DEVELOPMENT OF LOW ALTITUDE 4-DIMENSIONAL OPERATIONS MANAGEMENT SYSTEM FOR ADVANCED AIR MOBILITY

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Abstract

As part of a project from FY2022 to FY2026, we are developing technologies to achieve Urban Air Traffic Management (UATM) services for AAM (Advanced Air Mobility) in collaboration with domestic industries and government ministries. To enable medium to high-density AAM operations, which are target of our project, a centralized UATM system responsible for traffic management and separation assurance of AAMs is not suitable, because such UATM system would be overloaded and might not fully accommodate requests and preferences of AAM operator (AAMO). Furthermore, conventional Visual Flight Rules (VFR) operations, which are the starting point for AAM operations, are too imprecise in-flight planning for conflict management in the pre-flight phase and require frequent in-flight route changes and airborne holding for traffic avoidance, making it hard to attain medium-to high-density AAM operations. To address these issues, we are developing an operations management system for AAMO, including flight managers, dispatchers, and pilot to create a precise four-dimensional (4D) flight plans by sharing resource information with UATM system, thereby enabling decentralized conflict management before and during the flight. This paper presents the decentralized conflict management concept behind the proposed system, the specific design of the system to enable it, and its evaluation plan.

Keywords: AAM, UATM, 4-Dimensional Flight Plan, Operation Management System

Acronyms

AAM	Advanced Air Mobility
AAMO	Advanced Air Mobility Operator
ALTN	Alternate
ATM	Air Traffic Management
CONCERTO	Collaborative Operation Management of Next Coming Air Mobility for Ecosystem Revolution
ConOps	Concept of Operations
E4D	Estimated 4-Dimensional
ETA	Estimated Time of Arrival
FATO	Final Approach and Take-Off Area
4D	4-Dimensional
HMI	Human Machine Interface
InfoEX	Information Exchange
JAXA	Japan Aerospace Exploration Agency
NEDO	New Energy and Industrial Technology Development Organization
P4D	Planned 4-Dimensional
ReAMo	Realization of Advanced Air Mobility

RTA	Required Time of Arrival
RTS	Real Time Simulator
SDSP	Supplemental Data Service Provider
S-SDSP	Surveillance(S)-SDSP
UASA	UATM Service Area
UATM	Urban Air Mobility Traffic Management
UATMS	Urban Air Traffic Management System/Service
UTM	Unmanned Aircraft System Traffic Management
VAS	Vertiport Automation System
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

1. Introduction

There is a growing momentum towards achieving Advanced Air Mobility (AAM), an accessible and sustainable next-generation means of air transportation enabled by technologies such as electric propulsion and automation, which uses vertical takeoff and landing and other modes of operation. The AAM concept of operations (ConOps) developed in Japan by the Private-Public Committee for Advanced Air Mobility [1] outlines a phased approach to gradually mature the operation of AAM throughout the 2030s (Figure 1). In phase 1, which includes EXPO 2025, Osaka, Kansai, Japan the focus is primarily on low-density operations in the existing airspace using existing flight rules. In phase 2, starting in the late 2020s, medium-to-high density operations will begin, with the possible introduction of remotely-piloted passenger transport. Phase 3 from the 2030s onward will further scale up to even higher-density operations, anticipating the expansion of automated and autonomous operations.

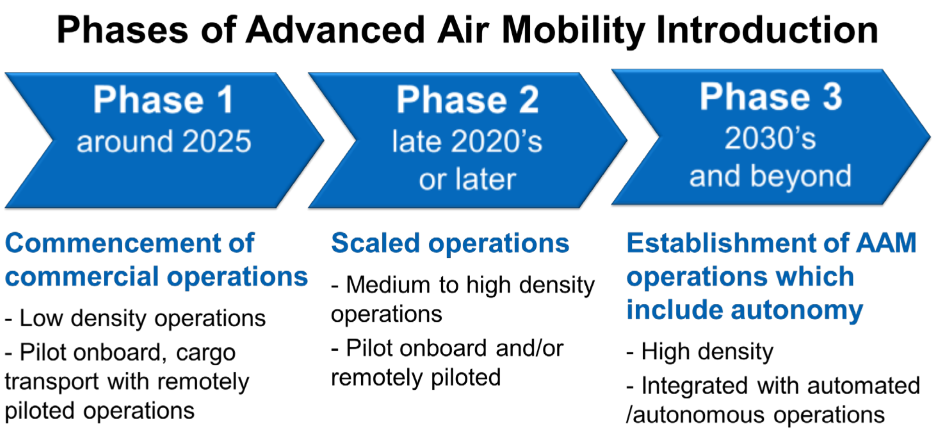

Figure 1 – Phase of Advanced Air Mobility introduction in Japan. [1]

