2020-2021 ACRP UNIVERSITY DESIGN COMPETITION

Conceptual Design of Vertiport and UAM Corridor

(March 2020 - April 2020)

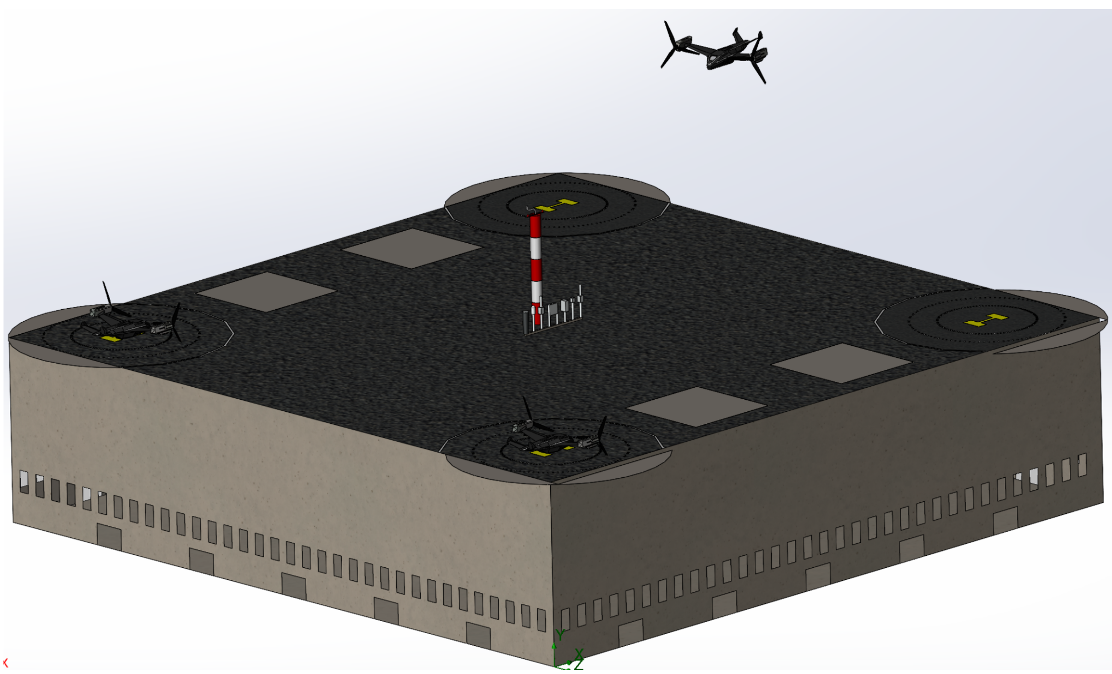
Design Challenge: Airport Operation and Maintenance: Section L

Team Members: Heungseok Park, Francis Sison, Brayan Mendez, Matt Marchetti, Guillermo Anaya

Number of Students: 5

Advisor: Wenbin Wei, PhD

Name of University: San Jose State University



SAN JOSÉ STATE UNIVERSITY

CHARLES W. DAVIDSON COLLEGE OF ENGINEERING

USRA

1. Executive Summary

Urban Air Mobility is “highly automated, cooperative, passenger or cargo-carrying air transportation services in and around urban areas” (FAA, 2020). The UAM market is estimated to increase over the next decade, totaling up to 130 million passenger trips per year by 2029. (NASA, 2018). However, inherent gaps within infrastructure and regulation must be fulfilled before the concept of UAM matures into a reality. Even though Vertical Take-off and Landing (VTOL) features allow UAM aircraft to utilize existing heliport infrastructure, the FAA urges for a dedicated infrastructure like vertiport and UAM corridor to fulfill the infrastructural gap of UAM operation (FAA, 2020). In the Spring of 2021, a group of undergraduates and graduate students were selected through a collaborative internship program between San Jose State University (SJSU), Universities Space Research Association (USRA), and NASA Academic Mission Services (NAMS). Project interns were assigned a responsibility to develop a schematic design of vertiport and UAM corridor to support its operation at NASA Ames Research Center located in Moffett Federal Airfield (KNUQ). The initial phase of the project is to participate in the ACRP design competition to better ensure alignment with the standards of the FAA.

The following proposal will present strategies for the safe and effective integration of automated and connected UAM into a complex airport environment. Safe and effective integration will be divided into two separate pillars since problem-solving methods are distinct from one another. Effective integration will consist of schematic design of a vertical vertiport that reduces surface footprint compared to conventional horizontal layout while achieving higher maximum throughput. The team will verify the design’s effectiveness through maximum throughput and cost-benefit analysis. On the other hand, the safety pillar will be achieved by developing a UAM corridor for a vertiport located inside Class D airspace (KNUQ) while adhering to FAA regulations.[1] Adhering to current regulations will ensure the safe integration of UAM into a complex airport operations environment. Furthermore, a safety risk assessment from FAA Advisory Circular 150/5200-37 will verify and reinforce the proposal's pillar of safe integration. Ultimately, this proposal will raise awareness of integrating Urban Air Mobility into national airspace system infrastructure through the 2020-2021 ACRP design competition.

2. Table of Contents

[1] Because specific regulations pertaining to the UAM corridor have not been published yet, existing FAA regulations (14 CFR Part 91, FAA Directive JO 7110.65Y, etc.) will provide justifications for our project's UAM corridor design.

2.1 Figures

2.2 Tables

3. Background and Problem Statement

Urban Air Mobility is proposed as an alternative mode of transportation to resolve traffic congestion in metropolitan areas. Consumers will utilize UAM to an extent that the first profitable year occurs by the end of this decade (NASA, 2018). However, there are inherent problems with the concept of UAM that must be resolved. The first problem is the large surface footprint of the conventional vertiport design. Preliminary research revealed that a conventional vertiport has a layout of multiple touchdown and lift-off (TLOF) areas, taxiways, and parking spaces in a horizontal plane. The surface footprint of the vertiport increases drastically when the design features more than one TLOF area because supporting structures (taxiways and parking spaces) need to be established while adhering to the separation requirements of the Heliport Advisory Circular.[2] Because of insufficient land availability in urban areas, there is an inverse correlation between the surface footprint of the vertiport and the flexibility of vertiport locations. In simple terms, larger vertiports that can support higher demand will have to be developed in the city's outskirts. This inverse relationship negatively impacts consumer's experience by increasing transfer time and money spent on traveling to and from the vertiport. Demotivating factors such as high transfer time will hinder the potential of UAM as an alternative mode of transportation. For this reason, the surface footprint of the vertiport must be decreased to achieve what is envisioned. This is the problem that will be addressed through this proposal. Our team has developed a schematic design of a vertiport that separates the TLOF area, taxiways, and parking

[2] Our team's vertiport design will adhere to the separation requirements listed in the heliport design advisory circular (AC 150/5390-2C). A decrease in separation requirements due to regulatory modifications remains a positive risk that can be exploited in the future.

spaces into different levels of the vertical structure.[3] The surface footprint of the vertiport is effectively reduced through the vertical distribution of our design.

Another problem of Urban Air Mobility is the lack of definition for the UAM corridor. FAA envisions the corridor to be designed specifically for the UAM operations that can be separated from the air traffic control (FAA, 2020). Even though the FAA has provided a few suggestions, clear solutions to develop a corridor that does not interfere with the existing airspace infrastructure have yet to be made. Because the next phase of the USRA internship will focus on the integration of the vertiport design at Moffett Federal Airfield (KNUQ), our team has been challenged to develop a UAM corridor for a vertiport inside the Class D airspace. One of the main challenges was safely separating UAM operations from the existing approaches and terminal operations at the Moffett Federal Airfield. Moreover, preliminary research revealed that the airspace above the vertiport is congested with the approach patterns of the neighboring Airport, Norman Y. Mineta San Jose International Airport (KSJC). Because of limited information on UAM aircraft performance and the regulations for the UAM corridor, unknown variables had to be filled in by assumptions and justifications. Even though the interns have become UAM experts throughout the project, interactions with industry experts ranging from airport directors of KNUQ to UAM systems modeling and integration lead at NASA AMES provided valuable guidance through the justification process. Ultimately, our team has made every effort to design a corridor that does not limit the vertiport operation while ensuring safety inside the complex airspace environment. We sincerely hope that this detailed documentation of the systemic approach can serve as a foundation for the UAM stakeholders to utilize and further exploit in the future.

---

[3] The schematic design includes considerations for lift systems and aircraft tugs to support the transportation of VTOL aircraft within the vertical structure.

4. Summary of Literature Review

4.1 Limitations of Horizontal Vertiport Design

For a low-density UAM operation, the Touchdown and Liftoff (TLOF) zone can also function as a passenger transfer and maintenance zone. However, high-density vertiport designs have to be developed to alleviate the demands for UAM maturity level 4 (UML-4): 100 simultaneous operations over a metropolitan area (NASA, 2021). Demand network analysis captured at Fort Worth concluded that 98 TLOF zones need to be distributed among 25 locations in UML-4 (Yilmaz et al., 2019). For this reason, UAM stakeholders must attempt to increase the maximum throughput of a vertiport with various methods. One way to increase maximum throughput is to taxi the UAM aircraft out to the parking area and utilize the TLOF zone for another approach/departure (Zelinski, 2020). The figure 1 is Lilium's vertiport concept that demonstrates the idea of multiple parking spaces dedicated to a single TLOF zone. Even though different illustrations of vertiport have been published by the various UAM stakeholders, exact dimensions and maximum throughput of the vertiport have yet to be published. Because of this limitation, the most meaningful literature review for our proposal was Dr. Shannon Zelinski's[4] article, "Operational Analysis of Vertiport Surface Topology". Dr. Zelinski "presents several generic vertiport topology design approaches and evaluates their relative surface area utilization and operational

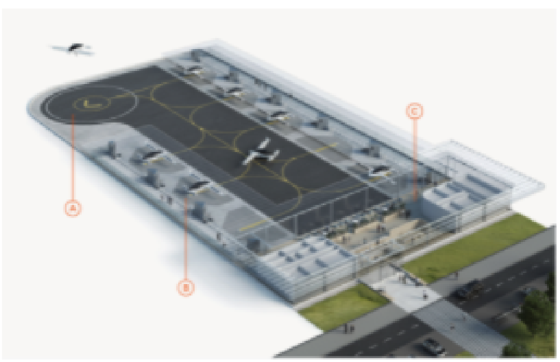


Figure 1. An exemplary urban vertiport layout (Lilium, 2020)

[4]Dr. Shannon Zelinski is the Aerospace High-Density Operations Branch Chief at Nasa Ames Research Center. Because of our team's affiliation with the NASA Academic Mission Services, we had the opportunity to discuss our design with her. Detailed interaction with Dr. Zelinski is described in Section 8 of this proposal.

efficiency under different wind constrained configurations while meeting safety-driven spacing constraints derived from heliport design standards" (Zelinski, 2020). Figure 2 presents four different vertiport layouts proposed by Dr. Zelinski. The green highlighted area is the taxiway, the blue circles are the parking spaces, and the four outer circles are the TLOF zone. Each design has five parking spaces dedicated to one TLOF zone except for the top left design. Additionally, the dimension for each design is depicted on the side [min:$(405ft)^2$ - max:$(489ft)^2$]. The maximum throughput of each horizontal layout is calculated and depicted below.

