

Aeropulse

A Network of Drones with Autonomous, AI-Driven Robotic Payloads to Optimize Delivery of Medical Perishables Across Urban Hospitals

** All authors contributed equally to this memo. The names are listed alphabetically by last name.*

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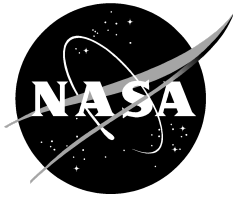
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Abstract

Each year in the United States, hundreds of lives are lost because organs, tissues, and critical medicines fail to arrive on time, often due to transportation delays, excessive handoffs, and human error. Aeropulse addresses these challenges by providing a fully autonomous, end-to-end delivery system that combines vertical takeoff and landing (VTOL) drones for inter-hospital transport with autonomous ground robots for internal hospital navigation.

The system is modeled to complete intra-regional, hospital-to-hospital deliveries in under 40 minutes, achieving a 40–50% reduction in transport time compared to current methods.

Following clinical packaging and mission authorization, the nearest available drone is dispatched from its charging station and flies to the origin hospital. Meanwhile, the ground robot begins the first-mile segment, navigating from the origin room to the hospital's rooftop, where the drone performs a tethered hoist pickup of the robot containing the medical payload. The drone then transports the robot to the destination hospital's rooftop, where the ground robot detaches and begins its last-mile internal navigation to the target room.

Inside the hospital, the robot follows color-coded LED virtual tracks while directly interfacing with building infrastructure such as elevator systems, door controls, and facility networks. Advanced sensors and autonomous navigation enable secure and efficient access throughout the hospital without requiring staff intervention, while integrated climate control systems preserve the integrity of temperature-sensitive medical supplies. The entire process operates autonomously, eliminating manual handoffs.

By seamlessly integrating aerial and ground robotics, Aeropulse offers a rapid, reliable solution for transporting time-critical medical perishables, with the potential to save lives by improving transplant success rates and reducing preventable mortality.

Introduction

Critical medical shipments, including organs, lab samples, and urgent medicines, often fail to reach their destinations on time, placing patient lives at risk. A United Network for Organ Sharing (UNOS) review of approximately 8,800 organ shipments between 2014 and 2019 revealed alarming statistics: nearly 170 organs were discarded entirely, and another 370 faced “near misses” due to transportation delays of two hours or more [1]. Even smaller setbacks can have disproportionate consequences. For instance, every 15-minute delay in delivering tissue plasminogen activator (tPA), a critical stroke medication, increases the likelihood of long-term disability by 5 percent [2]. Similarly, any interruption in the transport of transplant organs compromises their viability, reduces surgical success rates, and jeopardizes patient outcomes [3, 4]. In an area where every minute counts, reliability is not optional but essential.

Despite this urgency, today’s transportation system is fragmented and inefficient. Most transfers rely on human couriers navigating congested roads or ambulances that can be slowed by traffic, road closures, and weather. Helicopters, though faster, are prohibitively expensive and used in fewer than 3 percent of cases nationwide [5]. As shown in Figure 1, the hospital-to-hospital transport chain involves multiple transitions: courier to vehicle, vehicle to hospital intake, and intake to laboratory or operating room. Each handoff introduces new opportunities for miscommunication, mishandling, or delay, compounding the risk of failure at the worst possible time.

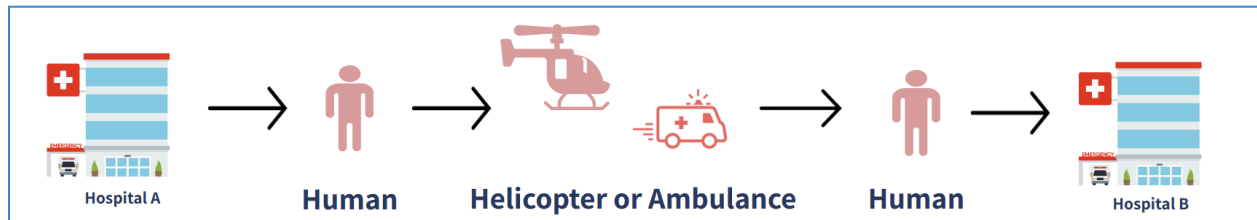


Figure 1. Current hospital-to-hospital transport system of medical perishables showing multiple handoffs and vehicle transitions

The vulnerabilities of the current system can be traced to three primary categories of delays. First, logistical and human errors remain widespread, ranging from mislabeling and poor courier coordination [6, 7]. Packages are also frequently left unattended or misrouted, an issue noted in the description of organ transport practices [8] and reinforced by recent incident reports [9, 10]. Second, external constraints such as road congestion and limited availability of trained pilots further slow transport [11, 12]. Finally, internal hospital bottlenecks such as crowded corridors, slow elevator access, and understaffed intake departments, introduce additional layers of delay [13]. Collectively, these factors create an unreliable and inconsistent network for transporting the most time-sensitive medical materials.

Innovations in unmanned aerial systems (UAS) offer a potential paradigm shift. Companies such as Zipline have pioneered long-range drone delivery of blood and medicines in rural regions of Rwanda and Ghana, demonstrating high reliability in challenging environments [14]. However, no comparable solution has been tailored to the dense, complex airspace and infrastructure of urban U.S. environments, where the majority of transplant and advanced care centers are located.

To address this critical gap, we propose Aeropulse, a fully autonomous, end-to-end delivery system capable of integrating both aerial and ground robotics to ensure rapid, secure, and consistent transport of medical perishables. Aeropulse is designed to complete hospital-to-hospital deliveries in under 40 minutes, a performance benchmark informed by both clinical and experimental data. This target builds on milestones such as the University of Maryland’s pioneering organ drone flight test [15] and early clinical studies demonstrating that unmanned aircraft can not only deliver organs safely but also monitor their temperature, pressure, and condition in real time during flight [16]. Complementary work has shown that drones can also transport blood products effectively and safely, demonstrating their broader potential in medical logistics [17]. By fusing these advances into a cohesive system adapted for urban hospital networks, Aeropulse has the potential to transform the reliability and speed of critical medical transport.

System Overview

Our Solution

The Aeropulse system is a fully autonomous network of hybrid VTOL (vertical takeoff and landing) drones and robotic payloads designed for end-to-end transport of time-critical medical supplies without human handoffs, as shown in Figure 2. Aerial drones handle inter-hospital transit, while ground robots provide internal hospital navigation. This integration minimizes human error, removes manual transfers, and creates a seamless delivery chain. By bypassing road traffic and automating internal transport, Aeropulse is projected to reduce delivery times by 40–50 percent under typical conditions and up to 60 percent in heavy traffic (modeled; see Table 1).



Figure 2. Proposed Aeropulse solution integrating drones and autonomous robots for hospital-to-hospital transport

Proposed Pilot Implementation

The San Francisco Bay Area has been identified as the pilot deployment site due to its dense urban environment, diverse geography, and extensive hospital network. This region provides an ideal testbed for high-stakes, time-critical deliveries. The proposed network, as shown in Figure 3, includes several major trauma centers, since these are typically where the most time-critical procedures and emergency transports occur. Level I facilities, such as Zuckerberg San Francisco General Hospital, Highland Hospital, Stanford University Medical Center, and Santa Clara Valley Medical Center, provide the highest level of trauma and transplant care. Level II centers, including Eden Medical Center, Washington Hospital Healthcare System, and Regional Medical Center, also handle urgent cases but often transfer the most complex patients to Level I hospitals [18].

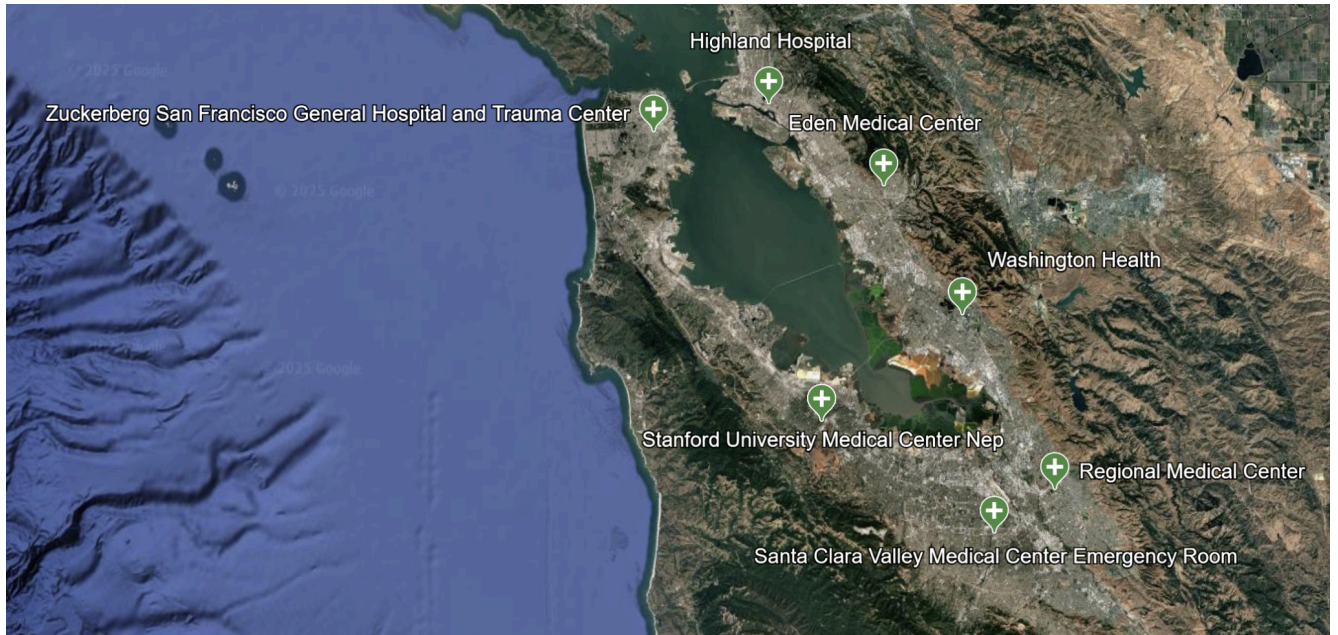


Figure 3. San Francisco Bay Area hospitals selected for proposed Aeropulse pilot deployment

Map data © Google, SIO, NOAA, U.S. Navy, NGA, GEBCO, Landsat/Copernicus, LDEO-Columbia, NSF, INEGI.

Imagery dates: 12/14/2015–1/1/2021; some visible imagery has unknown date information.

The pilot system would consist of eight hybrid VTOL drones, supported by four to five autonomous delivery robots at each participating hospital. This large-scale proof-of-concept goes beyond a traditional Minimum Viable Product (MVP), allowing comprehensive evaluation of system performance, reliability, and integration within hospital networks.

The initial deployment is estimated at \$1.38–1.51 million, leveraging existing commercial technologies to reduce development costs and timelines. The cost structure includes:

- Hybrid VTOL drones: \$100,000 each
- Autonomous delivery robots: \$15,000 each (24–32 units total)
- Secure delivery containers: \$1,000 each
- Virtual track implementation: \$10,000 per hospital
- Rooftop infrastructure: \$15,000 per facility

This estimate excludes operational, regulatory compliance, training, insurance, and maintenance costs, which will require separate analysis. The investment strategy emphasizes proven technologies with targeted modifications to enable rapid deployment at controlled cost.

Data collected during this pilot process would be used to refine routing algorithms, assess operational resilience under varying weather and traffic conditions, and optimize coordination between aerial and ground delivery components.

Expert Validation

To assess the clinical viability of Aeropulse, the team reached out to over 20 medical professionals from Level I and Level II trauma centers, as well as general-care hospitals. Dr. Yi Tang, M.D., a hospitalist specializing in Internal Medicine at Hoag Hospital in Irvine, California, provided detailed feedback on the proposed system.

Dr. Tang's assessment was positive, with the concept well-received for its efficiency compared to current transportation methods, thoughtful design, and overall feasibility. Dr. Tang suggested expanding the network to include pharmacies, nursing homes, and other high-demand environments, indicating broader market applications.

This preliminary assessment represents initial stakeholder feedback. Full system validation would require engagement with hospital administrators, aviation safety experts, and logistics professionals across multiple institutions before implementation.

Operational Scenario

To illustrate the potential performance of Aeropulse, we developed a modeled case for a time-critical scenario: transport of a donor heart from San Francisco General Hospital (SFGH) to Santa Clara Valley Medical Center (SCVMC) at 12:00 PM on a weekday under typical mid-day traffic conditions.

Process at a glance: (1) Dispatch the nearest ready drone; (2) the origin robot carries the sealed payload to the rooftop and docks to the drone; (3) the drone flies rooftop to rooftop; (4) the destination robot carries the payload to the designated room; (5) the drone is retasked and robots are redistributed as needed.

As shown in Figure 4, under current practice, ambulance transport between the two hospitals takes 40-45 minutes in light traffic. Including packaging, multiple human handoffs, and room-level delivery, the end-to-end time typically reaches about 70 minutes and can exceed 90 minutes under heavy traffic.

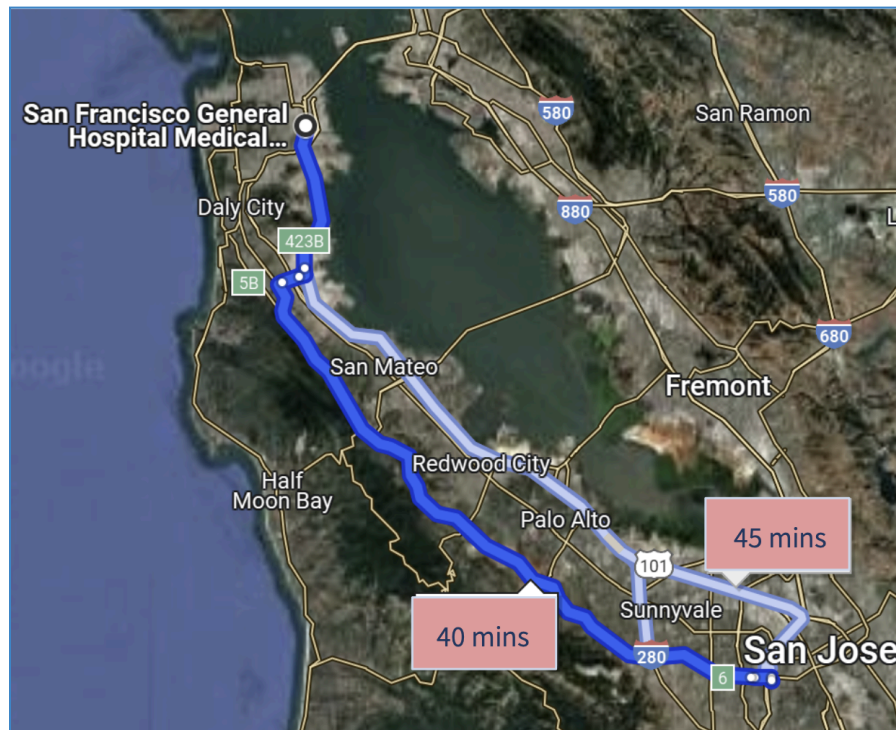


Figure 4. Modeled Aeropulse delivery route between San Francisco General Hospital and Santa Clara Valley Medical Center

Map data © Google, SIO, NOAA, U.S. Navy, NGA, GEBCO, Landsat/Copernicus, LDEO-Columbia, NSF, INEGI. Imagery dates: 12/14/2015–1/1/2021; some visible imagery has unknown date information.

In contrast, in the modeled Aeropulse mission, the same end-to-end delivery is approximately 37 minutes (Table 1), comprising approximately 27-28 minutes for the aerial segment and approximately 9 minutes for the combined indoor segments. Relative to the current practice, this corresponds to a 47% reduction versus a 70-minute baseline, and a 59% reduction versus a 90-minute heavy-traffic case. Performance estimates are preliminary and based on limited modeling. Actual results may vary significantly based on weather, traffic control, and operational conditions.

The significant time reduction achieved by Aeropulse is a result of the streamlined, end-to-end process. The subsequent section details the system's operational methodology, from dispatch to final room-level delivery, and the design features intended to overcome the logistical challenges observed in current medical transport workflows. Technical specifications for system components are provided in later sections.

Table 1. Modeled timing (SFGH to SCVMC)

Segment	Inputs (units)	Notes/Assumptions	Approximate time (min)
Drone flight time	Cruise time = distance/speed = 45 km/110 km/h = 24.5 minutes Add 1.5 minutes for vertical takeoff/landing and 1.5 minutes for tethering operations	Direct rooftop path, no weather or ATC holds; assumes optimized ATC clearances; speed may be reduced in congested airspace	27.5 minutes
Inside each hospital (robot)	Robot walk time = distance/speed = 250 m/1.2 m/s = 3.5 minutes Add elevator/doors = approx 1-2 minutes	Nominal indoor speeds; nominal elevator availability; virtual track corridors with minimal obstruction	4.5 minutes per hospital
End-to-end (Aeropulse)	N/A	Sum of segments above	36.6 minutes rounded to 37 minutes

Dispatch

The first step of this process is dispatch. Our drones are strategically positioned and maintained on designated rooftops or parking structures, where they are kept charged and undergo regular system checks as needed. This ensures that they are always ready for immediate deployment.

When an authorized delivery request is initiated, whether it's for organs, emergency medication, or other critical medical supplies, the nearest available and sufficiently charged or fueled drone is dispatched from its station. The drone then flies directly to the hospital that can supply the required medical item, shown as Hospital A in Figure 5. This direct dispatch approach eliminates unnecessary stops, reducing response times and increasing overall delivery reliability.

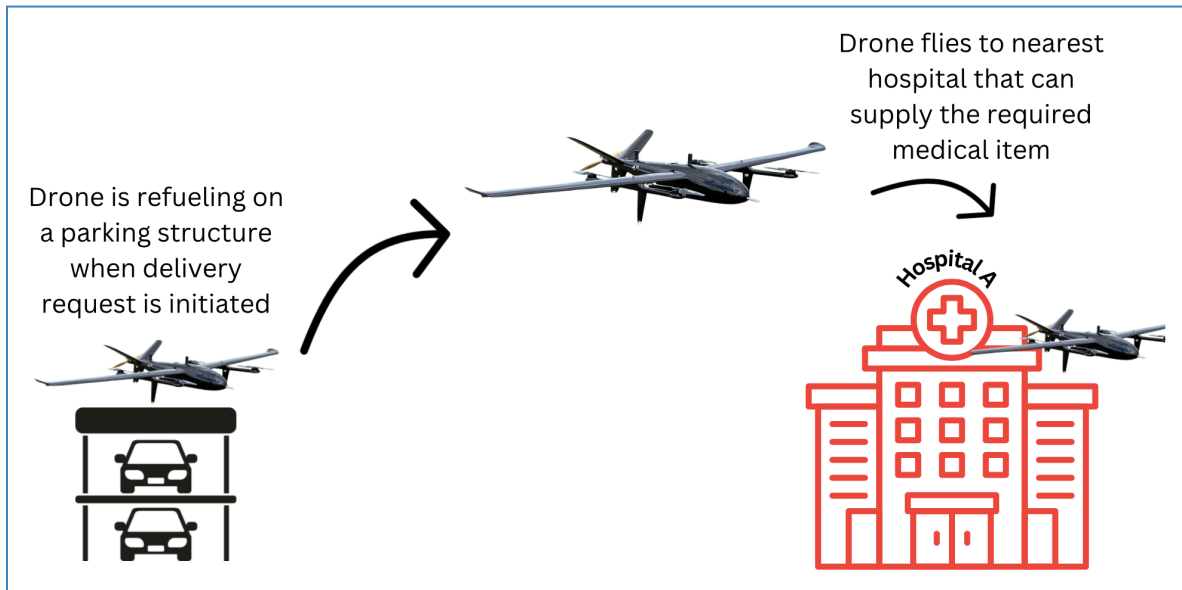


Figure 5. Conceptual diagram of drone dispatch from rooftop hub

Transport Within Hospital - Origin

Following packing by clinical staff, the sealed payload is placed into the autonomous robot; from this point onward, handling is automated. This begins the first-mile of the delivery. See Figure 6. Equipped with an AI-powered navigation system, the robot autonomously determines its optimal route from the origin room to the rooftop along virtual tracks, calling elevators as needed, navigating between floors, and, if required, taking alternative routes to bypass obstacles. The robot then positions itself at the marked pickup zone on the rooftop, where it establishes a guided connection with the drone's tether. The drone lifts and secures the robot and payload for flight.