To compensate for the operational limitations on AAM including its short range and flight duration and allow traffic to continue to grow, a new concept of airspace and traffic management has been proposed to ensure safe and smooth air traffic flows by coordinating operations in certain airspaces from the flight planning stage [1]. The AAM ConOps defines a UATM Service Area (UASA) as an airspace in which such new Urban Air Traffic Management (UATM) services will be provided according to expected AAM traffic conditions. UATM services will provide information sharing, airspace management, conflict management and conformance monitoring services to AAM. Among these UATM services, coordinated pre-flight conflict management is particularly important because of the reduced ability to apply airborne delay to AAMs due to their limited flight duration, and because of the limited capacity of vertiports. UATM services will also collaborate with the Air Traffic Management (ATM) service for existing aircraft and Unmanned Aircraft System Traffic Management (UTM) services for unmanned aircraft via an information exchange system (InfoEX) that enables timely and accurate data exchange. Supplemental Data Service Providers (SDSPs) provides supplemental data including terrain, obstacles, and specialized weather information (Figure 2).

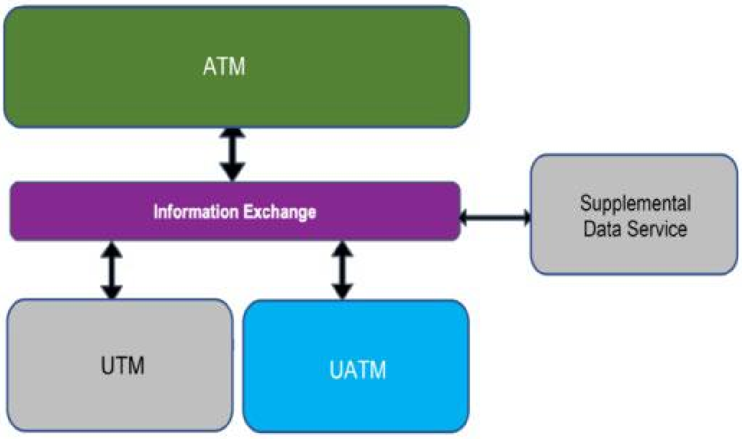

Figure 2 – UATM, ATM and UTM interfaces. [1]

As part of the "Realization of Advanced Air Mobility (ReAMo)" project [2] of the New Energy and Industrial Technology Development Organization (NEDO), JAXA's CONCERTO (Collaborative Operation Management of Next Coming Air Mobility for Ecosystem Revolution) project [3], planned for approximately five years from FY2022 to FY2026, is developing technologies to realize UATM services in collaboration with domestic private companies and government ministries. We aim to standardize internationally some of the technologies being developed by CONCERTO and transfer them to domestic companies, contributing to the advancement of AAM and the promotion of domestic industries.

The target of CONCERTO is mainly on the phase 2 of AAM ConOps mentioned above. Figure 3 shows the connections between AAM operator (AAMO) and relevant service providers envisioned in that phase, where Vertiport Automation System (VAS) is a system or a provider that manages a vertiport, including its apron and schedule, Surveillance (S)-SDSP delivers aircraft surveillance tracks, and UATMS provides UATM services. The AAMO operates AAM supported by UATM, VAS, SDSP and S-SDSP.

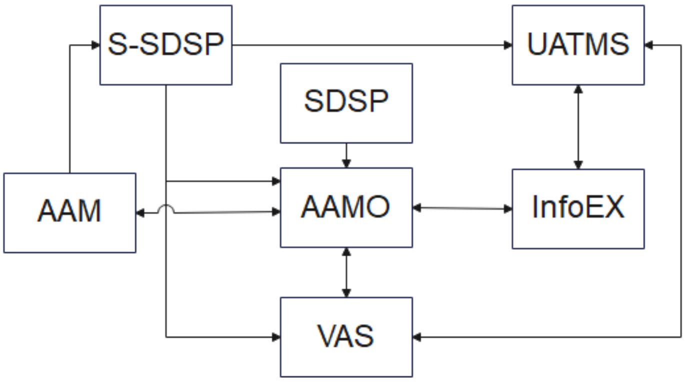

Figure 3 – Connection between AAMO and relevant service providers.

To realize flight operations in the phase 2 of the ConOps based on this service environment, the following issues must be addressed:

- The scale of AAM operations will be larger than that of conventional passenger aircraft, with approximately 20 to 100 AAM vehicles flying in the same airspace. If a centralized UATMS is responsible for traffic management and separation assurance of AAMs, the UATMS will be heavily loaded, and there is a concern that AAMO requests and preferences might not be fully accommodated.

- We assume that AAM flight operations will start from VFR flight, and VFR may still be applied as the primary flight rules during phase 2 of AAM ConOps. In conventional VFR operations, however, flight plans tend to be too imprecise to conduct conflict management in pre-flight phase. Traffic separation therefore must be coordinated during flight, which may lead to frequent changes of flight route or airborne holding for traffic avoidance. These are difficult for AAMs to accommodate due to their limited flight endurance, making it hard to sustain medium- and high-density operations.