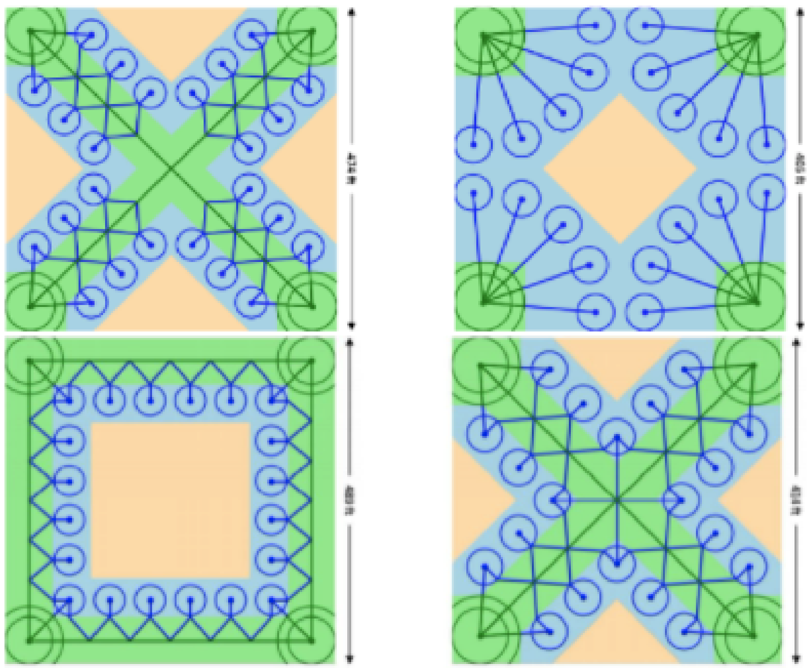


Figure 2. Horizontal Vertiport Topologies (Zelinski, 2020)

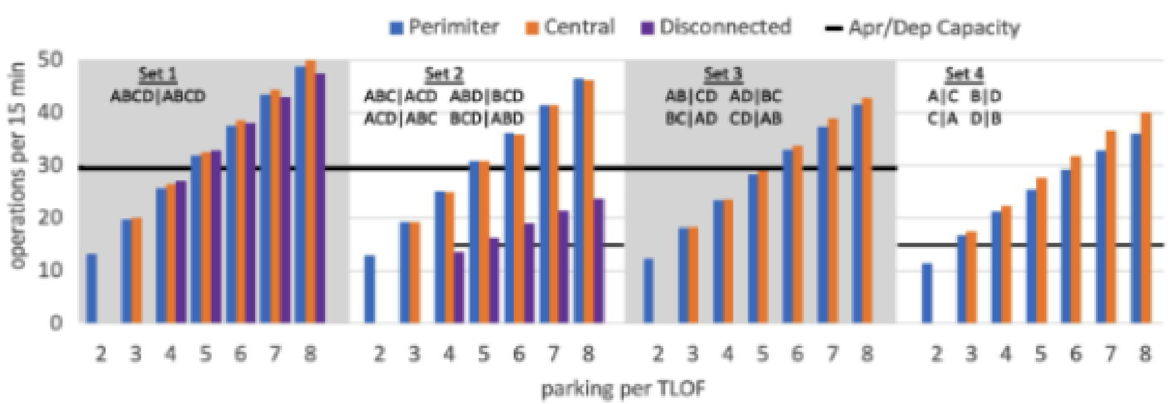


Figure 3. Surface Operations Capacity (Zelinski, 2020)

Because our vertiport design also utilizes 4 TLOF zones, we will adopt the same standards and assumptions of Dr. Zelinski's article to benchmark our design to the horizontal designs. Heliport design requirements and assumptions adopted from the article are listed in the tables below.

Table 1
Requirements from the Heliport Design AC 150/5390-2C

FATO-FATO edge separation for simultaneous operation	200ft
Diameter of Touch Down and Take Off (TLOF)	45ft
Diameter of Final Approach and Take Off (FATO)	70ft
Diameter of FATO Safety Area (FSA)	100ft

Table 2
Assumptions adopted from "Operational Analysis of Vertiport Surface Topology"

Turn around time (Passenger transfer, battery swap, and maintenance of the UAM aircraft)	480 sec
TLOF utilization time	60 sec
Maximum taxi speed	4ft/sec

Comparison between Dr. Zelinski's design and our design's maximum throughput will serve as part of the justification method. Ultimately, our design that reduces the surface footprint without jeopardizing the operational efficiency will increase the flexibility of vertiport locations.

4.2 Importance of Decreasing Transfer Time

The flexibility of the veritport location has an inverse relationship with the transfer time. Transfer time is defined as the time it takes for the consumers to get from the origin to the vertiport. Because Urban Air Mobility is proposed as an alternative mode of transportation that can effectively decrease the overall time spent on commuting, time and cost is the most determinant factor when it comes to consumer acceptance. For UAM to effectively be utilized by average commuters, overall travel time must be shorter than the conventional mode of transportation during high congestion on roads. One way to decrease the overall travel time is by reducing the transfer time by placing multiple vertiports throughout the city. Recent traffic demand analysis conducted specifically for the Bay Area consumers concluded that 45% of commuters would benefit from the UAM when the roads are congested. Furthermore, demand analysis confirmed that the time-saving benefits will change drastically depending on the transfer time (Bulusu et al., 2020). The table below accurately depicts the negative correlation between transfer time and time-saving benefits.

Table 3. *Maximum number of commuters benefited by UAM and the corresponding vertiport combinations for SF Bay Area with high congestion on roads. The number in parentheses are the vertiport number combinations (East, West) (Bulusu et al., 2020)*

Time Savings % of Trip Time	**Transfer Time (minutes)**		
	5	**10**	**15**
25%	(30,5) 297,507	(16,27) 258,056	(30,7) 217,191
50%	(30,25) 258,075	(30,24) 201,319	(30,24) 155,600

Commuters who benefit from UAM vary from about 80,000 to 100,000 depending on the transfer time. Ultimately our team will effectively decrease the transfer time by minimizing the surface footprint of the vertiport.

4.3 Federal Aviation Administration's Concept of Operations for UAM

Urban Air Mobility is a land of the unknown. Lack of regulations combined with UAM companies' reluctance to share their performance data makes it impossible to design a vertiport and UAM corridor without high-level assumptions. Therefore, this section will outline the general assumptions that are relevant to both infrastructure and airspace. Specific assumptions critical to the design of vertiport or UAM corridor will be provided at the beginning of each section. All assumptions below are extracted from the Federal Aviation Administration's Concept of Operations for UAM.

Table 4
Assumptions adopted from FAA CONOPS for UAM

1. UAM Maturity Level 4 (UML-4): 100s of simultaneous operations; expanded networks including high-capacity UAM ports; many UTM inspired ATM services available, simplified vehicle operations for credit; low-visibility operations.
2. UAM will operate within a regulatory, operational, and technical environment that is incorporated within the National Airspace System (NAS).
3. The architecture for UAM services will be flexible and scalable.
4. The FAA retains regulatory authority and is responsible for establishing operational parameters and maintaining oversight.
5. UAM Automation level is Human-over-the-Loop (HOVTL) -Human is informed, or engaged, by the automation (systems) to take action -Human passively monitors the system and is informed by automation if, and what, action is required. -Human is engaged by the automation either for exceptions that are not reconcilable or as part of the rule set escalation.
6. Providers of Services for UAM (PSUs) will be utilized by operators to receive/exchange information during UAM operations. -PSUs will be able to obtain UAS Traffic Management (UTM) flight information via -UAS Service Supplier (USS) network and the USS network will be ankle to obtain -UAM information via the PSU network.
7. UAM operators maintain conformance to shared intent; operators, via PSUs, are aware of the intent of other operations in the vicinity

(FAA, 2020)

5. Effective Integration of UAM into a Complex Airport Environment

5.1 Regulation Requirements, Assumptions, and Justifications

To develop a schematic design of a vertiport, a series of requirements and assumptions need to be made. These requirements and assumptions help to better understand the limitations of how the vertiport may be constructed as well as how the UAM operations within the vertiport must occur. Assuming that UAM aircraft will resemble helicopter flight characteristics, FAA advisory circular 150/5390-2C and Dr. Shannon Zelinski's articles were used to outline the base level requirement section. The requirements of this portion of the project mainly focused on heliport design standards, separation requirements, and speeds at which UAM aircraft can be operated inside the infrastructure. From these requirements, a list of assumptions was needed to allow for an accurate design of the vertiport. These include but are not limited to:

Table 5
General requirements and assumptions for the infrastructure

1. UAM aircraft will resemble helicopter flight characteristics and therefore be treated like a helicopter
2. Vertiport lift system will operate autonomously with manual override for redundancy
3. Vertiports located outside of airport environments will have the ASOS weather sensors installed on the center of the roof

5.2 2D/3D Schematic Design of a Vertical Vertiport

The proposed vertiport design is based on Dr. Zelinski's concept that maximizes the throughput of UAM operations (Zelinski, 2020). The proposed system aims to not only maximize UAM throughput while assuming high operating conditions but also minimize the working surface footprint of the overall infrastructure. With these two overarching design requirements, an overall surface footprint size of $(340\text{ft})^2$ was established for the vertiport infrastructure. In addition, the utilization of this footprint allowed for the placement of four touchdown and liftoff (TLOF) zones on the roof of the structure to minimize passenger risk during departure and approach procedures. It is important to note that there are a few key features that drove the design of this vertiport system; these assumptions are listed below:

Table 6
Required features of the vertiport design

1. Independent TLOF zones are required for high-density operations
2. Extra space not utilized by UAM operations is accessible to the passengers
3. Centralized passenger areas may only be accessed through the security checkpoints

It should be noted that vertiport design standards are unavailable to the proposed design, therefore current heliport design standards and procedures are adopted to establish safety-critical design requirements. The requirements for the TLOF zones, taxiways, and parking spaces are listed in Table 1 in Section 4 as established in AC 150/5390-2C for VFR heliports for general aviation purposes. These design requirements allow for a maximum of 20 working parking spaces within the $(340ft)^2$ surface footprints. The vertiport incorporates two levels where UAM vehicles can load and unload passengers and park for scheduled maintenance. A dedicated lift system is conceptualized to support high throughput operations and to transfer UAM vehicles from different levels; it is discussed in section 5.3. Furthermore, dedicated passenger terminal areas are centralized on each floor as illustrated in Figure 4.