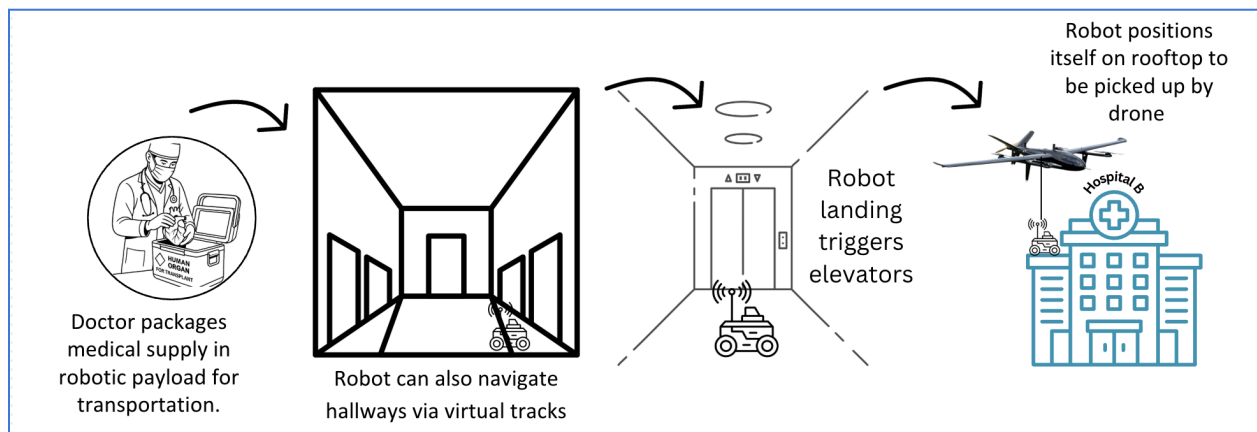


Figure 6. Robot transport process within the origin hospital prior to drone pickup

Transport Between Hospitals

The system transports the medical item from the supplying hospital (Hospital A) to the requesting hospital (Hospital B). After rooftop pickup at Hospital A via tethered hoist, the drone

leverages its speed and aerial advantage to bypass ground traffic, arriving at Hospital B. See Figure 7. Upon reaching Hospital B, the drone precisely lowers the payload to the hospital's rooftop via a tethered hoist system. This ensures a controlled and accurate transfer without requiring specialized rooftop landing infrastructure, offering flexibility to adapt to various hospital layouts.

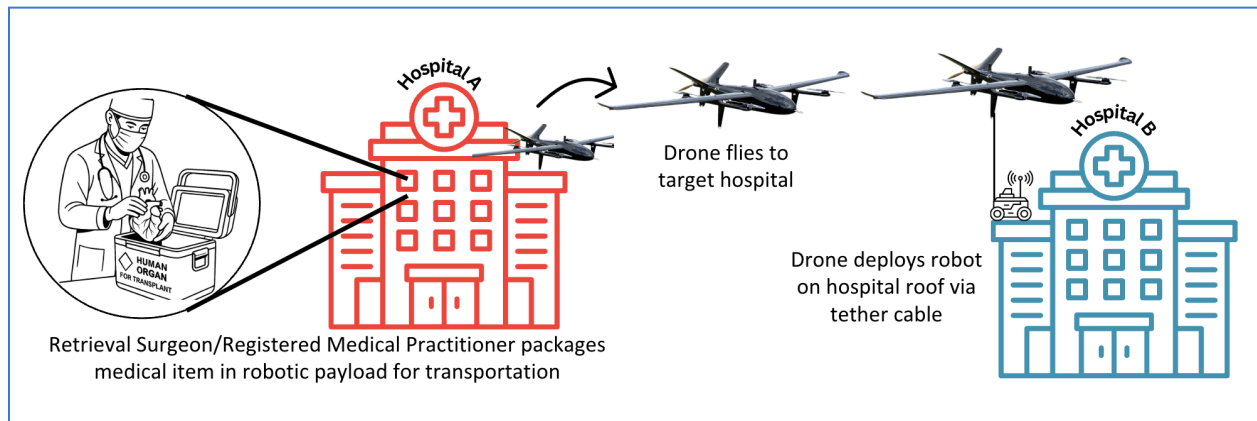


Figure 7. Drone transfer of medical payload between the origin and destination hospital

Transport Within Hospital - Destination

Following the deployment of the robot onto the hospital rooftop, securely holding the medical supply, it begins its last-mile delivery to the destination room. See Figure 8. Equipped with an AI-powered navigation system, the robot autonomously determines its optimal route within the hospital.

The robot travels across the rooftop, then transitions seamlessly into the hospital's interior. It can autonomously call elevators, navigate between floors, and, if required, take alternative routes to bypass obstacles. While moving through hallways, it continues to follow its virtual tracks, avoiding people and equipment while maintaining safe operating speeds and respecting the hospital environment. The robot then positions itself at the exact delivery location, where authorized medical staff can unlock the delivery box to retrieve the medical payload. This complete, end-to-end system, from dispatch to room-level delivery, minimizes human handoffs and maximizes the speed, security, and reliability of critical medical transport.

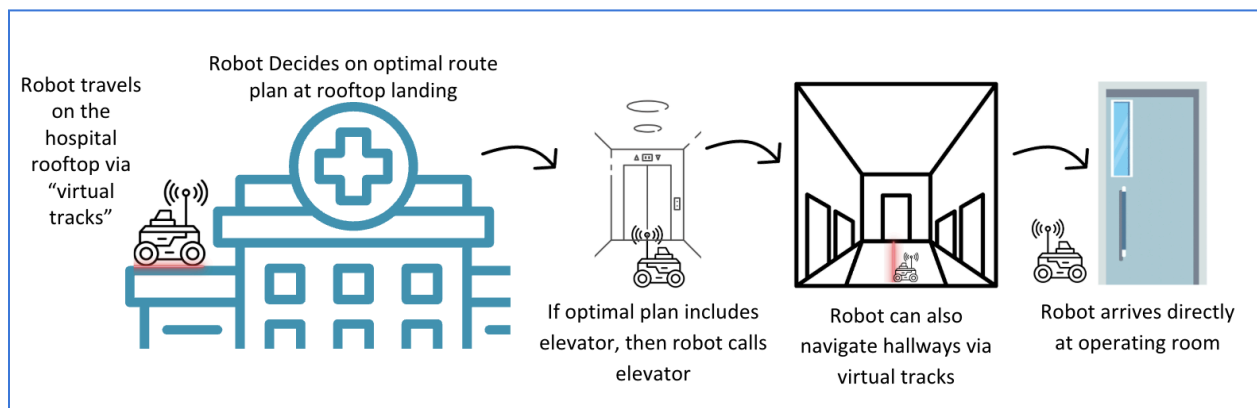


Figure 8. Robot delivery process inside the destination hospital from the rooftop to target room

Drone After Deploying Robot

Upon completing a delivery at Hospital B, the drone is not required to return to its original launch point. Instead, it can be dynamically retasked to the next pending delivery request within the network. See Figure 9. This flexible routing approach reduces idle time and maximizes fleet utilization. If no deliveries are pending, the drone returns to its assigned parking structure to recharge or refuel so that it is ready for its next mission. This operational model maintains near-constant drone availability across participating hospitals to respond to urgent requests. The entire fleet operates as a dynamic network, with all drones in constant communication to adapt to changing demand.

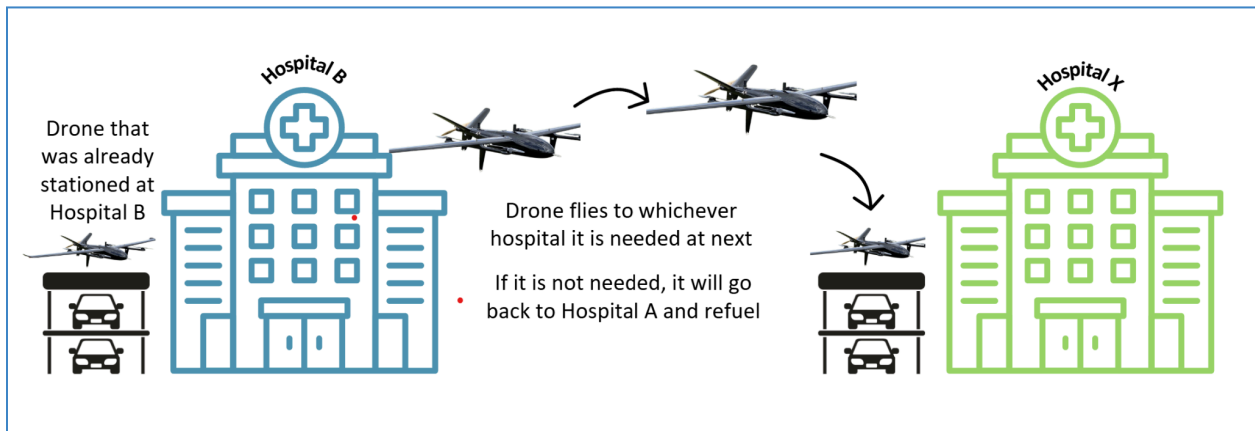


Figure 9. Drone retasking and return path following payload deployment

Redistribution of Robots

Upon mission completion, the robot remains at Hospital B, where it is sanitized, recharged, and staged for new delivery requests. This model minimizes the number of drone flights required for subsequent missions, improving operational efficiency.

However, during periods of low delivery demand, a robot redistribution protocol is activated to ensure that each hospital maintains a sufficient supply of robots and delivery boxes. See Figure 10.