As a solution to these issues, we are developing an operations management system for AAMOs, including flight managers, dispatchers, and pilots. The system (called the low altitude 4D operations management system) creates precise four-dimensional (4D) flight plans and enables decentralized conflict management before and during the flight by sharing resource information with UATMS. The shared resource information includes airspace congestion and the availability of FATO and parking spot.

This paper describes the decentralized conflict management concept to achieve medium-to-high density AAM operations that is the premise of the system and presents details of the design of the low altitude 4D operations management system. Finally, the flight evaluation plan is described.

2. Decentralized Conflict Management Using 4-Dimensional Flight Path and Available Resource Information

To manage the growing AAM traffic, we propose decentralized conflict management among the UATMS and AAMOs using 4D flight paths and sharing of available resource information. Figure 4 compares our concept with centralized UATM. Shared airspace resource information is represented by “cell density”, which is defined by the number of flight plans that pass through each subdivision of airspace (i.e., cell) per unit of time [4]. Additionally, FATO and parking spot availability information is also shared. Based on the resource information, AAMOs create and submit routes that avoid conflict in the air and ground, greatly reducing the amount of coordination required between flights.

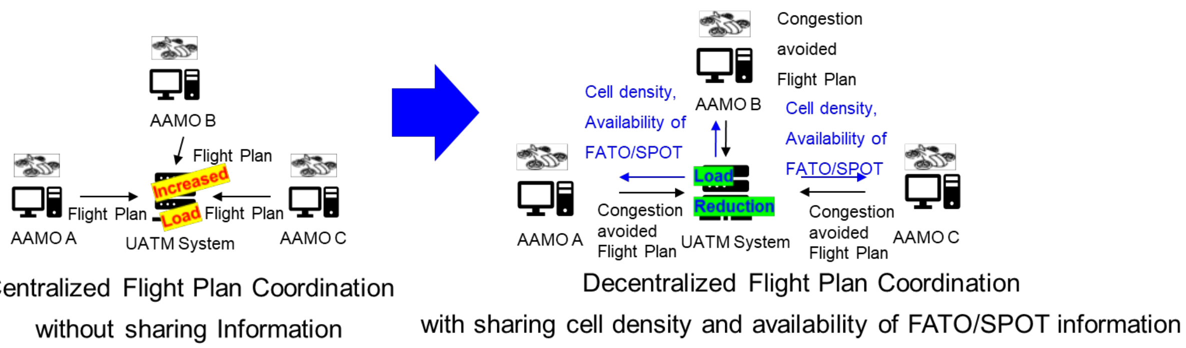

Figure 4 – Decentralized flight plan coordination concept compared with conventional centralized flight plan coordination.

To enable this concept, we propose a flight planning tool for AAMOs called the low altitude 4D operations management system. Using the system, an AAMO creates a flight plan and associated 4D planned flight path, obtaining airspace resource (i.e., cell density) information from InfoEX and weather information from SDSPs. The AAMO also obtains available spot and FATO information from the relevant VAS. Moreover, it will allow AAMOs to express operational preferences such as prioritizing departure time, arrival time, or shortest flight duration. Since the 4D flight path contains the estimated time of arrival (ETA) at the destination vertiport, vertiport congestion information from the VAS allows AAMOs to avoid unplanned airborne delays.

During flight, the low altitude 4D operations management system conducts conformance monitoring by checking difference between 4D planned flight path and actual trajectory. If the difference exceeds the limit, the AAMO is alerted and amends the flight plan in coordination with UATMS.

Based on the above concept, the low altitude 4D operations management system will make AAMO operations flying like driving a car using real-time traffic jam and parking information for navigation planning, and it is hypothesized that coordinated pre-flight conflict management using precise 4D flight paths will improve the accuracy and predictability of VFR operations.

3. System Design of Low altitude 4D Operations Management System

3.1 System overview

Figure 5 shows the architecture of the low altitude 4D operations management system, which has three core functions: (1) a flight plan creation function, (2) a conformance monitoring function between the actual flight trajectory and the 4D flight plan, and (3) a flight plan update/correction function. As shown in figure 5, the system will interact with the elements of the AAM operating environment in Figure 3 including O1 UATM, O2 InfoEX, O3 VAS, O4 SDSPs and O5 S-SDSP. In this section, we first describe how the functions are used, then present each function in more detail.

