４．SWIM による軌道ベース運用に関する実証実験

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1. Introduction

Global harmonization of Air Traffic Management (ATM) systems is envisioned and described in the International Civil Aviation Organization (ICAO) Global ATM Operational Concept (GATMOC) [1]. The GATMOC presents a holistic vision to improve the safety, operating economics, environmental sustainability, and security of civil air transportation. Trajectory-Based Operations (TBO) is fundamental to realizing the benefits anticipated from the GATMOC concept. An underlying premise of TBO is “ATM considers the trajectory of a manned or unmanned vehicle during all phases of flight and manages the interaction of that trajectory with other trajectories or hazards to achieve the optimum system outcome, with minimal deviation from the user requested flight trajectory, whenever possible”.

This idea of TBO outlined in the GATMOC is not new, but it is maturing as the advancement of concept development and standardization of System Wide Information Management (SWIM) [2] and Flight and Flow Information for a Collaborative Environment (FF-ICE) [3] make its implementation more feasible. Based on the definition and the scope of TBO described in the ICAO Global TBO Concept [4], it is therefore now an appropriate time to discuss technical solutions and approaches for TBO implementation.

There are several current limitations preventing the requirements of GATMOC being fulfilled. Lack of information sharing between Airspace User (AU) and ATM Service Provider (ASP), both within ASP systems and between ASPs, leads to inconsistent and inaccurate trajectory predictions. As air traffic control (ATC) voice clearances might not be input into automation and systems might not share known information of relevance to trajectory prediction, no consistent view of an expected trajectory is maintained using the best-known information. Moreover, decision-making is either not informed by a trajectory or is based on trajectories that are managed locally within systems, rather than a shared and collaboratively-obtained reference.

The TBO concept aims to coalesce the GATMOC components during tactical, planning and flight operations in the ATM system by coordinating the view of the trajectory between different actors in a collaborative environment, ensuring consistency between the trajectory and restrictions that originate from the various GATMOC components and actors that shape this trajectory. TBO represents a shift from present operations towards the use of a shared, collaboratively-developed trajectory which more closely meets AU objectives and serves as the basis for decision-making across ATM system actors. It thus provides an opportunity to increase the predictability of flight operations, with flight-impacting decisions being coordinated across concept components [4]. The TBO concept also incorporates the dynamic and flexible operational demands of real-time information exchange between AUs and ASPs necessary for Collaborative Decision Making (CDM) and Performance Based Navigation (PBN).

In order to validate this concept and promote the shift from current voice-based operation to TBO, the Multi-Regional TBO Demonstration (MR TBO) project has been conducted by the Federal Aviation Administration (FAA) cooperating with international partners (NAV CANADA, AEROTHAI, the Civil Aviation Authority of Singapore (CAAS) and the Japan Civil Aviation Bureau (JCAB)) through tabletop exercises and technical interchanges. This