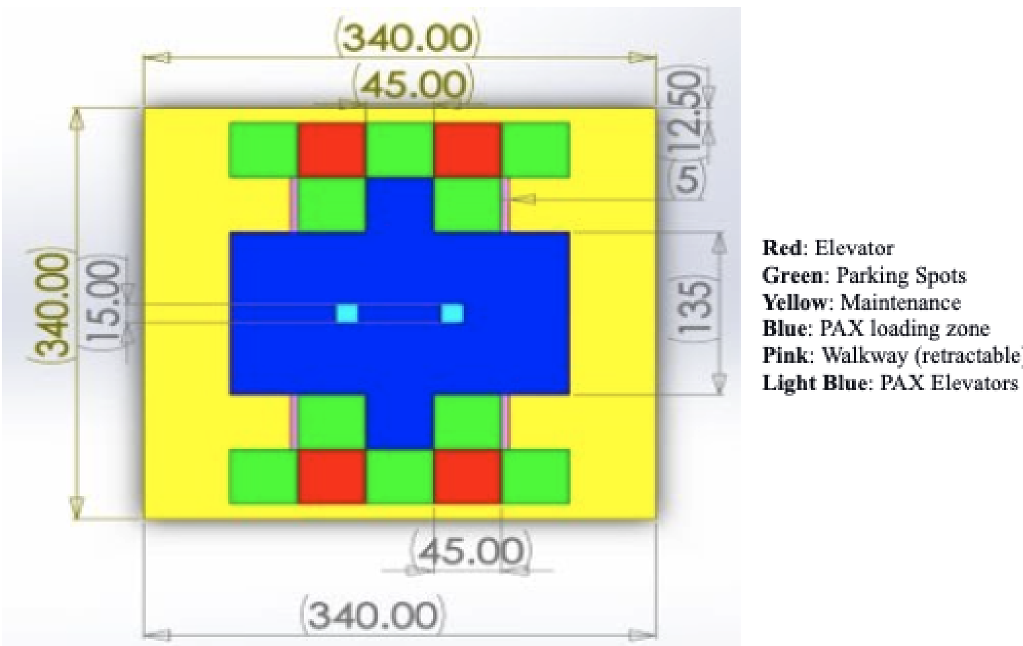


Figure 4. Schematic of lower levels of vertiport design showing placement of UAM parking

The schematic illustration above meets the safety-critical requirements presented in Table 1 in Section 4. It is important to note that both the parking-passenger separation and parking-parking separation are provided by the vertiport infrastructure. All sizing requirements for UAM parking spots and vertical lift platforms are equal to effectively reduce the complexity of the vertiport design. This specific design considerably reduces the complexity of movement within the vertiport. In addition, this effectively allows for lateral and vertical linear motion to transport the UAM vehicles from lift to parking and lift to TLOF. The four TLOF zones on the roof of the structure are illustrated below in Figure 5.

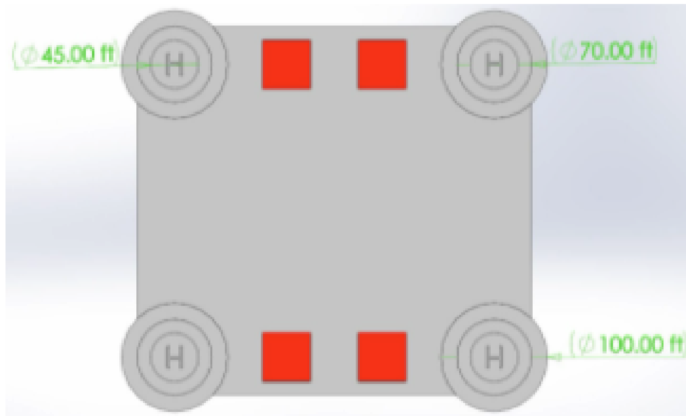


Figure 5. Schematic of the four TLOF zones that are placed on the roof of the vertiport infrastructure. The red squares indicate the vertical lift for the UAM vehicles.

As shown above, the perimeter of the vertiport infrastructure aligns tangent to the outer radius of the final approach and take-off area (FATO) diameter which is 70 ft. Therefore, the outer edges of the FATO safety area (FSA) are assumed to incorporate safety netting to effectively include the remaining area that is absent from the roof. However, all four 45 ft diameter TLOF areas have surface footprints on the surface of the vertiport. Incorporating the vertical lifts directly adjacent to the TLOF zones reduces the taxing time required before take-off and is discussed in a later section.

For 3-dimensional visualization purposes on the proposed vertiport design, Unity3D was utilized to simulate UAM vehicle operation and infrastructure location on the airfield at the NASA Ames Research Center. The simulation environment includes hangars 2 and 3 that are located on the north-east ramp of the airfield. The vertiport is placed directly north of both hangars which allows for a corridor placement that is parallel to runways 32-L and 32-R. Figures 6 and 7 illustrate the simulation environment created in Unity3D. It should be noted that the simulation utilizes Nvidia's PhysX engine to model rigid body dynamics and the fidelity of the simulated physics is fixed at a sampling rate of 50 Hz.

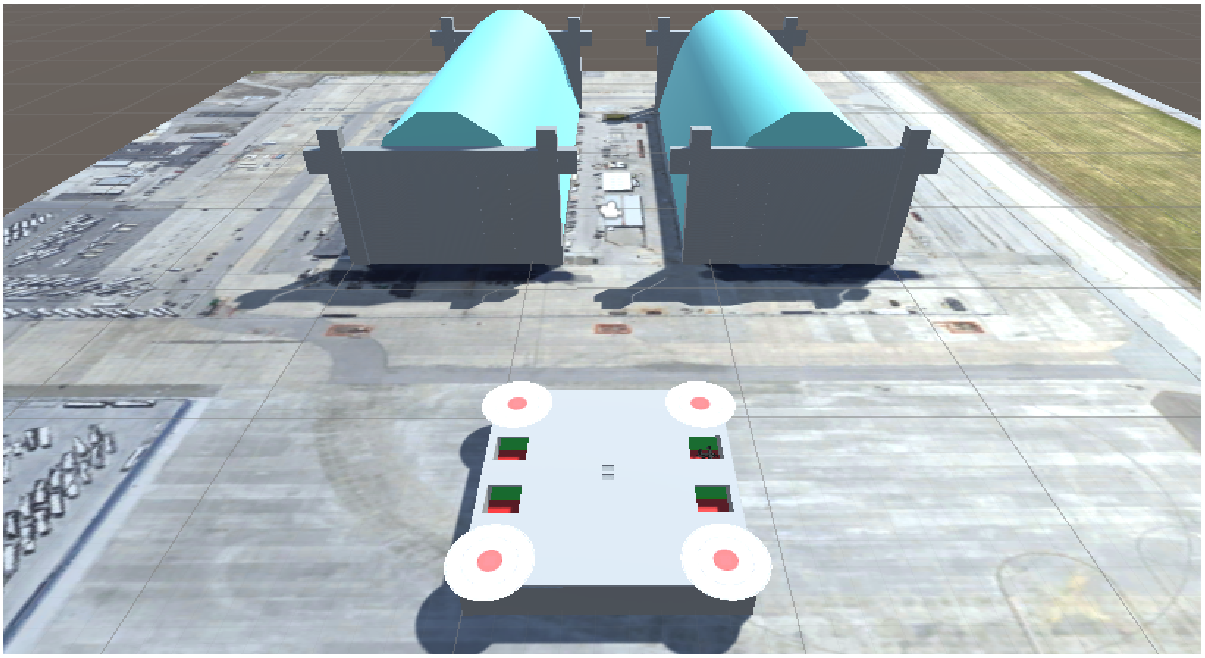


Figure 6. Simulation environment created in Unity3D showing the airfield and hangars 2 and 3 at the NASA Ames Research Center by Brayan Mendez

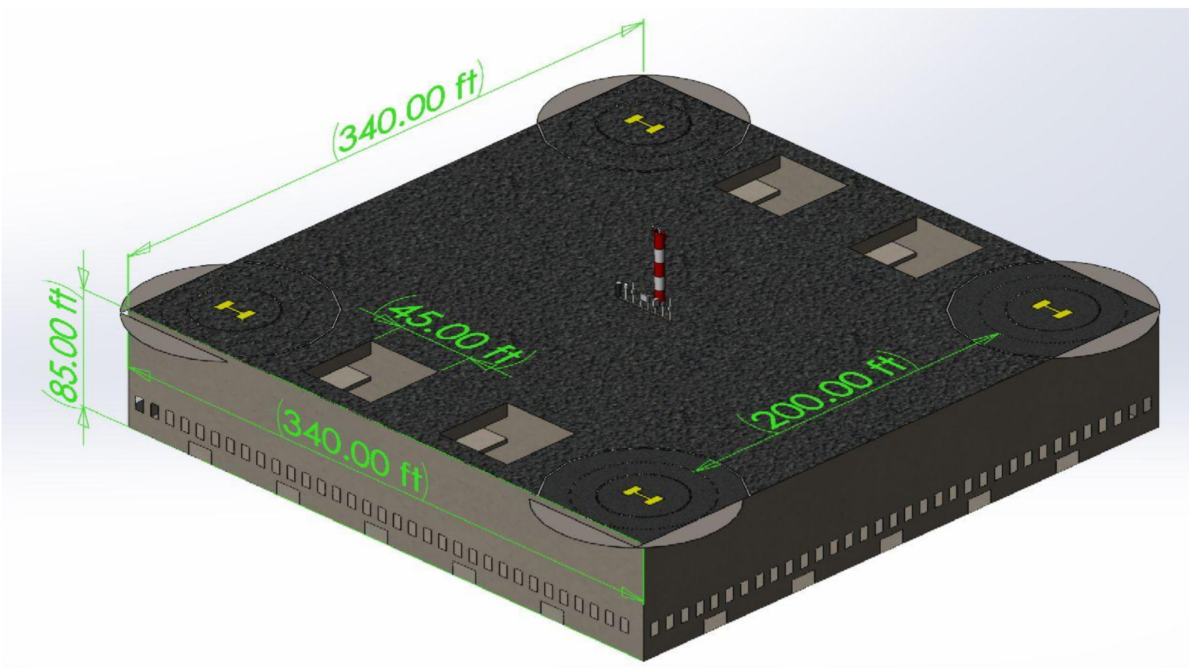


Figure 7. CAD design of vertiport by Matt Marchetti

5.3 Lift System Requirements

When developing the UAM lift system for the vertiport many options and ideas were considered due to the complication that the lift system entails. Originally, the plan was to develop a system similar to tower parking systems used for automobiles. However, after multiple meetings with tower parking system representatives, our team proposed to develop a system similar to aircraft lifts on aircraft carriers due to the wingspan of the UAM aircraft. The implementation of these lifts into our design was already proven in many aircraft carriers which had lifts with greater weight and size capacity that were designed for efficient transportation (Intrepid, 2021). The lift system in our vertiport was designed and implemented with assumptions and limitations presented by the FAA AC 150/5390-2C and Dr. Zelinski's article. Due to UAM aircraft's similarities to the helicopter, the UAM lifts must move at a speed of 4 ft/sec maximum and must be 1.5x the tip-to-tip span length (TTS) of the UAM, our system will be a 45ft TTS resulting in a size of $(45\text{ft})^2$ for lift and individual parking spot.