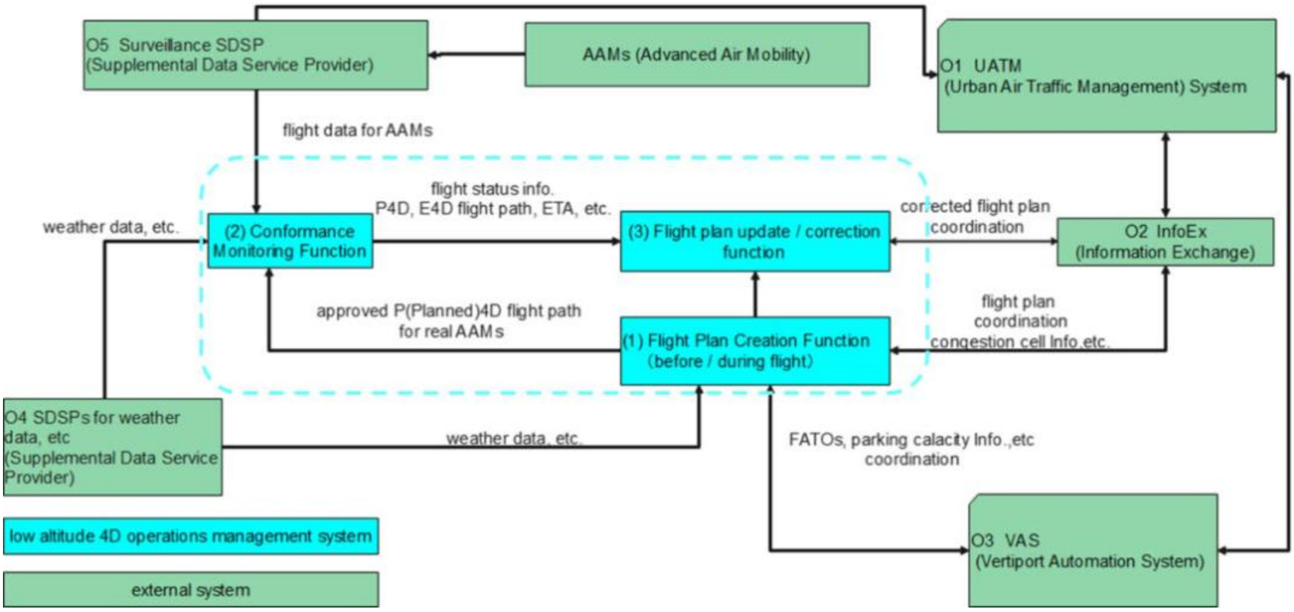

Figure 5 – Architecture of low altitude 4D operations management system.

The AAMO first activates the “Flight plan creation function” by inputting the departure and destination aerodrome, block out or block in time, and other information (e.g., aircraft identification, type of aircraft, persons on board, flight rule, type of flight), and selects preferences as shown in the HMI image of Figure 6. The “Route” button at the bottom right of Figure 6 is then clicked, and the 4D planned flight path (P(Planned)4D flight path, hereinafter abbreviated to P4D flight path) is created. The detailed P4D flight path is sufficiently precise to allow pre-departure deconfliction between flights, which cannot be achieved with relatively coarse conventional VFR flight plans.

The AAMO then checks the P4D flight path shown in the “AAMO Navigation Planning HMI Image” in Figure 7, and if it is acceptable, submits the flight plan and its associated P4D flight path to UATMS via InfoEX. Otherwise, the AAMO revises the flight plan using the “Flight plan update/correction function” as shown in the HMI image of Figure 8, then submits the updated/corrected flight plan and its P4D flight path to UATMS via InfoEX.

During a flight, the AAMO can monitor the flight’s progress and conformance to the plan using the “Conformance monitoring function” as shown in the HMI image of Figure 9. If the deviation from the plan become large, the AAMO updates the plan during the flight by using the “Flight plan update/correction function.”

