

Airport Take-off and Landing Operations for Advanced Air Mobility

Dependent and Independent Operations of AAM Flights Relative to IFR Flights

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Abstract—Advance Air Mobility (AAM), which is a new air transportation system featuring advanced technology, is expected to be applied to airport shuttle services. However, the increase in AAM take-offs and landings at airports raises concerns about airport capacity saturation and the increased workload of air traffic controllers. To address these challenges, this paper discusses independent operations of AAM flights relative to IFR flights at airports using advanced operational concepts, such as corridors. Independent operations enable AAM flights to take off and land at vertiports near runways without maintaining time intervals with IFR flights. We conducted take-off and landing scheduling simulations using radar data to estimate the potential benefits of introducing independent operations. In addition, the additional requirements necessary to achieve autonomous operations were discussed. The results and discussions contribute to the decision-making process for AAM stakeholders considering whether to adopt independent operations when introducing AAM airport shuttle services.

Keywords—advanced air mobility; airport take-off and landing; throughput; corridor

I. INTRODUCTION

Advanced Air Mobility (AAM) is a new air transport system for passengers and cargo that features advanced technologies such as high automation, electrification, and vertical take-off and landing capability. Currently, there are no AAM aircraft that can be used for commercial flights, but several companies are investing considerable efforts in the research and development of AAM aircraft and in obtaining type certification. To realize AAM transportation services, not only the development of the aircraft itself but also the development of its operational concept is necessary. Various organizations around the world have created a concept of operations (ConOps) for AAM to propose high-level operational concepts [1]–[3].

AAM has several proposed use cases. One of the most promising is an airport shuttle service that connects hub airports with nearby regional airports, urban areas, and tourist destinations [4]. To implement an airport shuttle service, AAM aircraft must be able to take off and land near hub airports. However, increasing the number of AAM flights around airports can negatively impact existing air traffic. The increase in AAM takeoffs and landings at airports raises concerns about airport capacity saturation and the increased workload of air traffic controllers.

Previous research has proposed the introduction of a corridor, which is the volume of airspace that defines a three-dimensional route segment, to integrate safely and efficiently AAM flights with the airspace where existing aircraft fly. The corridor is expected to allow an AAM to maintain an appropriate separation from other aircraft without the need for conventional ATC services [1]. Verma et al. designed corridors for the arrival and departure of AAMs at airports in the Dallas–Fort Worth (DFW) area [5]. They used track data obtained from the DFW area to verify the separation between the designed corridors and existing traffic. In Europe, six very large-scale demonstrations were conducted under the CORUS-XUAM project [6]. Stolle et al. designed the corridors for taking off or landing at Frankfurt Airport [7]. Riccardi et al. designed the corridor connecting to Grottaglie-Taranto Civil Experimental Airport and conducted demonstration experiments using a fixed-wing remotely piloted aircraft system [8]. In Japan, The authors discussed the design directions for corridors that allow an AAM to cross existing air traffic while maintaining vertical separation, focusing on Japanese airspace configurations around a hub airport [9].

The introduction of corridors is a promising option for allowing AAM aircraft to take off and land smoothly at airports. However, currently the corridor is just a concept, and there is no established system to ensure that AAM aircraft do not deviate from the corridor. Furthermore, take-off and landing are phases with the highest aircraft density, which requires discussions that prioritize safety. To increase the number of AAM takeoffs and landings at airports while ensuring safety, additional requirements for AAMs, such as equipment and operational rules, are expected to be necessary. Since the number of flights directly affects the profitability of the service, and the introduction of additional requirements incurs additional costs, stakeholders, such as aviation authorities and operators, must balance possible AAM flight numbers and additional costs. This balance is crucial for the business feasibility of the AAM airport shuttle service.