With the actual implementation of the system, the lift will move only in a vertical motion and will be flush with each level that it comes to allow for an automated UAM tug to pull the UAM either on/off the TLOF zone or the parking spot. Elevator systems are automated to distinctly place the UAM in the most efficient parking spot to allow for the fastest turnaround time to operation. Due to the high levels of automation, there is a risk of error and thus the precaution of allowing a human to take over and manually operate or fix the system will exist to eliminate automation errors. Lastly, there are two operating lift systems that must be considered (Darwin et al., 2005): hydraulic and a chain and rail system. Hydraulic systems tend to be more efficient and require less maintenance, but they are much more expensive and dangerous during the repair. In contrast, the chain and rail system are almost the complete opposite while losing a major portion of the financial toll. It is only losing a small amount of efficiency and increasing the safety of those repairing the system; thus, the chain and rail system was implemented in this design.

5.4 Other Technologies Implemented in the Vertiport Design

For the operational efficiency of the vertiport to stay consistent and continuously improve there must be some implementation of technologies to better increase the safety, security, and operational efficiency of the vertiport. These include but are not limited to UAM tug, ASOS weather sensors, and lift sensors for the UAM elevator system. Below are explanations why the major components will be critical for the success and implementation of the vertiport.

5.4.1 UAM Tug

The horizontal movement of UAM aircraft from TLOF to the elevator must be accomplished by a UAM tug that is similar in concept to a helicopter tug due to the nature of UAM aircraft typically being on skids and unable to hover consistently. UAM tugs must be adjustable to accommodate different sizes of UAM at the vertiport and be able to accommodate the various range of weight requirements of UAM. Specifically, the UAM tug must move at 4 ft/sec, similar to the elevator system, due to the FAA regulations on helicopter transport and the assumption that it is similar to future UAM regulations. Figure 8 is a helicopter tug that will be similar to the tug that is conceptually used at our vertiport. With the implementation of the UAM tug into the vertiport, there are a few issues that must be addressed. The UAM tug can

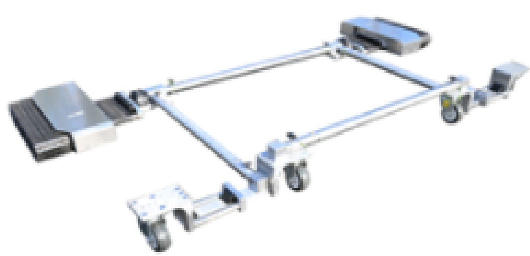


Figure 8. UAM tug model (AC Air Technology, 2020)

currently only last 30-45 minutes under full charge while being either remote-controlled or autonomously operated. The solution is either implementing multiple UAM tugs per station to compensate for battery swaps or for a direct power source to be connected to the UAM tug during the operation. Furthermore, the UAM tug must be able to operate in different weather conditions. The UAM tug will be operating on all three levels of the vertiport with one dedicated to each parking spot and multiple tugs on the top floor. These positions of the UAM tug will allow for seamless operation between UAM arrival to departure.

5.4.2 Automated Surface Observing System (ASOS) Weather Station

The automated surface observation system (ASOS) that incorporates various weather sensors is used to provide aviation observing data and meteorological data to ATC and pilots. This sensor suite can be placed at or near airports to provide climatological observing network services where the output data to this system is logged to the Global Surface Hourly database. For the purposes of this vertiport design, the ASOS weather sensor suite is centralized on the roof surface to provide accurate data for UAM operations. Key assumptions are made to successfully incorporate the weather technology into the vertiport operations environment which are listed in Tables 4 and 5. The reported weather details are listed below. This data can be updated every minute, 5 minutes, or hourly. For the purposes of this project, hourly updates are available to vertiport operations.

Table 7
ASOS weather information

Wind speed, character, and direction
Obstructions to vision such as haze and fog
Precipitation accumulation
Visibility up to 10 SM

Average pressure
Ceiling and cloud coverage

5.4.3 Lift Sensors

Sensor technology is conceptually incorporated within the vertiport design to support the UAM lift system and to increase safety for passengers. Various photoelectric sensors are used to detect passenger movement within the UAM lift area to prevent harm to both passengers and UAM aircrafts. Essentially, each passenger loading and unloading area will have photoelectric sensors on each floor detecting whether or not someone is in the direct path of the UAM lift. Passengers must be completely loaded or unloaded during sensor operation. If an object or person is to cross the operating environment of the lift sensor, the lift platform is faulted to stop. In addition, limit switches are used to precisely allow seamless platform to parking and platform to roof leveling. This seamless leveling allows for the UAM vehicles to be transferred smoothly through taxing conditions by using a rail system. Essentially, once the limit switch is tripped and the platform to parking and platform to roof transition is level, the rail system is allowed to smoothly transfer the UAM vehicles between the platforms. It is important to note that all four TLOF zones operate independently, therefore, each lift platform includes a rail system.

5.5 Maximum Throughput Analysis

Dr. Zelinski's equation is used to calculate the maximum throughput of our vertiport design. We utilized the equations below to compute our maximum surface and arrival/departure operations for the entire hour to compare to the horizontal layouts that have been proposed in Dr. Zelinski's article. Also, it will allow us to confirm if our system will be able to accommodate the demands of the UML-4.

$$C_{surf} = N_{park} * (t_{window} / (t_{taxi} + t_{park})) \qquad C_{apr/dep} = N_{TLOF} * (t_{window} / (t_{apr} + t_{dep}))$$

Equation 1: Equations for Maximum Throughput (Zelinski, 2020)

By utilizing equation 1, our vertiport has the operational capacity to support 120 arrival/departure operations and 159 surface operations per hour. When compared to the horizontal layout's maximum throughput, our vertiport has the highest operational capacity. However, these numbers are an estimate from the assumptions to represent a reasonable justification of what is possible. Furthermore, distinguishing the operational capacity allowed us to identify what areas are negatively impacting the maximum throughput. One of the largest factors was the turnaround time and the limitation that exists due to the battery swap technology and the speed at which passengers can load and unload safely.

5.6 Cost-Benefit Analysis

<u>Cost</u>

Cost-benefit analysis is conducted to analyze the viability of the vertiport design. The costs in this project also include high-level assumptions due to the limited information on the costs of materials needed as well as the custom manufacturing features needed. To increase the accuracy of the estimation, our team conducted multiple meetings with tower parking system companies during the preliminary phase of the project. Their insights have provided us with justifications for costs related to parking spaces, lift systems, and operational costs. In the preliminary stage of development, the CAD and Unity models had the largest impact on the budget due to the complexity of the design as well as the multiple renderings required for the visualization. This vertport's conceptual development cost is $13,900 as shown in Table 8.

Table 8: Vertiplex Concept Development				
Item	Rate	Quantity	Subtotal	Notes
Student Efforts	$25	160	$4,000	4 SJSU Students - 40 hrs. input
Concept CAD model	$40	30	$1,200	SolidWorks Model, GD&T
Concept Unity Model	$50	70	$3,500	Animation development
Safety Requirements	$35	20	$700	Safety requirements on Vertiplex construction and operations
Faculty Advisor	$100	42	$4,200	Project advisors
Misc	$300	-	$300	
Subtotal			**$13,900**	

The implementation stage focused on the development of a prototype as well as intellectual property protection. Furthermore, initial CAD and Unity models must be enhanced to better renderings as well as in-depth analysis on the operational efficiency and maximum load capacity must be conducted. Vertiport will be ready to be constructed upon completion of the prototype development. This stage is estimated to cost $245,200.

Table 9: Prototype Development				
Item	Rate	Quantity (hr.)	Subtotal	Notes
Academic Research	$50	-	$187,500	4 SJSU students and 3 Faculty Advisors
CAD Modeling	$50	100	$5,000	Building in depth model with GD&T through Solid Works
Unity Development	$50	400	$20,000	Building thorough model on Moffett Field to better show prototype
Consult with Experts	$100	70	$7,000	Consultation with multiple experts to better understand limitations and requirements
Engineer Approval	$100	200	$20,000	Approval for Construction and Safety signature on structure
Intellectual Property Protection	$5,000	-	$5,000	Intent to license design of vertiplex
Misc software	$700	-	$700	
Subtotal		**770**	**$245,200**	

Table 10 presents the initial fixed costs of building the vertiport as well as operational costs for 10 years. The main impactful budget changes that were assumed are the parking spots and the elevator systems as they will both need to be custom-built and installed. The initial cost of the vertiport is $37MM, with a 10-year estimated cost of $66MM. 10-year estimate includes the construction of the vertiport, operational costs (energy, security, maintenance, etc.), and the routine upkeep of the structure.