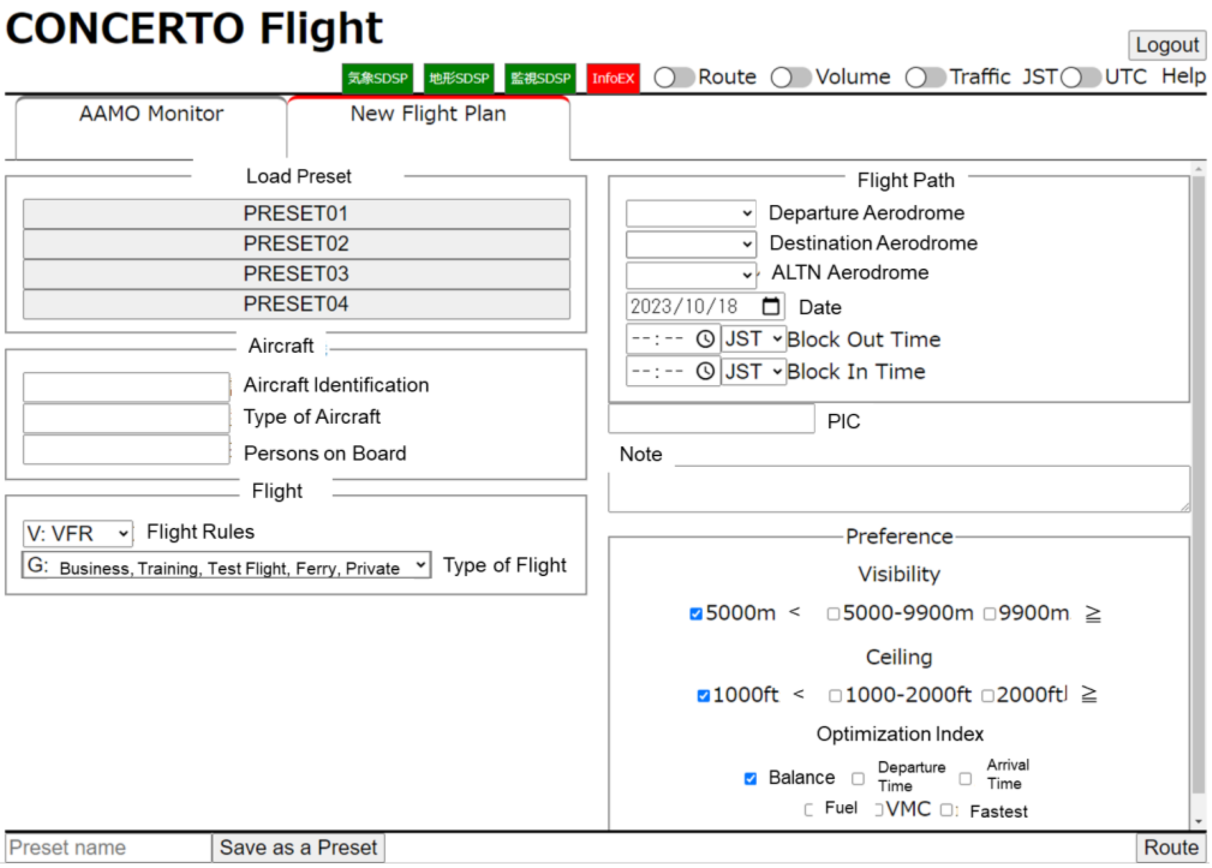

Figure 6 – AAMO flight plan input HMI image
of the low altitude 4D operations management system.

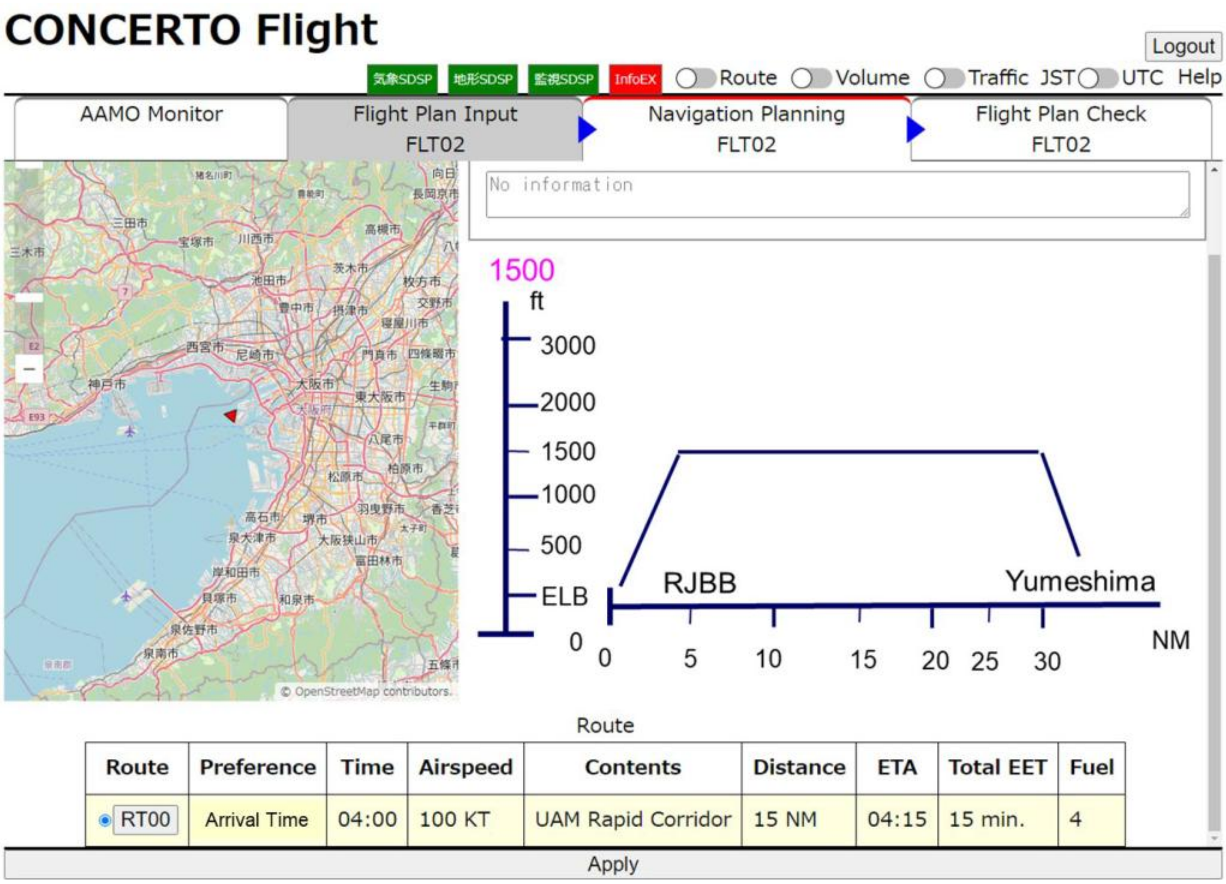

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Figure 7 – AAMO navigation planning HMI image
of the low altitude 4D operations management system.

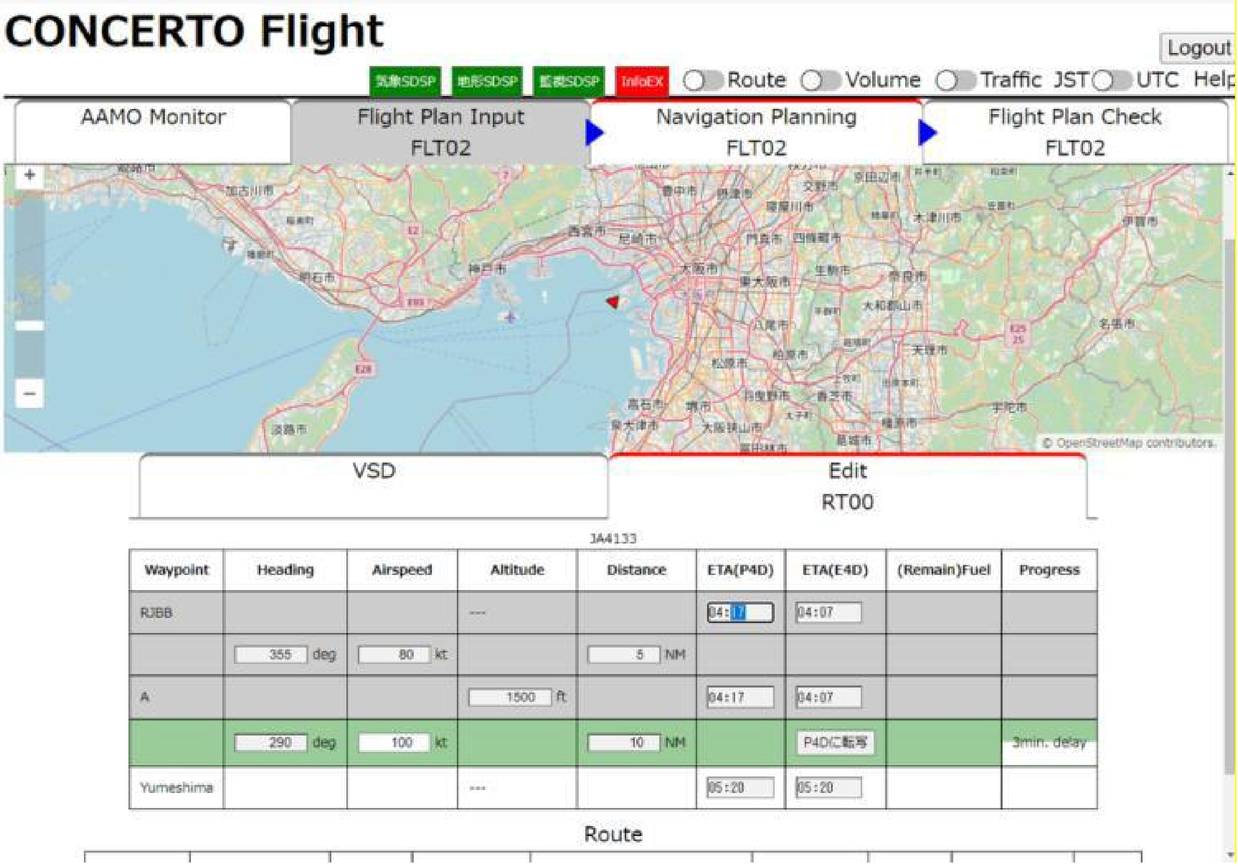

Figure 8 – Flight plan update/correction function HMI image
of the low altitude 4D operations management system.

