments: A review of potential safety risks. *Aerospace*, 12(4), 2025.

[25] J. Strives et al. Generic urban air mobility (GUAM) simulation framework for autonomous transition vehicles. Technical report, National Aeronautics and Space Administration, NASA Langley Research Center, 2025.

[26] S. S. Chauhan and J. R. R. A. Martins. Tilt-wing eVTOL takeoff trajectory optimization under passenger comfort constraints. Technical report, University of Michigan, Multidisciplinary Design Optimization Laboratory, 2020.

[27] AAM Research Group. Corridor design and separation definition in advanced air mobility: Systematic literature review. *IEEE Transactions on Intelligent Transportation Systems*, 27(2):112–128, 2026.

[28] N. Kundu et al. Trajectory generation based on power and kinematic constraints for urban air mobility. *Frontiers in Aerospace Engineering*, 2:1278726, 2023.

[29] D. G. Hull. *Optimal Control Theory with Aerospace Applications*. Springer, New York, NY, 2003. Chapter 4: Aircraft Flight Mechanics Point-Mass Approximations.

[30] U.S. Census Bureau. County population totals and components of change: 2020-2024, Mar 2025.

[31] Wayne County Airport Authority. 2024 annual comprehensive financial report, Dec 2024.

[32] Wayne County Airport Authority. Detroit metropolitan airport (dtw) enplaned passengers by month (by calendar year), 2024.

[33] Transportation Research Board, National Academies of Sciences, Engineering,, and Medicine. *Clean Vehicles, Fuels, and Practices for Airport Private Ground Transportation Providers*. The National Academies Press, Washington, DC, 2018.

[34] Ben Goldstein. How u.s. airlines are preparing to offer air taxi service, Dec 2024.

[35] Matthew A. Coogan. Ground access to major airports by public transportation. Technical Report ACRP Report 4, Transportation Research Board, 2008.

[36] Randall Jackson. *Input-Output Analysis: A Primer, 2nd ed.* West Virginia University, 2020.

[37] Karen Horowitz and Mark Planting. *Concepts and Methods of the Input-Output Accounts*. U.S. Bureau of Economic Analysis of the U.S. Department of Commerce, 2006.

[38] Eric Mueller. Integrating evtols at commercial airports, 2026.

[39] Michael Nealy. Commodity output or industry output.

[40] George Swisko. A note on scrap in the 1992 u.s. input-output tables. Technical Report 00-313, U.S. Department of the Interior U.S. Geological Survey, 2000.

[41] Ming Liu, Han Hao, Yong Geng, Hao Dou, Xin Sun, Fanlong Bai, Xiaobo Qu, Kai Wang, Zongwei Liu, and Fuquan Zhao. Adopting electric vertical takeoff and landing aircraft for green transport transformation. *Fundamental Research*, 2025.

[42] Ye Liang, Wei Zhang, and Li Chengjiang. Assessing the deployment of electric aircraft from energy, environmental, and economic perspectives. *Sustainability*, 17, 2025.

[43] Gary Locke, Rebecca Blank, J. Steven Landefeld, and Mary Streitweiser. Measuring the nation's economy: An industry perspective. Technical report, Bureau of Economic Analysi, U.S. Department of Commerce, 2011.

[44] Ronald Miller and Peter Blair. *Input-Output Analysis: Foundations and Extensions*. Cambridge University Press, 2009.

[45] Manfred Hader, Sven Kopera, Stephan Baur, Kolin Schunck, Jan Pertz, Malte Niklaß, Majed Swaid, and Volker Gollnick. Advanced air mobility on the runway to commercialization: A close look at evtol unit economics. Technical report, German Aerospace Center and Roland Berger, 2024.

[46] Government of Canada. North american industry classification system (naics) canada 2022 version 1.0, 2022.

[47] Government of Canada. North american industry classification system (naics) canada 2022 version 1.0, 2022.

[48] Sen Wang, Ningning Nicole Kong, Volodymyr Bilotkach, Fecri Karanki, and Yi Gao. What drives the dynamics of airport parking revenues? a panel study of u.s. airports. *Research in Transportation Business & Management*, 2025.

[49] Detroit Metro Airport. Long term parking.

[50] William J. Mallett. Long-distance travel by low-income households. In *The Long and Short of It*, number E-C026. Transportation Research Board, 2001.

[51] NAICS Association. Naics code description.

[52] Bureau of Economic Analysis. Interactive access to input-output accounts data.

[53] Timothy J. Kehoe. Comparative statics. In John Eatwell, Murray Milgate, and Peter Newman, editors, *General Equilibrium*, The New Palgrave, pages 76–83. Springer Nature, London, United Kingdom, 1989.

[54] Bureau of Economic Analysis. Purchasers' prices.

[55] Bureau of Economic Analysis. Producers' prices.

[56] Bureau of Economic Analysis. Bea data application programming interface (api).

[57] Bureau of Economic Analysis. Gross domestic product by state and personal income by state release—additional information.

[58] Rubén Martínez-Alpañez, José Daniel Buendía-Azorín, and María del Mar Sánchez-de-la Vega. A new improvement proposal to estimate regional input–output structure using the 2d-lq approach. *Economies*, 11(1):20, 2023.

[59] Bureau of Labor Statistics. Quarterly census of employment and wages.

[60] U.S. Department of Transportation, Federal Aviation Administration. 28 Day NASR Subscription, 2025.

[61] William Su, Jordan Kam, and Dr Vishwanath Bulusu. A flight simulator software for visualization of 3-dimensional airspaces and air traffic management. In *2025 Regional Student Conferences*, page 97940, 2025.

[62] Federal Aviation Administration. *Aeronautical Information Manual*. U.S. Department of Transportation, 2026.

[63] Federal Aviation Administration. United states standard for terminal instrument procedures (TERPS), FAA Order 8260.3F. Technical report, U.S. Department of Transportation, 2023.

[64] Federal Aviation Administration. Air traffic control, FAA Order JO 7110.65Z. Technical report, U.S. Department of Transportation, 2024.

[65] National Aeronautics and Space Administration. Urban air mobility (UAM) concept of operations, blueprint v2.0. Technical report, NASA, 2023.

[66] Francesco Vona, Julia Schorlemmer, Michael Stern, Navid Ashrafi, Maurizio Vergari, Tanja Kojic, and Jan-Niklas Voigt-Antons. Comparing Pass-Through Quality of Mixed Reality Devices: A User Experience Study During Real-World Tasks. In *2025 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pages 1432–1433, March 2025.

[67] National Academies of Sciences, Engineering, and Medicine. *Clean Vehicles, Fuels, and Practices for Airport Private Ground Transportation Providers*. Airport Cooperative Research Program (ACRP) Synthesis 89. The National Academies Press, Washington, DC, 2018.