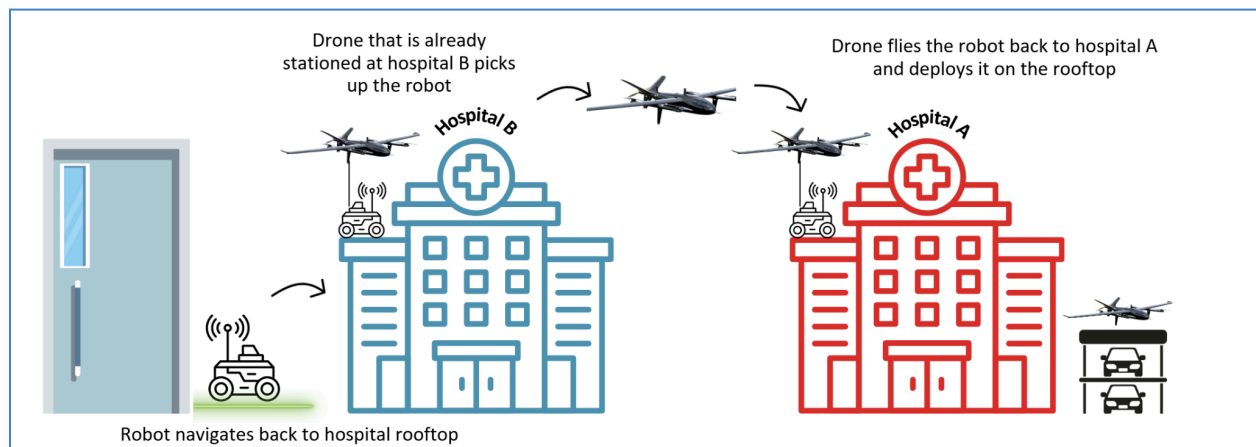


Figure 10. Redistribution of delivery robots across hospitals to maintain availability

This process is initiated after a successful delivery to the operating room, when the robot autonomously navigates back to the hospital rooftop using its internal guidance system. There, a drone allocated at Hospital B retrieves the robot and transports it back to its original deployment location at Hospital A. The drone then returns to its designated parking structure near Hospital B. This redistribution process maintains balanced resource distribution across the network and ensures immediate readiness for future medical transport requests.

Potential Impacts

Improved Patient Outcomes and Organ Viability

The system's primary impact is improved patient outcomes through reduced end-to-end delivery times (modeled; see Table 1). By enabling drones to bypass ground traffic congestion through direct rooftop-to-rooftop flight at high speed, combined with an autonomous robot that handles the first-mile and last-mile delivery within the hospital, Aeropulse mitigates common delays associated with traditional transport, such as navigating crowded hallways, waiting for elevators, and relying on staff availability. These shorter transport times are critical for maintaining the viability of organs and other time-sensitive medical items, directly improving patient outcomes. This efficiency also reduces the need for costly and complex-to-coordinate emergency backup organs. Furthermore, the system's ability to deliver to hospital rooftops, regardless of helipad or trauma team presence, significantly expands access to life-saving transplants in a wider range of locations.

Enhanced Resource Efficiency and System Reliability

The system streamlines the organ transport process, allowing emergency vehicles and highly trained hospital personnel to be reallocated to other critical patient care duties, thereby optimizing hospital resources. As an autonomous, continuously operating system, it ensures reliable and predictable deliveries around the clock, even outside of standard working hours. This continuous 24/7 operational capability is essential for time-sensitive medical transport where delays can have severe consequences.

System Scalability and Operational Flexibility

Built on a modular architecture, the system allows for easy adaptation to transport a diverse range of medical payloads, such as organs, blood, samples, and equipment. This modularity opens the door to numerous future applications beyond its initial scope. The system is inherently scalable: the network can seamlessly expand by adding more hospitals, drones, and autonomous robots as demand grows or geographic coverage broadens.

The system's design supports flexible operations. Drones and robots can be redirected in real time to hospitals experiencing higher delivery demand, helping to ensure resources are allocated efficiently where they are needed most. This adaptability allows the system to respond smoothly to fluctuating workloads and evolving hospital environments, helping maintain effective and timely delivery service.

System Design and Architecture

The following sections detail the technical implementation of this integrated system, starting with the aerial component specifications and ending with system integration analysis.

Aerial Component (Drone)

Platform Selection & Specifications

The drone selected for Aeropulse is the Skylane 510 manufactured by Sky-Drones Technologies Ltd., a hybrid petrol-electric VTOL drone [19]. It features a wingspan of 5.1 meters and a manufacturer-quoted cruise speed of ≈ 80 knots (≈ 148 km/h); for urban operations, our delivery-time modeling uses 110 km/h (≈ 59 knots) to reflect airspace restrictions, ATC coordination, and safety margins [18]. The hybrid propulsion system combines electric motors for VTOL operations with a petrol engine for cruise flight, offering greater range and endurance compared to fully electric systems. Its carbon fiber frame keeps it lightweight but durable, and it can handle winds up to 12 m/s (24 knots) in fixed-wing mode and 6 m/s (12 knots) during VTOL takeoff or landing. It also works in extreme temperatures, from minus 30 to plus 50 degrees Celsius, and provides a 100-pound payload capacity, which accommodates the 30-pound delivery robot plus medical cargo with sufficient safety margin.

This drone was chosen over larger, similar models for a few key reasons. First, this drone provides superior weather flexibility compared to fully electric alternatives, which is critical for consistent and reliable medical deliveries. It is also compact, portable, and can be quickly deployed, making it straightforward to integrate into hospital operations without requiring specialized infrastructure beyond standard rooftop access. Despite its small size, it offers stronger wind resistance relative to its weight class and provides longer range and endurance to complete deliveries and reliably return to its hub within tight time windows.

Route Optimization Systems

Pre-Flight Route Optimization

Prior to takeoff, each drone delivery mission undergoes a comprehensive pre-flight route optimization process (Figure 11) to ensure safety, efficiency, and compliance with regulatory airspace constraints. The process begins with mission definition: the transport of medical supplies between designated hospitals. Key operational parameters are then input into the system, including the origin and destination coordinates, minimum and maximum altitude constraints, real-time weather data, known no-fly zones, and current airspace availability via the Unmanned Aircraft System Traffic Management (UTM) network.

Subsequently, a three-dimensional occupancy grid is generated using satellite imagery, terrain data, restricted airspace zones, and weather overlays. This enables accurate identification of known obstacles and constraints within the operational environment. Using this grid, a global route is then planned to connect the departure and arrival points. The routing algorithm is designed to avoid obstacles and restricted zones while minimizing total travel time, energy consumption, and operational costs.

Once the optimal route is determined, the system then submits a request for airspace clearance. Given the critical nature of emergency medical transport, a priority status request is issued to expedite approval and reduce potential delays. Due to the use of structured and

deconflicted airspace through UTM, local pre-flight path planning onboard the drone is typically unnecessary.

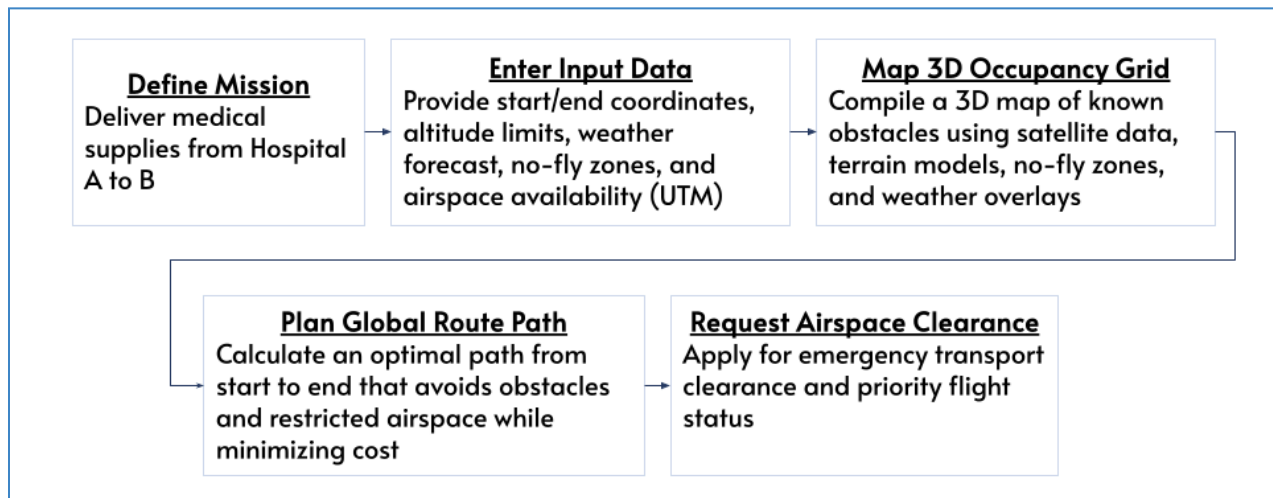


Figure 11. Pre-Flight Route optimization for drone missions

In-Flight Route Optimization

Once airborne, the drone transitions to an in-flight optimization phase, which prioritizes real-time environmental awareness, safety, and navigation accuracy. The process (Figure 12) begins with environmental assessment. Onboard sensors continuously scan the surroundings to update the 3D environmental map in real time.