This paper discusses AAM takeoffs and landings at hub airports. Initial AAM operations are expected to be conducted under Visual Flight Rules (VFR). Flying under existing VFR allows AAM traffic services to be launched early without



additional requirements. However, the number of possible takeoffs and landings of VFR flights at hub airports is limited, as VFR flights are dependent on Instrument Flight Rules (IFR) flights. VFR flights are generally not allowed to take off or land on the helipad near the runway when IFR flights are taking off or landing on the runway. To increase the number of AAM taking off and landing, it is necessary to allow AAM flights to operate independently of IFR flights. Increasing the throughput of AAM at airports through independent operations will improve the profitability of AAM airport shuttle services. To compare dependent and independent operations, we simulate the scheduling of take-offs and landings at airports including IFR and AAM flights. In addition, we discuss the additional requirements and means necessary to achieve independent operations. These simulation results and discussions are expected to inform stakeholder decisions about the implementation of AAM airport shuttle services.

II. AIRPORT TAKEOFFS AND LANDINGS OPERATIONS

A. Current VFR Operations

In many countries, Class B airspaces are established around busy airports in the shape of an upside-down wedding cake. However, in Japan, airspace around busy airports is established by combining Classes D, C, and E, as shown in Fig. 1. From a business viability perspective, the AAM airport shuttle is expected to be introduced at larger airports with multiple runways. However, for the sake of simplicity, we initially focus on an airport with a single runway. A Class D airspace in the shape of a cylinder surrounds the airport. Class C airspaces are shaped like boxes of different heights and are positioned to cover take-off and landing routes. A Class E airspace lies above the Class C and D airspaces, connecting enroute airspace with the Class C and D airspaces.

The operation of AAM flights is often compared to that of helicopters flying under VFR. Fig. 2 shows the schematic image of the existing helicopter operations that fly under VFR around hub airports. Helicopters can take off and land from runways and also directly from helipads. The location of helipads varies by airport, but this paper assumes a helipad located near the runway, considering the connectivity between IFR flights and AAM flights for the AAM airport shuttle service. In fact, several helipads are located near runways in

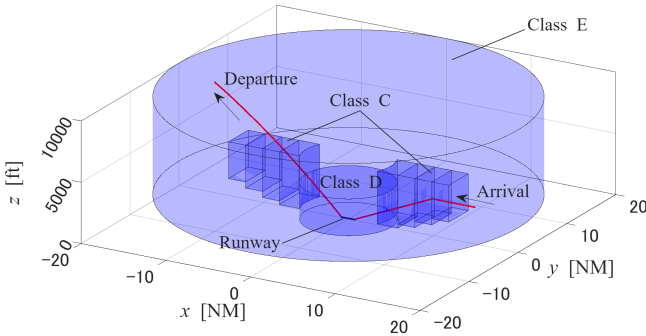


Figure 1. Airspace around hub airports in Japan.

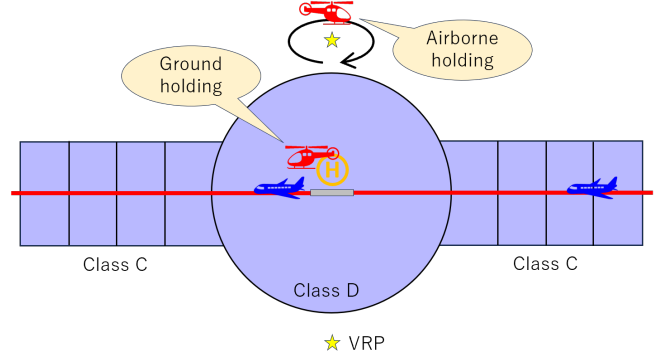


Figure 2. Helicopter operations flying VFR around hub airports.

many airports. Since the distance between the runway and the helipad is short, helicopter take-offs and landings are basically carried out when there are no IFR flights taking off or landing on the runway. To ensure safety between IFR flights and helicopters, helicopters must obtain take-off or landing clearance from air traffic controllers even when operating under VFR. Furthermore, air traffic controllers can issue instructions or advisories for VFR flights to maintain separation between aircraft within Class C or D airspace. There are several Visual Reporting Points (VRP), which are landmarks primarily used by VFR flights to report their position around Class D airspace. If a helicopter approaches Class D airspace to land while an IFR flight is taking off or landing on the runway, the helicopter may be instructed to be airborne holding at the VRP. Helicopters taking off are instructed ground holding when IFR flights take off or land on the runway.

B. Dependent and Independent Operations

The existing take-off and landing operations for helicopters can be considered dependent operations to IFR flights. When IFR flights take off or land, helicopters must hold on the ground or in the air. The dependent operations do not pose a significant problem in the current low-density helicopter environment. However, the AAM airport shuttle service requires a greater number of flights than current helicopter flights. In order to increase the number of AAM flights, it may be necessary for AAM aircraft to take off and land at airports independently of IFR flights. During independent operations, AAM flights can take off and land at the airport, even when IFR flights take off or land.

Independent operations of AAM take-off and landing can increase the number of AAM flights required for airport shuttle services. In existing air traffic control, dependent and independent approaches are defined based on the configuration of parallel runways [10]. However, at this time, there are no established operations for the simultaneous take-off and landing of VFR and AAM flights alongside IFR flights. Therefore, it is necessary to discuss the potential benefits of introducing independent operations and the additional requirements required for its implementation.

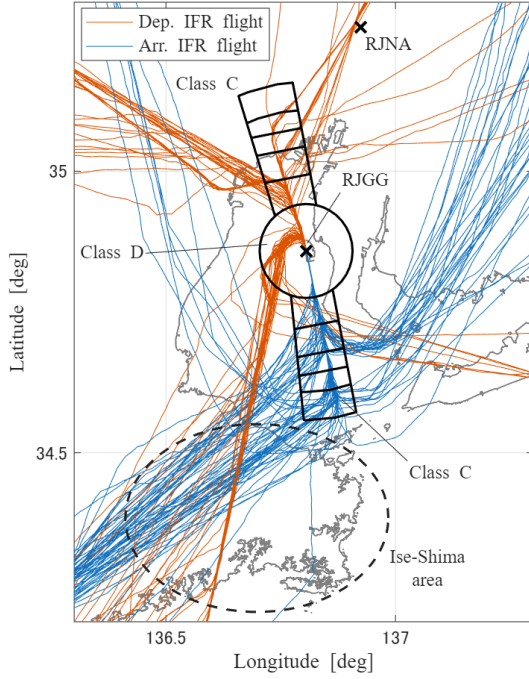


Figure 3. Airspace around RJGG and radar tracks.

III. TAKE-OFF AND LANDING SCHEDULING SIMULATIONS

A. Surrounding Conditions of a Target Airport

We perform take-off and landing scheduling simulations that include a mix of IFR and AAM flights to estimate the potential benefits of introducing independent operations. This simulation focuses on Chubu Centrair International Airport (RJGG). Fig. 3 shows the airspace around RJGG and the radar tracks for April 16, 2023. The radar data was obtained from CARATS Open Data provided for research and development purposes [11]. Due to the north wind operations all day, Runway 36 was used for take-offs and landings. RJGG has a single runway that can operate 24 hours a day. RJGG is located approximately 45 km south of Nagoya Airport (RJNA), a hub for regional and business jets, and approximately 50 km north of the popular tourist destination of Ise-Shima, where there is anticipated potential demand for AAM airport shuttle services.

RJGG has two helipads located 400 meters from the runway as shown in Fig. 4. There are four VRPs around RJGG: JUNCTION, MIHAMA, SHIROKO, and WEST POINT. For example, a helicopter flying under VFR approaching from the southeast to RJGG is instructed airborne holding above the Mihama VRP while IFR flights take off or land on the runway. After the runway is cleared, the helicopter resumes its approach to the helipad.