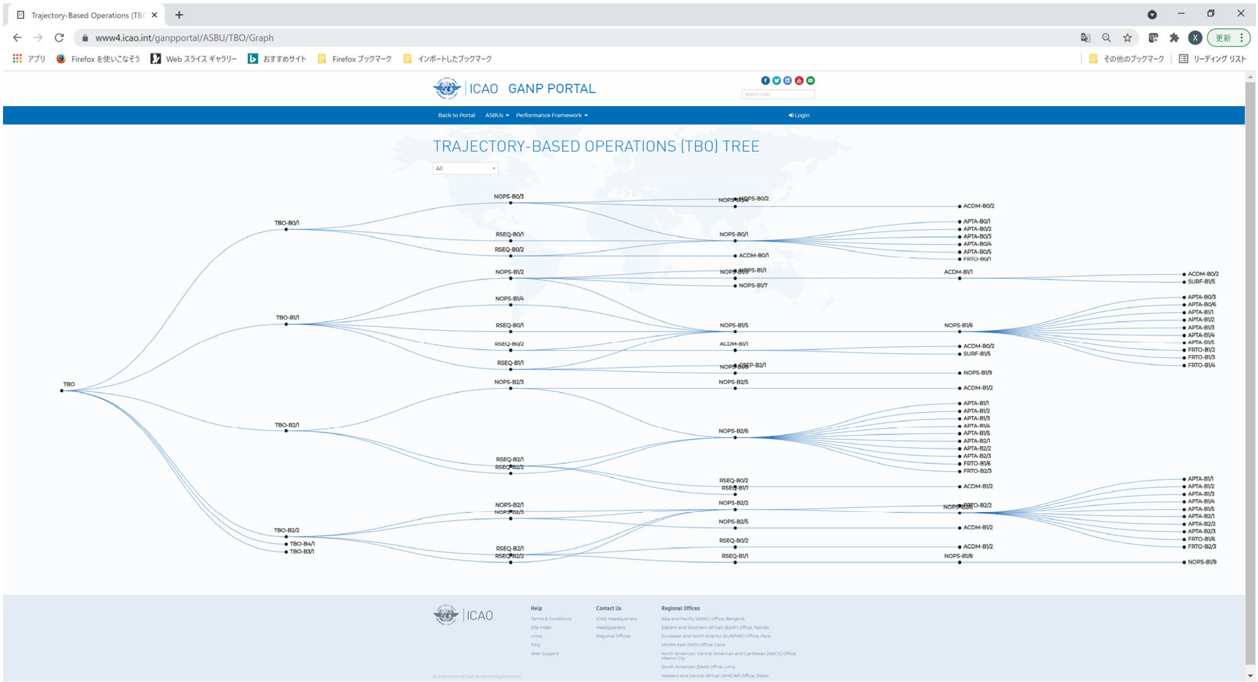

Figure 1: TBO Tree (https://www4.icao.int/ganpportal/ASBU/TBO/Graph)

collaborative effort explores the impacts of TBO related to post-departure flight operations, with various levels of equipage and crew capabilities, within the context of ATM system modernization initiatives, supporting the development of data exchange standards and relevant ICAO provisions, standards and guidance materials.

As a technical supporter of JCAB, the Electronic Navigation Research Institute (ENRI) has developed a test facility environment that provides simulation capabilities for TBO demonstration in collaboration with NEC Corporation. In this paper, the observations and analyses of MR TBO demonstrations consisting of scenario discussion and function development for TBO implementation is reported. Moreover, the coordination method and information exchange between SWIM-based services in the post-departure phase of flight for how to use managed trajectories is discussed. Finally, the lessons learned and challenges for trajectory sharing, management, and utilization are discussed.

The paper is structured as follows. In the next section, the roadmap of Global Air Navigation Plan (GANP) for full TBO implementation is introduced. In section 3, discussions of scenarios and operational values of TBO are presented. In section 4, the development and analysis of the ENRI test system for TBO demonstrations are presented. The paper is concluded in section 5.

2. SWIM, FF-ICE AND TBO

2.1 GANP

Figure 1 shows the roadmap towards the full implementation of TBO published in the ICAO GANP [5]. The GANP identifies necessary capabilities and technologies and breaks them down using the Aviation Systems Block Upgrade (ASBU) framework to provide a roadmap of incremental ATM system upgrades that will allow the global ATM community to more efficiently move into the TBO future. It provides a comprehensive understanding of the intent of, and delivery mechanisms for, the ATM system envisioned in the GATMOC. The ASBUs are divided into temporal Blocks to guide the ATM community's implementation of these new capabilities.

Flowing from the GANP are more focused individual concepts called threads, and threads are comprised of elements. Threads are distinct from each other; for example FF-ICE and SWIM are two threads that have dependencies upon one another at the element level as well as sharing common enablers in other threads.

2.2 Relationship

SWIM provides a digital data-sharing infrastructure that facilitates the data sharing required by TBO. SWIM consists of standards, infrastructure and governance enabling the management of ATM-related information and its exchange between qualified parties via interoperable services [2]. SWIM delivers integrated digital aeronautical information, weather information, constraint information while enabling the data collection and data sharing necessary for user collaboration and improved management of flight constraints. This will enable increased common situational awareness and improved ASP agility to deliver the right information to the right people at the right time.

Building on SWIM, FF-ICE provides a globally harmonized process for planning and sharing consistent flight information. The FF-ICE concept is split into two development cycles: provisions, standards and guidance for the first FF-ICE development cycle (FF-ICE/R1) focus on flight planning and trajectory negotiation from submission of a flight plan or up to the flight's departure. The initial concept for the second FF-ICE development cycle (FF-ICE/R2) focuses on the execution of the flight and post-departure trajectory negotiation. FF-ICE relies on the mutually-agreed 4 Dimensional Trajectory (4DT) of an aircraft from gate to gate to allow ASPs and AUs an improved understanding of operational expectations.

TBO relies on a globally standardized exchange of data via SWIM. The SWIM Global Interoperability Framework consists of information exchange models such as the Flight Information Exchange Model (FIXM) [6], Aeronautical Information Exchange Model (AIXM) [7] and ICAO Weather Information Exchange Model (IWXXM) [8]. Moreover, the operational and data frameworks for flow management, flight planning, and trajectory management provided by FF-ICE are also necessary for TBO implementation.

3. Scenario and Operational Values

To explore the primary characteristic of TBO that includes trajectory sharing, management and utilization, we consider a scenario with multiple flights in a trajectory-managed environment. Both eASPs (FF-ICE-capable ASPs) and eAUs (FF-ICE-capable AUs) benefit from this process by collaboratively establishing a mutually acceptable 4D trajectory for a flight not only prior to departure but also during the flight itself. Trajectory negotiation is conducted between eASPs and eAUs through the timely exchange of flight constraints and traffic flow information. This real time information sharing and trajectory negotiation support common situational awareness across stakeholders, creates more accurate demand predictions, and improves the safety, efficiency and capacity of operations.

3.1 Scenario

The scenario shown in Figure 2 consists of three flights: UAL5 and UAL7 departing from Denver International Airport (KDEN) and Houston International Airport (KIAH) respectively to Narita International Airport (RJAA), and JAL9 departing from San Francisco International Airport (KSFO) also to RJAA. Data exchanges include the participation of two eAUs (United Airlines (UAL) and Japan Airlines (JAL)) and three eASPs (FAA, NAV CANADA and JCAB). The eAUs are able to publish FF-ICE Flight Plan and related messages to share and negotiate the trajectory of the flight with the eASPs. FAA, NAV CANADA and JCAB are able to provide FF-ICE services and SWIM-enabled applications for pre-departure and post-departure trajectory negotiation with all downstream and upstream FIRs (Flight Information Region). This scenario focused on the post-departure phase with the integration of technical