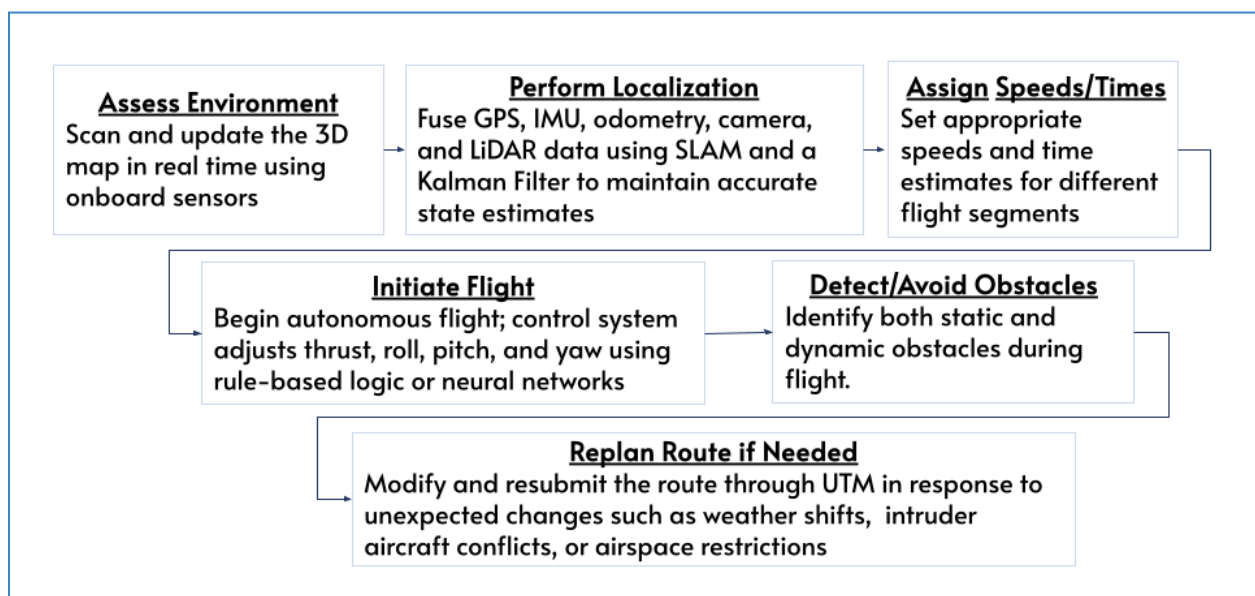


Figure 12. In-Flight Route Optimization

Simultaneously, the drone performs localization using a combination of GPS and onboard Simultaneous Localization and Mapping (SLAM). Sensor fusion is achieved through the integration of Inertial Measurement Units (IMU), odometry, visual data, and Light Detection and Ranging (LiDAR), with an Extended Kalman Filter employed to maintain accurate and reliable estimates of the drone's position.

Obstacle detection and avoidance are critical components that remain active throughout the entire flight duration. The drone must identify both static and dynamic obstacles. It then calculates appropriate speeds and timing for each flight segment to optimize efficiency and energy usage.

In the control phase, the drone autonomously manages flight parameters. These adjustments may be governed by traditional control algorithms or enhanced using machine learning techniques such as neural networks to enable more adaptive behavior.

In the event of unexpected disruptions, the system is capable of dynamic rerouting. Disruptions may include weather changes, intruder aircraft causing separation conflict, or temporary airspace restrictions. The revised flight path can be submitted to the UTM system by a remote operator to ensure the continued safety and legality of the mission.

Hub Infrastructure & Distribution

Figure 13 illustrates the geographic distribution of refueling hubs relative to nearby hospitals in the San Francisco Bay Area. Green and yellow markers represent Level 1 and Level 2 trauma centers, respectively, while blue markers indicate the refueling hubs. Each hub is strategically positioned within an 8-mile radius of each hospital, ensuring that drones can be rapidly dispatched. Combined with the aerial transit and ground delivery segments detailed in Table 1, this contributes to the overall end-to-end delivery time of approximately 37 minutes.

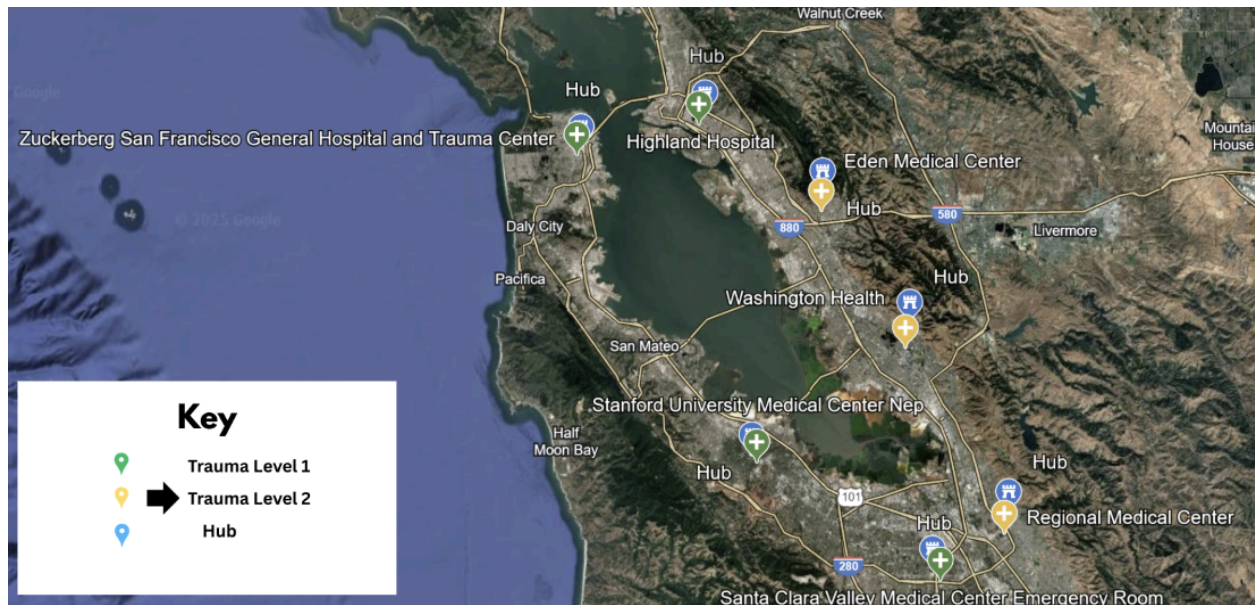


Figure 13. Proposed distribution of drone hubs and hospitals in the San Francisco Bay Area
Map data © Google, SIO, NOAA, U.S. Navy, NGA, GEBCO, Landsat/Copernicus, LDEO-Columbia, NSF, NOAA, INEGI. Imagery dates: 12/14/2015–1/1/2021; some visible imagery has unknown date information.

Consideration of airspace compatibility is also essential in this design. Given the proximity to major airports, where flight paths are strictly regulated, drone route planning must be carefully performed to avoid disrupting local air traffic control and aviation authorities. In many cases, flying over water may be preferred to flying above populated areas, both for safety and to meet regulatory standards.

Hub facilities provide charging/refueling infrastructure, maintenance capabilities, and secure storage for standby drones, with automated systems for pre-flight checks and mission preparation.

Ground Component (Robot)

Overview

The Aeropulse robot is the ground-based delivery component of the fully autonomous medical transport system designed to optimize hospital-to-hospital and intra-hospital delivery workflows. The robot is responsible for two critical segments: first-mile transport from origin rooms to the hospital rooftops for aerial deployment, and the last-mile navigation from destination rooftops to target rooms within medical facilities. Both segments require navigating complex hospital environments with crowded hallways, elevators, stairs, and unexpected obstacles, with the last-mile being particularly challenging as the final delivery step. In many hospitals, this step still depends on human couriers, which introduces variability, delays, and human error. The Aeropulse robot aims to eliminate these inefficiencies with a smart, stair-capable robot that can navigate autonomously in demanding hospital environments with consistency and reliability.

The system is designed to be compact, hospital-friendly, and familiar in form, making it easier for institutions to adopt. Its key value lies in removing the potential bottlenecks between rooftop delivery and operating rooms, addressing the gap that typically exists between rooftop delivery and the final destination.

Design & Fabrication

Current Hospital Delivery Box

The box currently used for organ or emergency medication transport is typically a hard-shelled, insulated container made from shock-resistant plastic or aluminum. These boxes are designed to withstand rough handling, pressure changes during air travel, and sudden temperature shifts. Inside, they are lined with insulation and cooled using reusable ice packs or phase change materials (PCM) such as salt hydrates. Some models also include passive data logging for temperature and/or motion, although many lack real-time feedback or connectivity.

Despite the quality of these containers, their biggest weakness lies in the delivery process and not the box itself. Staff members must manually carry them between hospital wings, elevators, rooftops, and surgical floors. Each of these transitions increases the risk of delays, misplacement, or temperature fluctuations that could compromise the payload.

To address this, Aeropulse takes a commercially available and widely used medical perishable box and upgrades it. The box maintains its core structure and insulation, but the ice packs are replaced with an active cooling system that offers better thermal regulation. This updated box (Figure 14) is mounted directly into the robot frame, creating a smart payload unit that blends legacy medical logistics with cutting-edge automation, providing a smoother path to hospital adoption.

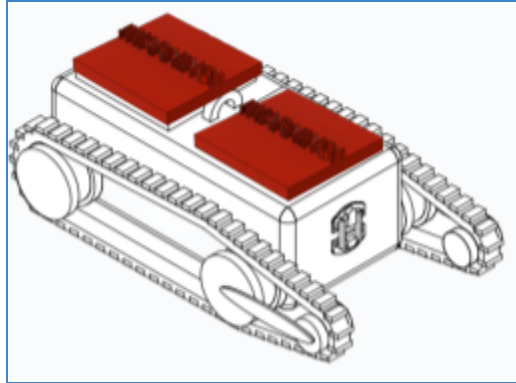


Figure 14. Proposed Aeropulse autonomous medical delivery robot

CAD Model & Prototype

The CAD model (Figure 15) of the Aeropulse robot was developed using Fusion 360, based on real-world hospital constraints and the dimensions of Delta T's medical container [20]. The payload compartment was built to accommodate a box measuring 18 x 10 x 9 inches, making it suitable for standard transplant and medication transport needs, while the overall robotized unit, including tracks and wheels, measures approximately 24 x 10 x 9 inches. The robot's compact footprint allows it to pass through standard 36-inch-wide doorways and fit inside standard U.S. elevators.

The mobility system includes 7.5-inch primary drive wheels, supported by 3-inch casters and a pair of angled track belts for stair climbing, similar to commercial stair-climber robots already in use [21]. These were modeled for real friction forces and stair inclines commonly found in hospitals. The upper chassis includes a protective casing for the onboard electronics and a mounting dock that connects with the drone's delivery mechanism. Additional features such as visual warning labels, flashing LEDs, and speaker enclosures are integrated into the top shell to make the robot clearly identifiable during operation.

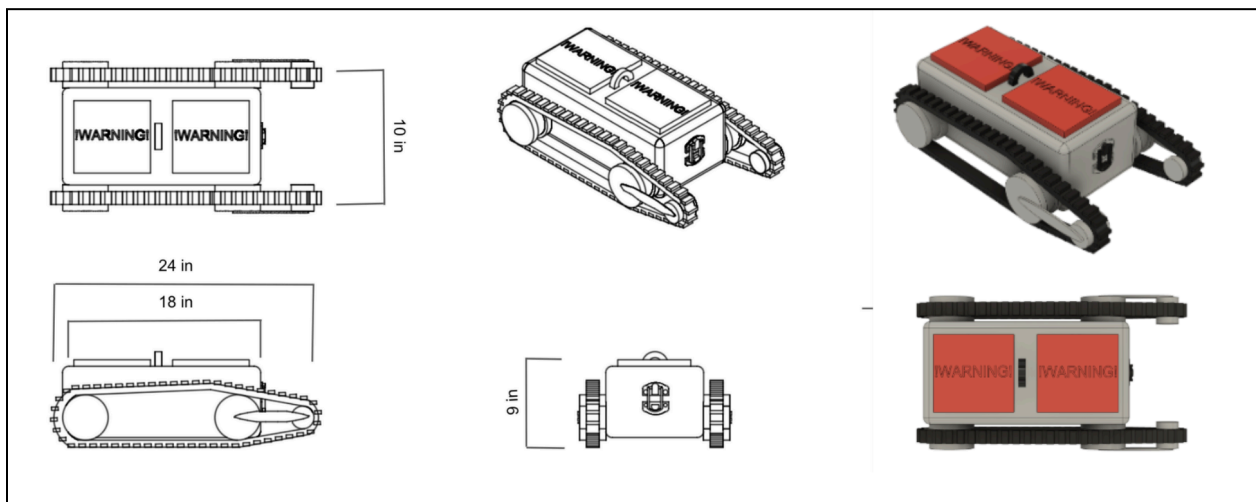


Figure 15. CAD model of Aeropulse delivery robot with payload compartment

This model served not only as a visual prototype but as a functional basis for early simulations and part prototyping. By maintaining familiar box dimensions and balancing new

mechanics with hospital safety and operational compliance, the design reduces implementation complexity and hospital staff training requirements.

To demonstrate feasibility and test basic design assumptions, a scaled-down 3D prototype of the Aeropulse robot was created, seen in Figure 16 below. The prototype was printed using PLA filament on a Flashforge Adventurer 5M 3D printer and includes critical features such as wheel dimensions, track shape, and payload housing. It was built at a reduced scale to allow for rapid iteration and showcase at presentations, while still demonstrating the physical proportions of the final product.

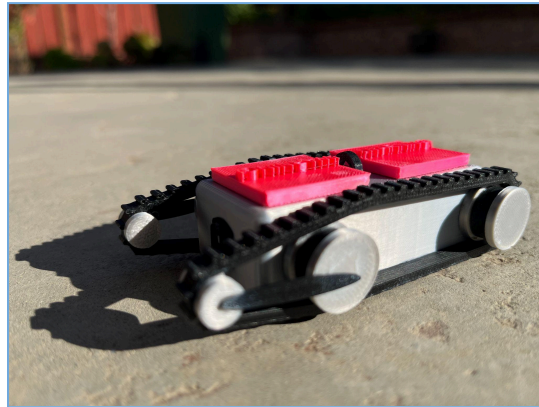


Figure 16. Sub-scale 3D printed prototype of Aeropulse robot

The prototype serves multiple purposes: as a proof of concept, as a visual aid for stakeholders, and as a platform for refining design elements like stair tread curvature, locking mechanism layout, and speaker positioning. By iterating with real materials and dimensions, the team was able to test assumptions about maneuverability, accessibility, and integration with the drone docking mechanism. This hands-on step was a key milestone in translating digital design into real-world hardware development.

Electronics & Hardware Components

Electronics Overview

Figure 17 illustrates the robot's electronic architecture, with each subsystem clearly represented. All components are available off the shelf, making the design affordable, easily scalable, and suitable for deployment in real-world hospital environments.

Power System

The Power System supplies 24V to the Main Circuit Board, 12V to the Motor System, and 5V to onboard processors and sensors. A built-in Battery Management System (BMS) protects against overcharging, short circuits, and cell imbalance, extending battery life and ensuring safe operation. A backup power unit enables uninterrupted performance during outages or voltage fluctuations.

Main Circuit Board

The Main Circuit Board serves as the robot's central processor. It hosts a high-performance microcontroller capable of executing AI models locally, allowing low-latency,

real-time decision-making without reliance on cloud infrastructure. It manages core functions such as autonomous navigation, sensor processing, cloud communication, and remote control. The board also performs sensor fusion, integrating multiple inputs to enable accurate environmental interpretation.

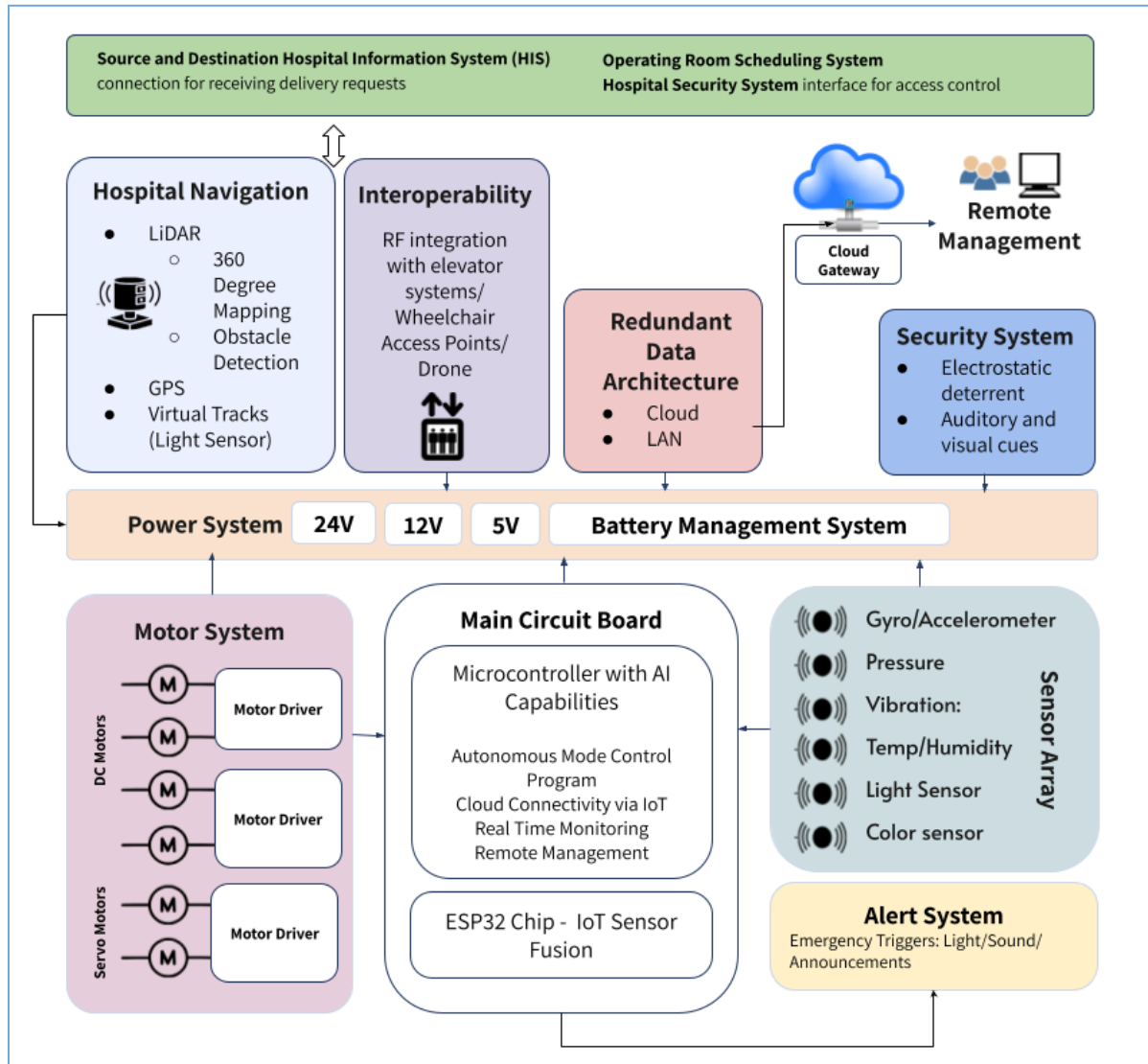


Figure 17. Electronic architecture of the Aeropulse delivery robot

Sensor Array

A multimodal Sensor Array provides real-time data for navigation, object detection, and safety monitoring. This array allows adaptive, intelligent behavior in dynamic clinical environments. Components include:

- **Gyroscope & Accelerometer:** Maintain balance and detect tilt during movement.
- **Pressure & Vibration Sensors:** Monitor surface conditions and impacts, critical when transporting fragile items.
- **Temperature & Humidity Sensors:** Ensure optimal conditions for electronics and medical payloads.

- **Light Sensor:** Detect unexpected exposure (e.g., payload tampering).
- **Color Sensor:** Follow projected virtual tracks for path guidance.

Motor System

The Motor System consists of four high-torque drive motors and two front-mounted servo motors, enabling the robot to operate using a tank-style tread design. Drive motors are managed by dual motor driver boards for precise control and load handling. Servo-actuated front treads adjust for stair climbing and maneuverability in confined hospital spaces. The continuous tread configuration offers stability and reliable ground contact on diverse indoor surfaces.

Visual and Audio Alert System

A Visual and Audio Alert System ensures transparent communication with hospital personnel. It consists of:

- **Buzzer:** Audible alerts for events such as low battery or obstruction detection.
- **Police-Style LED Light Bar:** Visual status indication (e.g., “in-transit,” “error,” “idle”).
- **OLED Display:** Text-based messages such as delivery ETA or elevator status.

These outputs provide clear feedback even from across the room, supporting human awareness and trust.

AI-Powered Navigation & Decision Systems

The Aeropulse robot employs a multi-layered AI navigation framework that combines global route optimization, virtual track guidance, and fail-safe LiDAR/AI navigation to ensure safe and reliable delivery in complex hospital environments.

Hospital Route Optimization + Core AI Intelligence

Navigation begins with the robot’s AI generating a global route plan. Using preloaded hospital floor maps—including elevators, service hallways, and emergency zones—along with real-time sensor data (LiDAR, IMU, cameras, odometry), the system determines an optimal path. Multi-objective algorithms (A*, D*, Dijkstra) balance speed, safety, energy efficiency, and accessibility

Primary Mode Virtual Track Navigation

Once the route is established, the robot’s primary navigation utilizes Virtual Tracks (Figure 18)—projected LED or laser lines on hospital floors. These dynamic, color-coded paths guide the robot using its onboard color sensor. Each color corresponds to a destination (e.g., red = ICU, green = pharmacy), and the robot tracks only the currently illuminated section to maintain course while minimizing visual clutter and power usage. Virtual tracks can be reprogrammed in real time to adapt to changing hospital needs, such as emergency rerouting or high-traffic avoidance, consistent with multi-criteria UAV routing approaches in prior logistics studies [24].



Figure 18. Conceptual AI-generated rendering of a hospital floor virtual track navigation system

Continuous AI Oversight and Communication

Across all modes, the AI performs real-time path replanning, safety checks, and optimization updates.

- Computer vision enables obstacle detection and classification of people, carts, and equipment.
- SLAM provides precise localization in GPS-denied environments.
- Sensor fusion through Extended Kalman filters integrates LiDAR, cameras, IMU, and optical sensors for robust positioning and LED/laser path tracking.
- Adaptive systems continuously adjust speed, reroute when obstacles are encountered, and dynamically evaluate optimization criteria.

Figure 19 outlines the end-to-end navigation process of the hospital delivery robot.

Real-time updates are transmitted to staff, allowing logistics teams to monitor location, estimated time of arrival, and any routing changes. This data is also logged for post-delivery diagnostics and process optimization. The robot operates using a redundant cloud and LAN communication system to ensure reliable data exchange throughout the mission. This system ensures the robot operates independently under varying hospital conditions, reducing its reliance on external infrastructure or human intervention.

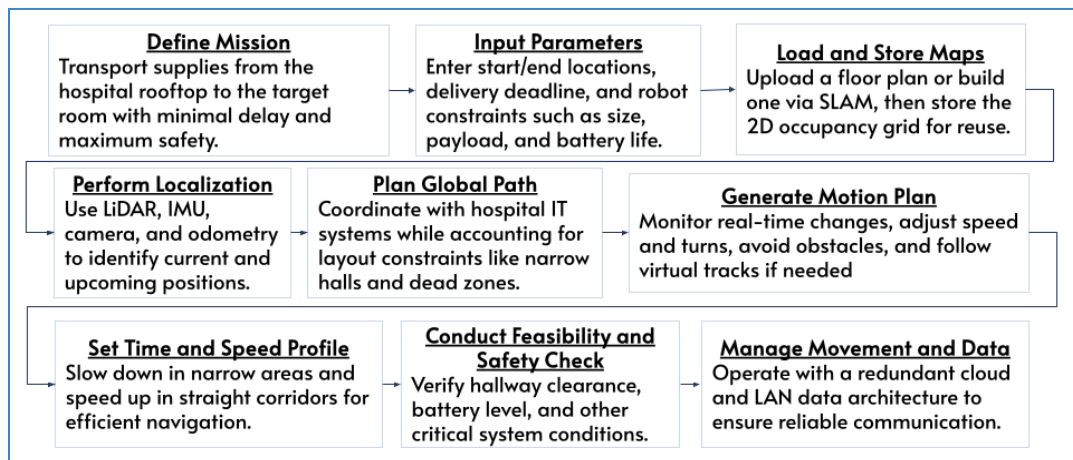


Figure 19. Process for robot route optimization within a hospital environment

System Integration & Interoperability

Robot's Hospital Integration

Wireless Communication

An onboard RF module facilitates short-range wireless communication with key hospital infrastructure, including elevator controllers, base stations, and peer robots. An external antenna amplifies and stabilizes signals to maintain reliable connectivity in interference-prone areas.

Redundant Data Architecture: Cloud & Local Area Network (LAN)

To ensure uninterrupted connectivity, the robot employs a redundant architecture (Figure 20) using both cloud and wired LAN pathways:

- Primary Path (Blue): The IoT Gateway enables cloud-based control, real-time system monitoring, and remote app access.
- Secondary Path (Green): A LAN (Ethernet) Module provides a high-speed, interference-resistant wired connection for periodic local access within the hospital network when the robot is docked or stationed.
- Failover Path (Red): If the cloud service is interrupted, the robot automatically transitions to LAN-only mode, maintaining full operational continuity. This is essential for zero-data-loss operation during outages or emergency conditions.

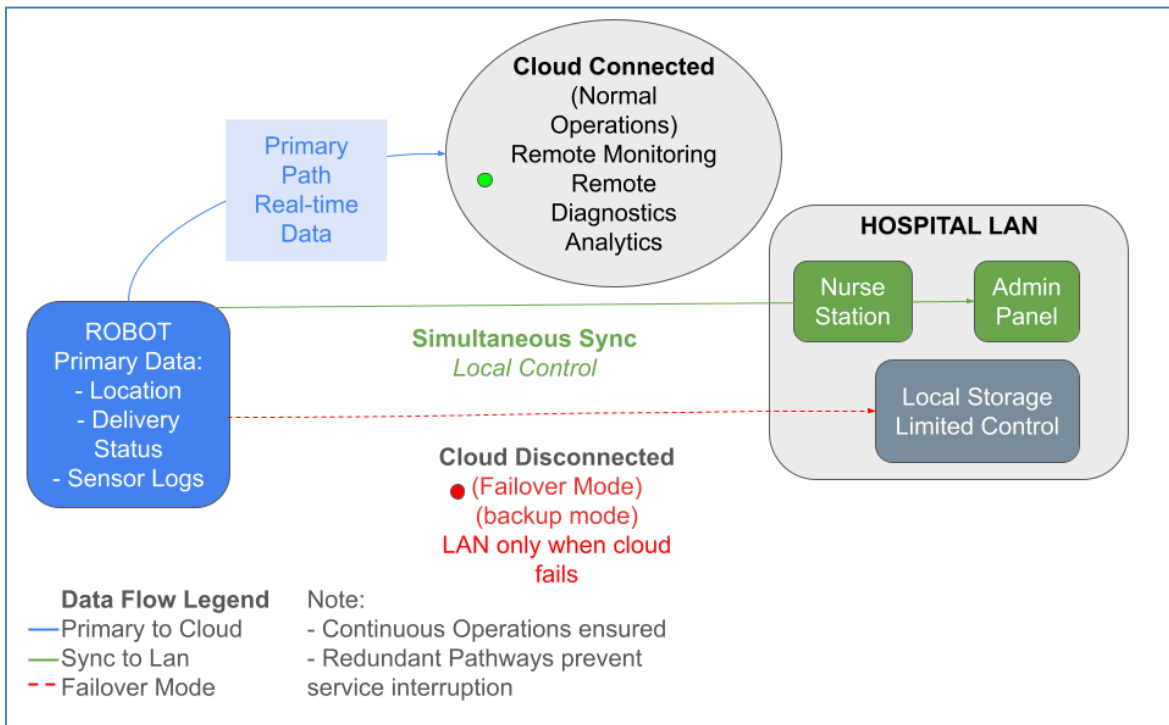


Figure 20. Redundant data architecture combining cloud and hospital Local Area Network (LAN)

Hospital IT System Integration

The system is designed for modular integration with the existing hospital infrastructure through multiple connection points. Hospital Information System (HIS) connection receives delivery requests and coordinates with the Operating Room Scheduling System to optimize timing and priority. Hospital Security System interface provides access control and monitoring capabilities, while LAN connectivity enables direct network communication for high-speed, reliable data exchange and local system integration. Implementation depends on site capabilities and vendor approval. Together, these features support secure, traceable handling of medical payloads.

Elevator Integration

The robot is fully equipped to autonomously interact with hospital elevators (Figure 21), enabling seamless multi-floor transport. The interaction sequence includes:

- Call: The radio frequency (RF) module sends a signal to summon the elevator.
- Entry: Upon boarding, the robot either selects a floor number via smart interface or communicates directly with the elevator control system.
- Monitoring: During transit, onboard sensors track elevator movement and door status.
- Exit: The robot disembarks at the correct floor and resumes navigation via its primary virtual track system.
- Fallback mode: If the elevator is unavailable or full, the robot automatically activates its stair-climbing mode using the adjustable front treads. This redundancy ensures mobility between floors under all conditions.

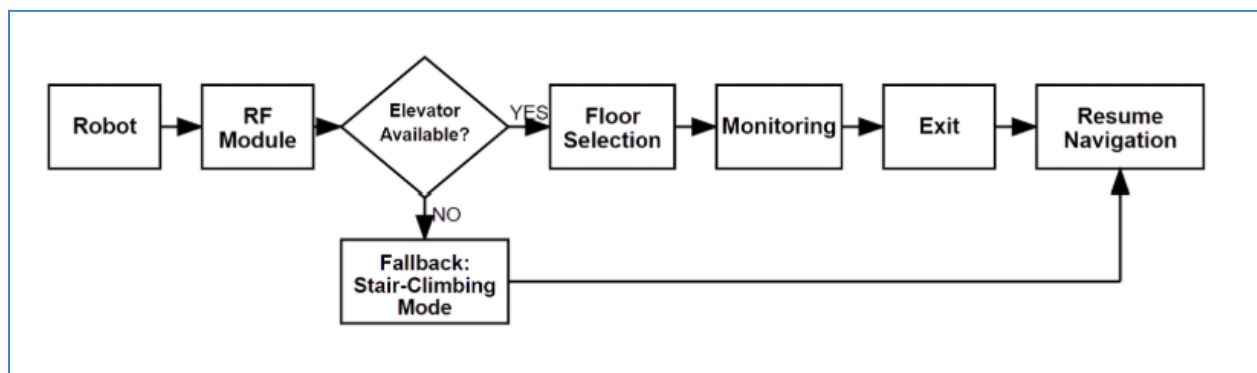


Figure 21. System architecture diagram of robot-elevator interoperability sequence

Security System

Transporting high-value, life-saving materials like organs or chemotherapy drugs requires more than speed; it demands airtight security. The Aeropulse robot addresses this with a layered protection system that begins with multi-factor authentication. The payload compartment is electronically locked and can only be accessed via verified PIN codes, hospital ID badges, or biometric scanners.

