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ASSEMBLY — 41ST SESSION

TECHNICAL COMMISSION

Agenda Item 33: Other issues to be considered by the Technical Commission

TRAJECTORY PREDICTION AS A SERVICE FOR TRAJECTORY-BASED OPERATIONS (TBO) AUTOMATION

(Presented by the United States)

EXECUTIVE SUMMARY

The *Global Air Traffic Management (ATM) Operational Concept* (Doc. 9854) describes future operations involving interactions between Air Traffic Management (ATM) and "the flight trajectory of a manned or unmanned vehicle during all phases of flight." These interactions are described further within the *Manual on Global Trajectory Based Operations (TBO)* (Doc. 10130)[1] involving the sharing, managing, and using of an Agreed Trajectory amongst relevant ATM System participants. Such an Agreed Trajectory represents a common plan for the flight that ensures all participants are operating from the same basis. The sharing of trajectory information is made possible on a global scale through the principles described in the *Manual on System Wide Information Management (SWIM)* (Doc. 10039).

At present, automation systems for ATM use a collection of different trajectory predictors, using different inputs, all developed to be fit-for-purpose. With the goal of TBO to use a common trajectory as a plan across systems, there are benefits to migration to a single common trajectory modelling service to be used by different domains. Some differences still must be supported for meeting objectives while supporting a common trajectory plan without the need for reconciliation.

This information paper summarizes work to define a trajectory prediction service that can accommodate the needs of different domains, while ensuring that the properties of a common plan for TBO are in place.

Strategic Objectives:	This working paper relates to the Air Navigation Capacity and Efficiency Strategic Objective.
Financial implications:	Not applicable.
References:	Doc 9854, *Global Air Traffic Management Operational Concept* Doc 10130, *Manual on Global Trajectory Based Operations (TBO)*[1] Doc 10039, *Manual on System Wide Information Management (SWIM)* AIAA-2022-3753, *Trajectory Prediction Service in an Info-Centric National Airspace System*

[1] At the time of publication of this paper, Doc 10130 was still in preparation.

1. INTRODUCTION

1.1 As automation has been introduced into air traffic management (ATM) over the past few decades, different systems have relied on trajectory modelling. These modellers have been used to forecast resource demand (e.g., airport, runway, and airspace) at any given time, to determine timing for future events (e.g., sector crossings, automatically initiate handoffs), to trial plan changes that could be cleared to an aircraft, and to predict future conflicts (e.g., conflict probe).

1.2 The systems that compute these trajectories evolved over time, with different algorithms, using different input data, and different assumptions and often provide different trajectories for the same flight. Yet as we move towards trajectory based operations (TBO), there is a need for accuracy and consistency of the trajectory across automation platforms and with the flight deck. Prior attempts were made at achieving accuracy and consistency through various means, without overwhelming success.

1.2.1 While wind forecasts have improved over time, there may be different sources of winds used by different predictors, and these may involve subsampling of the full forecast. For aircraft equipped with a flight management system, errors in the on-board wind model affect the profile used for the vertical navigation path. Methods to incorporate this effect in ground prediction are known yet require aircraft-derived data and algorithmic changes to existing ground predictors. Such changes could more easily be accommodated in a single common service.

1.2.2 Obtaining flight-specific parameters through aircraft data exchange can also improve consistency and accuracy. However, not all trajectory modellers can make use of the data (e.g., most kinematic modellers are insensitive to mass). When downlinking aircraft behaviour, such as *drive-and-dive* versus *dive-and-drive* versus *geometric* profiles, existing modellers have coded only one generic behaviour. This can be addressed through the expression of intent as data versus hard-coding behaviour.

1.2.3 When seeking consistency across ground-based trajectory modellers, input data could be synchronized, but significant changes would be required to capture the differences in behaviours, and not all predictors make use of the same sets of data.

1.3 The above prior work has demonstrated the difficulty of achieving accurate, synchronized trajectories when different trajectory modellers are used by multiple systems. One approach to mitigate the effects of using multiple trajectory modellers involves the use of common trajectory modelling services for use by all domains as described herein. Such an approach not only removes inconsistency, but it also simplifies the deployment of future enhancements.

2. DISCUSSION

2.1 An analysis of existing trajectory modellers was conducted across systems in multiple domains from flow management to air traffic control for both radar and procedural separation environments. A set of trajectory prediction services was defined that can accommodate differing requirements for the various systems through the provision of different input data versus having different algorithms. These services are as follows:

— *Lateral Path Conversion Service.* The lateral path conversion service translates the named procedures, waypoints, and airways of a flight’s planned route to a series of point locations suitable for trajectory generation. This service has applicability beyond trajectory modelling.

— *Lateral path initialization service*. The lateral path initialization service determines the path from the current state (characterized by lateral/vertical position, course, speed, and vertical speed) to the previously converted path. This service may incorporate heuristics or evolve to include more sophisticated inference methods when an aircraft is off path. The choice of initial position (on or off-route) is one difference between various trajectory applications.

— *Constraint specification service*. The constraint specification service determines high-level "flight plan" intent in terms of applicable constraints, including departure time constraints. Constraints can be imposed at the applicable locations along the converted route for application during trajectory modelling. Some applications require the addition or deletion of constraints.

— *Intent specification service.* The intent specification service determines aircraft intent, i.e., the succession of manoeuvres by which aircraft aim to meet applicable lateral, vertical, and speed constraints. Today, most trajectory predictors use implicit intent that is the algorithm has hard coded the sequence of aircraft behaviours with parameters as the only input. For a predictor to best apply aircraft-derived data, the intent specification service should rely on explicit intent, capable of modelling feasible aircraft behaviours provided as input data.

— *Meteorological prediction service.* The meteorological (MET) prediction service provides the meteorological data required for trajectory prediction.

— *Aircraft performance service.* The aircraft performance service estimates aircraft performance parameters for prediction of aircraft behaviours under specified meteorological conditions along the aircraft intended route of flight.

— *Trajectory prediction service.* The trajectory prediction service computes the aircraft trajectory from aircraft behaviours and constraints submitted by the intent specification service. It makes use of the MET prediction service and the aircraft performance service.

3. CONCLUSION

3.1 While TBO often describes the need for a singular trajectory representing the common plan across all ATM actors, this must not be interpreted to mean that only one trajectory is necessary for each flight. Different actors make their own decisions as input to the common plan, and they have a need to evaluate different trajectories with individual needs. For example, trial plans help to evaluate the outcome of different decisions before they are made. If a constraint is known with certainty, trajectory modelling will generally include that type of constraint. Yet, trajectories without controlled times are used as input when determining what the controlled times should be, or when determining how much delay to assign given the controlled time. When constraints are uncertain (e.g., interim altitudes), trajectory consumers may make different choices regarding the application of a constraint. As a result, a common trajectory service must be capable of accommodating these varying needs across different trajectory consumers.

3.2 To meet these individual needs, trajectory modelling has been decomposed into a collection of stateless services that forms the basis for a common trajectory service composed of microservices. Each trajectory consumer would be able to invoke this common trajectory service to deliver a trajectory consistent with their individual needs. An analysis of the needs of various systems across the United States National Airspace System today indicates the approach can be applied to meet these needs through the judicious selection of the inputs and outputs of each of these services. The same trajectory service can then also be applied to develop the TBO common plan, by using the appropriate inputs expressing those decisions that are planned to be implemented on any given flight.

3.3 The advantages of migrating to such an approach are numerous:

— *Scalability*. Use of micro services allows the modeller to scale services to deliver trajectories as required.

— *Consistency*. A single trajectory modelling service provides consistency across systems, ensuring that differences between modelled trajectories are due to differences in input.

— *Ease of evolution*. The decomposition of the modelling into the specified functions enables advanced algorithms to be applied as they become available.

— *Better tailoring of solution*. The approach facilitates the incorporation of aircraft or airspace user data into the trajectory modelling process.

— *Improved quality through third-party services*. Some trajectory services may be provided by third-party providers allowing improved quality when there is a reluctance to share private data.

3.4 The Assembly is invited to note the information provided in this paper.

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