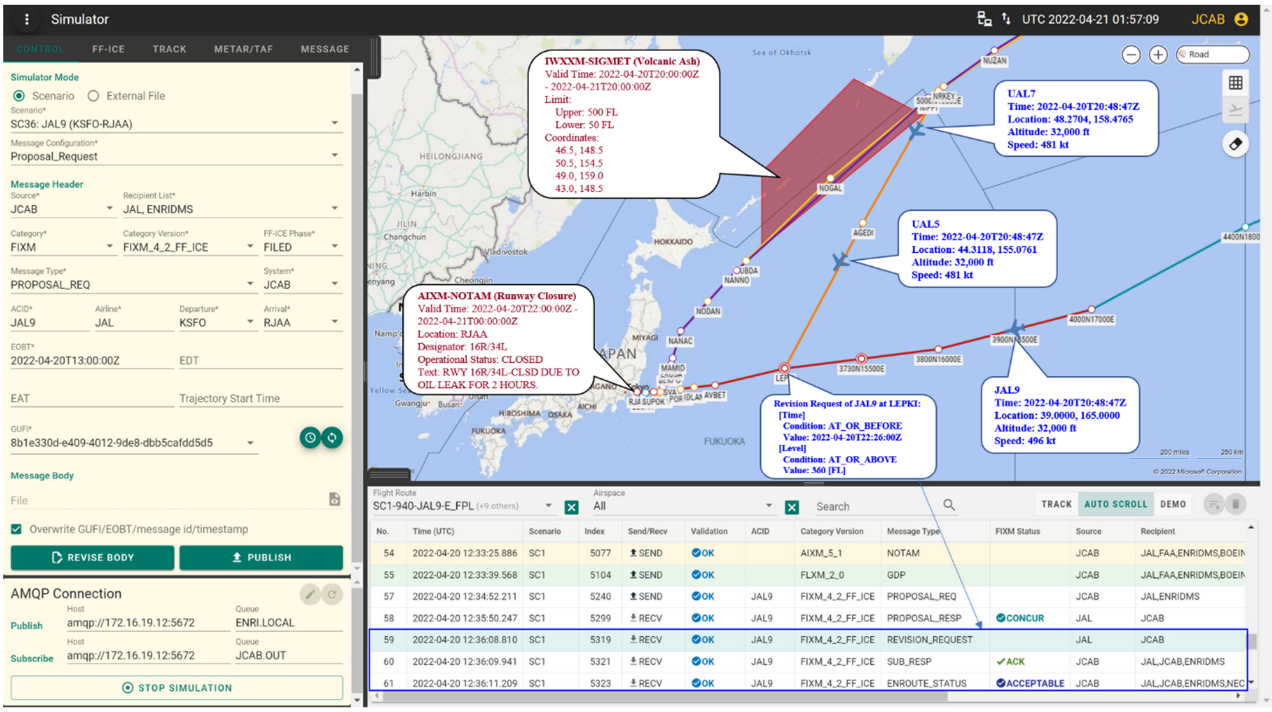

Figure 2: Trajectory Based Multiple Flights Operation

actions and strategic plan by cooperating with Air Traffic Flow Management (ATFM) services. The operational flow of this scenario using FF-ICE services over SWIM is as follows:

1) At approximately four hours prior to scheduled departure, the UAL dispatcher submits Filed Flight Plans for UAL7 and UAL5 to the FAA, NAV CANADA and JCAB, and receives a response of “Acceptable” from all three.
2) Four hours prior to departure, the JAL Flight Operations Center (FOC) submits a Filed Flight Plan to the FAA and JCAB for JAL9, and also receives a response of “Acceptable” from both.
3) When UAL5 is 90 minutes from the Fukuoka FIR boundary, the FAA sends an ABI (Advance Boundary Information) message for UAL5 to JCAB. At 30 minutes from the boundary, the FAA sends a CPL (Current Flight Plan) message for UAL5 to JCAB and receives an ACP (Accept) response. (The FAA also sends an ABI for UAL7 to JCAB 90 minutes before the FIR boundary.)
4) Shortly after the CPL message has been sent, the crew of UAL5 observes volcanic ash (VA) ahead on its flight planned route, so requests 100nm left deviation to KZAK. Since this deviation will also affect the trajectory in Fukuoka FIR, the FAA sends a CDN (Coordination) message to JCAB to respond to the urgent request. Fortunately, there is no other traffic affected, and JCAB responds with an ACP message to the FAA.
5) JCAB publishes a SIGMET message regarding the VA, which imposes a constraint that flights should not enter the affected area (Figure 2). This triggers the re-evaluation of FF-ICE Filing service to send an Enroute Status message with Not-Acceptable to UAL7, indicating that its current flight plan route is no longer acceptable.
6) The crew of UAL7 discuss the situation with the UAL FOC on “company” frequency and they agree to negotiate a new route to avoid the restricted area to the south. The UAL FOC then sends a Trial Request message to FAA and

JCAB, and receives a "Concur" response from both, indicating that the proposal is possible to be acceptable.

7) The UAL FOC sends a Revision Request to the FAA to "lock in" the proposal as a formal update to the agreed trajectory, and receives an "Acceptable" response. To notify the revised trajectory to downstream eASPs, the FAA then publishes the Agreed Trajectory to JCAB.
8) UAL7 is cleared to execute the agreed trajectory by the KZAC controller. The FAA then sends a CPL message for UAL7 to JCAB and receives an ACP response.
9) After UAL7 and JAL9 cross the boundary into Fukuoka FIR, a runway (16R/34L) at RJAA is closed for two hours due to an oil spillage, and a corresponding NOTAM (Notification To Airmen) of the runway closure is published via SWIM (Figure 2).
10) After issuing this NOTAM, JCAB initiates GDP (Ground Delay Program) for domestic departures to reduce the traffic flow into RJAA and updates the CLDTs (Calculated Landing Time) of affected flights that are already airborne. JCAB then submits a GDP message in FLXM (Flow information Exchange Model) format to UAL5, UAL7 and UAL9 to negotiate the updated landing time [9].
11) According to the agreed 4D trajectories of UAL7 and JAL9, there is a potential conflict at the waypoint LEPKI. To avoid this potential risk, JCAB sends a Proposal Request specifying a revised CTO (Calculated Time Over) and altitude (FL360) at point 37N/150E to JAL9. After evaluating the operational viability of the proposal of JCAB, JAL FOC responds with a Proposal Response of "Concur" to JCAB to indicate that the proposal is acceptable. Finally, JAL FOC amends the planned trajectory by submitting a Revision Request message with the same parameters to JCAB, and receives a Enroute Status response of "Acceptable" (Figure 2).
12) Similarly, JCAB then sends a Proposal Request with a revised CTO at LEPKI to UAL7. After evaluating the proposal, UAL FOC responds to JCAB with "Concur". As this is a minor change to the trajectory that does not require a new clearance, the UAL FOC then sends a Trajectory Update message to JCAB with agreed condition and receives a Submision Response of "ACK".
13) After receiving Enroute Status of Acceptable for its proposal to JAL9, JCAB issues clearance to JAL9 for step climb to FL360 at 37E/150E.
14) When UAL5, UAL7 and JAL9 cross the waypoint LEPKI, JCAB's ATFM service sends a Object Update message with ATO (Actual Time Over) to its AMAN (Arrival Manager) service to initiate their arrival handling processes.

Note that in some urgent situations, shorter-term tactical interventions and actual clearances to modify the flight path or speed will still be coordinated between ATC systems using AIDC and handled between the air traffic controller and the flight crew using voice or CPDLC via data link services. How to integrate these tactical actions with SWIM based strategic trajectory management is a future reaserch topic for us.

3.2. Operational Values

In a current environment, it is difficult to precisely calculate and predict the crossing time at certain waypoints for arrival management. Moreover, the labor is required to address constraints for runway closure and optimal flight level requests once an aircraft is in flight. A runway closure at a hub airport may affect hundreds of flights. With the opportunity for early information exchange, trajectory sharing and negotiation among stakeholders that FF-ICE and ATFM services provide, problems in all phases of flight that can exact a high cost in both financial and workload terms can be solved more efficiently and expeditiously. This improvement offers enhanced predictability to both ASPs and AUs. Even when airborne, the flight crews can initiate strategic negotiation to request a better route or flight level depending on actual flight conditions. As a result, the following operational values can be considered to be improved through TBO:

- Enhanced Predictability
- Alignment of Tactical Actions and Strategic Plan
- Increased Reliable Flexibility
- Improved Strategic Planning
- Decreased Uncertainty

4. TBO DEMONSTRATION

4.1. Test System

The ENRI SWIM test system used by JCAB in the MR TBO demonstrations provides a basic technical infrastructure, information services, and some SWIM-enabled applications to support the development, validation and demonstration of SWIM concepts and services built on its infrastructure [10]. Figure 3 shows the high-level system architecture (blue box in the figure) and international system connections (orange box) of the JCAB system in the MR TBO demonstrations. NEC is a Asian GEMS (Global Enterprise Messaging Service) provider who provides connectivity between Local SIWM test systems and SkyFusion Frontier (SFF), which connects to the FAA and NAVCANADA test systems. The communication between the SFF and NEC Corp. uses TCP/IP with Transport Layer Security (TLS). An IPsec VPN is used for the network connection within Asian GEMS between AEROTHAI, CAAS and JCAB.

To ensure the interoperability of the exchanged information, GEMS providers enforce the use of the standardized aeronautical, flight and weather exchange models (AIXM, FIXM and IWXXM) with the updated versions for each of their SWIM users.

The ENRI facility contains the simulation and test

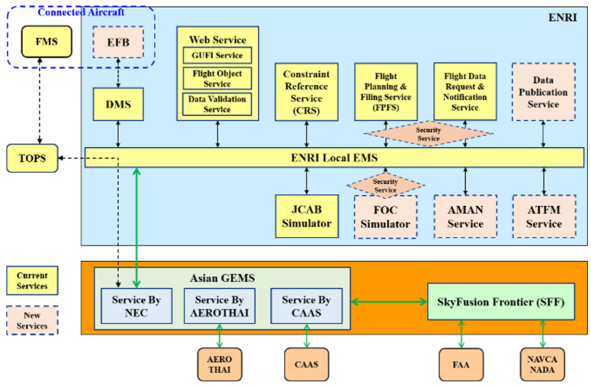

Figure 3: Test System Architecture

environment that allows the MR TBO demonstrations to carry out the required exchanges of information between all actors for both pre-departure and post-departure phases of flight. The test system as a whole provides not only Ground/Ground (G/G) SWIM information services but also Air/Ground (A/G) SWIM information exchange between an Electronic Flight Bag (EFB) on each aircraft and ground-based Data Management Services (DMS) [11]. In addition, a trust framework and security service have been developed to enable secured information exchange between trusted identities [10]. Moreover, data exchange between the surface/enroute/oceanic Air Traffic Control (ATC) systems in Japan and the aircraft onboard Flight Management Systems (FMS) can be simulated by the Trajectorized Oceanic Traffic Data Processing System (TOPS) provided by NEC.

4.2. Trajectory Management

In the post-departure phase, the eASP and the eAU may have to manage three sets of trajectories associated with a flight created by different operational processes: the Aircraft Trajectory (i.e., without ATC involvement), ATC Trajectory (i.e., with ATC involvement) and Agreed Trajectory (with FF-ICE services), and mismatches may arise between them. It is difficult to make large changes to well-established ATC systems and procedures in the short or medium term. It will become necessary to understand how to work with current ATC systems to reflect the least modifications of tactical actions in strategic plans. An approach to share the updated trajectory and assure trajectory consistency between different stakeholders and systems is therefore necessary in a TBO environment,.

In some situations, circumstances such as urgency will make it difficult to perform strategic negotiation between stakeholders before a tactical action is required, and it will be necessary notify the updated 4DT following a tactical intervention to a flight to related systems and downstream eASPs. In the demonstration, if an amended clearance was issued by ATC system or the sector controller, the Agreed Trajectory was updated with current ATC Trajectory and the updated Agreed Trajectory was disseminated to relevant downstream eASPs via the FF-ICE Notification Service.

Trajectory management will consist of two functions to evaluate an Agreed Trajectory. The first function is expected to involve a re-evaluation process to confirm the effect of new constraints on the Agreed Trajectory. The second function is expected to involve a monitoring process to align the Aircraft Trajectory with the Agreed Trajectory.

The re-evaluation process of FF-ICE Filing Service will be triggered when a new constraint is issued by Constraint Reference Service (CRS). If this constraint affects currently managed Agreed Trajectories, an updated Filing Status of "Not-Acceptable" and information on the constraint (in AIXM or IWXXM formats) will be published to relevant eAUs. However, not all Limitations/Restrictions/Constraints used in current operations should be considered as a "constraint" on flight planning or execution. For example, because of dynamic time property, it is difficult to allow forecast airspace congestion to trigger the re-evaluation process and be returned as an airspace entry constraint. To enable the eASP to allocate the access to resources and allow eAUs to swap access to airspace between flights, coordination between FF-ICE and ATFM has been implemented in the demonstration system.

Moreover, in the ENRI test system, to assure trajectory consistency of in-flight aircraft, a ATFM trajectory monitoring service has been developed by cooperating with surveillance service. If the discrepency of position and/or time between a flight's surveillance-derived position and a 4D point included in the Agreed Trajectory is more than a certain threshold, a notification will be published from the ATFM service to the aircraft and eAU. When the aircraft's EFB receives such a notification from the DMS, a re-calculation of current Aircraft Trajectory will be triggered via trajectory synchronization process.

5. CONCLUSIONS

This paper presents an operational view of the capabilities and services supporting TBO and introduces the development of the demonstration for MR TBO international project based on the ENRI SWIM Test Bed. Through the scenario discussion, the operational values of TBO and potential operational feasibility challenges between eASPs and eAUs are clarified. Moreover, additional functional capabilities of service and application required to support TBO are identified. Finally, the coordination approaches between ATFM and FF-ICE to achieve trajectory management of TBO is discussed and the efficiency is shown by the scenario-based demonstration.

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