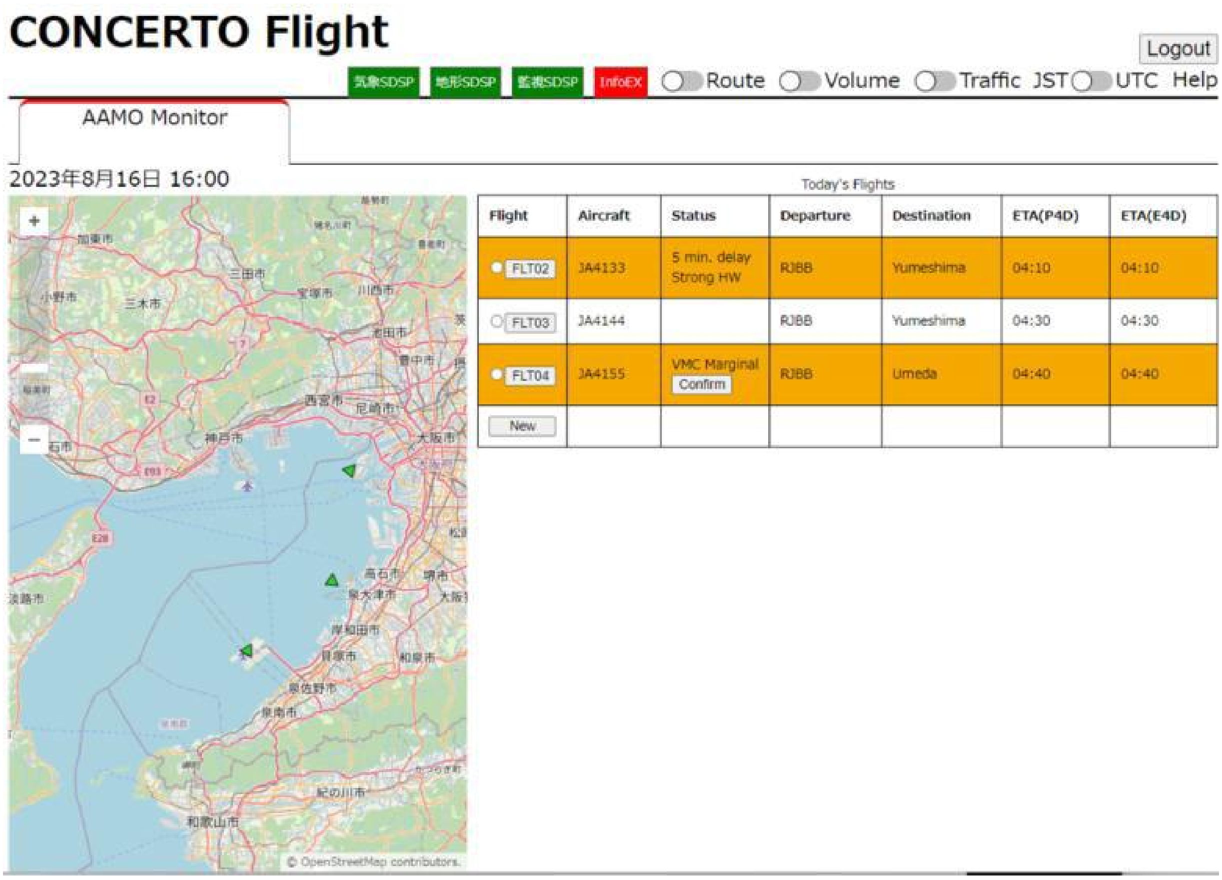

Figure 9 – Conformance monitoring HMI image
of the low altitude 4D operations management system.

3.2 Flight Plan Creation Function

The flight plan creation function shown in Figure 5 creates an AAM flight plan including a P4D flight path based on air vehicle performance, departure, and destination vertiports, airspace congestion, vertiport congestion, and weather conditions provided respectively by O1 UATM system via O2 InfoEX, O3 VAS, and O4 SDSPs. The P4D flight path is deconflicted in coordination with other airspace users and the UATMS by a pre-flight conflict management algorithm.

The P4D flight path creation function discretizes the decision variables (specified values such as cruise altitude, takeoff time, route, etc.) and exhaustively searches for the optimal values that minimize a selected evaluation function value calculated according to 1) to 4) below.

1) Generate a four-dimensional flight plan route including waypoints, times and altitudes corresponding to a candidate set of decision variables. This acts as a reference route for navigation purposes.
2) Calculate a candidate P4D flight path of the vehicle that tracks the reference route, using a model of the vehicle's dynamics, control performance, and predicted wind.
3) Calculate the evaluation function value of the candidate P4D flight path. The evaluation function is chosen from by the operator from one of the following: landing time, error from specified landing time, error from specified takeoff time, battery usage, favorable weather conditions along the route, or a weighted linear sum of these.
4) Check whether the candidate P4D flight path satisfies specified constraints, not only vehicle performance constraints such as remaining battery level, but also available resource constraints such as available slots/spots and air routes congestion based on information from UATMS. If even one of the constraints is not satisfied, the candidate P4D flight path and its corresponding reference route are considered infeasible, and the evaluation function value is set to infinity.

