GLOBAL TBO CONCEPT

(VERSION 0.11)

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CONTENTS

1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE DOCUMENT

The *Global Air Traffic Management (ATM) Operational Concept* (ICAO Doc. 9854) identifies some significant changes as the ATM system migrates towards the concept vision. One such change, Trajectory Based Operations (TBO) is described below (from §1.9.2 of ICAO Doc. 9854):

> *Air traffic management (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 document presents the global concept for Trajectory Based Operations (TBO). TBO is fundamental to realizing the ICAO Global ATM Operational Concept and affects many processes, procedures and information flows impacting a variety of ICAO Provisions. Moreover, TBO is the subject of several large-scale national and regional development and implementation programmes.

For TBO to succeed and to deliver its anticipated benefits it is of paramount importance that all the processes and procedures that are part of TBO effectively interact and that TBO is developed and deployed in a globally harmonised manner. This starts with a common understanding of what TBO is and a description of operations under a TBO environment. This understanding is reflected in the Global Air Navigation Plan (GANP, ICAO Doc. 9750), providing a framework for global harmonisation.

This document, presenting the Global TBO concept, is the first step in achieving the above objectives. Its aim is to explain the link with the ICAO Global ATM Concept, to give direction, to establish a consistent set of terms and definitions related to TBO and to define, at high level, the scope of TBO. Moreover, the document explains TBO to a wide audience in the aviation community familiar with the ICAO Global ATM Operational Concept

Being a concept, the scope of this document is high level and seeks to be non-prescriptive with regards to solutions, technology, and implementation. However, the scope is complete in terms of coverage of TBO and the context.

1.2 NEED FOR TRAJECTORY BASED OPERATIONS (TBO)

The ICAO's Global ATM Operational Concept (GATMOC) outlines the target global ATM system. This is presented at a high general level to ensure a common global presentation independent of regional differences. At this global concept level, as shown in Figure 1, the ATM system consists of the GATMOC Components Airspace Organization and Management (AOM), Demand/Capacity Balancing (DCB), Aerodrome Operations (AO), Traffic Synchronisation (TS), Conflict Management (CM), Airspace User Operations (AUO) and ATM Service Delivery Management (ATM-SDM).

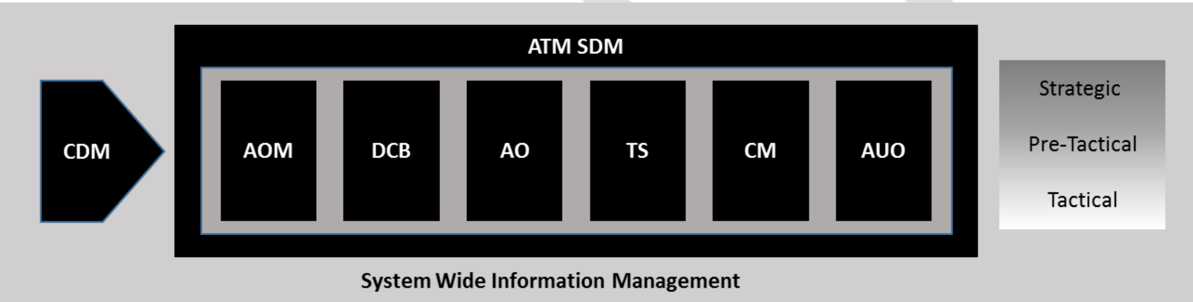
> *The trajectory describes the lateral, vertical and temporal profile of a flight. TBO shares the common plan for a flight's trajectory. Accuracy, and control to that plan is tailored to the performance needs of the circumstances. The ATC Clearance is the means through which the trajectory is delivered.*

There are many Airspace Users (AU), all of whom have expectations of the ATM system. Taking all relevant considerations into account, AUO would have established that at any given instant, flying a specific trajectory will best meet the AUs business interests. AUs have invested in powerful tools to develop trajectories optimized to their interest; TBO will enable the AU to align the operation of their flight with these interests.

From the ATM Service Provider (ASP) perspective, once trajectories are known, ASP decisions are made based upon the collection of all flight trajectories. Trajectories are used to detect problems and decisions can be made to affect the trajectories in such a way as to resolve those problems. In short, the concept components use and affect the trajectory. With the concept components being trajectory-based, coordination and collaboration occurs using the trajectory as the common plan for the flight.

Furthermore, due to the global nature of ATM System Participants, a global TBO Concept is needed to rationalize investments and deliver interoperable capabilities. It is also recognized that many enabling capabilities, with limited operational use today, may be leveraged for TBO. Deployment of these capabilities is expected to be based upon performance-needs thereby requiring the concept to also support a mixed environment.

Achieving TBO, this vision of collaboration based upon a shared trajectory as the common plan requires overcoming limitations under current operations.



CDM	- Collaborative Decision Making	**CM**	- Conflict Management • Strategic conflict management • Separation provision • Collision avoidance
ATM SDM	- ATM Service Delivery Management		
AOM	- Airspace Organization & Management		
DCB	- Demand/Capacity Balancing		
AO	- Aerodrome Operations	**AUO**	- Airspace User Operations
TS	- Traffic Synchronization	**TBO**	- Trajectory Based Operations

Figure 1 – The GATMOC Components

1.2.1 CURRENT LIMITATIONS

Inconsistent AU and ASP Planning due to Limited Information Exchanged- In the planning phase the AU provides flight plan information (route, estimated times, requested cruise altitude, etc.) to the responsible ASP. In some areas, this is done by using the paper flight plan form. In other areas flight plan information is shared electronically. Pre-departure, relevant updates to the flight plan may be provided to the ASP by the AU. Consistent with the flight plan data, the AU maintains a version of the trajectory prediction for internal purposes such as fuel and time calculations. The ASP may compute a trajectory prediction, for demand-capacity balancing. This prediction uses the flight plan, if available; however, more uncertain information such as schedules and historical routing might need to be used prior to a plan being filed. The ASP may inform the AU of some evolving constraints. The AU operates with limited knowledge of constraints impacting the flight and neither the ASP nor AU has an accurate trajectory prediction based upon information exchanged.

Inconsistent and Inaccurate ATM Ground System Trajectories - For some ASPs, Flight Data Processing Systems (FDPs) and other Decision Support Systems maintain custom trajectory predictions for each aircraft within the area of jurisdiction using surveillance information and algorithms based on aircraft and sometimes operator-specific parameters. These predictions do not contain any information from the AU's Flight Operations Center (FOC) or Flight Management System (FMS) beyond that which is available through the standard ICAO flight plan form and will often differ considerably from the FMS computed trajectory. They are typically not shared with the AUs. Where ASPs compute their own trajectory predictions, separate trajectory predictions may be computed for different purposes (e.g., DCB, TS or CM) by Decision Support Systems. Clearances issued via voice are not directly reflected in a trajectory prediction; either controllers must enter the information into the system or heuristics may be used to infer the intent. Conformance monitoring is mainly conducted through surveillance of present position, not through verification of downstream aircraft intent. Across ASPs, trajectory predictions are frequently not precisely synchronised.

Inconsistent Air and Ground Trajectories - During the execution phase, and if necessary prior to execution, the aircraft's FMS, if so-equipped, maintains a trajectory prediction using the current active route, altitude/speed constraints input into the auto-flight system (FMS & connected flight-guidance), aircraft and operations specific parameters, limited environmental data and more. Dependent on the sophistication of the FOC, input parameters used for trajectory prediction in the AU systems can be updated using messages (e.g. via Aircraft Communications Addressing and Reporting, ACARS). Open clearances verbally provided to the flight deck may be executed manually or through the Mode Control Panel (MCP) / Flight Control Unit (FCU). These verbal clearances might not be reflected in the FMS trajectory prediction. The FMS-computed trajectory also does not reflect internal ATC handover procedures between different facilities and/or sectors as these might not be shared with the AU.

The current situation described above is characterised by:

- Lack of information sharing between AU and ASP, within ASP systems and between ASPs. Voice clearances may not be input into automation and systems may not share known information of relevance to trajectory prediction.
- The above results in disparate information across participants and automation systems which leads to inconsistent and inaccurate trajectory predictions. No single, consistent view of an expected trajectory is maintained using the best-known information.
- Decision-making is not trajectory-based or is based on and affects local trajectories that are not shared and collaboratively-obtained.

All the above limit the ability of the ATM System to deliver performance enhancements across multiple Key Performance Areas, for example:

- *Efficiency and Predictability* - Tactical ATM decisions, without coordination with strategic plans, decrease the effectiveness of strategic decisions thus shifting the balance towards more tactical decision-making and reduced efficiency and predictability.
- *Capacity* – When capacity-limited, inaccurate trajectories result in delivery of demand that is not matched to capacity. In turn, this results in inefficient tactical actions to mitigate too much demand, or loss of capacity when demand is under-delivered. To protect from uncertainty, buffers on capacity may be applied thereby reducing throughput.
- *Flexibility* – In-flight re-planning and prioritization by the AU is not supported by automated processes.
- *Participation by the ATM Community* - ATM decisions are made with limited consideration of AU intentions submitted through today's flight plan form.
- *Global Interoperability* – Inconsistent trajectories are maintained across ground and airborne systems with limited information sharing.

1.2.2 TBO REMOVES CURRENT LIMITATIONS TO DELIVER BENEFITS

The main difference with today's operation is that Trajectory Based Operation aims to take away these limitations and constraints by means of:

- **Sharing** of trajectory information and providing access to the best data, eventually leading to a common more accurate view of the trajectory
- **Managing** trajectory information using Collaborative Decision Making (CDM)
- Using the trajectory that is shared and managed as a **common plan for the flight** by providing a common intent to be achieved during execution of the flight

Ultimately, use of trajectory Information exchange by automation allows the provision of more accurate, consistent and operationally-relevant information to human actors. This better supports performing their existing roles and responsibilities using improved methods and techniques leveraging the enhanced information. These are expected to deliver benefits across multiple Key Performance Areas:

- *Efficiency and Predictability* – Where possible, decisions are made more strategically, improving single-flight and system efficiency while reducing tactical interventions impacting predictability. Strategic decisions accommodate tactical interventions, and tactical interventions follow a strategic plan.
- *Capacity* – More accurate trajectories result in delivery of demand that is more closely matched to capacity. In turn, this improves efficiency by reducing tactical actions or capacity buffers to mitigate too much demand, and minimizes loss of capacity when demand is under-delivered.
- *Flexibility* – The AU is empowered to conduct in-flight re-planning and prioritization to meet individual business objectives.
- *Participation by the ATM Community* – Increased information exchange allows ATM decisions to better incorporate the AU perspective.
- *Global Interoperability* – Trajectories maintained across ground and airborne systems provide a consistent view. The AU and ASPs operate to a consistent plan expressed through the trajectory.

1.3 CONTEXT

Trajectory Based Operations are a foundation of the GATMOC exhibiting the following key properties:

- Trajectory Based Operations (TBO) are the glue between these GATMOC Components during tactical planning and flight operations by coordinating the view of the trajectory between different actors and ensuring consistency between the trajectory and constraints that originate from the various GATMOC Components and participants that shape this trajectory.
- TBO requires an efficiently-converging coordination process across concept components leading to stable, consistent and robust trajectory solutions.
- TBO supports a Performance-Based ATM System. For example, the use of trajectory constraints should be minimised to the extent possible and to the tolerance level commensurate with the performance needs of the GATMOC Component it serves. Airborne operations should not be constrained more than is strictly required to meet the performance needs of the ATM System.

By coordinating the trajectory including constraints for a flight between all involved ATM stakeholders, each stakeholder has the awareness to better anticipate and respond to the events that may impact them, while minimizing disturbances to other stakeholders. Continuous coordination is impossible for many reasons and even undesirable given the many uncertainties especially for long haul flights. However, there is a need to have consistency and continuity of the trajectory between participants.

TBO as described herein applies to a variety of types of airspace; however, not all aspects of the concept will always be applicable. For example, while the concept description fully applies to controlled airspace, the planning, coordination and sharing of trajectories is expected to also apply in select uncontrolled airspace while descriptions of clearance delivery would not be applicable.

TBO is part of ATM-SDM. ATM-SDM ensures coherency between the concept components supported by Collaborative Decision Making (CDM) principles (see ICAO Circular 335 on ATM-SDM and the Manual on Collaborative Air Traffic Flow Management, ICAO Doc. 9971). The establishment of a shared long-term investment planning method seeking to globally synchronise the evolution of capabilities and performance is described in the ICAO Global Air Navigation Plan (Doc. 9750). TBO focuses on trajectory-based coordination and performance optimization across concept components during all phases of a flight. (See Figure 2).

TBO involves the development of an Agreed Trajectory, coordinated across participants that extends through all phases of flight. Under TBO, principles are developed to ensure that the Agreed Trajectory and associated constraints are known to relevant participants. For example, ATC instructions should minimize the need for open-ended vectors, and their impact should be reflected as an update to the Agreed Trajectory in a timely manner. While TBO shares an Agreed Trajectory, accuracy of and control to this trajectory is tailored to the performance needs of the circumstances. In other words, not every aspect of a flight needs to be predetermined and captured precisely in the Agreed Trajectory prior to off-block.

With regards to Aerodrome Operations, while a gate-to-gate trajectory might describe a full taxi path with associated times on the surface; such detail is usually not required beyond local participants. Aerodrome Operations considering the en-route to en-route view with the turn-around process, must agree on, and subsequently manage the flight on the surface, to deliver expected surface event times with known impacts to the ATM System, and to ensure that the Agreed Trajectory is consistent with a local surface plan.

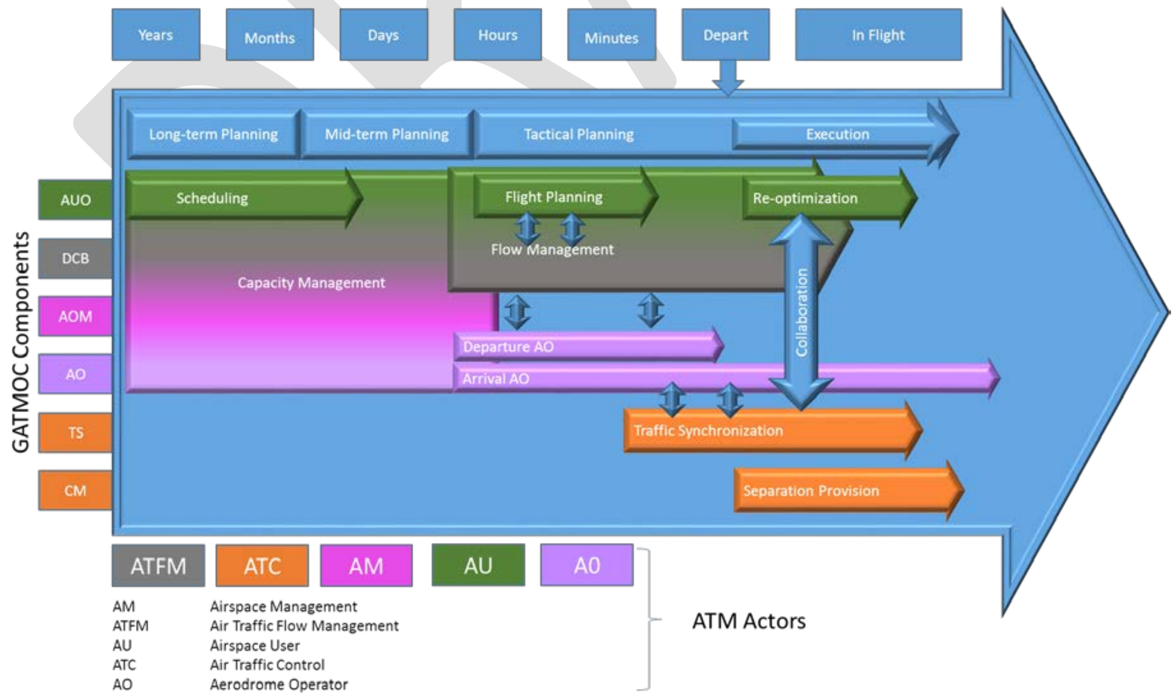


Figure 2 – Trajectory evolution

1.4 EVOLUTION NOT REVOLUTION

The introduction of TBO is subject to an evolutionary but phased process during which there will be a mix of capabilities and performance levels both from the aircraft's perspective as well as from the ASP's perspective. The TBO concept assumes that such a mixed scenario will evolve as ASPs, aircraft, and their FOCs adopt capabilities as dictated by ATM performance needs.

The evolution towards TBO is expected to align with the deployment of Aviation System Block Upgrades (ASBU) as described in the "Global Air Navigation Plan", (ICAO Doc. 9750). As the system evolves, some key properties of this evolution are described below.

- *Pre-Departure Trajectory Information Sharing & Negotiation* - The AU develops trajectory preferences while understanding known constraints and shares a trajectory with the ASP. These preferences can also include one or more (alternative) trajectories. For AUs that are not participating, the automation of the ASP would develop a more detailed trajectory based upon known information such as that contained in a flight plan. CDM processes are applied to manage trajectory information. CDM is not limited to any specific domain such as an airport or en route.
- *Flight-execution Trajectory Information Sharing & Negotiation* - Consistent trajectory information is shared between ground systems for all phases of flight. Coordination between systems allows each GATMOC Component to meet their objectives through a single consistent set of trajectory information. Flight-execution trajectory sharing and negotiation with the AU allows the meeting of flight-specific business objectives and improved ground-based trajectory predictions. The "Manual on Flight and Flow Information for a Collaborative Environment (FF-ICE)" (ICAO Doc. 9965) describes the end state of this sharing environment.
- *Aircraft downlink of Intent* - An initial level of synchronisation between airborne and ground systems is realised by means of downlinking the airborne trajectory prediction. This will enable improved and consistent trajectory predictions, sharing of feasibility of constraints, detection and resolution of inconsistencies and therefore be the basis for further improvements leading to efficiency and productivity gains.
- *Air-Ground Synchronisation* - Integration of the air (FMS) and ground -predicted trajectory through data communication clearance delivery and loading of the clearance into aircraft automation. Clearances are structured, as performance-needs dictate, to more precisely deliver the Agreed Trajectory by unambiguously describing the plan. This will open the door towards advances in ATM automation and hence performance benefits.

1.5 DOCUMENT ORGANISATION

This document describes the global concept for TBO, consistent with the target defined in the GATMOC. This document is organized as follows:

- Chapter 1 introduces the concept. This section articulates the need for TBO together with the current limitations that are addressed by the concept. An evolutionary approach towards the concept vision is anticipated as described by the Global Air Navigation Plan. Terminology and acronyms used by this document are defined.
- Chapter 2 provides the general characteristics of TBO in terms of the major changes introduced together with some high-level considerations for achieving these changes.
- Chapter 3 describes the TBO Concept end-state assuming full participation from pre-departure through flight execution. Considerations for flight across multiple ASPs are described.
- As the TBO Concept is expected to progress in a mixed environment, Chapter 4 describes the considerations for TBO in this mixed environment. Enablers and TBO capabilities are described both

for the AU and the ASP. The impact of both mixed-equipage and mixed-mode is described from pre-departure through execution.
- Chapter 5 describes the technical environment necessary for delivering TBO.
- Chapter 6 provides references.

Appendices provide further detail as follows:

- Appendix A describes Remotely Piloted Aircraft System (RPAS) operations
- Appendix B describes the relationship of TBO to each of the GATMOC Components.

1.6 DEFINITIONS AND ACRONYMS

1.6.1 DEFINITIONS

The TBO concept makes use of terms defined in reference ICAO documents, in particular ICAO PANS ATM (Doc 4444) and ICAO Doc 9965. The following definitions are in addition to definitions included in these documents:

<u>Trajectory Based Operations</u>

A concept enabling globally consistent performance-based 4D trajectory management by sharing and managing trajectory information. TBO will enhance planning and execution of efficient flights, reducing potential conflicts and resolving upcoming network and system demand/capacity imbalances early. It covers ATM processes starting at the point an individual flight is being planned through flight execution to post flight activities.

<u>ATM configuration</u>

An ATM configuration is the arrangement of the non-flight elements of the ATC System. The ATM Configuration imposes constraints on flights through such factors including military airspace reservations and releases, sector configurations, runway combinations and runway usage.

<u>ATM network</u>

The ATM network is considered as a series of nodes, including all stakeholders on the ground and in the air, providing or consuming information relevant for them [ICAO doc. 9965, P.5-1, 4.1.2 Line 3-4]. It acts as an integrated system of all ATM systems worldwide that are interconnected through the flights that they share.

<u>Four-Dimensional Trajectory (4DT)</u>

A four-dimensional (x, y, z, and time) trajectory of an aircraft from gate-to-gate, at the level of fidelity required for attaining the agreed ATM system performance levels.

> Note 1: The exact representation of the path is considered outside the scope of this document, and does not imply that all dimensions of the 4DT are being controlled to by the aircraft. For example, time may be the result of maintaining a constant airspeed.
>
> Note 2: While the 4DT includes the possibility of representing a full surface path, ATM system performance needs for TBO are not expected to require the full sharing, beyond local participants, of such a level of fidelity. Nevertheless, some expected event times impacting the ATM Systems must be surveyed and shared.

<u>Agreed Trajectory</u>

The current trajectory that is agreed between the AU and the ASP after collaboration, or imposition of pre-collaborated rules.

Explanation: The agreed trajectory is the trajectory that the AU agrees to fly. There is only one agreed trajectory for any given flight at any time. As the ATM system has unpredictable or uncontrollable events and to allow flexibility, it is likely that it will be necessary to renegotiate trajectories. The agreed trajectory therefore reflects the most recent agreement.

Update of Agreed Trajectory

As a flight operates, the Agreed Trajectory may need to reflect the impact of uncertainty. This updated Agreed Trajectory is shared across relevant participants. An update of the Agreed Trajectory need not require coordination across relevant ATM system participants. (See Section 2.2.2 for further discussion on trajectory updates.)

Revision of Agreed Trajectory

A revision to the Agreed Trajectory occurs when new information, including an Agreed Trajectory update, reveals the need to modify constraints or to re-optimize the flight. In general, the process for revising will require coordination across relevant ATM System Participants. A revision of the Agreed Trajectory is shared across relevant participants. (See Sections 2.2.2 and 3.3.6 for further information on revisions.)

Aircraft-Derived Trajectory

The aircraft-derived trajectory is the trajectory that is computed by the aircraft automation. With appropriate mode-selection, the aircraft-derived trajectory both: 1) provides input to the lateral and vertical guidance functions, and 2) represent the trajectory the aircraft intends to fly.

Expected use: The aircraft-derived trajectory represents what the aircraft is intending to fly, under appropriate mode selection. It is not necessarily the agreed trajectory. In normal operations, it is expected that the aircraft-derived trajectory will remain within the trajectory tolerances of the agreed trajectory.

Desired Trajectory

The current trajectory that is requested and generated by the AU with knowledge of the ATM system's operational constraints and resource contention.

Explanation: The AU determines the trajectory that is best suited to meet their mission objectives. The AU may elect to pre-emptively circumvent operational constraints and resource contention — or engage in collaboration on the trajectory. With full knowledge of constraints and resource contention, an AU may wish to engage in collaboration when the constraint(s) allow for flexibility and they are provided indication that the ASP has some flexibility on constraints. For example, as part of the negotiation process, the ASP may modify some constraints as more demand information is made available.

There is only one desired trajectory for any given flight at any time. To allow for flexibility and as the ATM system has unpredictable or uncontrollable events, it is likely that it will be necessary to renegotiate trajectories leading to a revision in the agreed trajectory. The desired trajectory reflects the most recent AU request. Where the agreed trajectory is not the desired trajectory then the ASP will negotiate to obtain a revised agreed trajectory.

Executed Trajectory

The actual trajectory of the aircraft from the start-up to the last known position.

Explanation: The executed trajectory is what was executed and is not necessarily the desired or agreed trajectories. The executed trajectory relates only to the current flight of the aircraft (and does not contain information from previous flights, even with an en-route to en-route perspective). The executed trajectory information can be used for performance and operational analysis.

Negotiating Trajectory

A trajectory proposed as a potential agreed trajectory.

Explanation: For trajectory negotiation purposes, multiple trajectories may be required during the negotiation process; however, each participant would be allowed only one negotiating trajectory at a time which represents their most recent proposal in the negotiation. These trajectories may not necessarily be a gate-to-gate trajectory. These trajectories are intended to be transitory.

Constraint

A limitation to free manoeuvring of an aircraft. Limitations are geospatial and temporal in nature and can originate from any GATMOC Component, including AUO (see ICAO Doc.9965, Section 4.4.5 describing operator constraints) as well as from meteorological conditions or local regulations. A constraint can be a trajectory constraint or a generic constraint.

Trajectory constraint

A trajectory constraint limits the freedom of a trajectory by fixing one of its 4D points or segments in one or more dimensions (vertical, lateral, time), with corresponding bounds (“between boundary values”) or direction (“before”, “after”, “above”, etc.) An example is an altitude constraint to avoid restricted airspace.

Generic constraint

A generic constraint consists of known information that limits the solution space for defining a trajectory. Examples include aeronautical information like predefined airspace structures, availability of military airspace for civil use, availability of conditional routes, night curfews, etc. A generic constraint, often caused by restrictions or regulation, may result in a trajectory constraint.

Closely associated with constraints are operator preferences which are described in Doc. 9965 in two forms:

Operator preferences

This item includes preferences on operator procedures and other operator specific information impacting manoeuvers and clearances. Unlike operator constraints, the operator expresses a preference but will accept alternatives based on the circumstances. Examples include procedures that would affect flight efficiency or a runway preference. This input may or may not be complied with based upon the impact to ATM system performance.

Movement preferences

This item contains movement preferences submitted by flight planners for consideration by traffic flow automation if a traffic management initiative becomes necessary. Examples include preferring a southerly course deviation if a re-route is necessary; preferring a ground delay over a re-route for a pre-departure flight; preferring any re-route less than 120 NM. This item is applicable in situations which prevent more specific indications of preference, such as an AU not equipped to engage in negotiation

When planning and managing the time dimension of a 4DT, we consider the following terms:

Controlled Time

An ATM imposed time constraint on a defined point on the flight path to be achieved within a required accuracy using feedback control. This feedback control may be via aircraft systems or ground-based instructions.

Target Time

A desired planning time at a defined point on the flight path. It expresses the desirable time for an aircraft at a specific point from the point of view of ground ATM services. There is no continual feedback control to meet the target time within a specified tolerance. If a flight is projected to miss the target within a specified tolerance, a revision may be initiated.

A Target Time consists of a nominal value and tolerance limits around the nominal value.

Air Traffic Control Clearance

Authorization for an aircraft to proceed under conditions specified by an air traffic control unit (ref Doc 4444).

Beyond the clearance definition above, the TBO Concept introduces two types of clearances, open and closed, due to their significantly different impacts on trajectory accuracy.

Closed Clearance

Closed clearances are issued by ATC units to authorise the flight to proceed in accordance with a 4D trajectory.

> Note 1: Closed clearances are preferred for trajectory-based operations. Closed clearances allow the coordination of trajectory intent between operational stakeholders and a reduction in trajectory prediction uncertainty for downstream trajectory synchronisation and demand-capacity balancing activities.
>
> Note 2: Ideally the closed clearance should be compliant with the Agreed Trajectory; however, a closed clearance issued for tactical purposes may require an update or revision to the Agreed Trajectory.
>
> Note 3: Through judicious selection of the clearance (e.g., use of PBN Procedures), a resulting 4DT, consistent with the Agreed Trajectory, can be obtained to varying levels of accuracy, within the capabilities of the aircraft and flight crew.

Open Clearance

Open clearances authorize or instruct an aircraft to deviate from compliance with a 4D Trajectory without additional authorization or instruction allowing a new 4DT to be defined. Examples of open clearances include: the assignment of a heading without a turn-back, or the assignment of an interim altitude on climb.

> Note 1: Open clearances produce greater uncertainty in the resulting 4DT, affecting decisions based upon these trajectories.

Clearance Limit

The point to which an aircraft is granted an air traffic control clearance.

TBO Environment

An environment in which trajectory information, including the information required to formulate the trajectory, is shared, collaboratively managed and the trajectory is used as a common plan for the flight by the relevant participants.

GATMOC ATM Components

The ATM system consists of the ATM concept components Airspace Organization and Management (AOM), Demand/Capacity Balancing (DCB), Aerodrome Operations (AO), Traffic Synchronisation (TS), Conflict Management (CM), Airspace User Operations (AUO) and ATM Service Delivery Management (ATM-SDM).

The following definitions are taken from ICAO's GATMOC and doc 4444 (PANS-ATM) and included hereunder for quick and easy reference. The TBO concept does not require any change to these definitions.

- **Conflict** is any situation involving aircraft and hazards in which the applicable separation minima may be compromised.
- **Conflict horizon** is the extent to which hazards along the future trajectory of an aircraft are considered for separation provision.
- **Hazards** that an aircraft will be separated from are: other aircraft, terrain, weather, wake turbulence, incompatible airspace activity and, when an aircraft is on the ground, surface vehicles and other obstructions on the apron and manoeuvring area.
- **Separation minima** are the minimum displacements between an aircraft and a hazard that maintain the risk of collision at an acceptable level of safety.
- **Separation mode** is an approved set of rules, procedures and conditions of application associated with separation minima.
- **Separation provision** is the tactical process of keeping aircraft away from hazards by at least the appropriate separation minima.
- **Air Traffic Control clearance**[1,2] is defined as an authorization of an aircraft to proceed under conditions specified by an air traffic control unit.
- **Clearance limit** is the point to which an aircraft is granted an air traffic control clearance.

1.6.2 ACRONYMS

4DT	4D Trajectory
ABI	Advanced Boundary Information
ACARS	Aircraft Communications Addressing and Reporting System
ANSP	Air Navigation Service Provider
AO	Aerodrome Operations
AOM	Airspace Organization and Management
ASP	ATM Service Provider
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
AU	Airspace User
AUO	Airspace User Operations
CDM	Collaborative Decision Making
CM	Conflict Management
CPDLC	Controller Pilot Data Link Communications

[1] For convenience, the term "air traffic control clearance" is frequently abbreviated to "clearance" when used in appropriate contexts.

[2] The abbreviated term "clearance" may be prefixed by the words "taxi", "take-off", "departure", "en-route", "approach" or "landing" to indicate the particular portion of flight to which the air traffic control clearance relates.

CTA, CTO	Controlled Time of Arrival, Controlled Time Over
DCB	Demand and Capacity Balancing
E-AMAN	Extended Arrival Management
EPP	Extended Projected Profile, downlinked FMS trajectory prediction
FDP	Flight Data Processing
FIXM	Flight Information Exchange Model
FF-ICE	Flight and Flow Information for a Collaborative Environment
FL	Flight Level
FMS	Flight Management System
FOC	Flight Operations Centre
FRT	Fixed Radius Turn
GATMOC	Global ATM Operational Concept
ICAO	International Civil Aviation Organization
MET	Meteorology
MTCD	Medium Term Conflict Detection
PANS	Procedures for Air Navigation Services
PBC	Performance Based Communication
PBN	Performance Based Navigation
RNAV	Area Navigation
RNP	Required Navigational Performance
RTA/RTO	Required Time of Arrival / Required Time Over (a waypoint)
SDM	Service Delivery Management
SEP	Separation Management
SID	Standard Instrument Departure
STAR	Standard Arrival Route
STCA	Short Term Conflict Alert
SWIM	System Wide Information Management
TBO	Trajectory Based Operations
TBO-CD	TBO Concept Document
TMA	Terminal Control Area
TS	Traffic Synchronisation

2 GENERAL CHARACTERISTICS

2.1 INTRODUCTION

Trajectory-Based Operations 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 the ATM System Participants. Thus, TBO provides an opportunity to shift operations towards greater predictability with flight-impacting decisions being coordinated across concept components, with highest priority for separation provision. The main differences, as described in Section 1.2.2, with today's operation involve:

- **Sharing** of trajectory information eventually leading to a common view as the Agreed Trajectory
- **Managing** trajectory information using Collaborative Decision Making (CDM)
- The trajectory that is shared and managed, the Agreed Trajectory, is used as **common plan for the flight** by providing a common intent to be achieved during execution of the flight.

This Section first provides additional explanation for each of the above main differences followed by some high-level considerations required for accomplishing them. These include:

- Incorporation of the AU perspective
- Rules for Trajectory Management
- Management of uncertainty via
  - Performance-based communications, navigation and surveillance
  - Robust trajectory solutions

2.2 TBO MAJOR CHANGES

2.2.1 SHARING OF TRAJECTORY INFORMATION

Building on SWIM, FF-ICE and new capabilities (see Section 4) for air-ground trajectory exchange, ground and airborne actors and systems have access to consistent and up-to-date flight information, meteorological information, airspace information and aerodrome information in four dimensions, to the fidelity required. This shared information provides a consistent view, across all ATM participants, of the factors that affect each flight's trajectory. These factors affect a flight's trajectory both directly, and through decisions impacting its trajectory.

Decisions on the trajectory are reached through a CDM process (see Section 2.2.2) coordinating across relevant concept components. The sharing of these decisions, in concert with rules for trajectory management (see Section 2.3.2), provide a mechanism for converging onto an Agreed Trajectory that is also shared across components.

Trajectory information to be shared consists of the following types of information:

- The sharing of environmental factors affecting trajectories (e.g., winds, airspace configuration, aerodrome capacities, generic constraints)
- The sharing of information allowing the coordination of decisions across concept components (e.g., trajectory constraints, trial plans)
- The sharing of additional information allowing improved trajectory predictions (e.g., aircraft downlinked data, or neighbouring ASP for entry conditions)
- The sharing of an Agreed Trajectory provided as a basis for managing and controlling this trajectory

Realistic considerations on network bandwidth and storage will impose limits on the sharing of information pertinent to any trajectory. For example, trajectories are not expected to be coordinated with every surveillance update to very large degrees of precision. The information exchange must also consider the relevant operational needs. The sharing of trajectory information should be conducted at a rate and within tolerances sufficient to achieve desired ATM System performance levels. Information will also only be shared with authorized participants (e.g., limiting the sharing of proprietary or sensitive data).

Operating in such an environment gives all stakeholders clear visibility of the Agreed trajectory with the lateral, vertical or time trajectory and/or generic constraints that define it, as well as of the operational factors that may affect it. This continuous sharing and updating is enabled through information management and automation.

2.2.2 MANAGING THE TRAJECTORY THROUGH CDM

As global demand for aviation increases, the number of flights operating through congested airspace and aerodromes also increases. This results in more flights being subject to constraints that may originate from different ASPs along their intended trajectory. TBO seeks to coordinate among global participants to ensure valid flight-specific constraints are met and deliver trajectories for improved ATM System performance including stability and robustness of the ATM network.

While different ASPs interact with a flight, each ASP may also instantiate multiple GATMOC Components relating to various time-horizons of a trajectory. As illustrated in Figure 3, these components all act on the same trajectory (often on different parts of it). This action may involve the adding or removing lateral, vertical or time trajectory constraints, or involve the creation and execution of a proposed trajectory meeting such constraints. The trajectory, shaped by these trajectory constraints, is the common denominator for these GATMOC Components. While the concept components affect the trajectory, the converse applies as well. Each component uses a collection of relevant trajectories for problem evaluation.

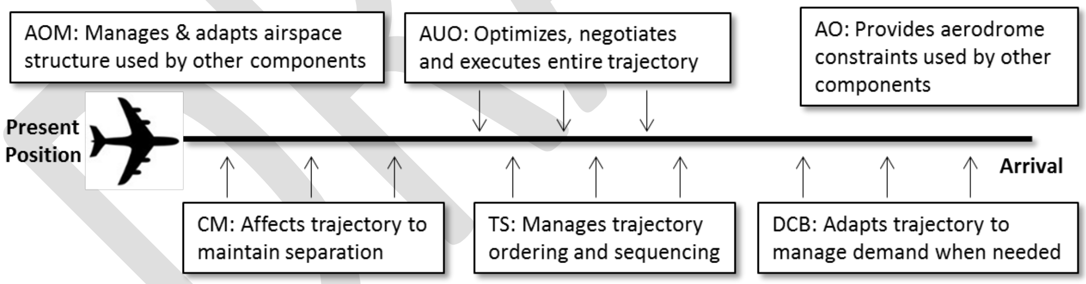


Figure 3 – Different ATM components use and affect the trajectory

The GATMOC Components are coupled through the trajectories of impacting flights. For example, adding or removing a trajectory constraint on one part of the trajectory will often impact another part of the trajectory. In turn, the modified trajectory may alter the decision of another GATMOC Component. This level of coupling requires that a flight's trajectory be managed for consistency across participants.

Managing the trajectory requires being able to ensure consistency of the shared trajectory information when information has changed from a prior consistent state. Circumstances include:

- A flight may be subject to disturbances (e.g., due to wind uncertainty) resulting in a present position deviating from the Agreed Trajectory
- Similar to the above, a planned decision is executed (e.g., take-off, crossing a point with controlled time) allowing the outcome to be reflected in the Agreed Trajectory

- An update to trajectory prediction input data such as forecast environmental conditions results in a need for an update to the Agreed Trajectory (e.g., a forecast temperature change affecting true airspeed prediction)
- One or more components seek a change to the Agreed Trajectory (e.g., a problem is detected or a more optimal solution is sought)

In response to changes to trajectory information, management requires that the Agreed Trajectory be made consistent where necessary. While the change is shared for use by all relevant participants[3], there are different levels of impact that should be considered (see Figure 4):

- *No Change* - A very small discrepancy (within tolerances) from the Agreed Trajectory would not require an update to be shared across participants.
- *Update* - When differences from the Agreed Trajectory exceed established tolerances, the Agreed Trajectory is **updated** and shared across relevant participants. Tolerances may be adjusted based upon local and temporal ATM Performance needs.
- *Revision* - Updates to the Agreed Trajectory may require a **revision** consisting of coordination of the plan across concept components & participants. This occurs when one or more components need to modify the Agreed Trajectory due to the update, a violation of established constraints, or new information affecting the flight.

Management of the trajectory requires a collaboratively agreed-to set of rules governing the process (see Section 2.3.2). The processes must be established for updating and sharing of the Agreed Trajectory, setting tolerances, detecting deviations from an Agreed Trajectory, and collaborating between ASPs and concept components to obtain or revise an Agreed Trajectory. Tolerances may be established across all dimensions of the 4DT, and include tolerances on airspeed.

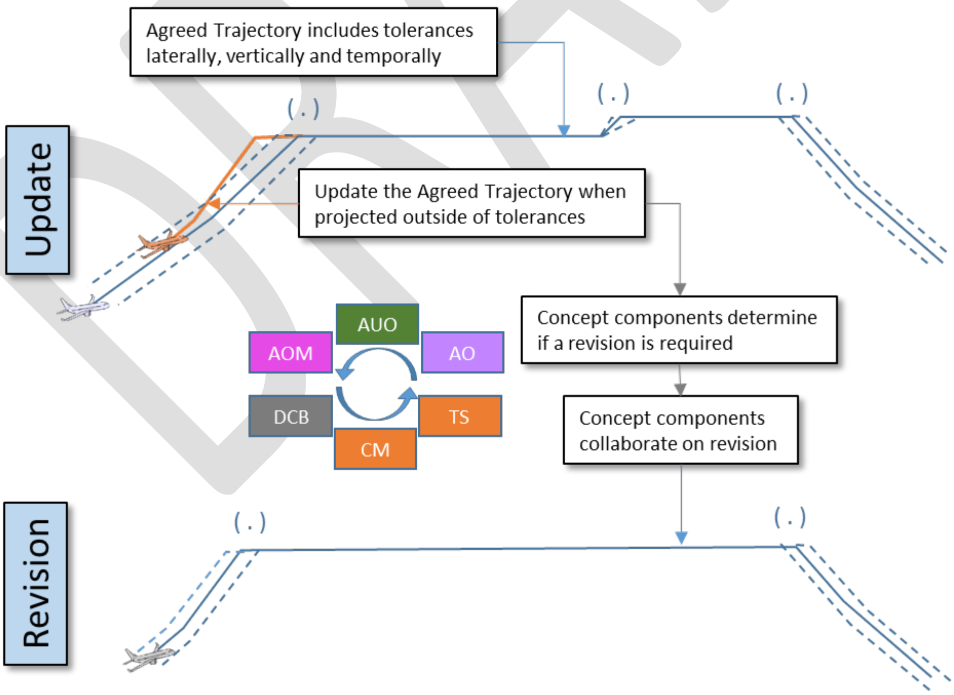


Figure 4 Update and Revision of the Agreed Trajectory

[3] Various mechanisms and responsibilities for updating and sharing the trajectory are possible and are expected to be developed as the concept progresses towards implementation.

2.2.3 THE TRAJECTORY AS A COMMON PLAN FOR THE FLIGHT

The sharing and management of trajectory information provides consistent information which allows the use of each flight's Agreed Trajectory as a unique, common plan for decision-making across concept components. This common plan is used by GATMOC Components to first determine if any action is required. If so, a trajectory revision is required generally necessitating coordination/negotiation with other components. The objective of coordination/negotiation is to ensure a trajectory emerges which is suitable across components. The resulting Agreed Trajectory is shared and managed and provides a common intent to be achieved during execution of the flight.

While the Agreed Trajectory provides a common intent to be achieved, the process by which this trajectory is delivered is through the provision of clearances by Air Traffic Control (ATC) which are accepted and executed by the flight crew.

While flight execution is based on the Agreed Trajectory, this does not mean that the flight must be precisely controlled to all dimensions of the trajectory. For example, an Agreed Trajectory may have no time constraints along the path requiring no time control along-path; however, the flight will continue to operate to a cleared or filed speed shared with relevant stakeholders. The update process will manage the Agreed Trajectory, and share the along-path progress. Components monitor the updates to ensure no revisions are required based on emerging problems.

Current Usage of Trajectories

In the current situation, different parts of the ATM network have different characteristics regarding their trajectory predictions. For instance, DCB typically needs the flight profile for the whole flight, while in sector operations, tactical functions need the trajectory prediction only with a limited look- ahead time. The different actors and their support automation also vary:

- *The FOC computes an optimal trajectory calculated with full range of inputs: full meteorological model, detailed aircraft type and specification, airline business rules, weight, however it is missing some information on the operational constraints that ATC may apply to facilitate the 4D trajectory execution. The goal of this trajectory is to optimize all economic criteria to define the optimum route and associated cost index.*
- *The aircraft FMS computes an optimal trajectory based on the FOC one if it exists and complying with known ATC clearances with a limited range of inputs: a simplified meteorological model (FOC datalink updates are possible); detailed aircraft type; actual weight; actual wind and temperature cost index when relevant; similar to the FOC, the FMS has little information on downstream constraints.*
- *The ASP computes a trajectory within their domain of interest, with precise knowledge of the local conditions, but sometimes using different constraint sets depending on the purpose of the calculation. Purposes include flow management, complexity management, Short Term Conflict Alert (STCA) and Medium-Term Conflict Detection (MTCD).*

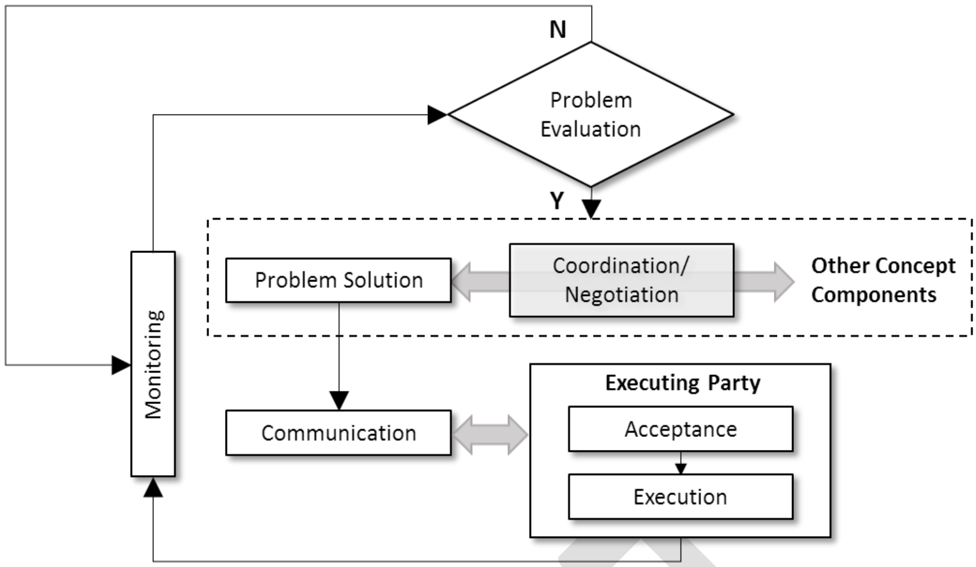


Figure 5 – GATMOC Component processes use and affect the trajectory

The process for use and revision of the Agreed Trajectory is illustrated in Figure 5. Convergence is facilitated through the application of trajectory management rules (see Section 2.3.2) considering, in part, decision timeliness. The process is common across the Concept Components and further described below:

1. Problem Evaluation – A trajectory is obtained (shared or predicted) for the purposes of evaluating the need for an action to mitigate a problem. Examples include evaluation of sector loading or conflict detection. If a need is identified, the process continues below.
2. Coordination / Negotiation – Iteratively with problem solution, each actor will share their decisions and consider decisions made by others. These may be constraints that can be met to solve a problem (coordination), or must be modified (negotiation).
3. Problem Solution – Alternative trajectory modifications are evaluated to identify an appropriate solution to an identified problem while coordinating/negotiating. Solutions must be feasible including the ability to communicate and execute.
4. Communication – Acceptable solutions are communicated to the appropriate party for execution. These solutions must be expressible in the form of a clearance whose acceptance and execution seeks to provide an Executed Trajectory matching the Agreed Trajectory within tolerances.
5. Acceptance – The solution is accepted by the executing party or parties. This may be the flight deck for a clearance, or the ground/local controller for an ATFM initiative.
6. Execution – The solution is executed by the executing party.
7. Monitoring – A monitoring function may be established to verify that the executing party is doing so within performance criteria.

2.3 CONSIDERATIONS FOR ACHIEVING TBO

Achieving the objectives of sharing, managing and using of the Agreed Trajectory as a common reference across concept components necessitates the consideration of several key aspects. These are described further in this Section and include:

- AU perspective
- Rules for Trajectory Management
- Management of uncertainty via:
    - Performance-based communications, navigation and surveillance
    - Robust trajectory solutions

2.3.1 INTEGRATING THE AIRSPACE USER PERSPECTIVE

While ATM's primary function is to enable the safe and expeditious handling of air traffic, another important objective is to do so while not adversely affecting the AU's optimized trajectories to the extent possible. There are a multitude of factors applied by AUs in determining the optimality of a flight's trajectory to the AU. Further criteria for optimization may vary not just between ASPs and AUs, but also between different AUs. For these reasons, involvement of the AU through the CDM process is essential to the success of TBO.

In the scenario where a flight traverses through multiple volumes of airspace and which involve multiple ASPs, the AU maintains an end-to-end flight perspective, even in a mixed-mode environment. Through the early consideration of ASP-provided constraints and flight limitations, the AU seeks to optimize their operations to the maximum extent possible within known limitations. This optimization is reflected in the Agreed Trajectory to the best extent possible. For those circumstances when the ASP must seek a revision to the Agreed Trajectory, the AU may also express flight limitations and operator constraints (e.g., not equipped for over-water flights) which should be considered by the ASP in the formulation of trajectory revisions. The AU still must verify and accept clearances even when operator constraints have been provided. Operator preferences may also be provided in advance to obtain AU-preferred trajectory solutions more quickly during negotiation or to influence tactical decisions when there is too little time to negotiate.

For those AUs with an FOC, the FOC is a key stakeholder with full awareness of the attributes of each flight and of the efficiency of their network, if applicable. The efficacy of the FOC and flight crew will evolve through increased automation support that enables them to be efficiently incorporated in the trajectory management loop. This improvement will take place in all domains of flight operations including pre-flight planning, surface, arrival and departures, and en-route. TBO, using CDM principles, defines how and to what extent to include AUs in the optimization process, balancing flexibility for prioritization and optimizing Airspace User Operations while simultaneously ensuring that sufficient predictability exists as needed to optimize the ATM network as a whole and ensuring that the flight safety is never compromised. SDM engages TBO to deliver performance of the ATM System aligned with expectations across all Key Performance Areas.

It is recognized that there exists and will continue to exist a diversity of operating and business models for different AUs. For example, some AUs may not wish to participate in exchange-based (negotiation) collaborative processes. However, these AUs must continue to cooperate with the ATM System. In these circumstances, while TBO seeks to be collaborative in the planning and re-planning of flights when circumstances warrant, decisions required by other concept components must therefore be made in accordance with established rules without "direct" collaboration of the AU, but may still be informed by submitted operator preferences and constraints.

2.3.2 RULES FOR TRAJECTORY MANAGEMENT

A coordination process, based on clear CDM decision criteria and supported by automation, is required to orchestrate the interaction between all stakeholders, ensuring stability of the ATM System. The rules of interaction between operational stakeholders, involved through the various GATMOC Components must be collaboratively developed. These rules must specify stakeholder's manners and techniques for managing or coordinating trajectory changes to ensure a single consistent version of the Agreed Trajectory emerges across participants.

The various ATM participants and components (AOM, DCB, AO, TS, CM and AUO) propose revisions to the Agreed Trajectory in accordance with individual objectives. An efficiently converging coordination process must be defined to ensure these proposals suitably address all objectives. This process may involve the unambiguous prioritization of objectives to reach a feasible trajectory solution. CDM processes and automation supporting the concept components need to ensure that trajectory constraints from the various processes result in an outcome balanced across Key Performance Areas.

Rules for trajectory management must address the interaction between participants and GATMOC Components to achieve an Agreed Trajectory. At a minimum, these require the following:

- Input, permissions, and allowable timing of relevant participants and concept components must be defined including rules on data ownership
- Criteria for updating, sharing and revising the Agreed Trajectory
- Information exchange patterns and timing constraints for coordination/negotiation
- A mechanism for ensuring a consistent trajectory emerges from coordination/negotiation and is observable to all required participants
- Identification of the arbitrating agent, or rules for prioritization, when trajectory proposals conflict across participants

The rules for trajectory management may vary throughout the planning and execution phases of a flight. For example, how participants may modify an Agreed Trajectory will differ prior to and subsequent to ATC involvement. Rules will also vary according to the scope of the change; local tactical changes may have different rules than changes affecting the flight several hours hence.

Rules for Trajectory Management, including requirements on provision of information, must be collaboratively developed with the goal of ATM Performance improvement balanced across key performance areas.

2.3.3 MANAGEMENT OF UNCERTAINTY

Through TBO, the level of trajectory accuracy and consistency will be substantially improved. This is brought about through:

- Improved machine-to-machine sharing of trajectory information requiring digital information exchange
- Access to the most accurate data available for trajectory prediction accuracy
- Maintaining consistency across the various operational actors and systems
- Use of a consistent Agreed Trajectory by all Concept Components for monitoring and controlling flights
- Where necessary, use of performance-based Communication, Navigation and Surveillance (CNS) capabilities for delivering trajectory control commensurate with trajectory accuracy requirements
- Improvements in meteorological forecasting, providing gains in both trajectory prediction and capacity-impacting factors

However, the ATM network will never become fully deterministic; some level of inherent uncertainty will remain, for example due to the following reasons:

- *Meteorological forecasts, while improved, will continue to have uncertainty in parameters affecting trajectory prediction accuracy (e.g., wind and temperature). Errors in the timing and severity of meteorological events impacting capacity (e.g., ceilings and visibility, convective activity) will continue to add disturbances which impact trajectories.*
- *The turn-around process involves many actors, systems and planning functions which work towards a shared common off-block time. Irregularities with security, passengers, fuelling, aircraft technical maintenance, baggage handling, etc. will continue to disturb operations contributing to off-block time uncertainty.*

- *Not all decisions made by the ATM System will be made prior to departure; some will be deferred until further or better information is available. AUs may require flexibility to meet their operational objectives. Any impact these have on the Agreed Trajectory will require a trajectory revision.*
- *The ATM System exhibits a high degree of interaction between individual flights (e.g., when density is high). In these cases, changes to one flight require accommodating changes to other flights magnifying the effect of uncertainty. Management of uncertainty can mitigate these effects.*
- *While TBO seeks to share and manage flights' trajectories, bandwidth and latency will result in some trajectory discrepancies between coordinating elements. Update mechanisms may be tailored to reduce these discrepancies.*

The ability to manage trajectory uncertainty is essential for TBO to maintain all flight trajectories as stable as possible and deliver accuracy where performance needs dictate. The management of uncertainty is facilitated through the use of Performance-Based CNS and ATM capabilities in concert with the development of trajectory solutions that are robust to disturbances. When trajectories need to be updated, TBO provides a shared information environment that facilitates CDM process.

2.3.3.1 PERFORMANCE BASED CNS

The ICAO Performance-Based Navigation (PBN) Manual (ICAO Doc. 9613) and Performance-Based Communication and Surveillance (PBCS) Manual (ICAO Doc. 9869) define Performance-based Communication, Navigation and Surveillance as follows:

> **Performance-based communication (PBC)**. Communication based on performance specifications applied to the provision of air traffic services.
>
> > *Note. — An RCP specification includes communication performance requirements that are allocated to system components in terms of communication transaction time, continuity, availability, integrity, safety and functionality needed for the proposed operation in the context of a particular airspace concept.*
>
> **Performance-based navigation (PBN)**. Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.
>
> > *Note. — Performance requirements are expressed in navigation specifications (RNAV specification, RNP specification) in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.*
>
> **Performance-based surveillance (PBS)**. Surveillance based on performance applied to the provision of air traffic services.
>
> > *Note. — An RSP specification includes surveillance performance requirements that are allocated to system components in terms of surveillance data delivery time, continuity, availability, integrity, accuracy of the surveillance data, safety and functionality needed for the proposed operation in the context of a particular airspace concept.*

TBO is not linked to a particular performance-based CNS specification, but rather supports operations with any performance-based CNS specification, which provides standards useful for managing trajectory uncertainty. With better knowledge of anticipated CNS performance, trajectory uncertainty can better be managed.

How TBO may apply performance-based CNS to manage uncertainty can be understood through the activities described in Figure 5, common across many Concept Components. The relevant application of performance-based CNS to some of these activities is described below.

1. Trajectory prediction is used for both problem evaluation and solution. The accuracy of a prediction affects the quality of the evaluation and solution. Prediction accuracy is, in part, managed through performance-based CNS through:
    a. Navigation performance (RNP) ensuring that the aircraft operates within known containment limits
    b. Requirements on surveillance (RSP) accuracy and timeliness, in concert with a trajectory update process
    c. Communication performance (RCP), together with judicious selection of clearances, ensures timely receipt of clearances to execute the Agreed Trajectory
2. Coordination requires a data standard allowing participants in the coordination to accurately reflect each other's considerations. RCP principles may be applied to manage communication delays in coordination which affect performance for decisions requiring timeliness.
3. Latency in the communication of instructions may delay the execution, resulting in the executed trajectory not matching the planned solution. RCP is applied to clearance delivery to manage these effects.
4. Execution of a specified instruction depends on the required precision of the instruction that was provided. For example, instructions can be specified with associated performance attributes (e.g., clearance to a PBN procedure) as necessary.
5. The ability of the aircraft systems to integrate functionally with ATM systems (e.g. the aircraft's ability to ingest trajectory clearances directly and to respond to data-linked queries) may significantly affect the overall system efficiency, depending on the airspace concept being applied.
6. When necessary, monitoring is impacted by the performance of the underlying surveillance function whether this is ground-to-air, or air-to-air for interval management. The ability to accurately monitor a solution may dictate the need for margins when selecting a problem solution

2.3.3.2 ROBUST TRAJECTORY SOLUTIONS

TBO needs to be robust to changing circumstances and resilient to adverse conditions. A robust TBO requires the pro-active management of perturbations and uncertainty through a variety of mechanisms such as:

- Decision-making at appropriate time frames commensurate with the accuracy of information available
- Application of bounds or margin to decisions thereby minimizing the impact of future perturbations and uncertainty
- Control of individual flights to trajectory constraints within performance bounds
- Dynamic re-planning and coordination of trajectories for optimal ATM System performance

While the first three mechanisms focus on ensuring a stable, robust trajectory for a single flight, the dynamic re-planning addresses robustness and resilience for system-level performance.

Increasing performance of the overall system is therefore not simply a matter of freezing a plan and ensuring that all aircraft follow that plan. It requires agreed trajectories to be updated and revised during all phases, based on latest data, observations and predictions, in order to find the optimum balance between sometimes conflicting demands from different stakeholder perspectives: the flight itself, the AUs, the ATM network, the airports and Air Traffic Services.

From an AU perspective, some level of flexibility is required in trajectory management for optimization in an environment that contains uncertainty. This flexibility is important to all classes of AUs including airlines, business aviation, general aviation, military operations, rotorcraft, and remotely piloted aircraft. However, exercising that flexibility and flight re-optimization must be cost-effective. From an ATM perspective, a certain level of certainty of flight behaviour is also needed to ensure the required performance of the GATMOC

Components in support of these flights. There is, therefore, a need for a balance between the actual need of the ATM system and the needs of individual AUs.

3 THE CONCEPT IN PRACTICE

The Global ATM Operational Concept (ICAO Doc. 9854) "defines seven interdependent concept components that will be integrated to form the future ATM System." This integration is accomplished through Service Delivery Management (SDM) which will "manage the balance and consolidation of the decisions of the various other processes / services, as well as the time horizon at which, and the conditions under which, these decisions are made." Trajectory-Based Operations is the means through which SDM integrates these components from tactical planning through execution.

Understanding the concept components' relationship to the Agreed Trajectory and the use of this trajectory as a common plan for integrating the components is key to understanding TBO in practice. This Section describes the concept in practice by describing:

- An overview of trajectory management including the use of concept components and the relationship of each concept component to the trajectory
- Planning through flight execution highlighting the integration of concept components through the trajectory
- Interactions across multiple ASPs
- Including robustness in practice

While there may be circumstances where performance needs will dictate a full-equipage TBO environment, the TBO Concept must support the reality of a mixed-mode, mixed-equipage environment. This is essential for transition and for those cases for which ATM Performance needs do not warrant investment. This Section describes TBO without detailing additional considerations for a mixed environment, these considerations are described in the next Section.

3.1 OVERVIEW OF TRAJECTORY MANAGEMENT

The management of ATM operations in a changing environment consists of two interacting management processes: one managing ATM configurations, the other managing individual trajectories (Figure 6). Each of these management processes monitors the various GATMOC Components against their objectives, detecting any issues requiring action, and generating solutions through collaboration between components. These solutions consist of either changing ATM configuration or adding or changing trajectory constraints. These processes interact as changes to ATM configuration may constrain trajectories and changes to trajectories will impact the flows which affect the ATM configuration. Interactions also occur between ASPs; for example, changing a local ATM configuration may impact GATMOC Components in other regions further upstream or downstream through changes to trajectories.

Trajectory Management is illustrated on the right of Figure 6 and involves the use, modification, sharing and coordination of trajectories to achieve the objectives of the concept components across multiple ASPs. Following the process described in Section 2.2.3, once a monitoring function has established the need for a revision, the concept components use and modify trajectories through:

- *Proposing* a change to trajectories or trajectory constraints consistent with generic constraints
- *Predicting* trajectories meeting the collection of known trajectory constraints
- *Evaluating* the impact on component objectives and *coordinating* the outcome
- *Agreeing* on the resolution including trajectories and trajectory constraints

Once agreed to, trajectories are executed through the provision of clearances consistent with the agreement. For each flight, the Executed and Agreed trajectories are monitored in two ways:

- The executed trajectory is monitored, triggering a trajectory update to ensure accuracy
- The updated Agreed trajectory is monitored by the GATMOC Components to detect when a trajectory revision is needed to meet the component objectives

The Trajectory Management process must be supported by established *Rules for Trajectory Management* (see 2.3.2) allowing the convergence of trajectory solutions across components through automation.

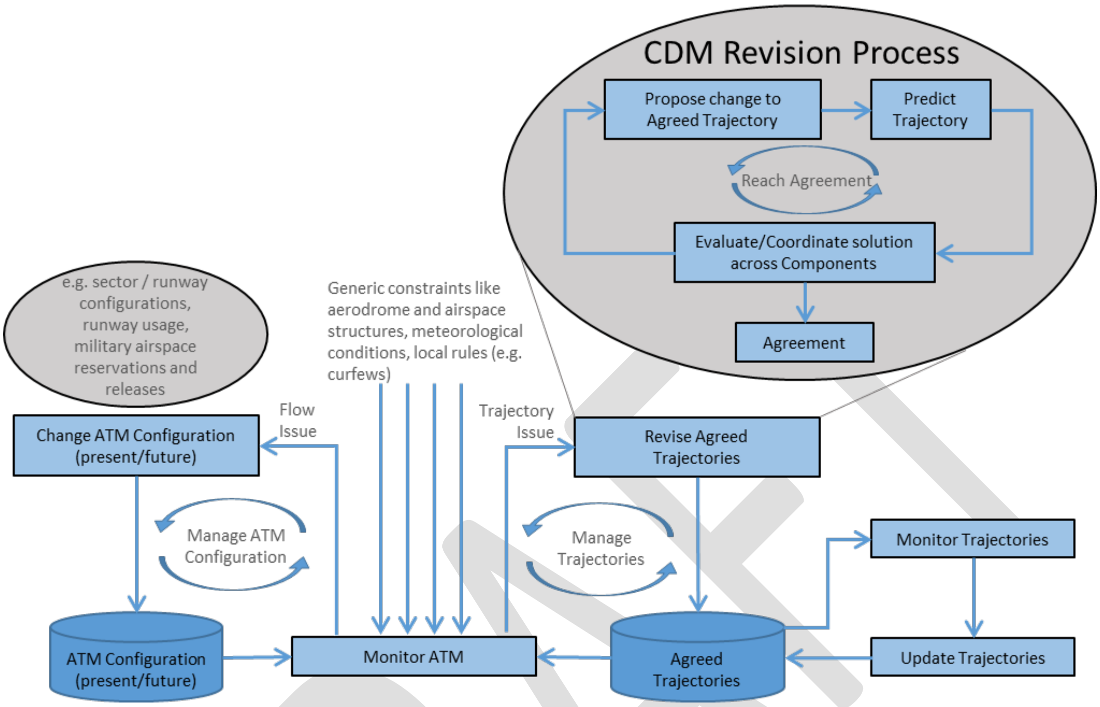


Figure 6 – Management of ATM Operations in a TBO environment

As implied by Figure 6, the outcome of coordinated solutions across concept components is affected by the accuracy of the predicted trajectories used by each GATMOC Component. Progressive deployments (even partial) of both higher accuracy trajectory predictions (e.g., from aircraft or FOC), and the enhanced tools within the GATMOC Components, will lead, in the most demanding airspaces, to the delivery of significant performance enhancements through TBO.

The management of ATM Configuration, as shown on the left side of Figure 6, makes flow-based decisions which impact trajectories through constraints. These flow-based decisions can occur without flight-specific trajectories; however, as trajectories become known, they can be aggregated to form the very flows used in the management of ATM Configurations.

Figure 6 describes the management of ATM Operations in a TBO environment. This description is not meant to preclude operations within a volume of airspace, distinct from TBO, as described in ICAO Doc, 9965, Section 3.12.

Chapter 5 provides some views on the ground and airborne related enablers.

3.1.1 CONCEPT COMPONENTS AND THE TRAJECTORY

The seven concept components all must interact in the management of ATM Operations as illustrated in Figure 5. Under TBO, components use, modify and coordinate through trajectories. The use and modification of trajectories is summarized in Table 1 and described in more detail in Appendix B – *TBO and the Concept*

Components. While concept components must coordinate to reach an Agreed Trajectory, SDM establishes and applies rules for Trajectory Management (see Section 2.3.2) which govern the prioritization between these components.

Table 1 – Concept Component Uses of and Modifications to Trajectories

Component	Use of Trajectory	Modification of Trajectory
AOM	• Individual planned trajectories aggregated into flows used to plan and select ATM Configuration	• AOM provides ATM Configuration • ATM Configuration constrains trajectories
AO	• Planned trajectories aggregated into arrival, departure and taxi flows as input to runway configuration plan • Trajectories with time constraints impact surface planning times and taxi path choices available. Time constrained trajectories must be coordinated with AO. • Arrival (wheels-on) time estimates from trajectories are input to surface planning	• AO impacts ATM Configuration through runway configuration • ATM Configuration may constrain trajectories with departure and arrival paths • AO informs DCB and TS of capacity / timing needs • Surface events update trajectory timing • Runway or large surface event time changes trigger trajectory revision (coordinated)
DCB	• When known, individual trajectories aggregated into flows for strategic evaluation of expected demand / capacity balance • Trajectories used for demand evaluation, uncertainty is considered	• Identifies strategic problems • DCB proposes modifications to path or constraints to reduce demand when demand exceeds capacity • Trajectory revisions coordinated with AOM, AO and AUO
TS	• Evaluates trajectory timing for short-term capacity problems and conflict likelihood • Trajectory uncertainty is considered regarding when to control to meet a time	• Applies time constraints with bounds (tighter than for DCB) to synchronise flights within flows • Controls the flight to meet controlled times where control is required to meet constraints within bounds
CM – Separation Provision	• Updated trajectory reflecting clearance is used for hazard detection • Obtains constraints provided by other components • Other concept components do not create conflicts and seek to reduce likelihood of conflicts (Strategic Conflict Management)	• Seeks solution respecting constraints imposed by other components. If not feasible, CM for separation provision takes precedence over other components and might trigger a revision • Proposes solutions, preferably closed, to be issued as clearances. These are hazard-free over some conflict horizon. • Clearances update the trajectory, which may result in a revision.
AUO	• Operates the flight in accordance with clearances, consistent with Agreed Trajectory • Uses known generic constraints to be incorporated into proposals for revisions	• Proposes user-preferred trajectory consistent with known ATM Configuration • Trajectory constraints incorporated into plan when known • Provides preferences for component decisions • Shares best trajectory prediction consistent with shared inputs

Component	Use of Trajectory	Modification of Trajectory
SDM	• Establishes rules for Trajectory Management including use of shared data (e.g., constraints by components)	• Establishes rules for Trajectory Management arbitrating trajectory modifications • Considers ATM System performance in prioritizing and deferring decisions

3.2 PRE-DEPARTURE PLANNING

Prior to operating a flight, an AU must plan the operation of the flight to ensure safety, comply with rules pertaining to eligibility, meet flight or mission objectives, and maintain the efficiency of the flight and ATM system. This planning is accomplished through a collaborative process across multiple concept components seeking to meet their own objectives. The collaboration is accomplished through timely information sharing across components in conjunction with established rules for Trajectory Management. Ultimately, the role of pre-departure planning is to reach agreement on an Agreed Trajectory representing the current agreed-to trajectory plan for the flight. In so doing, participating AUs are better able to manage and optimize the performance of flights under their operational control.

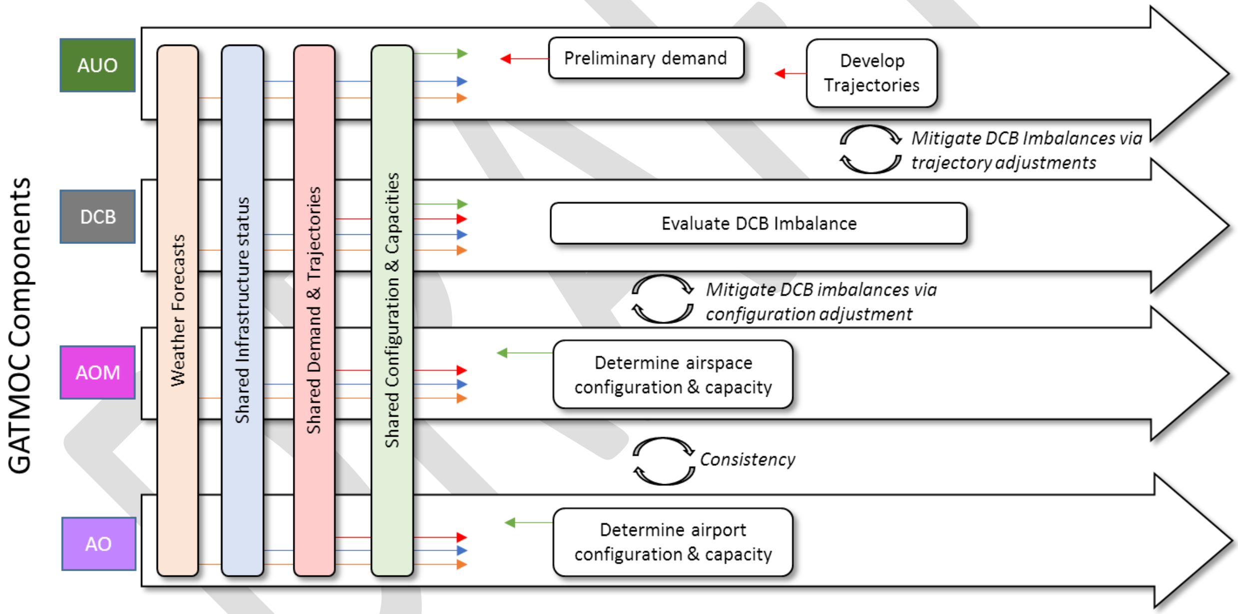


Figure 7 – Collaboration across GATMOC Components prior to departure

Pre-departure agreement on the Agreed Trajectory engages the concept components of Airspace User Operations (AUO), Airspace Organization and Management (AOM), Aerodrome Operations (AO) and Demand Capacity Balancing (DCB). These concept components collaborate as illustrated in Figure 7. Negotiation focuses on the sharing of information for better planning configuration decisions and mitigating demand/capacity imbalances through trajectory adjustments. The following methods are applied:

- AOM considers the forecast circumstances including weather, resource availability, system outages, and demand to develop plans best meeting the anticipated circumstances. These plans may contain required performance criteria for the utilization of constrained resources. Plans developed by AOM are shared, allowing other concept components to consider them. The process is collaborative; while demand is considered by AOM, it may be adjusted through DCB, AO and AUO collaboration.

- For pre-departure planning, AO provides estimates of airport capacity together with airport configuration information coordinated with AOM. Airport configuration choice may be affected by anticipated flows. Anticipated surface constraints, provided to and considered by AUO, may impact trajectory timing.
- DCB also considers the same forecast circumstances as for AOM, but manages forecast demand-capacity imbalances in more real time in collaboration with AUO. These may be accomplished:
    - through modification of capacity allocation in collaboration with AOM which provides and modifies the ATM System Configuration (e.g., sectors, procedures),
    - through the collaboratively-agreed modification of flow by agreeing to modify trajectories, or
    - through the agreement on trajectory constraints for individual Agreed Trajectories
- AUO considers the shared forecast information together with shared AOM plans, performance criteria and flow regulations in developing flight-specific trajectory proposals meeting objectives. Through collaboration across components, an Agreed Trajectory is obtained meeting the objectives of AUO, DCB, AO and AOM under anticipated circumstances.

For flights operating across multiple ASPs (see Section 3.4), collaboration extends across the concept components and the ASPs. During planning, the Agreed Trajectory represents a collaboratively Agreed Trajectory meeting the objectives of the collaborating participants, given the information as known at the time. The Agreed Trajectory is specified to the level of detail required at the time it is agreed-to. Practically, this implies that such details as taxi-path, arrival sequence and arrival runways might not be specified in a pre-departure planning phase. In addition, revisions to the Agreed Trajectory will be required to incorporate changing situations, and as a flight progresses, to incorporate processes within their applicable time horizons.

It is recognized that planning is based on forecast information that is not certain. For this reason, as information is updated to reflect improved forecast closer to observation (e.g., weather begins to develop, gate delays are expected), the Agreed Trajectory may need to be revised. Revision follows the same collaborative process across the concept components, with the realization that flexibility may be reduced as look-ahead time is reduced.

As the time approaches the planned off-block time, Traffic Synchronisation (TS) and Aerodrome Operations (AO) require further consideration, resulting in updates and potential revisions to the Agreed Trajectory. These updates should reflect a further refinement of the Agreed Trajectory within bounds established by the AOM-DCB-AUO collaborative process (these bounds may be pre-agreed and need not be established dynamically). There will also be circumstances under which the Agreed Trajectory must be revised when refinement within bounds is not sufficient to meet AO or TS objectives. In these cases, the Agreed Trajectory must be revised, through collaboration across the concept components of AO, TS, AUO, and DCB. AOM would provide ATM Configuration information.

3.3 EXECUTION

Once an Agreed Trajectory has been developed for a flight, execution seeks to deliver an Executed Trajectory matching the Agreed Trajectory and meeting its constraints (Figure 8). This is accomplished through the provision of clearances by ATC which are known to deliver the requisite trajectory. In turn, the flight deck executes the clearances which meet the Agreed Trajectory. As not all details can be pre-planned in the Agreed Trajectory, execution of the flight may also require additional clearances for separation provision, traffic synchronisation and tactical aerodrome operations. These additional perturbations must be considered when developing the Agreed Trajectory, with margin built-in for robustness.

This Section describes these aspects of flight execution as follows:

- ATC Clearances to deliver the Agreed Trajectory

- Open versus Closed Clearances
- Trajectory Constraints
- Trajectory Tolerances

- Traffic Synchronisation and the Agreed Trajectory
- Conflict Management and the Agreed Trajectory
- Aerodrome Operations and the Agreed Trajectory
- Constructing a Robust Agreed Trajectory
- In-flight Re-planning and Trajectory Revisions

This section focuses on interactions with a single ASP, multi-ASP considerations are described in Section 3.4.

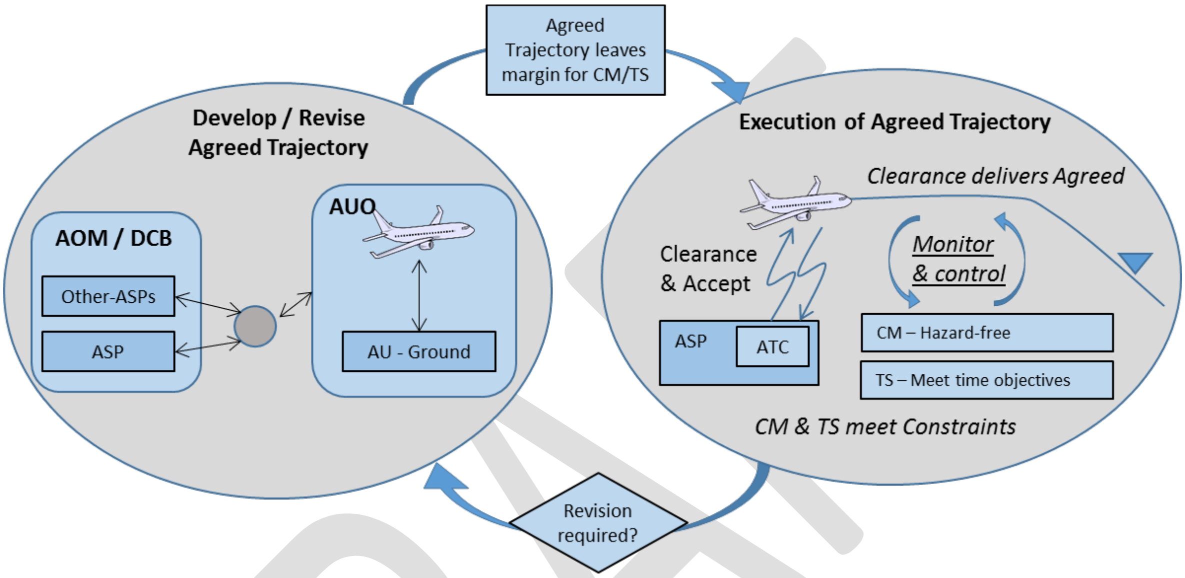


Figure 8- Development and execution of the Agreed Trajectory

3.3.1 ATC CLEARANCES AND AGREED TRAJECTORY

In TBO, clearances will continue to provide the authorization for an aircraft to proceed under conditions specified by an air traffic control unit. It is expected that TBO will make it possible for the ATM system to use a wider set of clearances than we have today (e.g. different types of time constraints, 2D routes to be followed with vertical and/or speed constraints, etc.) This wider set of clearances will allow the more accurate delivery of an Agreed Trajectory when circumstances warrant.

TBO allows for a "gate-to-gate" Agreed Trajectory to the level of fidelity required for ATM performance needs. It is the goal of TBO to provide clearances that deliver the Agreed Trajectory. Much as today a flight is provided an end-to-end route clearance prior to take-off, the Agreed Trajectory extends this clearance to other dimensions beyond the route including constraints where necessary. In this manner, when a flight has been cleared to the Agreed Trajectory, <u>without further clearances both the route and profile will be executed by the flight</u> (though the need for positive clearances associated with runway operations remains). Even though a flight may be cleared to an Agreed Trajectory, this does not indicate that the flight will be conflict-free end-to-end. Intervention will continue to be required to provide separation.

While the goal of TBO is to provide clearances that deliver the Agreed Trajectory, there are many circumstances requiring deviation from the Agreed Trajectory with some examples described below.

- An aircraft may need to deviate due to convective weather. In this case, the flight manoeuvres around the weather operating with an open trajectory for some period. At some point downstream, when predictable behaviour can be resumed, collaboration on a revision may be initiated. If deviations result in downstream differences in the Agreed Trajectory within bounds, a revision may not be required.
- An aircraft is operating on a clearance to fly an Agreed Trajectory with a known top-of-descent (TOD). As the flight approaches the TOD, crossing traffic requires that an earlier descent be cleared. The flight may be provided an updated closed clearance (see 3.3.1.1) with a constraint on descent reflected in the Agreed Trajectory. If a tactical clearance is required, the open clearance (see 3.3.1.1) would not be reflected in the Agreed Trajectory until the flight resumes operating to a closed clearance and the Agreed Trajectory is coordinated across relevant parties.
- The Agreed Trajectory developed pre-departure may not include all details including runway and approach procedures. As the flight approaches the destination, coordination between Traffic Synchronisation (e.g., arrival management), Aerodrome Operations and Airspace User Operations provides a revision incorporating more precise specification of the Agreed Trajectory.
- A mixed-mode environment will likely continue for a significant period. Flights operating through non-TBO environments may encounter perturbations impacting the trajectory in a downstream TBO environment. In this case, the Agreed Trajectory may not be coordinated within the non-TBO environment; however, it may continue to be coordinated within the downstream TBO environment.

The above circumstances lead to a combination of open/closed clearances and subsequent trajectory revisions. While the Agreed Trajectory may need to be revised due to a significant manoeuvre for separation provision, coordination on the revision may occur subsequent to a CM action due to urgency of action. It is therefore desirable, for stability of the Agreed Trajectory, that conflict management operate with knowledge of downstream constraints, and exercise its function while meeting those constraints to the maximum extent possible. Conversely, the Agreed Trajectory should be developed with sufficient margin to allow CM to have feasible solutions available to provide separation while meeting downstream constraints (see Figure 8).

3.3.1.1 OPEN VERSUS CLOSED CLEARANCES

A closed clearance is an ATC clearance issued to authorise an aircraft to follow a 4D Trajectory. The trajectory is thus deterministic and can be anticipated. These include end-to-end route clearances, “climb via” procedures in the altitude dimension, as well as those ATC clearances resulting in a closed trajectory revision. For example, a direct from one point to a downstream point allows a continuous trajectory to be constructed, and is therefore a closed clearance.

Clearances that are not closed are said to be open.

An open clearance authorizes or instructs an aircraft to deviate from a 4DT without additional authorization or instruction allowing a new 4DT to be defined. Open clearances include (but are not limited to) heading without a turn-back, track, route or altitude related instructions that need to be closed by a subsequent ATC instruction to allow the flight to complete. Note that information about future clearances (e.g., EXPECT …) cannot be considered a way to close a clearance. Additionally, when a flight is no longer following the aircraft intent, an aircraft-derived trajectory may no longer be available.

While closed clearances are preferred for trajectory-based operations, it is recognized that open clearances may still be required under some circumstances. The following examples illustrate this point:

- A heading instruction may be unsafe to close until an external event happens (e.g. heading needs to be maintained until another aircraft vacates a certain level)

- A pilot cleared to deviate due to weather will probably not be issued a "resume route" clearance until he reports clear of weather
- An aircraft flying a holding pattern can be given an expected time to leave the hold, but will usually not actually be cleared to do so in advance

In these cases, the coordination of a trajectory intention should be achieved as soon as practicable. Even when a flight is operating for some period open-loop, an Agreed Trajectory may be negotiated downstream with tolerances on time to allow the flight to resume operating on the Agreed Trajectory downstream of the open clearance. This Agreed Trajectory allows planning to continue with knowledge of the open clearance effect.

3.3.1.2 TRAJECTORY CONSTRAINTS

Concept components collaborate on the development of the Agreed Trajectory which is expected to be compliant with the ATM Configuration. Components may also incorporate trajectory constraints to meet their objectives. For example, DCB may constrain a flight's timing for airspace capacity limitations and an AU may impose constraints to meet operational objectives. In general, the use of trajectory constraints should be minimised to the extent possible commensurate with the GATMOC Component it serves, to avoid limiting airborne operations more than is strictly required.

These trajectory constraints may take various forms. These may constrain the path laterally, vertically, or temporally using time and/or speed.

- The route provides one form of lateral constraint on an Agreed Trajectory. These are defined around a specified route through the use of PBN criteria. The terminal procedures (SID, STAR and APPs) are defined through the use of leg types (i.e., path and terminator concepts) and transitions that may provide increased precision depending on the choice. Although the path and terminator concept does not apply to en-route airways, the increased level of accuracy is assured through the PBN (RNAV or RNP) specification. In a TBO environment, the operational need for precision will dictate the application of performance criteria.
- A second form of lateral constraint involves the addition of lateral bounds around a nominal route. For example, a flight may be permitted to deviate up to 50 NM left of route for weather. This type of constraint is not consistent with a high accuracy environment and is consistent with open clearances.
- Vertical constraints may be specified on the Agreed Trajectory in the form of altitude constraints to be met or initiated at a specified location or time. Altitude constraints may provide a range to be met (e.g., "AT OR BELOW", "BETWEEN") or an absolute value to be met (e.g., "AT" constraint). How the constraint is specified determines the precision of the resulting Executed Trajectory meeting the constraint. For example, a constraint to initiate a climb to FL 370 at a fix is not precise on where FL 370 must be reached.
- Similar to vertical constraints, speed constraints on the Agreed Trajectory describe a speed to be met or sought at a specified location or time. These may also constrain an absolute value or a range, and the method of specifying the constraint will also dictate the precision of the resulting Executed Trajectory. When speed is constrained, typically as an airspeed, the resulting trajectory accuracy is also influenced by the impact of the winds and wind uncertainty.
- Time constraints may be imposed at a specific point. These may specify an absolute value or a range.

Trajectory constraints typically must be achieved within a required accuracy through the use of feedback control. This may be through a ground-based and/or an aircraft-based closed-loop control process. These constraints are to be met within bounds which are known either explicitly or implicitly.

In the time domain, time constraints can be controlled, as defined above, requiring closed-loop control of the trajectory to meet the constraint, or be defined as a target time (see also 1.6.1). This target time is used to construct a “fire-and-forget” solution. This solution is defined as an Agreed Trajectory meeting the target. As the flight operates, the target is not subsequently monitored and controlled through additional closed-loop control actions. An example is the control of take-off time to meet a target time over a fix.

For controlled trajectory constraints, when these specify a range or an absolute value, performance criteria for meeting the constraint during execution are necessary. These performance criteria establish the degree to which a flight meets the specified constraints. For example, even an "AT" constraint can be met within an acceptable level of execution precision. Execution techniques coupled with CNS performance levels will affect adherence to the Agreed Trajectory constraints. For example, time trajectory constraints may be implemented through active management by ATC through speed instructions or CTA/CTO, but could also be managed by the flight crew through an FMS RTA. Feasibility requires consistency between criteria for meeting a constraint, execution techniques and CNS performance levels.

3.3.1.3 TRAJECTORY TOLERANCES

In addition to constraints, tolerances across all dimensions can be applied to the Agreed Trajectory for a variety of purposes, including:

- Trajectory prediction update – Whenever surveillance data or valid trajectory inputs (e.g. AU-provided parameters, MET) are modified resulting in the flight no longer being within specified tolerance of a prior prediction, the prediction must be updated. Note that these tolerances may be used internal to a system, an ASP or a concept component. For example, separation management in highly tactical airspace may require highly accurate prediction and correspondingly tight tolerances on trajectory prediction update. However, this does not imply that this local update would be shared with all parties.
- Trajectory notification – A consumer of the Agreed Trajectory may only be interested in receiving or processing updates when the perturbation to the Agreed Trajectory exceeds specified tolerances. A trajectory notification may result in a re-evaluation by a concept component which in turn may necessitate a trajectory revision.
- Trajectory revision – When an Agreed Trajectory is modified beyond the bounds of a constraint imposed by a concept component, a revision is required involving coordination across concept components.
- Performance limits – As a trajectory is being executed in accordance with a clearance matching an Agreed Trajectory, there may be performance limits imposed on the execution of the flight. These performance limits inform the degree of precision with which an aircraft must control to meet the lateral path or a specified trajectory constraint. Aircraft capabilities, ground infrastructure and environmental circumstances must all be considered in imposing these limits.

Tolerances may be defined explicitly (specified for the individual Agreed Trajectory) or implicitly (i.e., known by all parties). For example, an implicit tolerance may be specified for certain airspace. In all cases, the tolerances are known to the participants implementing the concept components.

3.3.2 TRAFFIC SYNCHRONISATION AND THE AGREED TRAJECTORY

Traffic Synchronisation focuses on the adjustment of individual trajectories in the time dimension to allow for a “safe, orderly and efficient flow of air traffic”. TS is involved during the planning and re-planning of the Agreed Trajectory to ensure that TS timing constraints are included in that trajectory. When subject to a controlled time constraint, during execution the flight is controlled to meet that controlled time within performance criteria. For example, a time constraint may be required to be met within +/- 30 seconds.

TBO does not restrict the methods through which control is to be executed. A clearance may be provided for the flight deck to use onboard Required Time of Arrival (RTA) capabilities, or ATC may monitor the flight to provide speed instructions as required to meet the time. Regardless of the method, performance criteria on the time constraint must be consistent with the achievable execution accuracy of the method applied.

DCB and TS operate collaboratively to deliver trajectories that are synchronised to most efficiently meet capacity constraints. One of the important decisions of this interaction is to determine how much control should be applied when, given anticipated uncertainty in capacity and demand estimation. This is best illustrated through an example.

> During pre-departure planning, AUO proposes a trajectory with an estimated landing time. DCB determines that capacity constraints are likely to occur on arrival. If capacity, demand and the trajectory were known with certainty, DCB could allocate a departure delay on the take-off time to mitigate arrival capacity constraints. However, with uncertainty, a delay taken at take-off may turn out to not have been required, resulting in excess delays. In this uncertain case, DCB should defer some of the delay absorption, if required, to a later time when information is more certain. This can be accomplished by agreeing on a controlled take-off time to meet a target time of arrival (landing) allowing for some delay to be taken later. This plan is reflected in the Agreed Trajectory.
>
> Once the airborne flight approaches the arrival airport, the demand/capacity picture becomes more certain and the flight has been subject to unplanned disturbances. The Agreed Trajectory has been updated to reflect the disturbances, and revised to account for modifications to the demand/capacity picture. At some point, the Agreed Trajectory is revised to include a controlled time to synchronise the arrivals and TS controls to this time. When this point occurs should be determined based upon a variety of factors such as the balance between more efficient early control (e.g., small speed manoeuvres versus vectors), and unnecessary early control due to uncertainty (e.g., slow down, then speed up). Other factors include ensuring acceptable workload, availability of airspace for path-stretching if necessary and interactions with other flights.

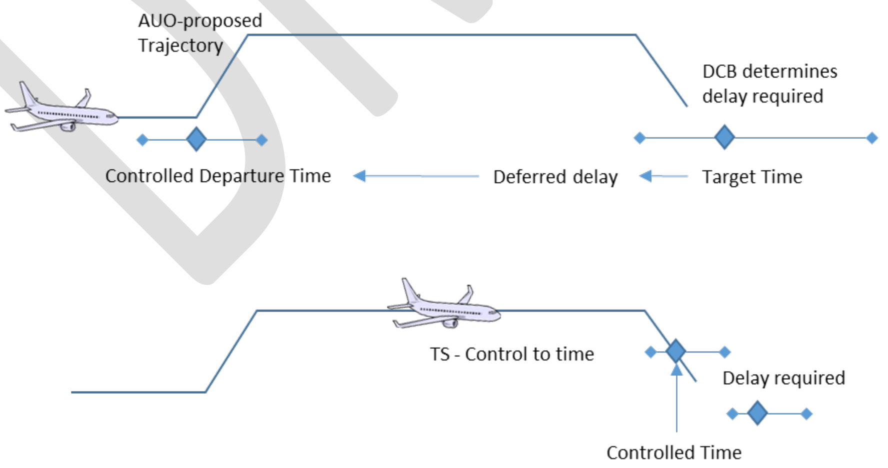


Figure 9 – With uncertainty, DCB defers delay to be absorbed by TS

TS may also be required on departure, for example timing a departure to merge into an overhead stream. In this case, an Agreed Trajectory may have been developed with a controlled take-off time and associated performance window for DCB purposes. TS and AO collaborate to develop a take-off time within the DCB performance criteria meeting the goals of merging into the stream. Using such nested constraints (Figure 10), TS and AO can coordinate without having to coordinate with DCB because its timing objectives are met. Aerodrome operations executes a surface plan to deliver the take-off time within the TS performance criteria.

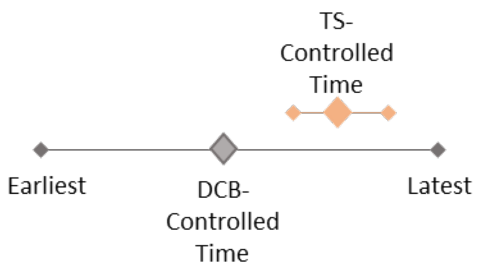


Figure 10 – Nested DCB and TS Controlled Time Constraints

Once TS is controlling to a time constraint, trajectory revisions impacting the Agreed Trajectory prior to the controlled time must be coordinated with TS. This includes the participant setting the time constraint and, if different, the one controlling to the time. If the controlled time is being altered, many interacting flights may be affected.

3.3.3 CONFLICT MANAGEMENT AND THE AGREED TRAJECTORY

Conflict Management under TBO will continue to be provided through three layers: strategic conflict management, separation provision and collision avoidance. Strategic conflict management consists of reducing the likelihood of conflicts through proper airspace organization (AOM), traffic demand management (DCB) and synchronisation of flows (TS). At the tactical end, collision avoidance remains an independent safety net after separation provision has been compromised.

Separation provision involves the separation of a flight's trajectory from hazards and is conducted during flight execution for a limited look-ahead time along the trajectory. This look-ahead time is described as the conflict horizon. The conflict horizon is dependent upon many factors including the trajectory prediction uncertainty, traffic density, or separation techniques being applied. TBO does not specify the separator, but does integrate separation provision with the other concept components in managing the Agreed Trajectory. Under TBO, where the provision of ATC services is the norm, ATC will normally be the separator. Accomplishing this requires the following:

- Separation provision seeks to respect constraints in the Agreed Trajectory
- Separation provision provides closed clearances where possible
- The Agreed Trajectory is developed to be robust to disturbances from separation provision
- Agreed Trajectory revisions must be coordinated with the separator for changes within their conflict horizon and with ATC within their area of responsibility

As a flight executes, the separator determines whether a flight will encounter hazards within the conflict horizon, requiring additional separation. This is accomplished using an updated trajectory prediction. If a conflict is detected, a resolution is considered to obtain the minimum separation required. This resolution consists of a manoeuvre or constraint that results in a closed trajectory which continues to meet known constraints in the Agreed Trajectory (see Figure 11).

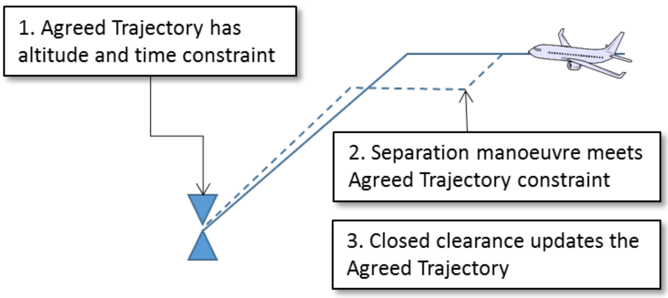


Figure 11 – Separation Provision considers the Agreed Trajectory

Prior to any separation provision action, the Agreed Trajectory must have been developed to be robust to separation provision. Practically, this means that the trajectory constraints in the Agreed Trajectory must not infringe separation, and that there is confidence that actions required for separation provision can be undertaken (See Section 3.3.5).

While steps can be taken to minimize the need for coordination of the Agreed Trajectory due to separation provision, there will be circumstances when trajectory coordination is required. For example, complex conflicts may not be solvable without violating downstream constraints, or an immediate open-clearance may be required to solve a conflict. The priority will be on separation provision, allowing safe separation while subsequently revising and coordinating the Agreed Trajectory to meet objectives of the other concept components.

As described previously, the conflict horizon provides the limit of detection for separation provision. In addition to the conflict horizon, ATC has an area-of-responsibility for the flight that may extend beyond the conflict horizon. Modification of the Agreed Trajectory by other concept components within the conflict horizon or area-of-responsibility requires coordination with the separator.

Agreed Trajectory modifications beyond the conflict horizon or area-of-responsibility may be made without coordination with the separator or ATC if the modifications do not impact the Agreed Trajectory within the limits (Figure 12). Care must be taken to understand the modification being requested to properly evaluate whether the Agreed Trajectory is impacted within the conflict horizon. For example, the imposition of a required time of arrival 30 minutes hence will likely impact the speed selection now. In this case, even though the constraint is beyond the conflict horizon, the Agreed Trajectory has been modified within the conflict horizon.

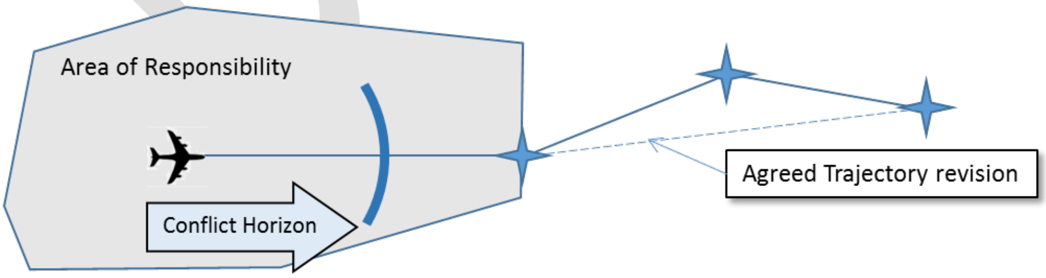


Figure 12 – Agreed Trajectory revision outside of conflict horizon or ATC area-of-responsibility

3.3.4 AERODROME OPERATIONS AND THE AGREED TRAJECTORY

Prior to execution of surface movements on departure, aerodrome operations have been involved in the coordination of the Agreed Trajectory. This Agreed Trajectory includes a planned departure time (e.g., wheels off) and runway selection. The planned take-off time may be controlled to meet known constraints.

During execution of departure surface operations for the flight, the AU and ASP (surface operations) collaborate to deliver the Agreed Trajectory as planned. As surface events occur modifying the plan and estimates, the Agreed Trajectory is updated to reflect the new information. Should this new trajectory result in constraints no longer being met, a revision is required. Some examples are described below:

- Taxi times are taking longer than expected, resulting in an update to the take-off time. Without time constraints on the flight, the Agreed Trajectory is updated and the update is shared.
- An unexpected delay on the surface has resulted in a controlled take-off time violating an established constraint. A revision is required. Proper selection of constraints to allow deferred delay absorption compensating for surface delays can mitigate the need for an Agreed Trajectory revision.
- Tactical changes have resulted in a runway re-assignment on departure. A revision is required.

Even though revisions are required, routine revisions are expected to be machine-to-machine interactions with timely resolution. Revisions may require human intervention at times, supported by automation.

On arrival, AO collaborates in trajectory planning and revisions including arrival path selection and arrival event timing. Arrival path selection includes consideration of feasible taxi paths (e.g., due to runway exit points acceptable to the flight crew) affected by the operations in use. Timing decisions impact Traffic Synchronisation constraints which the flight controls to during execution. As the flight operates, trajectory updates inform AO of changes to arrival event timing.

3.3.5 CONSTRUCTING A ROBUST AGREED TRAJECTORY

Having a robust Agreed Trajectory implies that expected perturbations to the trajectory do not result in frequent trajectory revisions. These perturbations may be due to uncertainty or actions required for separation provision, traffic synchronisation, or departure aerodrome operations. When an Agreed Trajectory is developed to be robust, constraints should not be placed upon it without sufficient margins to be able to deal with these expected perturbations. Margins may be placed on various variables in the Agreed Trajectory, some examples include:

- Constraints may include bounds accommodating variability
- Airspeeds must leave margin between the speed in the Agreed Trajectory and the maximum or minimum acceptable airspeed
- Descents might consider thrust margin above idle to compensate for perturbations during the descent path

While the construction of a robust trajectory comes with the costs of incorporating margin on specific flights, these are balanced against the ATM System benefits of network stability, throughput, predictability and efficiency.

In a mixed-equipage environment, some non-participating flights may be subject to larger uncertainty than others. Constructing a robust Agreed Trajectory implies that these non-participating flights will require larger margins. As a result, the non-participating flights will not incur the predictability or efficiency gains associated with the shift to more strategic decision-making.

An example of the consequences of a robust Agreed Trajectory while managing time uncertainty is shown in Figure 13. An Agreed Trajectory is developed pre-departure, with a DCB-driven controlled take-off time. This time has bounds built to accommodate anticipated surface delays and known variability. As the flight operates, the Agreed Trajectory is updated to reflect the actual take-off time. As it operates within constraint bounds, the Agreed Trajectory does not require a revision. Later in the flight, as the destination is approached, additional wind uncertainties and manoeuvres for separation provision have updated and revised the Agreed

Trajectory as well. TS initiates a revision to set a controlled time for synchronising the arrivals while incorporating sufficient margin to deal with remaining separation provision that might occur.

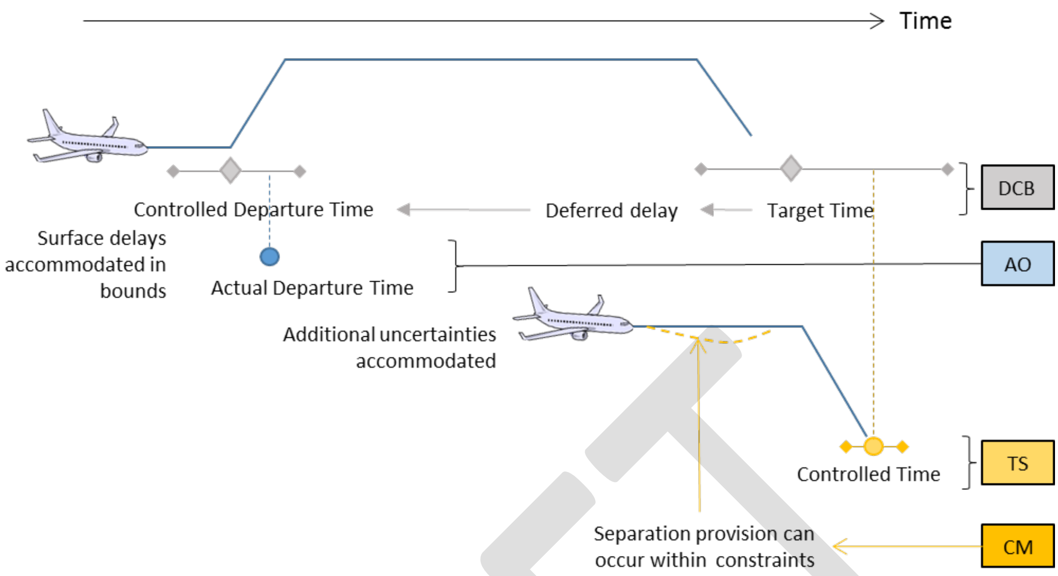


Figure 13 – A robust Agreed Trajectory does not require many revisions

Considering the case of separation provision, estimates of the expected perturbation due to separation provision across a portion of a flight can be obtained through historical data analysis, or flight-specific statistical modeling. This estimate can be used to derive a margin to be incorporated into a time constraint, allowing the accommodation of some percentage of all expected separation manoeuvres. This simple example is illustrated in Figure 14. In this example, given a time constraint, separation provision may also increase speed to offset the additional manoeuvre distance. This speed increase is only possible if speed margin is provided.

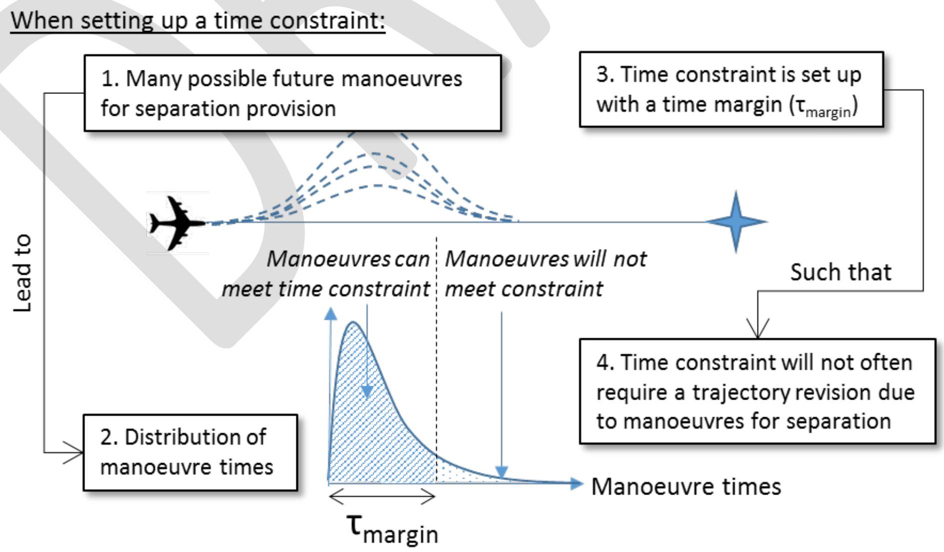


Figure 14 – Example illustrating margin for separation provision manoeuvre in time constraint

3.3.6 IN-FLIGHT RE-PLANNING AND AGREED TRAJECTORY REVISIONS

This Section describes the in-flight re-planning processes (e.g., between AOM, DCB, AUO and AO, some TS). Note that AUO may be conducted by the flight deck, a flight operations centre, or both.

While the Agreed Trajectory has been coordinated pre-departure from origin to destination, circumstances may change as the flight is airborne, requiring in-flight revision of the Agreed Trajectory. This activity may be required for a variety of reasons, including:

- The AU may initiate re-planning as updates to forecasts, fleet management, or changing mission objectives may require modifications to the Agreed Trajectory
- Perturbations to a previously-agreed trajectory (e.g., due to wind uncertainty, or CM actions) may result in the update no longer complying with required constraints
- Updates to forecasts result in the re-evaluation of the concept component objectives, these may require revisions to the Agreed Trajectory to meet the objectives (e.g., a change in arrival capacity requires a revision for DCB)
- Improvements in prediction accuracy as the flight operates allows constraints to be relaxed for all impacted flights

Regardless of the reason, in-flight re-planning and revisions require the collaborative development and agreement on a new Agreed Trajectory meeting the objectives of the concept components. These objectives include balancing adequate system-level performance and flight-specific performance. This process need not involve all concepts components across all ASP interacting with a flight. As illustrated in Figure 15, various concept components may pertain to different portions of the flight. Depending on which portion of the flight is being re-planned, coordination need only occur across the impacted concept components. It is the role of Service Delivery Management (SDM) to determine the appropriate components requiring involvement which may be through collaboratively agreed rules for Trajectory Management.

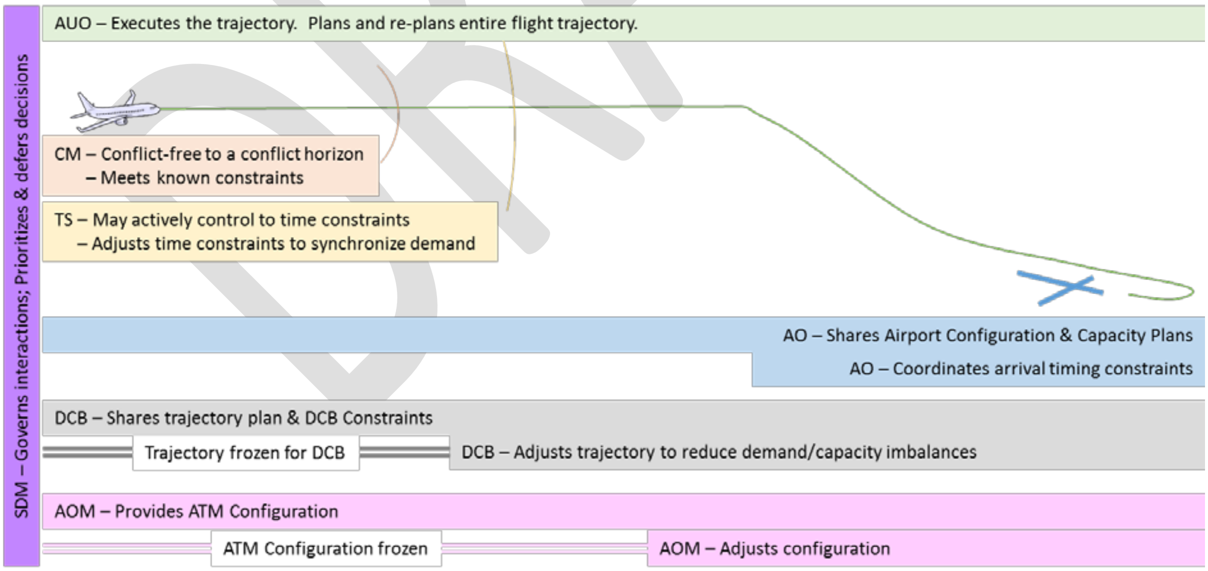


Figure 15 – Concept Component Influence In-flight

As an example, consider a flight with nine hours remaining with an AU desiring to revise the Agreed Trajectory to account for improved winds. As was conducted during pre-departure planning, coordination between AUO, DCB, AO and AOM may occur across multiple ASPs leading to a revision of the Agreed Trajectory. In so doing, the Agreed Trajectory may be modified outside of the CM or TS influence horizon thereby not necessitating direct coordination with those concept components. The resulting Agreed Trajectory must be robust to uncertainty. Practically, this means that the plan can still be met given expected perturbations for separation provision. Also, given downstream uncertainty, the Agreed Trajectory must not prematurely delay a flight for future capacity limitations (i.e., early delay with later uncertainty may require an increase in speed, or lose capacity if additional delay due to uncertainty cannot be recovered).

3.4 MULTI-ASP CONSIDERATIONS

Under TBO, flights operating across multiple ASPs encounter some additional considerations in the planning and execution of trajectories.

Rules for Trajectory Management must be defined for flights operating across ASPs. These rules must be collaboratively agreed-to and consider the factors as described in Section 2.3.2. In addition, for the multiple ASP case, the process for constructing, updating and revising an end-to-end Agreed trajectory in an effective and highly efficient manner must be identified. Strategies may include:

- A responsible entity for each flight, which may change as the flight progresses, constructs an end-to-end trajectory upon revision and update
- Boundary conditions are exchanged for constructing a piecewise end-to-end trajectory upon revision and update
- The AU, or designated representative, constructs the end-to-end trajectory upon revision and update
- Sufficient information is exchanged to allow all participants to construct an end-to-end trajectory upon revision and update

Whatever the strategy, powerful automation and interoperability standards will be required to support consistent management of the trajectory across ASPs. When developing trajectory agreements and ATM Configurations, each ASP must consider the ATM System performance improvement goal. However, it is recognized that ASPs may have differences in goals that must be collaboratively resolved.

3.4.1 MULTI-ASP PLANNING

In a full TBO environment, information about flights' trajectories and ATM Configuration are shared across all relevant ATM System participants. From the AU's perspective, whether planning or re-planning a flight across multiple ASPs, full accurate knowledge of present state and constraints enables the creation of an end-to-end Agreed Trajectory that meets known constraints. In practice, uncertainty remains and full knowledge of constraints does not occur instantaneously as these emerge in response to evolving flows, trajectories and events causing capacity constraints. Nevertheless, *at any given time*, the AU can negotiate to obtain the most favourable Agreed Trajectory, meeting their objectives, given knowledge of existing conditions and constraints across all ASPs. Consideration of uncertainty can also be deliberately incorporated into the Agreed Trajectory by the AU to provide future re-planning flexibility.

Regarding AOM, airspace is organized through coordinated planning between adjacent areas ensuring the removal of operational discontinuities. Practically, this coordination can be achieved through collaborative airspace design with consideration of anticipated flows. As flows for a given day become more certain through schedules, meteorological information, restricted activity airspace and shared trajectories, consistent ATM Configurations accommodating those flows can be shared by ASPs. Locally, Aerodrome Operations coordinates with AOM to ensure arrival/departure flows are incorporated into the ATM Configuration (present and forecast).

Similar to AOM, strategic and pre-tactical DCB relies on anticipated flows to assign resources to deliver anticipated capacity needs, where possible. The sharing of information across ASPs allows a consistent view of flows to develop, as each ASP makes resource-allocation decisions consistent with anticipated flow patterns.

Constraints, including those emanating from resource allocation decisions, should be shared to ensure that ASPs do not over-allocate resources when downstream constraints prevent the utilization of those resources.

When tactical and pre-tactical DCB seek to modify individual trajectories, coordination between AUO and DCB across the ASPs is required. The TBO Concept does not prescribe a methodology for the coordination; however, CDM principles should be applied to develop a process and a set of rules governing the interaction. Some considerations include:

- How will the timing of demand/capacity evaluation and trajectory constraints issuance be synchronised across ASP?
- When flights are subject to constraints due to multiple DCB imbalances, what are the rules for delay allocation?
- Can ground delay be allocated in one ASP for DCB imbalances in another ASP?
- How should robustness considerations be incorporated into the trajectory solution?

Failure to collaborate on processes for DCB assignment implies the need for exemption for flights operating across multiple ASP with the consequence that DCB imbalances are inequitably assigned to other flights, or managed tactically. Either approach is deleterious to ATM System Performance.

3.4.2 MULTI-ASP EXECUTION

During the execution phase of flight, trajectory updates and revisions are expected to be shared with relevant ASPs in accordance with agreed-to rules for exchange. ASP-provided updates modify an Agreed Trajectory mostly within the ASP's area-of-responsibility, but in some cases the trajectory modification may also impact surrounding ASPs (e.g. direct routing across FIR boundary or trajectory offset along an airway). AU-provided updates may be provided end-to-end or in multiple ASPs. Updates may trigger the need for a revision (see 3.3.1.3) to the plan.

For clearances affecting flights across multiple ASPs, the ATC Unit delivering the clearance must ensure that clearances are provided with appropriate clearance limits. These must ensure that the upstream ATC Unit issues an appropriate clearance through downstream airspace, and that the downstream ATC Unit is fully aware of the clearance provided. As is the practice today (from ICAO Doc. 4444):

> *When prior coordination has been effected with units under whose control the aircraft will subsequently come, or if there is reasonable assurance that it can be effected a reasonable time prior to their assumption of control, the clearance limit shall be the destination aerodrome or, if not practicable, an appropriate intermediate point, and coordination shall be expedited so that a clearance to the destination aerodrome may be issued as soon as possible.*

As for the single-ASP case, Separation Provision is conducted locally and its impact is reflected in trajectory updates. Trajectory revisions must coordinate with the separator if trajectory revisions are proposed within the conflict horizon, and with ATC if within their local area-of-responsibility. Revisions spanning over a boundary require a coordination and negotiation process among ASPs. Trajectory constraints should incorporate sufficient margin for conflict management to reduce the need for trajectory revisions. Across multiple-ASPs calculation of required margin necessitates knowledge of trajectory disturbances typically expected. This may be derived through historical analysis, collaboration between ASPs or access to the FMS trajectory.

Traffic synchronisation time constraints may be met across ASP boundaries using various methods, including:

- Assignment of control to meet time to the flight deck, where the Agreed Trajectory reflects the controlled time

- Allocation of time constraints between ASPs consistent with an Agreed Trajectory

Prior to controlling to a time, an Agreed Trajectory may have been developed that included a speed targeting a time for DCB with a deferred delay for TS to absorb. As the solution is being planned for, the allocation of delay absorption at the appropriate time must be coordinated across ASPs with involvement of the AU. In part, the development of this plan should consider:

- The ability of the participants to execute within certain tolerances
- The ability of participants to absorb certain levels of delay
- The resulting ATM System Performance impact
- The level of prediction uncertainty in trajectory, capacity and demand

3.5 UNCONVENTIONAL OPERATIONS

Various types of operations, some of which have unique characteristics, will continue to be supported in a TBO environment. This Section describes some of these types of operations including flights operating in formation and Remotely Piloted Aircraft Systems (RPAS).

3.5.1 FORMATION FLIGHTS

Formation flights continue to be operated in accordance with ICAO Annex 2, *Rules of the Air*. Flights operating as a formation exhibit characteristics differentiating them from other flights in a TBO environment. These include:

- *Physical extent* – Formation flights operating within a specified lateral, longitudinal and vertical distance from the flight leader, as specified in ICAO Annex 2, are managed as a single trajectory by all GATMOC Components. When the occupied airspace volume exceeds that prescribed, the formation may be managed through a moving airspace reservation characterized as a volume-of-airspace operation.
- *Aircraft Capabilities* – The capabilities applied for control and management of the formation must consider: the capabilities of the individual flights, any unique capabilities required of the formation leader, and the within-formation command and control methods and capabilities.
- *Formation Properties* – Flights in formation may exhibit additional properties to be considered by the various concept components (e.g., formation leader, additional separation requirements, size of formation).
- *Join up and Breakaway* – Individual flights within the formation may join and breakaway from formation either as individual flights or separate formations. Trajectory updates and revisions must consider the dependencies between these various trajectories to ensure consistent and accurate information. Negotiation and re-negotiation on these dependent trajectories may need to occur as one.

While flights are operating as a formation, concept components continue to use and modify the trajectory of the formation as described in the Section “Concept Components and the Trajectory”. Where necessary, planning decisions will need to consider all of the aspects described previously. For example:

- Airspace Organization and Management must consider volume-of-airspace operations and constraints based upon formation capabilities.
- Aerodrome Operations must consider the appropriate demand depending on how the formation properties including how it is to operate on departure and arrival.
- Demand/Capacity Balancing and Traffic Synchronisation must consider aircraft capabilities and trajectories preceding join up and subsequent to breakaway.

3.5.2 RPAS OPERATIONS

Operations for Remotely Piloted Aircraft Systems (RPAS) are described in "Remotely Piloted Aircraft System (RPAS) Concept of Operations for International IFR Operations". As the term implies, RPAS remain piloted, fully autonomous aircraft are considered out of scope.

Differences in the types of operations expected to be conducted by RPAS introduce the need for additional information requirements and constraints to be considered by an ASP when interacting with the operations. These apply regardless of whether the operations interact with a TBO environment. For example, high-endurance operations may require trajectories of longer duration. Some operations (e.g., monitoring or tracking) are also expected to operate on trajectories that are highly dynamic. While such characteristics (e.g., high-endurance and more dynamic trajectories) are a function of the operation, such operations are expected to be more prevalent with RPAS.

RPAS operations will interact with a TBO environment in one of two manners:

- *Integrated as a TBO aircraft* – Integrated RPAS operations must fully meet requirements for operations within a TBO environment. These include procedures that are transparent to the ASP such as the transfer of control between Remote Pilot Stations (RPS). Some requirements, such as the Required Communications Performance (RCP) might need to be tailored for RPAS to account for differences in communication architecture. Additional considerations for a lost C2 link include the need for emergency and contingency procedures to be planned and coordinated as part of trajectory revisions.
- *Operations within a volume of airspace* – RPAS that are operating on missions requiring highly dynamic (versus defined) trajectories and small RPAS not being controlled by ATC participate in operations within a volume of airspace. Airspace Organization and Management must engage in the definition and management of these volumes. TBO will ensure trajectories of flights not participating in volume-of-airspace operations are generally segregated from these volumes; however, transit may be permitted.

Appendix A provides additional information on RPAS operations in a TBO Environment.

3.5.3 SPACE VEHICLE OPERATIONS

Space vehicle operations are expected to increase in frequency and regularity as the ATM System evolves towards TBO. Further, these operations will likely be conducted by an increasing diversity of space vehicles with vastly different launch, sub-orbital and re-entry flight characteristics. Launch and recovery methods and locations will also expand across a wider global network.

TBO accommodates these varied space vehicle operations, as they transit TBO airspace, largely through the use of operations confined to a volume segregated from flights operating under TBO. Required airspace volumes are expected to be transient and coordinated between the GATMOC Components and actors responsible for space vehicle operations. With improved technology, information and operational procedures, exclusionary airspace volumes may be reduced in extent and duration.

In certain cases, space vehicles meeting performance requirements will be capable of operating within TBO-enabled airspace without necessitating volume-of-airspace operations. These vehicles will transit TBO airspace with defined entry and exit points and times coordinated with space vehicle control.

4 CONSIDERATIONS FOR TRANSITION AND THE MIXED ENVIRONMENT

TBO will be deployed in a gradual fashion within an extended timeframe. During that period, ASPs will have to manage mixed-equipage operations, and AUs will be operating within ASP's airspaces having different degrees of TBO implementation. For this reason, the TBO Concept supports a mixed environment. This includes a mix of aircraft and supporting FOC that are equipped with a variety of capabilities and a mix of ASPs supporting and not supporting those capabilities. In order to deliver those capabilities, both the AU and the ASP require some technical enablers that together deliver capabilities in support of TBO. This Section first describes the relationship between enablers and capabilities.

The mixed environment will support a blend of technical enablers and the capabilities they deliver, both from the ASPs and the AU. How the mix of these capabilities interacts with the full participation concept described in Section 3 is described in this Section.

In a mixed environment, there may be significant difference in the level of investment across participants towards TBO capabilities. Individual AUs invest in airborne and ground systems, ASPs invest in ground systems and communication means are upgraded in support of TBO. In such a mixed environment, implementation choices require due consideration to ensure an equitable allocation of benefits resulting from investment in TBO capabilities. Towards this end, the evolution of this mixed environment is expected to apply a Performance-Based Approach (PBA) as described in the *Manual on Global Performance of the Air Navigation System* (ICAO Doc. 9883). Through the application of this collaborative process, implementations are defined in ways balancing Key Performance Areas thereby ensuring an equitable balance between costs and operational performance across participants. Fundamental to the PBA is the need to iteratively assess the achievement of objectives. TBO facilitates this process through the collaborative sharing and maintaining of trajectory and supporting information for post-operational evaluation.

Under some circumstances, consideration of ATM System Performance needs will necessitate full TBO by all participants. For example, some very high-density, and highly-constrained airspace may require full TBO participation at certain times.

4.1 ENABLERS AND CAPABILITIES

This Section first describes technical enablers supporting TBO, followed by the technical capabilities that are enabled by them. A description of which enablers are required and help improve the technical capabilities is also described.

4.1.1 TECHNICAL ENABLERS

Trajectory-Based Operations relies on the adoption of some important technical enablers to deliver capabilities to both the AU and ASPs. Technical standards are available or expected to be available for each of these enablers. It is not the intent of this Section to detail those standards, but rather to briefly describe the utility of select newer technical enablers in delivering capabilities as required for TBO.

4.1.1.1 AUTOMATIC DEPENDENT SURVEILLANCE – BROADCAST (ADS-B)

Through the use of ADS-B out, aircraft-derived state information (position, altitude and speed) is available to ground-systems allowing greater precision in initial conditions for trajectory prediction and conformance monitoring against the Agreed Trajectory.

Multiple other forms of surveillance systems are available with differences in accuracy, integrity and information content. The attributes of the surveillance will impact trajectory prediction accuracy.

4.1.1.2 AUTOMATIC DEPENDENT SURVEILLANCE – CONTRACT (ADS-C)

ADS-C allows for contract-based surveillance and aircraft-derived trajectory downlink to be made available to ground-systems. Updates can be periodic, upon request or event-based (e.g., based upon tolerances). Contracts can be between the aircraft and the controlling ATSU and with a maximum number of additional ATSUs. This capability provides an aircraft-derived trajectory allowing ground systems to synchronise intent air/ground and improve trajectory prediction using information contained in the downlinked trajectory. Through downlink to non-controlling ATSUs, an ASP that is so-enabled can obtain aircraft-derived trajectory information on the flight while the flight is operating in another ASP's airspace which may not be providing the trajectory information ground-to-ground (i.e., not yet providing full TBO services).

4.1.1.3 CONTROLLER-PILOT DATA LINK COMMUNICATION (CPDLC)

Through CPDLC, closed clearances resulting in an end-to-end trajectory can be provided to the flight deck and these can be loaded into the Flight Management System for execution upon approval by the crew. These more complex TBO clearances are workload-intensive to communicate by voice and load into the FMS.   Use of data communication with FMS loading allows more extensive, end-to-end clearances than voice does and ensures that both the ground and aircraft automation systems are aware of the clearance without relying on further human input beyond what is required to communicate and execute the clearance. Together with the downlink of aircraft intent, this improves the quality of the intent data contained in ground automation for the trajectory.

4.1.1.4 PERFORMANCE-BASED COMMUNICATION, NAVIGATION AND SURVEILLANCE (PBC, PBN, PBS)

The application of Performance-Based Communication (PBC) standards ensures that a clearance affecting a trajectory can be delivered and acknowledged within integrity and timeliness requirements. This can ensure that the proposed trajectory change remains effective. Different service functions may require different RCP standards. Trajectory changes proposed by DCB pre-departure can be negotiated with much less stringent PBC requirements than changes required by CM.

Through the application of PBN procedures, selection of the ATM Configuration (see 3.1) can tailor the needs of aircraft navigation accuracy to the local ATM Performance needs including increases in throughput. Where required, the precision with which lateral clearances must be adhered to may be defined.

PBS standards, and their application, provide knowledge on surveillance performance characteristics necessary for managing aircraft position uncertainty. This information assists in the management of decisions reliant on short-term trajectory prediction accuracy, and conformance monitoring for determining trajectory updates.

4.1.1.5 FLIGHT MANAGEMENT SYSTEMS (FMS)

The FMS provides the ability to input an end-to-end closed clearance (together with additional flight-specific information), including defined procedures and constraints at waypoints, resulting in an aircraft-derived trajectory computed from the aircraft present position. This aircraft-derived trajectory provides input to the lateral and vertical guidance functions which, with appropriate mode selection, result in the trajectory that is executed for the flight. The FMS allows:

- A closed clearance seeking to deliver the Agreed Trajectory can be input into the FMS
- The aircraft can execute the closed clearance and deliver the Agreed Trajectory within execution precision limits
- The aircraft-derived trajectory can be formatted and downlinked to ground systems for synchronisation
- Constraints in the closed clearances can include altitude, speed and time constraints (e.g., Required Time of Arrival, RTA)

Atmospheric parameters such as winds must be input into the FMS for an accurate aircraft-derived trajectory.

As described in Section 3.3.1, the Agreed Trajectory and its associated closed clearance is not expected to be conflict-free end-to-end. As a result, interventions to provide separation will continue to be required. With increased trajectory prediction accuracy, these interventions can be provided as closed clearances which are updated in the FMS, through the use of CPDLC as described in 4.1.1.3.

4.1.1.6 ELECTRONIC FLIGHT BAG (EFB)

The Electronic Flight Bag (EFB), when combined with connectivity to Air/Ground SWIM (see below) provides the capability for the AU to connect the flight deck to the shared information available via SWIM together with customized applications for analysing and graphically presenting the information to the flight crew. The EFB allows the flight deck to collaborate in trajectory negotiation across all capable ASPs, with involvement of their FOC, as applicable. In a mixed environment, the AU may negotiate, via the EFB connected through A/G SWIM, with downstream ASPs.

4.1.1.7 FLIGHT AND FLOW – INFORMATION FOR A COLLABORATIVE ENVIRONMENT (FF-ICE)

ICAO Document 9965, "Manual on Flight and Flow – Information for a Collaborative Environment" describes a concept for flight information sharing between members of the ATM Community. One of the major changes necessary for TBO is the greater sharing of information. The environment provided by FF-ICE provides this change. Adoption of this information exchange environment by the ATM Community, is essential for various TBO capabilities including:

- Trajectory Negotiation both prior to and subsequent to ATC involvement
- Coordination of trajectory information across concept components and between ASPs
- Provision of Trajectory Parameters, AU constraints and AU trajectory preferences as described in Section 4.4.4 of the ICAO Doc. 9965.

A necessary piece of FF-ICE is the development and application of global standards for information exchange. These include:

- Standards for flight data, aeronautical data and meteorological information (e.g., FIXM, AIXM and IWXXM)
- Standards, recommended practices, procedures and guidance, as appropriate to ensure global harmonization while ensuring the flexibility required by a performance-based ATM System.

4.1.1.8 SYSTEM-WIDE INFORMATION MANAGEMENT (SWIM)

System-Wide Information Management is described in ICAO Doc. 10039. SWIM provides the supporting technical infrastructure for implementing the collaborative environment described in FF-ICE. By providing global connectivity across ASPs and making information “system-wide”, the transition environment supports the exchange of a richer set of data amongst SWIM-enabled participants regardless of their relative geographical location.

Connectivity of the aircraft through Air-Ground SWIM allows the AU to incorporate the flight deck, via the EFB, in the receipt and delivery of SWIM information including trajectory negotiation. In a mixed environment, Air-Ground SWIM provides a mechanism for trajectory revisions integrated with downstream ASPs.

4.1.2 CAPABILITIES

The ability of an AU or an ASP to support TBO is not a binary characteristic. As described in Section 1.4, migration towards TBO is an evolutionary process as more capabilities get introduced in support of performance needs. In practice, interoperability requires that the migration be coordinated through the phased deployment of capabilities as described through the Global Air Navigation Plan and the Aviation System Block Upgrades. The outcome of such an approach is a discrete set of increasingly capable ASPs and AUs, not participants possessing any arbitrary set of capabilities.

These TBO-supporting capabilities are described below from the perspective of the AU, then the ASP. The impact of these capabilities on trajectory accuracy and the subsequent effect on Concept Components is then described. The discussion is then followed by a description of the accommodations required by the TBO Concept described in Section 3.

4.1.2.1 AIRSPACE USER TBO CAPABILITIES

The following AU capabilities support various processes described in the TBO Concept:

- *Pre-departure AU Trajectory Negotiation* – An AU is capable of participating in the development and any subsequent revision of the Agreed Trajectory prior to ATC involvement.
- *Flight-execution AU Trajectory Negotiation* – During flight-execution, the AU, including both the flight deck and FOC, is capable of participating in the revision of the Agreed Trajectory. This includes involvement of the flight deck to ensure acceptability of the Agreed Trajectory when cleared.
- *Trajectory Parameter provision* - The AU provides information to ASPs allowing increased ground trajectory prediction accuracy and trajectory preferences.
- *Aircraft Receipt and Execution of TBO Clearance* – The flight is capable of receiving and executing an ATC closed clearance and subsequent amendments delivering the end-to-end Agreed Trajectory.
- *Provision of aircraft-derived trajectory* – The AU is capable of providing an aircraft-derived trajectory prediction updated periodically, upon request and in accordance with tolerance requirements.
- *Precise clearance execution* – The flight is capable of executing some clearances in such a way as to deliver the trajectory within specified levels of precision when required. In a TBO environment, ATC clearances may be specified with requirements on execution precision as necessary for ATM System performance (e.g., RTA delivery accuracy, or RNP level).

Each of the above capabilities require one or more of the enablers previously described. As aircraft operate within a TBO environment, lack of any of the above capabilities results in a mixed-equipage environment which introduce additional considerations into the Concept as described in Section 3. One significant impact of several of the above capabilities is through trajectory prediction accuracy.

4.1.2.2 ASP TBO CAPABILITIES

Each of the AU capabilities previously described must be supported by corresponding ASP capabilities to enable their use. These are summarized below:

- *Pre-departure Trajectory Negotiation* – An ASP participates in pre-departure trajectory negotiation, including constraint feedback, to reach an Agreed Trajectory.
- *Flight-execution Trajectory Negotiation* – During flight execution, the ASP is capable of participating in the revision of the Agreed Trajectory. This includes the ability of an ASP to engage in trajectory negotiation prior to a flight being within their Area of Responsibility.
- *Use of Provided Trajectory Parameters* - The ASPs incorporates provided trajectory parameters allowing an improvement in ground trajectory prediction accuracy and consideration of trajectory preferences by relevant concept components.
- *Creation and delivery of a TBO Clearance* – The ASP is capable of creating and delivering an ATC closed clearance and subsequent amendments in accordance with an end-to-end Agreed Trajectory.
- *Use of aircraft-derived trajectory* – The ASP is capable of receiving an aircraft-derived trajectory prediction and using that information to obtain improved trajectory prediction accuracy. The ASP is capable of specifying the type of update and associated parameters (i.e., periodic, upon request and in accordance with tolerance requirements) and updating the trajectory prediction using updated information.
- *Precise clearance creation and delivery* – The ASP is capable of imposing requirements on clearance execution precision and delivering such clearances. For example, this may occur when developing the ATM Configuration through the AOM Component, or in providing time constraints with delivery accuracy requirements. