33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

OPERATIONAL FEASIBILITY STUDY OF AIR TAXI SERVICE USING EVTOL

Haruki Takizawa[1], Zhong Lei[1]

[1]Suwa University of Science, Toyohira 5000-1, Chino, Nagano, Japan 391-0292

Abstract

Operational feasibility was studied for air taxi service using the future eVTOL aircraft. Tokyo metropolitan area was investigated, and 30 takeoff and landing sites were assumed as UAM ports in the service area with consideration of constraints and flight performances of eVTOL aircraft. Dimensions of the parking area were calculated under constraints. It was found that for the access between Narita and Haneda International Airport, the air taxi costs up to ¥67,000 more than existing ground taxi, and consumers could potentially save 49 minutes compared to the ground taxi.

Keywords: eVTOL, Urban Air Mobility, Air Taxi, Airport Shuttle, Operation Model

1.Introduction

In recent years, because of the growing need for transport, urban air mobility (UAM), which moves people with zero emission and low noise by air in urban districts, has been getting a lot of attention in the world. Up to now, land transportations, such as road cars and railway trains, are popular in the world. Due to major advances in electric propulsion, light material and control technologies, the eVTOL (electric vertical takeoff and landing) aircraft has been researched and developed for UAM. Many companies from major aircraft manufactures to venture companies joined to develop electric-powered aircrafts. On the other hand, it is important to predict the demand for a new transportation such as the eVTOL aircraft, for both air operators who need to pursue profitability and consumers who look for convenience to deploy the appropriate means of transportation and service.

Some consultancies forecasted the future market, as shown in Figure 1. For example, Roland Berger reported that the market of eVTOL aircraft was expected to grow rapidly in the next 30 years [1]. To obtain reasonable the market forecast, it is important to make a mathematic model and set reasonable constraints.

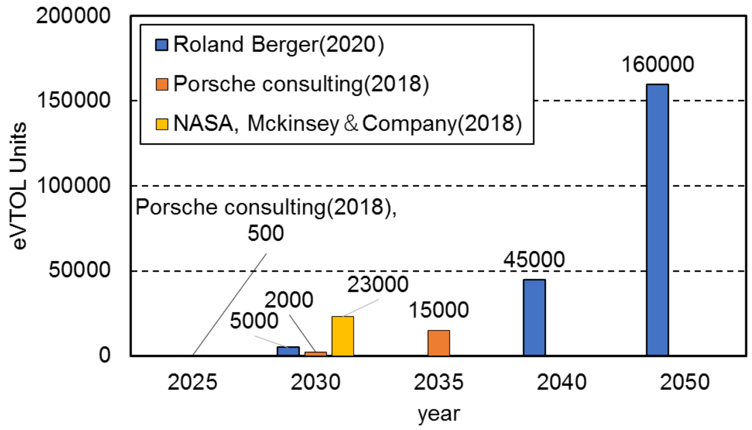

Figure 1. Results of forecasting the number of eVTOL in operation by 2050 [2][3][4]

There is a possibility which new transportation demand will be generated in regions and routes by introduced a new mode of transportation. With increase of the technological competition, the demand forecast is becoming increasingly important for social implementation. The development of eVTOL aircraft is quite different from the development of conventional airline in many ways. Also, it is important agenda to harmonize new infrastructures that take into account the flight characteristics of eVTOL aircraft with existing infrastructures that have been developed in the past.
The purpose of this study is to investigate on-demand services with consideration of flight performance of the eVTOL aircraft and discuss the operational feasibility of the eVTOL-based air taxi. In this paper, the eVTOL aircraft is assumed to be operate in the metropolitan area of Tokyo, the capital of Japan. The UAM port for takeoff and landing, and a business model for operation will be studied by comprehensively taking into account some constraints existing in the area and the flight characteristics of eVTOL aircrafts.

2.Study of UAM port in the Tokyo metropolitan area

2.1 Investigation to distribute takeoff and landing sites in whole area of Tokyo metropolitan

Because the existing facilities and infrastructure of Tokyo Haneda International Airport (Tokyo) have been well organized, it is a good example to discuss a take-off and landing area for social implementation. First, as part of the demand forecasting, the possibility of building an UAM port for take-off and landing in the metropolitan area was examined. The estimation method and criteria of takeoff and landing site were shown in the following Figure 2. Calculation was conducted based on Geospatial Information Authority of Japan' data[5], and the measurement was done on the map.

・Selecting the top 100 railroad stations with the highest number of passengers
・Selecting locations with induced demand such as airports, events, and large commercial facilities

↓

Selecting a railroad station with a river or bay within a 1.5[km] radius
*exclude airports

↓

Selecting areas with a flat area of 2,500[ft^2] (16[m]x16[m]) along rivers and bays

Figure 2. The step of takeoff/landing site estimation

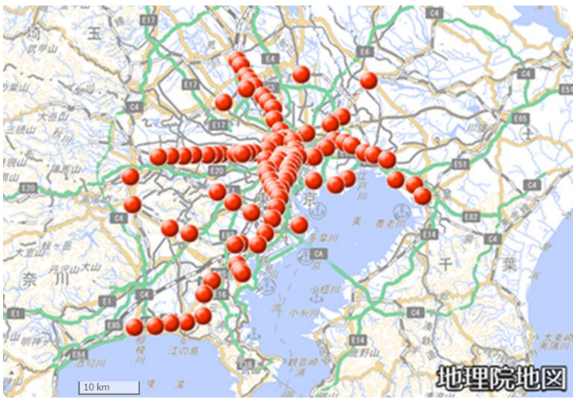

Figure 3. 100 railroad stations

Figure 4. Locations of the selected UAM ports

It is realistic to fly the eVTOL aircraft over rivers and bays in order to avoid crowded areas in an early stage of commercial operation. Based on this consideration, an UAM port for takeoff and landing in the Tokyo metropolitan area was investigated with constraints of the infrastructure and the flight performance of the eVTOL aircraft. As a result, 30 sites were assumed to be used as UAM ports. Some criteria were set to select the UAM port with sufficient potential, mainly near train or subway stations with a large flow of passenger. Selected 100 candidates in Tokyo metropolitan area are shown in the following Figure 3, and chosen suitable 30 sites for takeoff and landing are shown in the following Figure 4, and an example of the selected UAM port is shown in the following Figure 5.

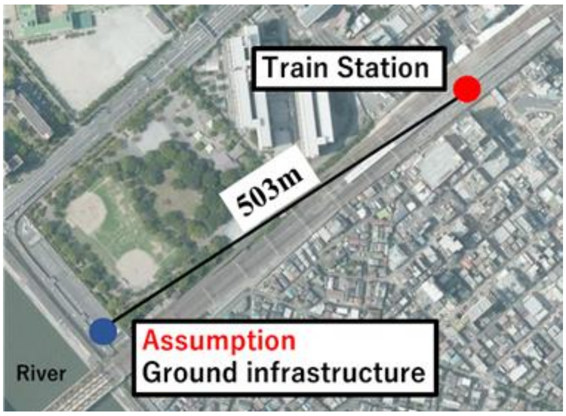

Figure 5. An example of the selected UAM port

2.2 Investigation of parking area

Investigation was focused on the Haneda airport in order to determine the possibility of locating more reasonable UAM ports and to forecast on-demand services with high fidelity. Top view of whole the Haneda airport passenger terminal is shown in the following Figure 6. The Haneda Airport terminal has 4 multi-storey buildings for car parking (P1~P4 in Figure 6.), and a takeoff and landing site on rooftop of P4 was considered as an example of UAM port in this paper.

According to the eVTOL size, takeoff and landing conditions, it is assumed that the area required for a multicopter type eVTOL aircraft is not smaller than 2500ft^2 (=232m^2) [1]. For comparison, space dimensions for the car parking in the same building is shown in Figure 7, and are calculated according to the parking design guideline published by Ministry of Land, Infrastructure, Transport and Tourism of Japan. It was shown that more than 12 parking space for passenger cars will be occupied for a multicopter type eVTOL aircraft.

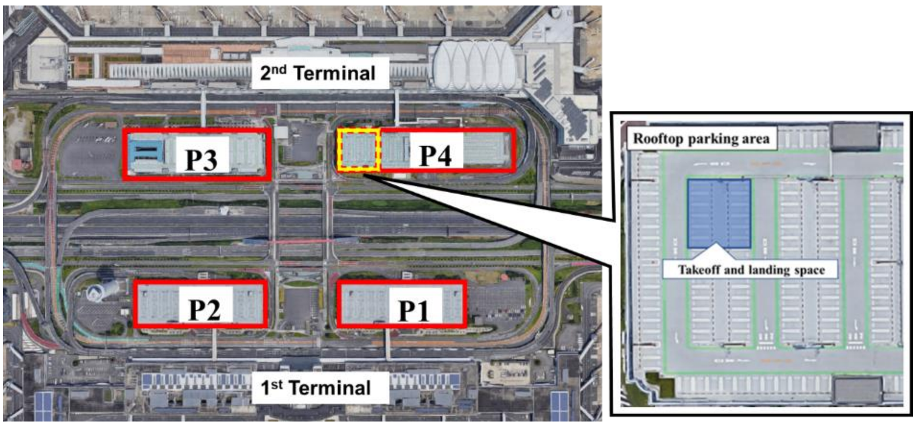

Figure 6. Required area for eVTOL take-off and landing area in rooftop of multi-storey parking building

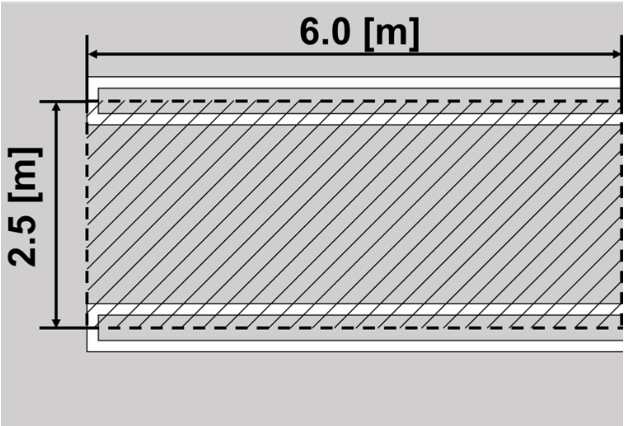

Figure 7. Car parking space dimensions from parking design guideline published by MLIT[6]

Although the minimum area physically required was calculated above, a larger space should be realistically considered for the sake of safety in takeoff and landing of the eVTOL aircraft. A parking space is then setup as shown in the Figure 8. The blue area is the minimum area required in takeoff and landing, and the area is extended to the yellow part for cordon safety and operability, and the red area is set as the no-parking area for restricted use. According to these assumptions, dimensions of the parking area were calculated and summarized in Table 1.

Figure 8. Assumed results of takeoff/landing site installation

Table 1. Parking space for each constraint

	Exclusive parking dimension [m]	exclusive area [m^2]
Landing and Taking-off site	12	233
Restricted area (A)	16	767
no-parking area (B)	26	390
total exclusive area (A)+(B)	42	1157

2.3 The present situation of Charging Infrastructure for Electric Vehicles

Currently, about 300,000 EVs and PHVs cars are operated in Japan. There are about 8,000 quick chargers and about 21,700 normal chargers in charging infrastructure. These charging infrastructure in Japan have been constructing and operating by e-Mobility Power co., Inc. that is largely funded by Tokyo Electric Power Company Holdings, Incorporated, Chubu Electric Power Company, Incorporated. Charging infrastructure has the problem that is aging charger in 8 to 10 years, therefore, it needs replacement the new charger at right time and it will incur costs.[7]

2.4 preferential measures of 2 incoming line for EV charger installation

In the case of power shortage of existing installation, there is the way to lead the new another wire. Previously, in case of a building and charger on same site, it is necessary to contract as one, as of April 2021, it was able to apply the preferential measures to normal charger. Accordingly, it can avoid high voltage when the power can't afford.
Cost comparison of Normal charger and Quick charger is shown in the following Table 2. In addition, it needs another cost of maintenance (hundreds of thousand yen per year) by licensed electrical engineer in high voltage facility. In the case of installing multiple chargers in takeoff and landing site at the same time, construction cost per one charger is predicted to get cheaper.

Table 2. Normal and Quick charger costs[8]

Charger Type		Normal Charger	Quick Charger	
Output		3~8	20~150	[kW]
Charging time		4~8	0.25~1.0	[h]
Product cost		0.2~0.4	2.0~	[million yen]
Construction cost		0.3~3.0	2.5~10※	[million yen]
Maitainance cost (Communication fee, maintenance fee, Contract fee of call center and etc)		tens ~ hundreds of thousands	30 ~ 40 thousands	[yen]
Electricity cost	basis charge	1638		[yen/(kW・month)]
	commodity charge	16.65		[yen/kWh]

※Including the cost of installing cubicle that is needed to install charger equipment with output power of 50kW or over.

3.Study on eVTOL taxi fare by air

The fare of the eVTOL transportation service is estimated between airports in the Tokyo metropolitan area. Table 3 is the air taxi fares estimated in literature. In this study he on-demand air taxi is investigated. In contrast, the Air Metro, which is defined to operate on regular routes of scheduled flights, just like conventional bus and train, is not included in this study.

Table 3. eVTOL fares estimated in literature [3][4][9][10]

Company	Porsche Consulting	NASA, Mckinsey & Company	Booz Allen Hamilton	Uber Elevate
Report year	2018	2018	2019	2016
Fare	8~18＄/min	~50$/trip	~50$/trip	2.09~2.97$/mile
Remarks	Air taxi On-demand	Air metro 1 trip: maximum 70miles assumed	Air taxi On-demand 2~5seat	Air taxi Not limited to "eVTOL"

The estimation used above was converted to Japanese fares in this study. For the reason of conversion, the estimated region is assumed to be New York, and the exchange rate is assumed to be 127 Japanese yen to the US dollar in May 2022. Tokyo and NY ground taxi fare structure is shown in the following Table 4, and the ground taxi fares in New York City were compared and then converted to Tokyo prices. Figure 9 shows fares for a trip of 82.9 km, the land distance between Haneda and Narita airports as shown in Figure 10.

Table 4. Ground taxi fare structure in Tokyo and New York

	Initial fare	after
Tokyo [11]	410[Jp yen] up to 1052[m]	+80[Jp yen] every 233m
New York [12]	2.5[U.S.$] up to 322[m]	+50[U.S.$] every 322m

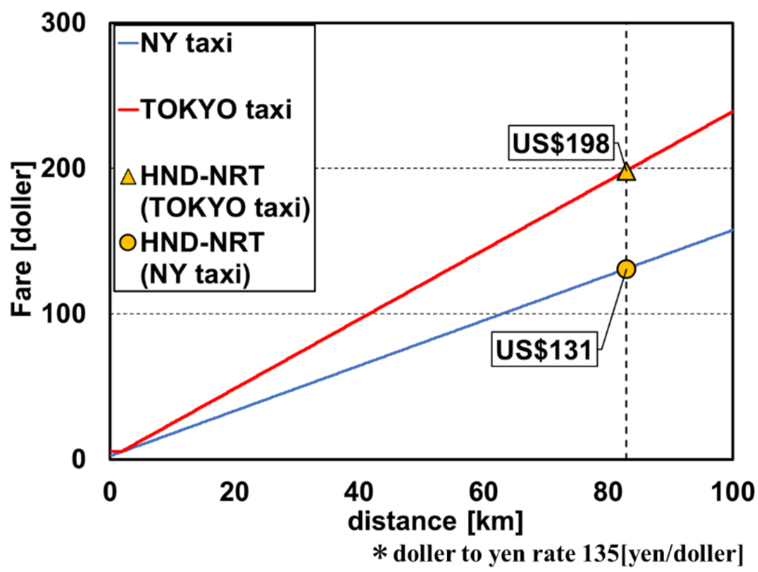

Figure 9. The comparison with Tokyo's taxi fare and NY's taxi fare

Figure 10. The root of Narita to Haneda airport using ground taxi (82.9km)

As shown in Figure 9, the fares in Tokyo are 1.61 times of those in New York, based on the analysis of the taxi market between the two cities. Then, with these results, a comparison is conducted between the price of an air taxi service using eVTOL and the price of ground transportation methods between Haneda and Narita airports. Figure 11 shows that air taxi fares are significantly expensive than existing means of transportation. On the other hand, Uber Elevate's fares estimated are 18% to 23% cheaper than existing ground taxi (including flat-rate services), and it suggests that the air taxi may be used more cheaply than ground taxi in Tokyo.

There are a few access ways to be used to move between Haneda and Narita airport by train [13].

・Route 1

Number of transfers: 0
3 direct ways: Keisei Line airport limited express
Fare (Adult): 3,130[yen]
Required time: 1[h]30[min]
Operation Interval: 40[min]

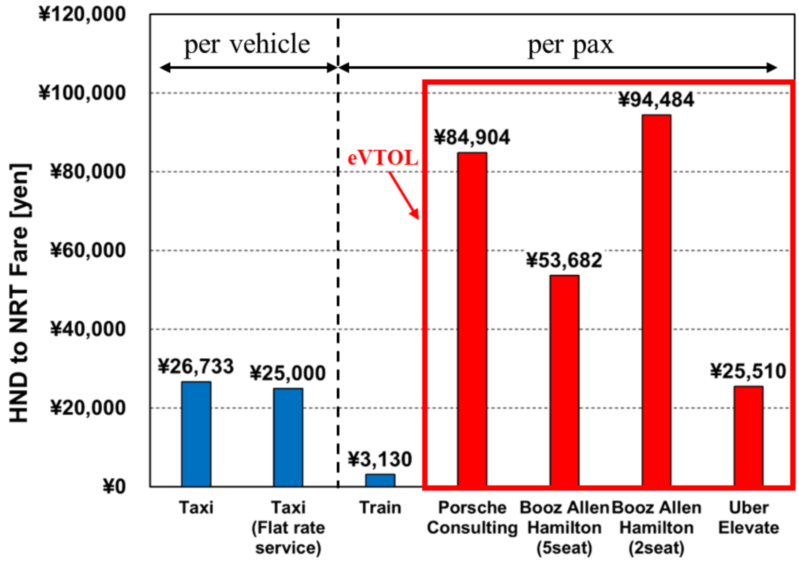

Figure 11. Comparison of fares of transportation between Haneda and Narita Airport

・Route 2
Number of transfers: 1
Keikyu Line (13min) →JR Narita express (59min)
Fare (Adult): 3,400[yen]
Required time: 1[h]12[min]
Operation Interval: 30[min]
Transfer sta.: Shinagawa Sta.

・Route 3
Number of transfers: 3
Tokyo monorail (13min) → JR Yamanote Line (16min) → Keisei Line express skyliner (36min)
Fare (Adult): 3,130[yen]
Required time: 1[h]5[min]
Operation Interval: 20~40[min](express)
Transfer sta.: Hamamatucho Sta., Nippori Sta.
Total transit time: Minimum 5[min]

Time required of moving between Haneda airport to Narita airport by train is 1 ~ 1.5 hour, and train is the cheapest public transport. On the other hand, time required by bus going between the airports is 1 h 5 min ~ 1 h 25 min, and it costs 3200 [yen].
The bus and the train compete against each other; however, the train has an advantage of regularity, and not affected by traffic jam. In contract, for bus and taxi, it is affected traffic condition, but it is able to leave baggage or keep comfort without additional transfer.
In that context, the air taxi using eVTOL aircraft can flight between Haneda to Narita airport in 20 minutes. Also, the air taxi service can provide both comfortability and time saving. However, the air taxi service has challenges for future such as securing punctuality regardless of weather.

4.Comparison of airtaxi flight time and cab travel time

The flight time of the eVTOL aircraft was then estimated for a straight-line distance of 59.6 [km] between Haneda and Narita airports. Because the flight route is usually designated for navigation and to avoid accidents, the flight distance is set to 65.6[km] that multiplies the straight-line distance by a factor of 1.1 in this study. And to estimate flight time, 4 different models of eVTOL aircraft were selected. Specifications and performance of 4 models of eVTOL were shown in following Figure 12 to 15 and Table 5 to 8.

Figure 12. Ehang 216[14]

Table 5. Ehang 216 specifications and performance [14]

Company	eHang	
Establishment	2014	
Country	China	
Model	eHang 216	
Release	2018	
Crew (0: Autonomous)	0	
Passenger	2	
Maximum payload weight	220 (kg)	4180 (lb)
Cruise speed	100 (km/h)	54 (knot)
Maximum speed	130 (km/h)	70 (knot)
Range	35 (km)	19 (nm)
Maximum flight time	21 (min)	
Maximum altitude	3000 (m)	9800 (ft)

Figure 13. Volocity[1]

Table 6. Volocity's specifications and performance [1]

Company	Volocopter GmbH	
Establishment	2011	
Country	Germany	
Model	Volocity	
Release	2019	
Crew (0: Autonomous)	1(0)	
Passenger (Target number)	1(2)	
Cruise speed	90 (km/h)	48.6 (knot)
Maximum speed	110 (km/h)	59.4 (knot)
Range	65 (km)	35 (nm)
Maximum flight time	40 (min)	

Figure 14. Joby S4 2.0[15]

Table 7. Joby S4 Specifications and performance [15]

Company	Joby Aviation	
Establishment	2009	
Country	USA	
Model	S4 2.0	
Release	2020	
Crew	1	
Passenger	4	
Cruise speed	322 (km/h)	174 (knot)
Range	241 (km)	130 (nm)

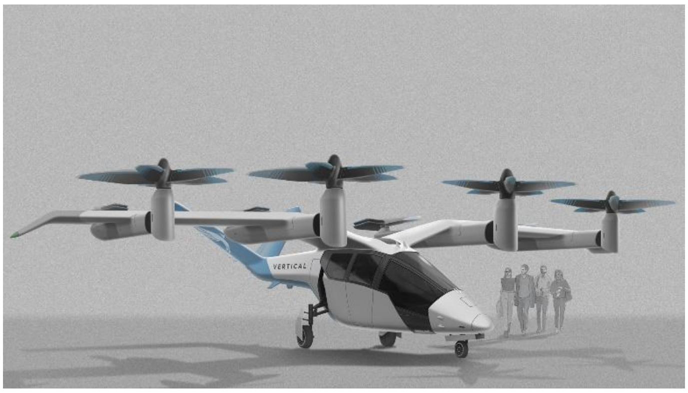

Figure 15. VX4[17]

Table 8. VX4 specifications and performance [17]

Company	Vertical Aerospace	
Establishment	2016	
Funding	305m$	
Country	UK	
Model	VX4	
Release	2020	
Crew	1	
Passenger	4	
payload weight	450 (kg)	992 (lb)
Cruise speed	241 (km/h)	130 (knot)
Maximum speed	325 (km/h)	176 (knot)
Range	141 (km)	76 (nm)

For all eVTOL aircrafts, the climb and descent rate of the eVTOL aircrafts were assumed to be constant at 4 [m/s], and the cruise altitude was assumed to be 1500 [ft], the common conditions of flight are shown in Table 9 and the inverse proportional relationship of flight time and cruise speed are shown and compared in Figure 16.
The eHang 216 has a maximum cruising speed of 100 [km/h], and Volocity has a maximum cruising speed of 80 [km/h], and Joby S4 2.0 has a maximum cruising speed of 322 [km/h], VX4 has a maximum cruising speed of 241 [km/h]. In this study, it is assumed that the eVTOL will cruise between Haneda and Narita Airport at a maximum cruising speed to compete with the speed of high-speed vehicles.
As a result, the flight time of Joby S4 2.0 was estimated to be about 16 [min], and the flight time of VX4 was estimated to be about 20 [min], therefore, it was suggested the possibility that the 2 models of vectored thrust type eVTOL, i.e., S4 and VX4, may fly between Haneda and Narita airport within 20 minutes. The flight time of Ehang 216 was estimated to be about 43 [min], and the flight time of Volocity was estimated to be about 48 [min]. The minimum time required for a taxi on the ground is 1 h 5 min, but the time required is considered to increase further if traffic congestion peculiar to the city center is taken into account. Therefore, the advantage of choosing air taxi will increase to save time. Additionally, as shown in the figure, the cruise speed is 64.3 km/h for the flight time of eVTOL, which is equal to the time required for ground taxi.

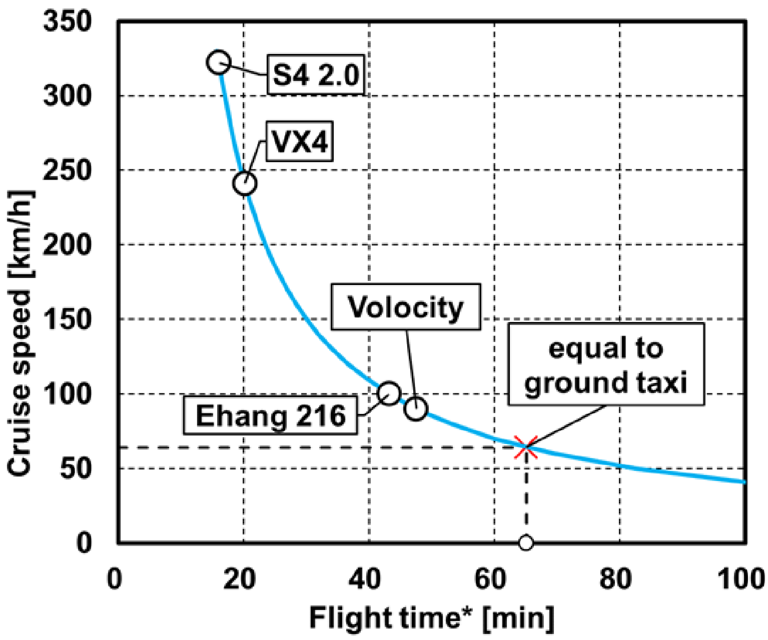

Fig16. Comparison of for different eVTOLs at a specified flight distance.

Table 9. Common conditions of eVTOL

Assumed eVTOL performance	Climb speed [m/s]	4	
	Descent speed [m/s]	4	
Cruise altitude [m][ft]		457	1500
HND-NRT Direct distance [km][mile]*1.1		65.6	40.8

5.Operation of Air taxi service between main airport and takeoff and landing sites

Based on the research above, the airway network of UAM, linking Haneda and Narita airports to ground transport stations, is made as shown in Figure 17. In this paper, all flight distances are defined as 1.1 times of those responding straight distances as described above. The distance between Narita Airport (Pref. Chiba) and Hiratsuka Station (Pref. Kanagawa) is the longest distance of 115 [km] in this estimation area. The fare of Narita Airport to Hiratsuka Station was 212 US dollar using upper limit fare of 2.97 US dollar per mile of air taxi service published by Uber Elevate in 2016.

To compare air taxi to ground taxi, this fare of 27,136 [Jp yen] was 0.53 times as cheap as ground taxi fare of 51,400 [Jp yen]. According to specifications of eVTOL aircraft, the cruise range of both multicopter types is limited in a short range less than 40 km, and not suitable for a long-range flight. The flight time between Narita Airport and Hiratsuka Station of vectored thrust eVTOL aircraft is 23 [min] by Joby S4 2.0 or 43 [min] by VX4, which is much faster than transit time of 1 hour 55 minutes by train or 2 h 10 min by ground taxi.

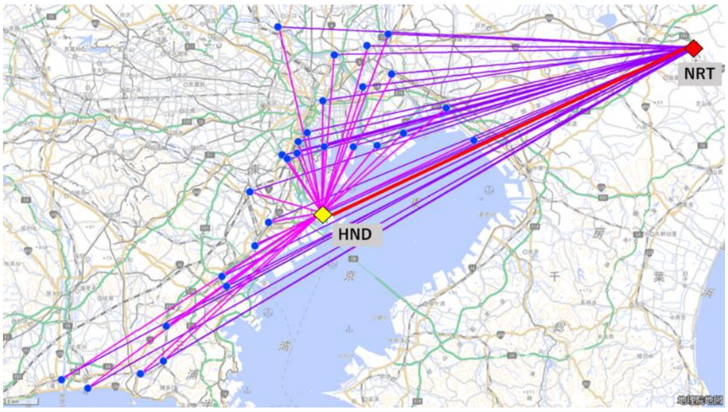

Figure 17. Takeoff and landing site network centered on Haneda and Narita airports

6.Operating costs estimation

To estimate operating costs, it is used to estimation method based on Booz Allen Hamilton's method, and the operating cost was estimated targeting at Joby S4.[9]

6.1 Capital Cost

Each parameter of eVTOL were assumed refer to general aircraft life data. The precondition is shown in Table 10 below.

Joby S4 has maximum flight time of 2,555 hours per year, so the average flight time of day is assumed 7 hours. Assuming flight time of 2,555 hours and vehicle life of 12,000 hours, the life of aircraft is 4.7 years. From the above, it is assumed that the loan term was 5 years, and capital cost consist of the sum of depreciation cost and finance cost.

Table 10. Precondition of aircraft.

Parameter	Min	Max	Source
Vehicle Life (flight hours)	12,000	25,000	SAG Interviews Cirrus SR20 Cessna 350
Depreciation Rate (%)	5	10	Booz Allen Hamilton
Finance Rate (%)	5	10	Booz Allen Hamilton

$$Depreciation\ Cost = Aircraft\ price \times (1 - e^{-depreciation\ rate}) \quad (1)$$

$$Finance\ Cost = Aircraft\ price \times finance\ rate \times \frac{(1 + monthly\ finance\ rate)^{12 \times Loan\ Term}}{(1 + monthly\ finance\ rate)^{12 \times Loan\ Term - 1}} \quad (2)$$

Table 11. Estimation results of each cost for Joby S4

Joby S4		Depreciation Cost		Finance Cost		Capital Cost	
Passengers	Price ($)	Min	Max	Min	Max	Min	Max
4	1,256,000	61,256	119,524	63,062	126,647	124,318	246,171

Estimation result of each cost for Joby S4 is shown in Table 11. The capital cost of Joby S4 is estimated 0.88 [US dollar/mile/person]. Using this result, capital cost of flight operation between Haneda to Narita airports distance (65.5 [km]) was converted 8,348 [yen/person] using exchange rate of 136 [yen] / 1 [dollar].

Table 12. Estimation result of Capital cost for Joby S4

Joby S4			Capital Cost						
Precondition			/year		/day		/mile・per		
Cruise Speed [km/h]	Flight time [h]	Loan Term [year]	Min	Max	Min	Max	Min	Max	Ave.
320	2,555	4	31,079	61,543	85.1	169	0.590	1.17	0.879

6.2 Cost of Electricity

The flight profile was assumed as that shown in Figure 18. The cost of electricity was estimated in each phase of the flight operation between Haneda to Narita airports.

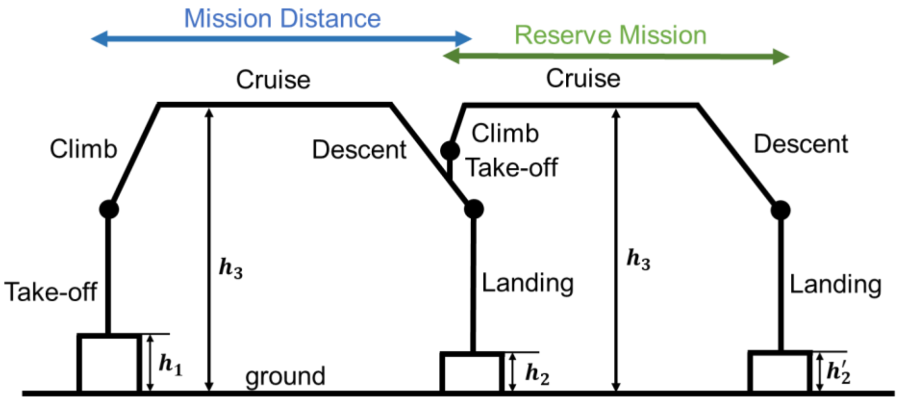

Figure 18. Flight phase of vectered thrust type eVTOL

Flight phase is defined as following.

- Take-off: Climb vertically at hover power(no horizontal movement)
- Climb: Climb to cruise altitude
- Cruise: Flight phase that occurs when the aircraft levels after a climb to a cruise altitude and before it begins to descend
- Descent: Aircraft begins approach to final landing. Has both horizontal and vertical component
- Landing: Vertical landing at hover power (no horizontal movement)

Table 13. Estimation result of electric energy *W* and costs using Joby S4

	W [kWh]	Condition
Take-off (Vertical climb)	0.823	Climb to 150[ft](46m) in 20[s]
Climb (to Cruise altitude)	17.2	P_{cruise}×130%, flight distance：2[mile]
	19.8	P_{cruise}×150%, flight distance：2[mile]
Cruise	92.8	Altitude：1500[ft](457[m]) Range：40.8[mile](65.6[km])
Descent (to Transition point)	0.760	P_{hover}×10%, flight distance：2[mile]
	1.14	P_{hover}×15%, flight distance：2[mile]
Landing (Vertical descent)	0.0370	Descent to 150[ft](46m) in 20[s]
Total *W*	113.9	Using average value under different condition
Operating electric energy costs	22.78 $	0.2 [$/kWh]
	3,075 [yen]	135 [yen/$]

As the result, the electric cost of flight operation was 9.3 [yen/kg/person], and in the case of Haneda to Narita airports flight, it costs 760 [yen/person] under the 4-person condition by Joby S4.

6.3 Cost of Battery

- Charging cycle and Depth of Discharge

Charging cycle of lithium-ion battery has affected to depth of discharge, and the relation is shown in equation (3) and Figure 19. Depth of discharge (DOD) is the percentage of discharge to capacity. DOD was closely related degradation of battery that repeated charging and discharging, the deeper DOD, the deteriorate progress. As a result, the battery suffering damage by charging condition.

$$Life\ Cycle = -1666.7 \times Depth\ of\ Discharge + 3833.3 \tag{3}$$

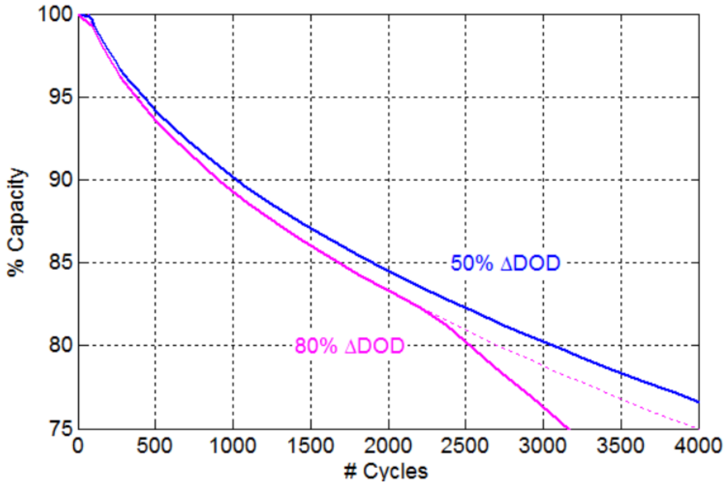

Figure 19. The relation between the number of cycle and charge capacity by effect of depth of discharge.

Source: National Renewable Energy Laboratory, 2014

In this estimation, it assumed that the DOD was 80%, therefore, it was set charging cycle was 2500 times.

- Estimation result of Battery Energy

In this paragraph, the battery energy cost of Joby S4 was estimated, and the cost of flight operation between Haneda and Narita airport was derived. The derivation and estimation result are shown in Table 14.

Table 14. Precondition of battery costs and estimation result for Joby S4

	Joby S4		
the number of Flight at full charged	3	1	
Battery energy density	235		Wh/kg
Battery weight	998		kg
DOD	80		%
Battery cost	200		$ /kWh
Charge cycle	2500		
Battery energy	234.5		kWh
Available battery energy	187.6		kWh
Flight time	17.7		min
Flight time in year	2555		h
The number of Charging	2,887	8,661	Times
The number of battery replacement	1	3	Times
Battery cost in year	46,900	140,700	$

According to Table, the number of battery replacement is rounded up the decimal point. The flight operation of between HND and NRT, the battery cost was incurred 2,192 yen per operation under charging the battery every 3 flight operations, 2,923 yen per operation under charging the battery every flight operation.

- Labor costs

It assumed that pilot and ground crew of eVTOL operation is 1 person for each at initial stage of starting flight operation. The ground crew operation is assumed Check-in confirmation of passenger, Safety inspection, Service for customer, and so on. According to some references including Uber, the cost of ground crew and pilot of helicopter is shown in Table 15 below. Average cost of maximum and minimum cost from references is used this estimation.

Table 15. Costs of helicopter pilot and ground crew

	Min	Max	Median
Pilot salary per year (US ＄)	50,000	90,000	70,000
Ground Crew Salary per year (US ＄)	20,000	30,000	25,000
Pilot training cost per year (US ＄)	10,000	20,000	15,000
Ground Crew training cost per year (US ＄)	5,000	10,000	7,500
Total Crew cost per year (US ＄**)**	85,000	150,000	117,500

According to Table 15, the average crew cost was 117,500 [US dollar]. Assuming flight operation condition that flight of Haneda to Narita airports is limited to 18-minutes operation, operating to maximum of flight time of 2,555 hours, and eVTOL of the last flight operation always return to the affiliated port, it is operated at most 11-round trips per day. From the above, the labor cost was 497 [yen] per person under the full occupancy rate (4 passengers on board).

- Infrastructure costs

In this estimation, adopting the method of installing port on rooftop of multi-storey parking building. According to various company, considering the hub-port which have capable of parking approximately 10 eVTOL installation at airports and other which can be secured sites. Based on the above, it is assumed that construction of the port of capable parking 10 eVTOLs at Haneda and Narita airports. A breakdown of port is 2 takeoff and landing space, and 8 charging and parking space, and installing the charging facilities to each charging and parking space in total 8 charging facilities (5 normal charger and 3 quick charger) is installed. The condition and costs of each infrastructure is shown in Table 16.

Table 16. Condition and cost of each infrastructure

	Min	Max	Joby S4
Tip to Tip length of aircraft(m)	5	15	10.7
Number of Parking/Landing Spots	1	12	10
Number of Super chargers (% of landing spots)	0	30	30
Number of regular chargers (% of landing spots)	0	50	50
Cost of one super charger (US ＄)	200,000	300,000	250,000
Cost of regular charger (US ＄)	10,000	15,000	10,000
Indirect Costs (％ of total cost)	15	25	25
Overnight parking cost (US ＄)/eVTOL	50	75	90
Parking Occupancy (%)	50	100	80

Table 17. Assumed the number of hub-port installation

			Spot
Hub-port	Takeoff and Landing spot		2
	Charging and Parking spot	Normal charger spot	5
		Quick charger spot	3
	Total		10

According to reference, the construction costs of one spot in port without the charger, it costs 15,000 [dollar] (=2.04 million [yen]). Therefore, assuming that the spot set up to one airport and installed charger to spot, construction cost of one airport was 0.98 million [dollar] (approximately 133.3 million [yen]).

- Maintenance costs

Equation of maintenance cost is shown in below using each parameter.

$$Maintenance\ Cost = Mechanic\ Wrap\ Rate \times \frac{MMH}{FH} \times t_{missuon} \tag{4}$$

Where, Mechanic Wrap Rate is the hourly rate of mechanic, *MMH*/*FH* is Ratio of maintenance hours to flight hours, and $t_{mission}$ is the average mission time for range of mission distances

Table 18. Maintenance cost conditions

	Min	Max	Joby S4
Mechanic Wrap Rate ($ per hour)	100	100	100
Maintenance man-hours per flight hour (MMH/FH)	0.25	1	0.62

The ratio of maintenance hours rate to flight time *MMH*/*FH* is used the average value 0.62 in this estimation. Assuming the average mission time is 30 minutes including the time of ground alert, maintenance costs is incurred 31 [dollar] per one operation. From the above, the cost of Haneda to Narita airports flight operation was estimated 1,054 [yen] per one passenger under the full occupancy rate (4 passengers on board) condition.

7.Conclusion

This study investigated feasibilities of the UAM operated for air taxi services in urban areas from three aspects of location, fare, and time. It was studied the use of river and bay networks and the installation on the roof of the parking building. Flight time was estimated focusing on the distance on Haneda Airport and Narita Airport. Tokyo metropolitan area was investigated, and 30 takeoff and landing sites were assumed AUM ports in the service area with consideration of constraints and flight performances of eVTOL aircraft. Dimensions of the parking area were calculated under constraints. It was found that in study, Air taxi cost up to $67,000 more than the existing ground taxi, and consumers could potentially save 49 minutes compared to ground taxi.

8.Contact Author Email Address

mailto: lei#rs.sus.ac.jp (replace # by @)

9.Copyright Statement

10.Acknowledgement

The Authors would like to thank Mr. Akinobu Okuda, the President of Aerospace Kousou Research Institute, Inc. for his great help.

References

[1] THE ROADMAP to scalable urban air mobility, White paper2.0, published by Volocopter, 2021.03.
[2] Focus Urban Air Mobility, published by Roland Berger, 2020.11.
[3] The Future of Vertical Mobility, published by Porsche Consulting, 2018.03.

[4] NASA, Mckinsey & Company, URBAN AIR MOBILITY(UAM) MARKET STUDY, 2018.11.
[5] Technical Report of the Geospatial Information Authority of Japan, 2022.05.
[6] Ministry of Land, Infrastructure, Transport and tourism Road bureau, Parking Design Guidelines, 1994.06.
[7] e-Mobility Power, 2021GA, published by e-Mobility Power, 2021
[8] Next Generation Vehicle Promotion Center, Quick charger installation study document for electric vehicles, published by Next Generation Vehicle Promotion, 2013.10
[9] Colleen Reiche and Booz Allen Hamilton, UAM Market Forecast, 2019.09.
[10]UBER Elevate, Fast-forwarding to a Future of On-Demand Urban Air Transportation, published by Uber, 2016.10.
[11]NAVITIME, Taxi fare search, https://www.navitime.co.jp/taxi/, (2022.05 access).
[12]Yellowcab, fare, https://www.newyork.jp/, (2022.05 access).
[13]Jorudan, Haneda Narita search, https://www.jorudan.co.jp/norikae/route/ (2022.7. access)
[14]The Future of Transportation: White Paper on Urban Air Mobility Systems, published by eHang, 2020.01.
[15]Joby S4, Electric VTOL News by the Vertical Flight Society, https://evtol.news/joby-s4, (2022.04 access)
[16]Vertical Aerospace VX4, Electric VTOL News by the Vertical Flight Society, https://evtol.news/vertical-aerospace-VA-1X, (2022.04 access)
[17]https://evtol.com/news/vertical-aerospace-evtol-aircraft-could-fly-turkey/, (2022.04 access)