B. Simulation Method

In this simulation, it is assumed that IFR flights do not change take-off and landing times in order to maintain separation from AAM flights. The take-off and landing times for IFR flights were derived from air traffic information provided by CARATS Open Data [11]. Note that the number of flights

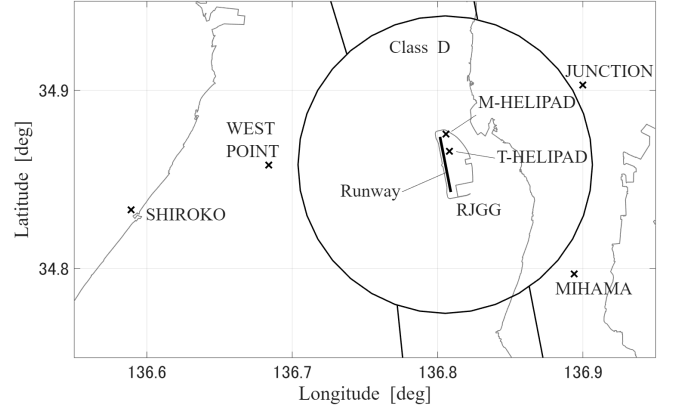


Figure 4. Helipad and VRP layout at RJGG.

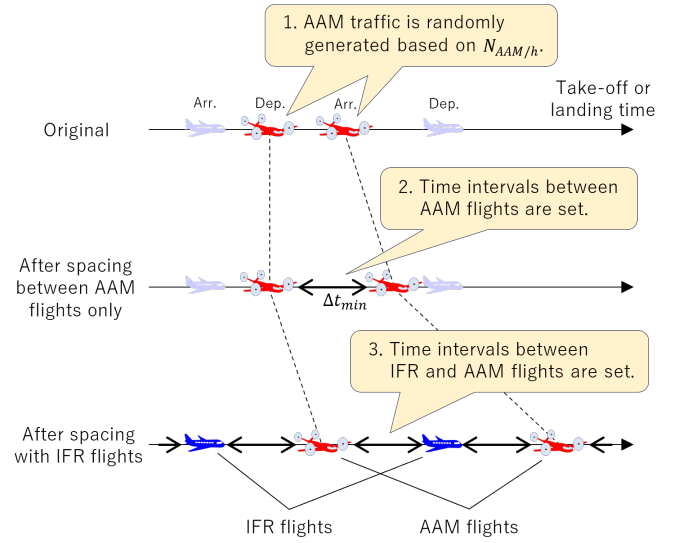


Figure 5. Simulation flow.

is slightly lower than the actual number because CARATS Open Data only includes scheduled IFR flights. Fig. 5 shows the computational flow in the simulation. To simulate AAM flights taking off and landing at RJGG, random AAM traffic is generated. The density of AAM traffic is determined by the number of take-offs and landings per unit hour $N_{AAM/h}$. Each AAM flight is randomly assigned as a departure or arrival flight and receives an original take-off or landing time. Assuming that RJGG has one vertiport, if the original take-off or landing time of the leading and following AAM flights is smaller than the minimum time interval Δt_{min} , the following flight is held to separate Δt_{min} from the leading flight. This interval spacing corresponds to ground hold for departures and airborne holding above the VRP for arrivals. In addition, Δt_{min} is also set between IFR and AAM flights for dependent operations. The minimum interval on the runways is determined by various conditions, such as wake turbulence and runway occupancy time. However, for simplicity, the constant Δt_{min} is set at two minutes between all departures and arrivals.