The robot's exterior shell is made from impact-resistant material, designed to protect against tampering and minor collisions. Internally, the robot is equipped with sensors that monitor temperature, light exposure, humidity, and movement, ensuring that if the payload is

exposed to light unexpectedly or shaken during travel, an alert is triggered and logged. These alerts can be forwarded to logistics dashboards or central systems using encrypted communication protocols.

Externally, the robot uses flashing lights and a speaker to broadcast alerts such as “Medical Delivery in Progress” or “Authorized Access Only.” These are designed to deter interference from patients, staff, and visitors. In the event of a power loss or failure, a backup battery system ensures the robot maintains locking, tracking, and monitoring functionality for a limited period, long enough to complete delivery or allow staff to safely retrieve the unit.

Drone-Robot Integration

Physical Connection System

The drone and robot interface through a tethered hoist system that enables precise payload deployment and retrieval. The drone precisely deploys the robotic payload to the hospital roof via a strong tethered hoist system, ensuring a controlled and accurate transfer without requiring specialized rooftop landing infrastructure.

Mounting and Docking Mechanism

The robot’s upper chassis includes a protective casing for the onboard electronics and a mounting dock that connects with the drone’s delivery mechanism. This guided connection allows the drone to securely lift and transport the robot between hospital locations.

Payload Transfer Protocol

Upon rooftop delivery, the robot detaches from the drone at the rooftop and immediately transitions to autonomous ground operation. When redistribution is needed, the drone allocated at Hospital B retrieves the robot and transports it back to its original deployment location, ensuring balanced resource distribution across the network.

Drones Integration in Existing Airspace

The Aeropulse drone is designed to safely integrate within urban airspace while complying with national and regional aviation standards. Operating primarily in low-altitude corridors (under 400 feet above ground level), the system employs advanced flight management to avoid interference with commercial and emergency aircraft [22]. Based on the SkyLane family VTOL UAVs, Aeropulse leverages Skylane’s long-range Beyond Visual Line of Sight (BVLOS) capability, payload capacity, and AI-assisted autonomy while integrating a comprehensive airspace management and safety architecture tailored for hospital logistics.

Air Traffic Coordination

Through integration with UTM protocols, the drone receives live updates on temporary flight restrictions, emergency routes, and authorized flight corridors [23]. Each drone transmits its telemetry via ADS-B Out and receives updates through ADS-B In, ensuring continuous visibility to nearby manned and unmanned aircraft [24].

Geofencing & No-Fly Zones

Embedded geofencing software prevents the drone from entering restricted areas such as airports, heliports, or high-security zones [25]. These boundaries are updated dynamically through cloud connectivity, enabling real-time compliance with evolving regulations.

Detect-and-Avoid Systems

To ensure collision-free operation, the drone integrates multiple sensor modalities, including radar, optical cameras, and LiDAR [26]. These provide both short-range obstacle detection for buildings, power lines, and birds, as well as long-range awareness of other air traffic. If an unplanned obstacle is detected, the drone executes automated rerouting or return-to-base maneuvers.

Emergency & Contingency Procedures

In the event of severe weather, loss of communication, or restricted airspace incursions, the drone executes predefined fail-safe responses such as loitering in a safe holding pattern, descending to a low-risk landing area, or returning to its base station [27]. Emergency parachute deployment is available for rapid descent in catastrophic failures, protecting both the payload and people below [28].

Regulatory Compliance & Hospital Coordination

Aeropulse operations comply with FAA Part 107 regulations for unmanned systems, with extensions for BVLOS flights under waiver conditions [22]. Hospital heliports and designated rooftops serve as approved drone entry points, coordinated with hospital operations to avoid conflicts with helicopter ambulances and other aerial responders [29].

Failure Modes & Redundancy

The system design incorporates multiple redundancy layers: redundant cloud and LAN communication ensure connectivity during outages. LiDAR and GPS backup navigation when virtual tracks are obstructed, stair-climbing capability when elevators are unavailable, and backup battery systems maintain security and monitoring during power loss. Weather limitations require reverting to ground-based systems when wind speeds exceed 24 knots cruise or 12 knots VTOL thresholds. Additional failure protocols include: drone return-to-base capability if payload cannot be deployed, robot docking stations for charging failures, and manual override capabilities for critical situations.

Together, these features enable the Aeropulse drone to operate safely and reliably within complex hospital networks while meeting strict aviation safety requirements.

Performance Analysis & Discussion

With the integrated system architecture established, the following analysis examines current limitations and future scalability potential.

Current Limitations

One key limitation of the current Aeropulse concept is the weather. The drones have a maximum wind tolerance of 24 knots in cruise and 12 knots when performing vertical takeoff and landing. When wind speeds exceed these thresholds, hospitals must revert to the current mostly ground-based delivery systems. Weather restrictions may require ground backup systems for 20-30% of operational time. Furthermore, current FAA regulations restrict the operation of unmanned aircraft in this manner in dense urban environments [30]. These operations also fall under FAA Part 107 small UAS regulations [31]. Implementation would require extensive coordination with aviation authorities, likely requiring 3-5 years for initial corridor approvals, and would need to comply with ASTM standards for unmanned aircraft systems [32]. Significant steps must be taken to ensure the safety and reliability of the drone's routing system to avoid other aircraft and obstacles [33]. In fact, the agency overseeing organ transplants has faced intense scrutiny for failures in oversight that led to late, damaged, or even diseased organs being delivered [34]. Additional challenges include enhanced system reliability requirements, as any hardware or software failure could jeopardize patient outcomes; the need to integrate with varying hospital infrastructure designs, APIs, and network configurations; and cybersecurity and data protection requirements for medical systems that require further development.

If these limitations can be overcome, Aeropulse can prevent hundreds of failed organ transplants and ensure that urgent medicines, organs, and laboratory samples reach their destination quickly and reliably. These measures have the potential to save hundreds of lives annually.

Scalability & Extensions

As of now, Aeropulse is focused on transporting medical perishables between urban area hospitals within approximately 25 nautical miles, as demonstrated in our modeled SFGH-SCVMC scenario. Assuming Aeropulse shows success within the San Francisco Bay Area, it can be expanded to other major metropolitan areas in the United States.

Aeropulse also has the potential to be extended to fulfill many different missions. For example, in discussions with our mentors and multiple medical experts, the need for an Aeropulse-like system exists in organ transport and medicine transport across the country, and also to/from rural hospitals and clinics. The current Aeropulse concept is not designed for this because Zipline and other companies have conducted these types of deliveries in Africa and could expand to the U.S. However, if that does not occur, Aeropulse could serve this mission with only minor modifications to the robot, including enabling it to more effectively navigate rough terrain that can be present around rural clinics.

For emergency response applications, the system could fill critical shortages with blood/plasma for transfusions, tPA, insulin, and antivenom, and equip teams in the field with AEDs, ventilators, surgical kits, and portable diagnostics delivered directly to the scene. It could also extend to vaccines, where drones have already proven economically valuable [35]. During

natural disasters, it could bypass damaged infrastructure to reach clinics and aid stations across rough terrain or isolated areas.

The underlying aircraft platform has a theoretical maximum range of up to ≈500 miles; however, all modeling in this paper and the initial Aeropulse deployment focus on short-range urban missions (≈25 nm), as demonstrated in the SFGH-SCVMC scenario, optimizing for rapid response times and frequent short-distance deliveries, which represent the majority of critical medical transport needs in metropolitan areas. Aeropulse can also be expanded to include longer-range drones and conduct organ transport across the nation. The longer range capability enables future expansion to regional networks and emergency response scenarios. The current system for completing long-range deliveries uses commercial aircraft and shares similar drawbacks to the current shorter-range medical delivery systems addressed by Aeropulse. In summary, Aeropulse is a versatile system that can be extended to solve many current and future medical transportation needs.

Conclusion

As road traffic, hallway congestion, and other logistical failures associated with medical item transport in urban areas continue to delay deliveries, the well-being of patients is put at risk. The Aeropulse multimodal system of hybrid VTOL drone and robotic payloads can mitigate these delays through fully autonomous, end-to-end delivery.

The drone's high speed and long flight endurance allow it to complete deliveries quickly while avoiding congestion on the ground. The drone's comprehensive pre- and in-flight route optimization system allows it to operate within complex urban environments. The robot's use of virtual tracks at hospitals allows it to navigate autonomously and ensure pedestrian awareness of the system when in operation. The Aeropulse system is modeled to potentially complete deliveries of medical perishables 47-59% faster under optimal conditions compared to current methods, as demonstrated in our SFGH-SCVMC modeling. While implementation will require regulatory approval and comprehensive validation, this can be achieved through an estimated pilot implementation of approximately \$1.5 million for an 8-drone, 8-hospital network utilizing already available commercial products with modifications, excluding ongoing operational costs, regulatory compliance, and hospital infrastructure modifications.

Whether responding to organ transplant emergencies or urgent medication transport, Aeropulse ensures that time-sensitive items are delivered quickly, securely, and independently, minimizing touchpoints and maximizing trust. By eliminating the guesswork and vulnerabilities associated with manual transport, Aeropulse gives hospitals peace of mind while increasing accountability and safety at every step.

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