Table 10: Vertiplex Construction, Operation & Maintenance (per year)

Item	Rate	Quantity	Subtotal	Notes
Parking Spaces	$200,000	20	$4,000,000	Install and Material
Elevator Systems	$400,000	4	$1,600,000	Install and Material
UAM Tug	$18,000	40	$720,000	1 per TLOF and 1 per parking spot with extra for maintenance or swapping
Building Material (per sqft)	$200	115,600	$23,120,000	Material cost assumed from avg cost in San Francisco
ASOS Weather Sensor	$80,000	1	$80,000	Acquistion of sensors
Passenger Elevator Systems	$80,000	24	$1,920,000	26 person elevators
Land (per sqft)	$20	115,600	$2,312,000	Price of land in Bay Area
Glass (per sqft)	$12	9000	$108,000	Material cost only
Operational Cost	$3,200,000	1	$3,200,000	Electrical, Security and Misc Costs
Year 1 *Subtotal*			**$37,060,000**	
Yearly Maintenance and inspections year 2-10	$20,000	9	$180,000	Repair, Upkeep of facilities
Year Operational Costs year 2-10	$3,200,000	9	$28,800,000	
Recurring Years subtotal			**$3,220,000**	**Per Year**
Year 2-10 *Subtotal*			**$28,980,000**	
10 Year total cost			**$66,040,000**	

<u>Benefit</u>

UAM is envisioned to serve as an alternative mode of transportation. Our vertiport design will greatly relieve congestions in the Bay Area. Currently, Bay Area commuters travel 36 miles at an average speed of 36 mph due to congestion. In terms of public transportation, Bay Area Rapid Transit (BART) has been in place but is limited due to the railing systems and slow turnaround time. Individual BART stations handle about 9,000 passengers per station a day; in comparison, our vertiport can handle up to 12,000 passengers a day. Moreover, vertiports can generate financial revenue by utilizing the airport's Passenger Facility Charge (PFC) model. Assuming a passenger facility charge of $4.50 per trip (FAA,2021), 20-hour operation, and 4 passengers per trip; the vertiport would generate up to $43,200 a day, and cover 4.9x the operational cost in a year of operation.

5.7 Noise Level Analysis

Noise is a critical component when constructing any type of aircraft operational structure because it must be integrated into society and may be in close proximity to residential or commercial areas. FAA has recommended that eVTOLs must be 15 dB less than helicopters dB level of 87 dB at hover due to their high use in commercial and residential zones (Johnson et al., 2020). Using the equation below, noise level at the vertiport during high demand is computed.

$$L = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\left(L_i/10\right)}\right)$$

Equation 2: Equations for Noise Level Analysis (Taylor et al., 2020)

Assuming the noise level of one eVTOL is 70 dB at 500ft and that our proposed vertiport has two flight paths per TLOF zone our total noise level is 73.01 dB, around the noise of a vacuum cleaner and normal conversation. Because calculated noise is louder than the desired 72 dB there must be special distancing from residential zones to major vertiports such as increasing distance by several hundred feet or employing noise deterrent systems.

5.8 Additional Benefits of Vertical Vertiport

5.8.1 Mitigation of Ramp Access from Outsiders

Ensuring the safety of the passengers is one of the main concerns when designing an aircraft terminal structure. In the past 12 years, there have been 345 passenger perimeter breaches at airports due to the lack of security and ease of access to the runway areas (Pritchard et al., 2016). Horizontal vertiport concepts are far more vulnerable to outsider threats and passenger interference in the ramp area. On the other hand, our vertiport eliminates ramp access from passengers or outsiders because parking spaces and TLOF zones are vertically separated. Also, the entire loading and unloading procedure is carefully monitored through the designated lift systems and lift sensors installed throughout the vertiport. To further eliminate passenger interference, the terminal zone will be accessible only when all the security checks are completed. To “clean” the passengers, a dedicated zone akin to normal TSA checks at airports will be installed. Ultimately our design will eliminate the risk of terrorism and instill a feeling of security and safety amongst all involved.

5.8.2 Prolonged Lifespan of UAM Aircraft Due to Indoor Storage

Another advantage of our vertiport design is the prolonged life span of UAM aircraft due to indoor storage. As depicted from the 2D/3D schematic design of the vertiport, there are a total of 20 parking spots available inside the vertiport. Although most UAM aircrafts are assumed to have high levels of weather resistance, indoor parking during severe weather conditions will reduce the risk of damage on onboard sensors and electric motors of UAM aircraft. Also, indoor maintenance areas may improve preventative maintenance schedules and decrease the turnaround time of UAM aircraft. The maintenance area colored in yellow in Figure 4 is centralized for battery storage and any other equipment necessary for the operation of the vertiport and maintenance of the UAM aircraft.

6. Safe Integration of UAM into a Complex Airport Environment

In order for UAM to be an effective way of transportation, it must be assumed that UAM can safely operate in complex airport environments. The complexity refers to current airspace regulations and restrictions. It is assumed that the UAM maturity level will be at 4, and adhere to the current limitations of the current airspace, with little to no ATC intervention. For UAM aircraft to safely operate, a special UAM corridor will need to be created, as outlined in section 6.3.

6.1 Regulations Requirements, Assumptions, and Justifications

The safe implementation of UAM into a complex airport environment is a challenging endeavor. As stated before, high-level assumptions and requirements acquired from various industry expert consultations will fill in the missing information required to design a UAM corridor.

Table 11
General requirements and assumptions for the airspace

1. The UAM Corridor is separate from existing approaches and terminal operations (FAA, 2020).
2. Corridor is specific to UAM aircraft, and only to UAM aircraft. In normal operations, the corridor is restricted to any non-UAM traffic (FAA 2020).
3. Minimal to zero Air Traffic Control (ATC) intervention inside the UAM corridor (FAA, 2020).
4. Responsibilities of the ATC: -Set UAMSet UAM Corridor availability (e.g., open or closed) based on operational design (e.g., time of day, flow direction of a nearby airport) -Provide advisories regarding UAM operations to other aircraft on a workload permitting basis -Respond to UAM off-nominal operations as needed (FAA, 2020)
4. Cruising altitude for UAM aircraft is 1500ft - 4000ft AGL (FAA, 2020).
5. UAM aircraft's normal approach angle is assumed to be at 9 degrees.

6.2 Designated Vertiport Location at Moffett Federal Airfield (KNUQ)

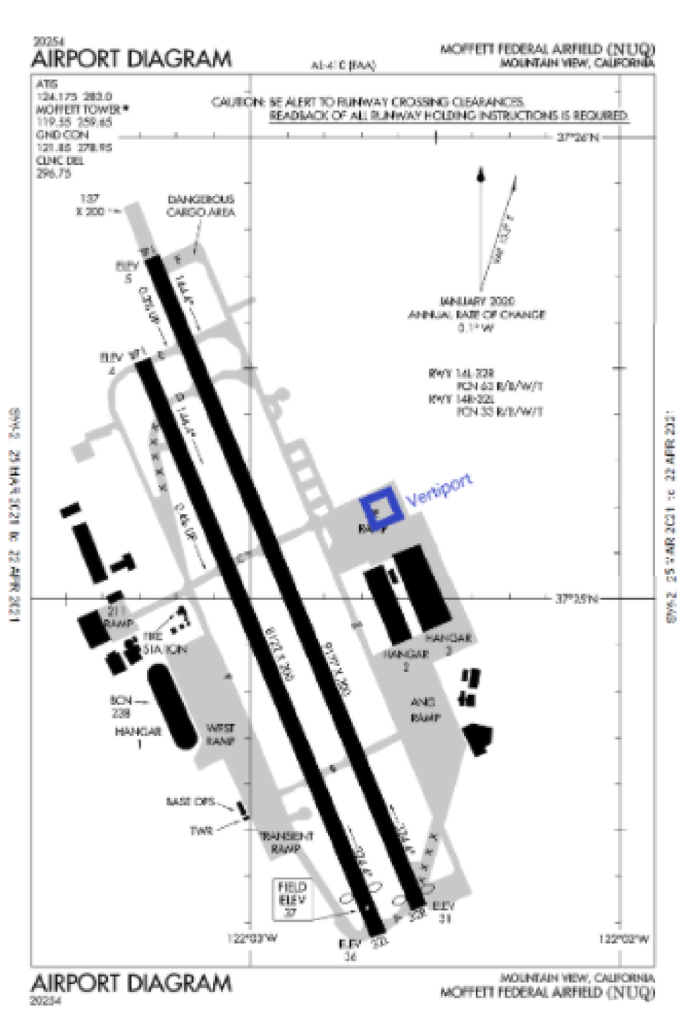


Figure 9. Proposed location of vertiport at Northern Ramp of Moffett Field

Our proposed location of the vertiport will be on the northern ramp of Moffett Federal Airfield (KNUQ) as marked in Figure 9. Our team determined the exact location of the vertiport by consulting industry experts working at Moffett Federal Airfield (KNUQ). Airport Operations Manager, Derek Pristavok and Airfield Maintenance Manager, Chris Nucci proposed two possible locations. The first location is the Northern Ramp near the blimp hangars. The second location is further up north located next to the armory. Though the second location is further away from the runway, additional research identified that UAM operations will disturb the existing departure and approach procedures of KNUQ. Moreover, the second location will require the removal of bunkers and a new foundation to be laid out, increasing the construction cost. There is also a Southern Ramp, however, it is off-limits due to military activity. Out of the options, the Northern ramp is the most ideal choice for our vertiport. The location is already paved, large enough to fit $(340ft)^2$ vertiport, and the location will minimize UAM aircraft's interference with the legacy traffic.

6.3 UAM Corridor at Moffett Federal Airfield (KNUQ)

A UAM Corridor at Moffett Field will need to be created to safely integrate UAM into the airport's current airspace. This corridor will be specific to the airspace at KNUQ but can serve as a baseline for future Vertiport locations. In regards to airspace, our vertiport is surrounded by class Charlie airspace from San Jose International (KSJC), Class Bravo airspace from San Francisco International (KSFO), and existing approaches and terminal operations of KNUQ. UAM corridor will support the autonomy of UAM aircraft and minimize ATC interaction. More specifically, only UAM aircraft will be allowed to operate inside the UAM corridor during nominal situations to minimize interference from current ATM and UTM operations.

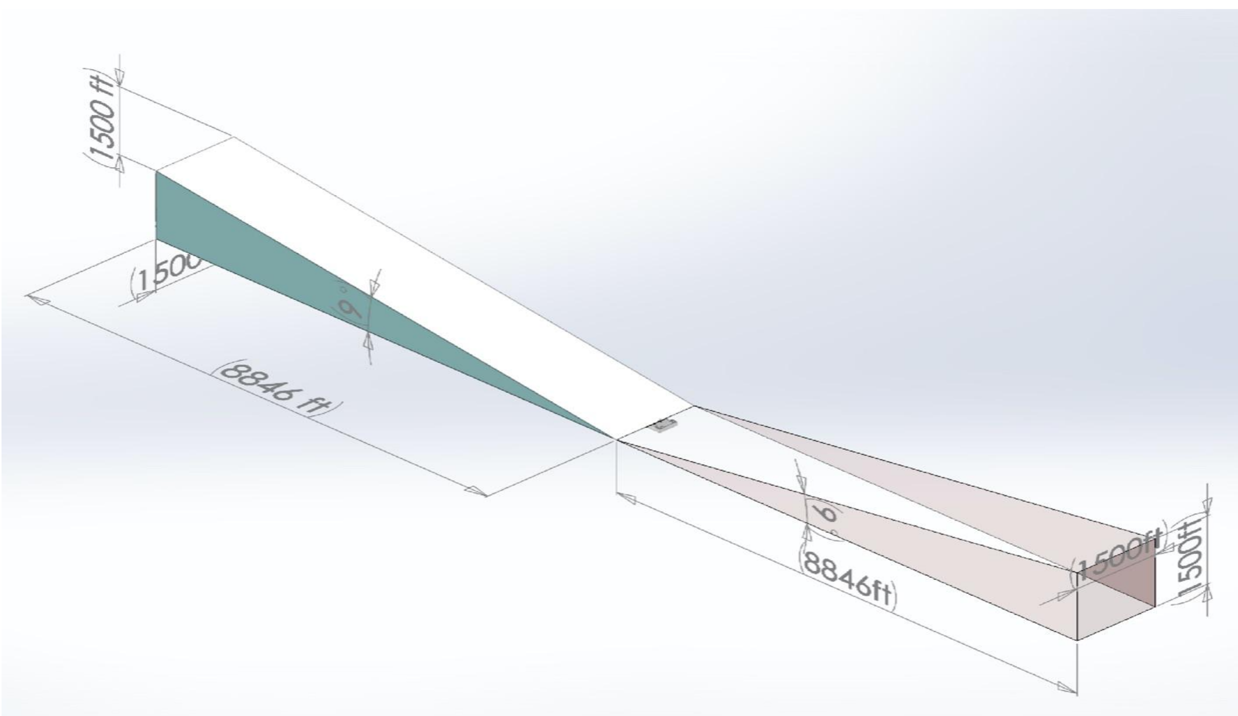


Figure 10. 3D view of UAM Corridor at KNUQ

The corridor's goal is to transport UAM aircraft from the vertiport to the cruising altitude of 1500ft agl as identified by the FAA CONOPS for UAM. The UAM corridor that extends to the destination is outside of the project scope. The width of 1500ft for the UAM corridor was advised by a subject matter expert in UAM Airspace Integration, Robert Wood to incorporate 1500ft lateral separation between approaching and departing UAM aircraft. Corridor length of 8846ft accounts for the proposed approach angle of 9 degrees. Steeper approach angles have been considered to reduce the size of the UAM corridor but there is insufficient performance data of UAM aircraft. The 9-degree approach angle can be justified from the Helicopter Flying Handbook. Once more performance data of UAM aircraft is collected, the approach angle may be subject to change to reduce the size of the UAM corridor.

The corridor will integrate an Eastern/Western approach and departure procedure as recommended by Mr. Wood. This allows for the approach and departure procedures to operate perpendicular to runways 14-32L and 14-32R. The UAM aircraft crossing directly above the mid-runway would be the safest way to minimize interference with the current approach and departure procedures at KNUQ. On easterly departures, the UAM aircraft will make a straight-out departure until it reaches over the peninsula, then either turn to the north or south depending on the destination. In westerly headings, the departures will be made straight out then a turn to the north or south will be made near highway 85 to aid in noise abatement issues. During the early maturity level of UAM, ATC clearance will be required before UAM aircraft is cleared to fly above the runway. Figure below is the scaled view of the UAM corridor aligned perpendicular to the runway at KNUQ.

Figure 11. Google Earth view of scaled UAM Corridor at KNUQ

Additional considerations also have been made to safely integrate a UAM corridor. The easterly/westerly approach and departure corridor do not favor the prevailing winds of KNUQ, which are northerly or southerly based on the runway headings. This has been taken into consideration and the solution would be to add leg to the final approach. The UAM aircraft will approach the vertiport in an easterly or westerly direction as the base leg, then turn final into the wind in the direction of the TLOF zone. The maximum speed inside the corridor has also been taken into consideration. This speed was also determined through our interaction with Mr. Wood. The speed limit in the corridor will be 70 knots. At this speed, UAM aircraft can perform a 90 degree bank, within a 78 foot radius. This allows for safe and controllable obstacle avoidance if needed within the corridor. The comfort of passengers was also taken into consideration for these parameters.

Another consideration is the missed approach procedure which was recommended by Aeronautics SME at Nasa Aeronautics Research Institute, Richard Walsh. Although the assumption is that UAM aircraft will be operating autonomously, there still needs to be redundancy implemented in the approach procedure to ensure safety of UAM operation. However, the complexity of developing a missed approach would lie outside of our project scope. Ultimately, it was a very challenging task to identify parameters based on the performance of the UAM aircraft. However, meetings with various industry experts allowed for more accurate assumptions and design of the UAM corridor. Similar to how we received invaluable assistance from the industry experts, our team sincerely hopes that our effort to design a safe UAM corridor can assist other UAM stakeholders in the near future.

7. Safety Risk Management

Risks of conventional heliport and airport operations will not be analyzed in this safety risk management (SRM). This SRM will focus on specific risks associated with the proposal's vertiport design. Furthermore, the SRM of vertiport operation is categorized into infrastructure and airspace. Some hazards and risks can be shared between two categories, but mitigation tactics may be different.

Phase 1. Describe the System:

- Reference **Section 5 and 6** of this proposal for a detailed description of the system.

Phase 2. Identify the Hazards:

Infrastructure

- Severe weather conditions
  - Gust, icing, and low visibility
- Congestions at the TLOF zone

- UAM automation failure
- Lift/tug system malfunction
- Passenger interference in the maintenance area
- Maintenance personnel operating near the lift system
- UAM battery malfunction

Airspace

- Unauthorized aircraft inside the UAM corridor
- UAM automation failure
- Communication failure between Providers of Services for UAM (PSU)
- Severe weather conditions
  - Gust, icing, and low visibility
- UAM engine failure

Phase 3. Determine the Risk:

Risks are caused by the hazards identified in Phase 2. Causation for each risk is matched and listed accordingly.

Infrastructure

- Crash landing on the ramp
  - Severe weather conditions
  - UAM automaton failure
- Inoperable TLOF area
  - UAM automation failure
  - Lift/tug system malfunction
- Passengers or maintenance personnel from falling down to the lift area

    - Lift system failure
    - Passenger interference in the maintenance area
    - Maintenance personnel operating near the lift system
- UAM Battery explosion
    - UAM battery malfunction

Airspace

- Mid-air collision
    - Unauthorized aircraft inside the UAM corridor
    - UAM automation failure
    - Communication failure between PSU
    - Severe weather conditions
- Emergency landing at an undesignated spot
    - UAM engine failure

Phase 4. Assess and Analyze the Risk:

Predictive Risk Matrix from AC 150/5200-37 was used as a guideline to estimate the severity and probability of risks identified in Phase 3. Federal Aviation Administration (FAA) advises that initial risk assessment will be "more qualitative in nature, based on experience and judgment more than data" and as time progresses, "quantitative data may support or alter the determination of severity or probability" (FAA, 2007). Because of insufficient quantitative data on Urban Air Mobility, our team interacted with various subject matter experts of UAM to increase the quality of the risk level assumptions. Subject matter experts who have verified this risk analysis are provided in the next section: Interaction with Industry Experts.

Severity / Likelihood	No Safety Effect	Minor	Major	Hazardous	Catastrophic
Frequent	7	16	20	23	25
Probable	6	13	18	22	24
Remote	4	10	15	19	21
Extremely Remote	2	8	11	14	17
Extremely Improbable	1	3	5	9	12

Figure 12. Predictive risk matrix (FAA, 2007)

Table 12

Risk Register for the Vertiport and UAM Corridor

Risk Description	**Probability level**	**Severity level**	**Priority Level**	**Mitigation Tactic**
Crash landing on the ramp	Extremely Remote	Catastrophic	17	A
Inoperable TLOF area	Remote	Minor	10	B
Passengers or maintenance personnel from falling down to the lift area	Extremely Improbable	Catastrophic	12	C
UAM battery explosion	Extremely Improbable	Hazardous	9	A
Mid-air collision	Extremely Improbable	Catastrophic	12	A
Emergency landing at undesignated spot	Extremely Improbable	Hazardous	9	D

Phase 5. Treat the Risk:

According to FAA Advisory Circular, there are four mitigation tactics. Below is an excerpt from the AC 150/5200-37 that defines each tactic. Six risks identified in table 12 will be treated by using at least one mitigation tactics listed below.

- **Avoidance:** Selecting a different approach or not participating in, or allowing, the operation or procedure
- **Assumption:** Accepting the likelihood, probability, and consequences associated with the risk
- **Control:** Development of options and alternatives that minimize or eliminate the risk
- **Transfer:** Shifting the risk to another area

(FAA, 2007)

A. The committee has decided to **control** the risks of **aircraft crash landing on the ramp, battery explosion, and mid-air collision** by developing emergency response procedures with the fire department at Moffett Federal Airfield to minimize the severity of the risk. Furthermore, the committee accepts the probability associated with the risk.

B. The committee has decided to **accept** the risk of an **inoperable TLOF area** because the independent lift system can operate regardless of the one TLOF area closure. However, the committee agrees that sudden closure of the TLOF area can cause congestion inside the UAM corridor. The committee has decided to **control** the risk of congestion by installing an emergency landing pad on top of the ramp. The emergency landing pad will be utilized only when PSU declares an emergency or when the maximum capacity of the UAM corridor is exceeded.

C. The committee has decided to **control** the risk of **passengers or maintenance personnel falling to the lift area** by installing physical barriers surrounding the lift system. Furthermore, maintenance personnel will be required to complete safety training specific to the vertiport operation before being allowed to operate.

D. The committee has decided to **control** the risk of **an emergency landing at undesignated spots** by installing landing pads throughout the UAM corridor. These landing pads will support automated precision landing as they will be identical to the ones installed on the vertiport. Further determination on locations and amount of landing pads will be made during the latter phase of the project. Installation of emergency landing pads may increase the cost of the infrastructure but it's in the best interest of the safety.

8. Interactions with Industry Experts

Due to unknown variables of Urban Air Mobility, interaction with industry experts was the most crucial aspect of the project. For this reason, our team interacted with a total of eleven industry experts of Urban Air Mobility. All of the interactions were conducted by virtual meetings for an average of 45-60 minutes in length. Additionally, our team had an opportunity to participate in NASA's Advanced Air Mobility (AAM) Ecosystem Community Integration Working Group to collect the most current information surrounding UAM. The team was able to interact with the following experts below:

- **Zaheer Ali** - Senior Manager at Universities Space Research Association (USRA)
- **David Bell** - Director and Chief Technologist at USRA
- **Paul Fast** - Project Manager, Aeronautics Project Office at NASA
- **Saba Hussain -** Program Manager, R&D Collaborations at USRA
- **Srba Jovic** - UAM Systems Modeling and Integration Lead at NASA AMES
- **Chris Nucci** - Airfield Maintenance Manager at Moffett Federal Airfield

- **Derek Pristavok** - Airport Manager at Moffett Federal Airfield
- **David Shapiro** - Aeronautics SME at Metis Technology Solutions
- **Richard Walsh** - Aeronautics SME at NASA Aeronautics Research Institute (NARI)
- **Wenbin Wei** - Aviation Department Professor at San Jose State University
- **Robert Wood** - Air Traffic Control Subject Matter Expert
- **Scott Woodworth** - Business Development Ambassador at Citylift
- **Shannon Zelinski** - Aerospace High Density Operations Branch Chief at NASA AMES

Zaheer Ali, Davild Bell, Richard Walsh, and Wenbin Wei (Weekly Meeting)

Four mentors were fundamental to the success of this project. Weekly meetings with the mentors allowed for an iterative process to systematically develop the frameworks of the vertiport design. Mentors' knowledge and suggestions have been embedded deeply in all sections of the proposal. Moreover, mentors provided valuable connections to other industry experts. Lastly, mentors have confirmed and provided feedback on the probability and severity of risks identified in Section 7: Safety Risk Management.

Srba Jovic and David Shapiro (April 09th/Duration of 90 minutes)

Dr. Jovic and Mr. Shapiro are subject matter experts (SMEs) at Metis Technology Solutions. Both have experience in UAM vertiport design and operations. Their experience in Regional Modeling and Simulation Tool (RMST) was instrumental in providing assistance to the proposed UAM corridor design. Dr. Jovic provided insight to wind disturbance models and weather sensor technology that emerges within the vertiport design. Lastly, Dr. Jovic and Mr. Shapiro have confirmed and provided feedback on the probability and severity of risks identified in Section 7: Safety Risk Management.

Chris Nucci and Derek Pristavok (March 30th/Duration of 60 minutes)

Mr. Nucci and Pristavok provided suggestions for vertiport locations based on their specific experience at the Moffett Federal Airfield (KNUQ). Moreover, they were able to enlighten us about terminal and military operations occurring inside the airport. Our team was able to safely integrate the UAM corridor at KNUQ based on the valuable information they provided us. Lastly, Mr. Nucci and Pristavok have confirmed and provided feedback on the probability and severity of risks identified in Section 7: Safety Risk Management.

Robert Wood (April 15th/Duration of 60 minutes)

Mr. Wood proposed a perpendicular orientation of the UAM corridor at our airport. Moreover, he assisted in establishing speed limitations and approach angle for UAM aircraft by taking into consideration of passenger comfort and UAM performance during the final approach procedure.

Scott Woodworth (Conversation via Email)

Mr. Woodworth is the Business Development Ambassador for CityLift, a tower parking systems company located in the Bay Area. He provided valuable insight into the lift system's limitations and price estimation.

Shannon Zelinski (March 23rd/Duration of 40 minutes)

Dr. Zelinski's research paper, "Operational Analysis of Vertiport Surface Topology" was the fundamental reference for the proposal. Dr. Zelinski provided further insights into the assumptions utilized in her calculations of maximum throughput. Dr. Zelinski also pointed out a concern for air vortices that can be formed because the TLOF zone is located on top of the vertiport.

Paul Fast and Saba Hussain (Special Acknowledgement)

We would also like to thank Paul Fast (NASA Ames Research Center) and Saba Hussain (USRA) who were instrumental in formulating and launching the project in collaboration with David Bell (USRA) and Wenbin Wei (SJSU). Paul leads the NASA Ames Smart Mobility initiative, and Saba Hussain leads the USRA/NAMS R&D Collaboration Program for university engagement. Paul was instrumental in connecting us to some of the key experts identified above, and Saba was instrumental in forming the multi-disciplinary student team that worked on this project.

The land of the Urban Air Mobility would have been impossible to navigate without the experts' guidance. We would like to thank them for their relentless dedication, interest, and assistance towards this project.

9. Projected Impact of the Vertical Vertiport

9.1 Sustainability Assessment

Sustainable airport development involves initiatives for increasing integration within local communities, reducing environmental impacts, and achieving economic benefits (FAA, 2021). For this reason, this section will examine the operational, economic, environmental, and social impact of the vertiport design.

Operational Impact

Proposed vertiport design will have a beneficial impact on the operation of Urban Air Mobility by increasing the flexibility of vertiport locations without compromising the demand capacity. Additional benefits from the vertiport design include increasing the security of the vertiport by mitigating ramp access from the passengers and outsiders and prolonging the lifespan of UAM aircraft through indoor storage. In terms of the airspace, the UAM corridor is designed to minimize the operational impact on the legacy air traffic. For the airspace design to have a long-lasting beneficial impact on the operation, the vertiport will have to transform and adhere to the latest regulations and performance data concerning Urban Air Mobility. On the other hand, there are major considerations to be fulfilled for an effective vertiport integration.

The operability of the vertiport design for advanced air mobility will need an effective integration of four specific supply chains to manage the transportation system which includes ground infrastructure, dedicated air traffic management, eVTOL aircraft manufacturing, and aircraft operators. Each vertiport location will need to be methodically located and designed to maximize passenger value and convenience. With the addition of multiple vertiport locations, network configurations will need to be implemented and expanded, such as ATM, which will ensure the safe integration of general aviation vehicles. In addition to safety, eVTOL pilots are needed to assist in-flight regulations and training procedures with integration into densely populated urban environments.

Economic Impact

Our vertiport's initial and operational cost may be higher than other horizontal integration of the vertiport, but it can generate 4.9 times the operational cost by adopting the financial model of Passenger Facility Charges (PFC). We strongly believe that economic impact will be far more beneficial than anticipated as there are additional benefits that can't be measured in financial terms. Increased flexibility of vertiport locations, increased security by mitigating ramp access, and increased life span of UAM aircraft by indoor storage are few additional benefits of the proposal's design.

Environmental Impact

The environmental impact of the vertiport is relatively minuscule due to the carbon neutrality of the building. The vertiport is completely operated by non-carbon-based electricity and will have little to no detrimental impact on the environment. Another environmental factor that influences the integration of vertiports is the noise pollution of structure and eVTOLs. Currently, the vertiport operation produces a maximum dB level of around 73, one dB higher than desired by the FAA. Due to this limitation, the structure must implement noise deterrent systems on the incoming and departing eVTOLs or implement spacing requirements between the nearby communities.

Social Impact

With the rise of tech companies in Silicon Valley, the bay area has become populated. An increase in commuters has caused congestion in roadways between San Francisco and San Jose. The property value of surrounding cities is rising to record highs. Many people have opted out of living near their work and live on the city's outskirts. The trade-off is a longer commute for a more affordable cost of living. Making vertiport accessible to all classes of wealth will be beneficial to society as it will present an alternative mode of transportations to the citizens of the Bay Area. They would no longer have to sacrifice hours spent commuting on congested roads. These benefits may even encourage more people to move out of crowded cities and reduce the overall congestion.

9.2 How Project Meets ACRP’s Goals

According to the ACRP's goal, the project should “Engage students at U.S. colleges and universities in the conceptualization of applications, systems, and equipment capable of addressing related challenges in a robust, reliable, and comprehensive manner” (ACRP, 2020). Because our vertiport is an innovative solution to an industry that is encompassed heavily by conceptualization, we concentrated on producing a design based on justifications that are reliable and comprehensive. Our effort to aggregate knowledge of industry experts to design infrastructure and airspace is demonstrated throughout every section of the proposal. We further hope that this project encourages and serves as a guideline for undergraduate and graduate students to contribute to innovative ideas and solutions to issues facing the National Airspace System. Progressing through the unknown realm of Urban Air Mobility was oftentimes very frustrating. However, the sense of accomplishment for being able to impact the industry is far more deserving.

10. Conclusion

In this design project, the proposed design is presented for the ACRP challenge “Strategies for safe and effective integration of automated and connected vehicles into the complex airport operations environment” (ACRP, 2020). To achieve effective integration, our team proposed a schematic design of a vertical vertiport with a surface footprint of $340ft^2$ to increase consumer benefits by increasing accessibility and operational efficiency of the vertiport. For a safe integration, our team proposed a UAM corridor with minimal interference with legacy air traffic while adhering to current regulations and assumptions surrounding Urban Air Mobility. The design is justified through maximum throughput analysis that yielded the highest operational efficiency when compared to the existing horizontal vertiport concepts. Additionally, our team conducted a cost-benefit analysis and determined revenue of 4.9 times the operational cost by adopting the financial model of Passenger Facility Charges that are used in commercial airports. To further promote the safe integration of our design, safety risk management was distributed to 11 industry experts who provided qualitative insights on our team's risk assumptions. Ultimately, the proposal's schematic design of the vertical vertiport and UAM corridor will fulfill the inherent gaps of Urban Air Mobility.

Appendix A: List of Complete Contact Information

Advisor Information:

Wenbin Wei, PhD

Professor

San Jose State University, Charles W. Davidson College of Engineering

wenbin.wei@sjsu.edu

Student Information:

Heungseok Park

Undergraduate Student in Aviation

San Jose State University, Charles W. Davidson College of Engineering

heungseok.park@sjsu.edu

Francis Sison

Undergraduate Student in Aviation

San Jose State University, Charles W. Davidson College of Engineering

francis.sison@sjsu.edu

Brayan Mendez

Graduate Student in Aerospace Engineering

San Jose State University, Charles W. Davidson College of Engineering

brayan.mendez@sjsu.edu

Matt Marchetti

Undergraduate Student in Aerospace Engineering

San Jose State University, Charles W. Davidson College of Engineering

matthew.marchetti@sjsu.edu

Appendix B: Description of the University

About San Jose State University (San Jose State University, para. 1) “As one of the most transformative universities in the nation, San José State is ready for big change. As part of Transformation 2030, SJSU's strategic plan, the campus community is dedicated to realizing the university's potential as a nationally prominent urban public university. San José State provides a comprehensive university education, granting bachelor’s, master’s and doctoral degrees in 250 areas of study. With approximately 36,000 students and nearly 4,300 employees, SJSU is an essential partner in the economic, cultural and social development of Silicon Valley and California. Founded in 1857, San José State's history began before the Civil War, as the first State Normal School, which trained teachers who educated the people of a young California. Now, SJSU is a dynamic comprehensive university that anchors the 10th largest city in the United States, and Spartans are found around the globe.”

About San Jose State University's College of Engineering (San Jose State University, para. 1) “The Davidson College of Engineering prepares graduates from all walks of life to be career-ready collaborative team players with a strong sense of cultural awareness and social responsibility. The college launches more graduates into Silicon Valley careers than any other college or university. With its hands-on learning environments, applied research opportunities, and interdisciplinary projects with industry professionals, the Davidson College of Engineering continues to earn top rankings among national public engineering programs. Our students are, indeed, the right engineers in the right place, at the right time.”

Vision Statement (San Jose State University Strategic Plan, para. 2) “The College of Engineering aspires to be: an engineering school of choice for all students; a valued campus, industry, and community partner; and a trusted member of our local and global community”

Appendix C: Description of Non-University Partners Involved in the Project

Universities Space Research Association (USRA)

The Universities Space Research Association (USRA) is an independent, nonprofit research corporation where the combined efforts of in-house talent and university-based expertise merge to advance space and aeronautics science and technology. USRA works across disciplines including aeronautics, aerospace, computer science, engineering, Earth Science, planetary science, and other domains through programs and projects ranging from fundamental research to facility management and operations. USRA manages the NASA Academic Mission Services (NAMS) program at NASA's Ames Research Center, which has a large focus on supporting NASA's Aeronautics Research Mission Directorate (ARMD) for projects that include Advanced Air Mobility (AAM) and Urban Air Mobility (UAM).

NASA's Ames Research Center

NASA's Ames Research Center is one of the four main NASA facilities that conduct aeronautics research in support of the NASA Aeronautics Research Mission Directorate (ARMD), and it is the location of the NASA Aeronautics Research Institute (NARI). NASA Ames and NARI work to develop partnerships that maximize impact to meet future aviation demands and opportunities consistent with ARMD strategic thrusts, including extensive research and development related to Advanced Air Mobility (AAM). NASA Ames is the location of the Moffett Federal Airfield, which is a joint civil-military airport with two active runways. Recent projects of NASA Ames and NARI have included the highly successful UAS Traffic Management (UTM) project and current Advanced Air Mobility (AAM) projects.

Appendix E: Evaluation of the Educational Experiences Provided by the Project

<u>Students</u>

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Yes! The ACRP University design competition provided a meaningful learning experience for our team by allowing us to effectively communicate with industry experts and apply previous project experience on innovative projects. In addition, working in a team environment not only improved communication skills within the interns, but also improved leadership skills that we will take and apply to other projects. The ACRP University design competition also allowed us to learn and apply industry standards to effectively accomplish our project deliverables in a fast-paced environment.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

One of the main challenges our team faced was a shorter than preferred timeline. We were given a little over a month to complete the scope of our work, which was quite the task. However, through time management and delegation of tasks, we were able to accomplish our goal. Another challenge we faced was the remote nature of our internship. This created obstacles in communicating ideas that needed to be visualized. We overcome this obstacle by taking advantage of our technology. We used the Microsoft Teams platform in order to conduct meetings, visualize ideas through screen share, and consolidate all of our research.

3. Describe the process you or your team used for developing your hypothesis.

First, our team identified the problem of a decrease in flexibility due to the large surface footprint of high-demand vertiports. With the mission to solve this problem, our team began an iterative process to designing a vertical vertiport. Aside from the literature analysis, the visualization and designing phase took the longest duration. Within 1 month, our team produced a total of 5 layouts of the vertiport and 5 different approaches to the UAM corridor. Our current design revolves around high-level assumptions due to the uncertainty of Urban Air Mobility. We strived to provide quality assumptions that can be justified through the experiences of industry experts or the existing regulations. We are certain that every design feature and dimension implemented in our vertiport and UAM corridor can be justified through one or either way.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Industry participation within the project was greatly useful and appropriate since industry experts provided guidance and insight on many conceptual and technical topics that emerged during project execution. The ability to reach out and discuss these topics with various industry experts was extremely beneficial to our project deliverables. In addition, the technical discussions with industry experts helped improve our communication and problem-solving skills within the team environment. These discussions also led to meaningful connections with industry experts that may help us in future projects.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

When producing this project our team learned many important skills about the overall operations of UAM as well as the requirements of aeronautical structures and airspace in general.

This project allowed us to expand what we learned in college into the practical world and granted us the opportunity to be able to further study a major area of our interest in a practical aspect in the workforce. This is due to the fact that the nature of the project directly corresponds to multiple companies mission plans as well as the overall nature of where the next development of commercial aeronautics is going. Furthermore, this project helped to enhance our critical thinking skills as well as our ability to formulate a plan, operate software and communicate our ideas to peers and superiors.

Faculty

1. Describe the value of the educational experience for your student(s) participating in this competition submission.

The value of the educational experience exists in several aspects: 1) students learned how to do literature review and research in order to get a better and thorough understanding of the theory and practice in design of vertiports, and operations and management of drones and Electric Vertical Take-Off and Landing (eVOTL) vehicles; 2) students took this competition as an opportunity to propose a very innovative idea for design of vertiports based on their broad range of knowledge and experience in the aviation field; 3) students learned how to work together as a team to complete this project as a team project, since they are from two different programs (aviation and aerospace engineering), and one of them is a graduate and other four are undergraduate students at San Jose State University (SJSU); 4) students learned how to adjust their topics, solution approaches, and scope of work in the course of completing this project when they kept getting new information from literature, interviews with industry experts, and researches from other resources; students learned how to organize all the material, schedule all the tasks, and finally complete the whole report in consistency with the requirement of this competition.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes. It is perfectly appropriate to our senior capstone class for the aviation program at San Jose State University (SJSU). We have five students in this team: three students enrolling in the capstone seminar class of aviation program, and two other students from aerospace engineering at SJSU. Four of these five students are working on the same internship project at NASA Ames through Universities Space Research Association (USRA).

3. What challenges did the students face and overcome?

One of the challenges that our students faced at the beginning was that there are no standards or clear rules for operations of drones, eVTOL vehicles, and vertiports, especially in the airport space environment. This problem was resolved through interviews and discussions with NASA researchers and Moffett Field airport operators and managers. Some assumptions were made and specific scenarios were developed.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes. We will definitely use this competition as an educational vehicle in the future, and it will be a very important component in our capstone senior class. One major reason is that this competition has brought a lot of values to students’ learning experience, such as team work, application of knowledge to practice, focused literature review and research, scheduling and organization, flexibility and adjustment, and etc. Also, the theme of this competition is consistent with my research interest in airport operation and management, air traffic management, Urban Air Mobility (UAM), and Advanced Air Mobility (AAM).

5. Are there changes to the competition that you would suggest for future years?

I have one suggestions: it would be great if the deadline for submission in the Spring semester could be changed to the middle or late of May, which will be close to end of the Spring semester for most universities.

Appendix F: Reference

AC Air Technology. (2020, October 23). *T1H2 Helicopter Tug*. https://acairtechnology.com/product/t1h2-helicopter-tug/

Airport Cooperative Research Program. (2020). *2020-2021 Design Competition Guidelines*. https://vsgc.odu.edu/acrpdesigncompetition/guidelines/

Bulusu, Vishwanath, Onat, Emin Burak, Sengupta, Raja, Yedavalli, Pavan, & Macfarlane, Jane. (2021). *A Traffic Demand Analysis Method for Urban Air Mobility*. IEEE Transactions on Intelligent Transportation Systems, 1–9. https://doi.org/10.1109/TITS.2021.3052229

Dalvit, D. (2011, July 14). *Price Per Square Foot Construction Cost for Multi Story Office Buildings*. EVstudio. https://evstudio.com/price-per-square-foot-construction-cost-for-multi-story-office-buildings/

Darwin, R., Bowman, H., Hunstad, M., Leach, W., & Williams, F. (2005, January). *Aircraft Carrier Flight and Hangar Deck Fire Protection: History and Current Status*. NAVAL AIR WARFARE CENTER WEAPONS DIVISION. https://apps.dtic.mil/sti/pdfs/ADA432176.pdf

Federal Aviation Administration. (2020, June 26). *Concept of Operations for UAM v1.0*. https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf

Federal Aviation Administration. (2021, January 12). *Passenger Facility Charge (PFC) Program*. https://www.faa.gov/airports/pfc/

Goldman, B. (2020, January 29). *Noise Comparison of Aerospace Vehicles* [Slides]. HAI Heli Expo 2020. https://evtol.news/__media/PDFs/3-GOLDMAN-Joby-eVTOLAcoustics-HeliExpo2020.pdf

Hill, B. P., DeCarme, D., Metcalfe, M., Griffin, C., Wiggins, S., Metts, C., Bastedo, B., Patterson, M. D., & Mendonca, N. L. (2020, December). *UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4* (1.0). Deloitte Consulting LLP. https://ntrs.nasa.gov/citations/20205011091

Intrepid Sea, Air & Space Museum. (2021). *Exhibits at the Intrepid Museum*. Intrepid Museum. https://www.intrepidmuseum.org/The-Intrepid-Experience/Exhibits

Johnson, C., Josephson, D., Rinsler, D., & Goyal, R. (2020, April 29). *eVTOL Infrastructure Workshop Virtual Workshop #3 April 29, 2020* [Acoustics and Noise Question & Answer Session]. eVTOL Infrastructure Workshop, online, N/A. https://vtol.org/files/dmfile/2020_vfs_uam_infrastructure_acoustics-noise_qa---ppt.pdf

Lilium. (2021). *Designing a Scalable Vertiport*. https://lilium.com/newsroom-detail/designing-a-scalable-vertiport

San Jose State University. (2021). *About SJSU.* https://www.sjsu.edu/about/

San Jose State University. (2021). *Strategic Plan.* https://www.sjsu.edu/engineering/about-us/strategic-plan/index.php

Taylor, Megan, Saldanli, Asya, & Park, Andy. (2020). *Design of a Vertiport Design Tool*. 2020 Integrated Communications Navigation and Surveillance Conference (ICNS), 2A2–1–2A2–12. https://doi.org/10.1109/ICNS50378.2020.9222989

US Department of Transportation & Federal Aviation Administration. (2007, February). *Advisory Circular* (150/5200-37). US Department of Transportation. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5200-37.pdf

US Department of Transportation & Federal Aviation Administration. (2012, April). *Advisory Circular* (150/5390-2C). US Department of Transportation. https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5390_2c.pdf

Vaisala White Paper. (2008, November). *How Airports can Increase Competitive Advantage and Profitability*. Vaisala. https://www.vaisala.com/sites/default/files/documents/WCO-APS-AMER-%20How%20airports%20can%20increase%20competitive%20advantage%20and%20profitability.pdf

Yamashina, H., & Otani, S. (2001). *Cost‐optimized maintenance of the elevator – single unit case* (No. 1). MCB UP Ltd. https://doi.org/10.1108/13552510110386946

Zelinski, Shannon. (2020). Operational Analysis of Vertiport Surface Topology. 2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC), 1–10. https://doi.org/10.1109/DASC50938.2020.9256794