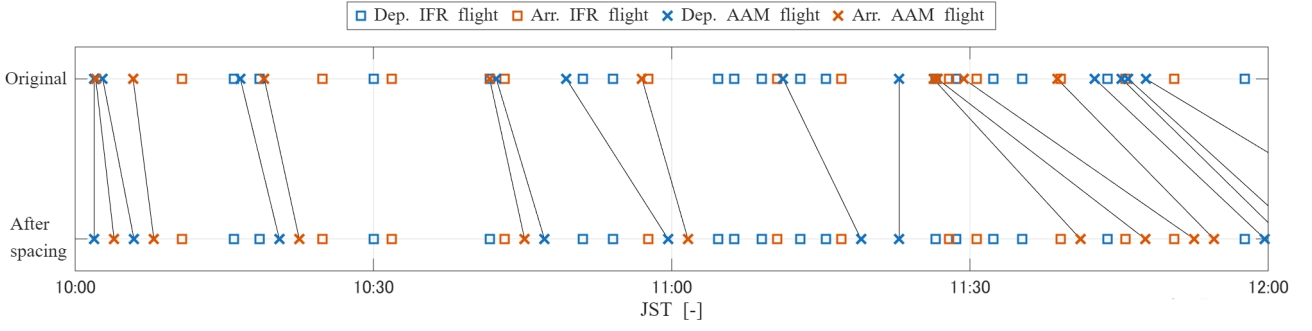


Figure 6. Example of runway scheduling results.

Frequent AAM take-offs and landings result in accumulated holding time for AAM flights and delaying the take-off and landing times. The simulation results yield the take-off and landing throughput of AAM flights, as well as the ground and airborne holding times.

C. Simulation Results

Fig. 6 shows the take-off or landing time of the IFR and AAM flights during the dependent operations when $N_{AAM/h} = 10$. The simulation was carried out between 7:00 and 22:00 Japan Standard Time (JST), when the AAM airport shuttle services are expected to be active. However, for clarity, the figure only shows the period from 10:00 to 12:00. The upper row shows the original take-off or landing time, and the lower row shows the times after spacing. The black lines connect the same AAM flights before and after spacing. As shown in the figure, AAM flights can maintain Δt_{min} with IFR flights after spacing, while most AAM flights in the original schedule cannot. Consequently, many AAM flights were held on the ground or in the air, resulting in delayed take-off and landing times. Fig. 7 is a stacked bar chart showing the holding time for AAM flights in the same simulation case as Fig. 6. The average holding time based solely on the spacing between AAM flights was 0.47 min. This holding time corresponds to the holding time in the independent operations. Meanwhile, the average holding time based on the spacing between all

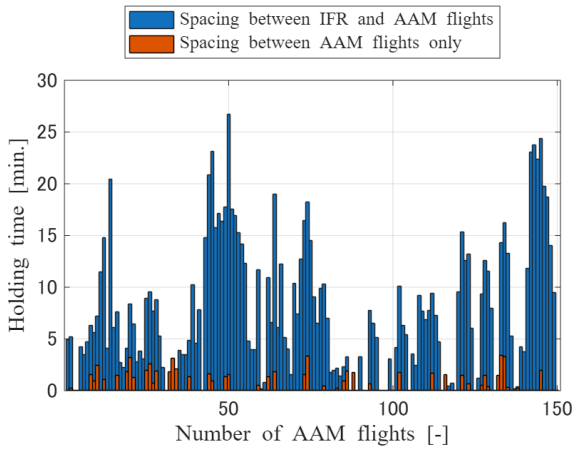


Figure 7. Example of holding time results.

flights, including both IFR and AAM flights, was 7.49 min. Therefore, approximately 16 times more holding time occurred in the dependent operations than in the independent operations.

Fig. 8 shows the AAM flight throughput in each time period when $N_{AAM/h} = 10$. The throughput fluctuated over time, but the average throughput between 7:00 and 22:00 was 10, which is the same as $N_{AAM/h}$. Fig. 9 shows the results of the simulations with ten trials. Although the original take-off or landing time was generated randomly, the average throughput was 10 in most trials. The average of ten trials of the average throughput was 9.99. These results indicate that while AAM flights were imposed on ground or airborne holding as shown in Fig. 7, they were almost able to fly as requested when $N_{AAM/h} = 10$.

Fig. 10 shows the average throughput of AAM flights, specifically the average of ten trials of the average throughput between 7:00 and 22:00, with different $N_{AAM/h}$. When $N_{AAM/h}$ is 14 or less, the average throughput was approximately equal to $N_{AAM/h}$. However, beyond $N_{AAM/h} = 14$,

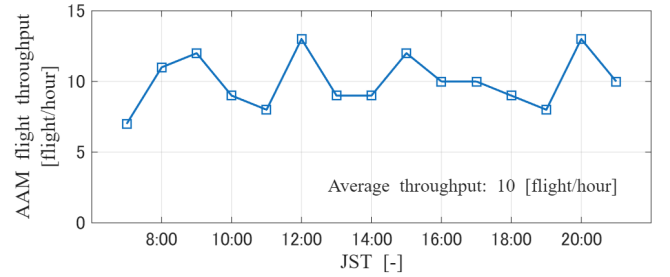


Figure 8. Results of AAM flight throughput in a single trial.

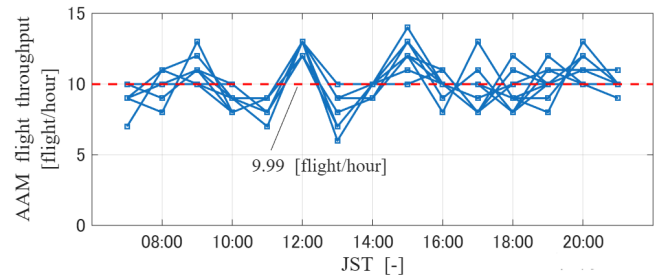


Figure 9. Results of AAM flight throughput in 10 trials.

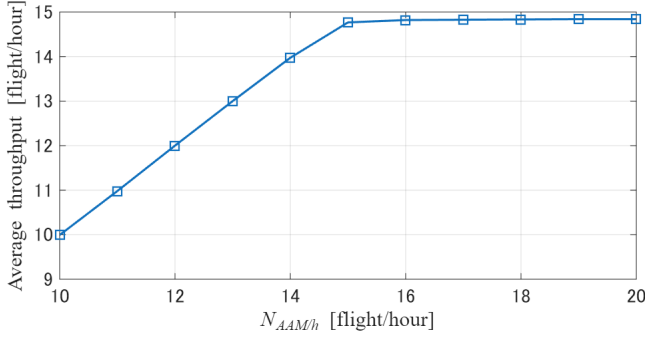


Figure 10. Number of AAM take-offs or landings per unit time vs. average throughput of AAM flights.

the rate of increase deteriorates. When $N_{AAM/h}$ is 16 or greater, the average throughput is constant at 14.8. This indicates that the maximum potential throughput of AAM flights during the dependent operations at RJGG on this day is 14.8. However, in independent operations, AAM flights do not need to maintain intervals with IFR flights; they only need to maintain intervals with each other. The maximum potential throughput for AAM flights in independent operations is $60/\Delta t_{min} = 30$ flights per unit hour. Therefore, although these results are for only one day, the introduction of independent operations has the potential to increase the average throughput of AAM flights at RJGG by 15.2.

IV. DISCUSSION

A. Additional Requirements for Independent Operations

The take-off and landing scheduling simulation demonstrated that the introduction of independent operations has the potential to roughly double the throughput of AAM flights on April 16, 2023. However, additional requirements are necessary to achieve independent operations. Although the specific additional requirements are unclear at this stage, discussing anticipated requirements will provide information for making decisions toward achieving independent operations.

Fig. 11 illustrates the concept of independent operations. In this concept, we consider the following assumptions about AAM aircraft and their flights:

- AAM aircraft are equipped with Automatic Dependent Surveillance – Broadcast (ADS-B) in/out, in addition to the equipment required to fly within Class D airspace.
- AAM aircraft are either piloted by an on-board pilot or remotely piloted by a pilot on the ground.

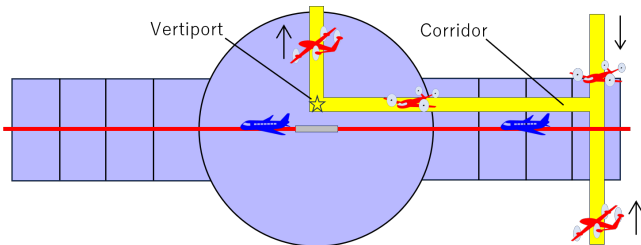


Figure 11. Concept of independent operations.

- AAM flights operate at altitudes lower than IFR flights, typically around 1,000 feet.

AAM flights fly along pre-established corridors (or routes) within Class D airspace. When the runway operations for IFR flights change due to changes in wind direction, the corridors used by AAM flights also change accordingly. AAM flights can take off or land at a vertiport while IFR flights are using the runway. As long as an AAM aircraft remains within the corridor, it is considered to be separated from IFR flights. Within the corridor, AAM flights monitor their surroundings and maintain an appropriate separation from other AAM flights themselves. Air traffic controllers usually do not issue instructions for AAM flights. However, if an AAM flight deviates from the corridor, it must fly according to the controller's instructions.

The following additional requirements are necessary to implement the operation shown in Fig. 11.

- Capability to fly along a corridor
Since the corridor is very close to IFR flight routes, it is crucial to ensure that AAM flights do not deviate from the corridor during independent operations. Furthermore, if an AAM flight deviates from the corridor, the pilot must be alerted. An option is to have AAM flights operate under IFR utilizing Performance-based Navigation, such as the Required Navigation Performance Authorization Required (RNP AR) approach near airports. An RNP AR-capable pilot and an AAM aircraft approach Class D airspace under VFR and is then given an IFR clearance. RNP AR ensures that AAM aircraft remain within the corridor 95% of flight time. The other option is to require advanced flight rules for AAM, such as digital flight rules, which include advanced automation and navigation technologies [12], [13]. No matter which option is chosen, realizing this capability requires more than just implementing the corridor. It also requires designing the supporting navigation systems and flight rules as a complete package.
- Surveillance capabilities on the ground and in the air
When an AAM flight deviates from the corridor, an air traffic controller issues instructions to the AAM flight. Therefore, air traffic controllers must be able to constantly monitor AAM flights near airports, even though they do not need to monitor them in nominal conditions. The low altitudes at which AAM flights operate may fall outside the coverage area of the airport radar. Therefore, it is necessary to install an airport surveillance system that can reliably monitor low altitudes, such as a multilateration system or an ADS-B receiver.
In addition to ground surveillance, AAM aircraft must monitor surrounding aircraft themselves, as air traffic controllers do not monitor AAM aircraft flying in a corridor. A promising option is ADS-B in/out. However, while AAM aircraft are assumed to be equipped with ADS-B in/out, ADS-B is not mandatory in Japan, and some jet passenger aircraft and most general aviation

aircraft are not equipped with ADS-B out. The other option is to implement the Traffic Information Service – Broadcast (TIS-B), which is a system that rebroadcasts aircraft information obtained by other ground surveillance systems to aircraft equipped with ADS-B in [14]. Combining multilateration with TIS-B as shown in Fig. 12 allows AAM aircraft to monitor all surrounding aircraft near airports, since all aircraft flying near airports are equipped with transponders in Japan.

- Traffic management capability for AAM flights
AAM flights within the corridor must maintain adequate separation without instructions from air traffic controllers. Self-separation technology, which has been developed for jet passenger aircraft equipped with ADS-B in/out as Flight Deck Interval Management, is effective for maintaining separation without instructions from air traffic controllers [15], [16].
Additionally, the take-off and landing scheduling simulations demonstrated that several AAM flights were held on the ground or in the air even with independent operations. Since AAM aircraft are electrically powered, they have a shorter maximum flight duration than existing aircraft, making airborne holding undesirable. To minimize airborne holding as much as possible, pre-flight traffic management, such as demand capacity balancing, is considered necessary [17].

B. Design Methods for Corridors

In addition to the additional requirements for realizing independent operations, the corridor design also requires further discussion. Fig. 13 shows the top and side views of Fig. 11. The vertical separation is set to ensure an appropriate separation between the IFR flight route and the corridor at the intersection. However, the appropriate amount of vertical separation remains unclear. Considering interference between IFR flights and AAM flights, such as wake turbulence and TCAS false alarms, an appropriate vertical separation must be established. Furthermore, we must design corridors that take into account safety during off-nominal situations, such as IFR flight go-arounds and AAM flight corridor deviations.

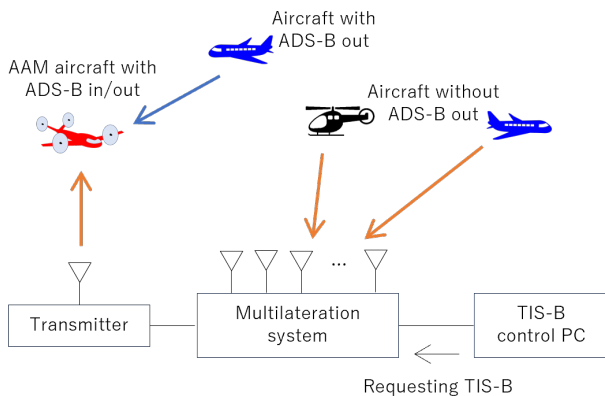


Figure 12. Combination of multilateration and TIS-B.

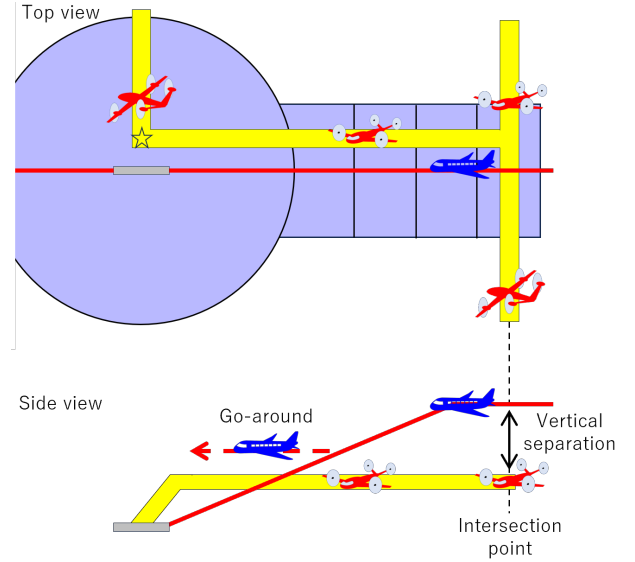


Figure 13. Corridor design for Independent Operations.

In Fig. 13, the corridor is configured to prevent interference between IFR and AAM flights even in these off-nominal cases. Note that the diagram is merely a schematic illustration. Specifically, corridors must be designed based on the actual configurations of the airport, such as runways, vertiports, and flight paths.

V. CONCLUSION

This paper discussed independent and dependent operations for airport take-offs and landings of AAM flights. Dependent operations are based on conventional helicopter operations flying under VFR and require time interval with IFR flights during take-off or landing at airport helipads. In contrast, independent operations allow AAM flights to take off or land at vertiports without maintaining time intervals with IFR flights. The take-off and landing scheduling simulations conducted at RJGG on April 16, 2023 demonstrated that the implementation of independent operations could potentially double AAM flight throughput compared to dependent operations. However, the realization of independent operations was found to require additional capabilities, such as the capability of AAM flights to remain within corridors.

Future work will conduct a further examination of each additional requirement to achieve independent operation. To verify the safety of independent operations, various quantitative investigations are necessary, such as fast-time simulations and full-flight simulator experiments. Future work will also address airports with multiple runways, while this paper focuses on a single-runway airport. For multiple runways, more complex simulation conditions and additional requirements are expected to be necessary.

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