The above process is carried out for all possible combinations of values of the discretized decision variables, and the candidate P4D flight path with the smallest value of evaluation function and its corresponding reference route are selected.

The AAMO submits the P4D flight path satisfying the various constraints as a flight plan to UATMS. UATMS re-checks the conflict with other flight plans. If no conflict discovered, the UATMS approves the submitted plan. Otherwise, it rejects the submitted plan and provides the updated available resource information to facilitate the AAMO in modifying the flight plan.

3.3 Conformance Monitoring Function

The conformance monitoring function estimates and updates the flight status, flight trajectory from the present position to the destination vertiport, time of arrival, and remaining fuel/battery charge using the AAM performance model and flight data provided by O5 S-SDSP and weather data from O4 SDSPs. In case of a discrepancy between the estimated route and the approved flight plan and P4D flight path, the system provides a status message to the AAMO shown in the example HMI image of Figure 9.

3.4 Flight Plan Update / Correction Function

As shown in a flight plan update/correction HMI image of Figure 8, an AAMO operator may amend or cancel a generated flight plan before flight using the flight plan update/correction function. During flight, based on the instructions of the operator in response to a received conformance status message, the flight plan may be adjusted in real time according to the latest conditions.

4. Flight Evaluation Plan

Figure 10 shows a schematic of the flight evaluation of the low altitude 4D operations management system. Evaluations are planned to be conducted from 2025 to 2026 by connecting our system to external systems: the UATM service via InfoEX, VAS, SDSPs, S-SDSP, and the Real Time Simulator (RTS). We apply "a live-virtual-constructive approach", which includes real UATMS and VAS, a helicopter emulating an AAM, and virtual AAMs simulated by a RTS. In ReAMo and the CONCERTO project, the UATM service, the VAS and S-SDSP systems will be developed by NEC Corporation, and the RTS developed by JAXA [5] will generate virtual AAMs and provide their flight data to S-SDSP.

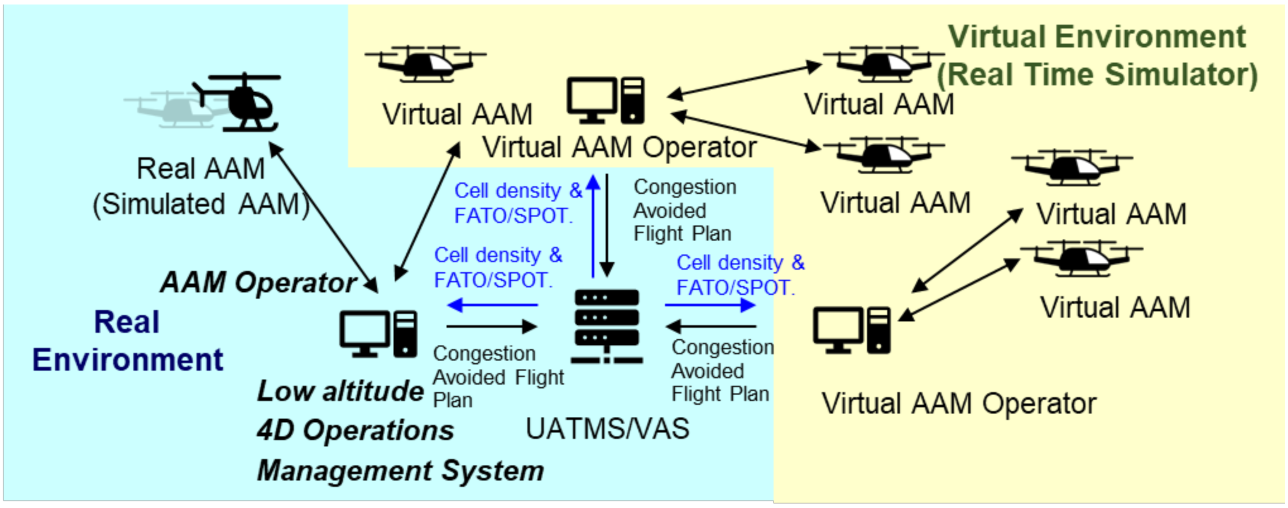

Figure 10 – Flight Evaluation Image.

5. Conclusion

This paper described a flight operations concept to realize medium- and high-density operations of future Advanced Air Mobility (AAM) and the design of a low altitude 4D operations management system to realize the concept. The concept is characterized by decentralized conflict management among UATMS and AAMOs using 4D flight paths and the sharing of available resource information. In 2025 and 2026, the proposed system will be connected to external systems - UATM, InfoEX, VAS, SDSPs, S-SDSP, RTS - and we will validate the effectiveness of our concept in a “live-virtual-constructive approach” environment. The evaluation will identify refinements to the concept and system design and utilization issues for future development.

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6. Copyright Statement

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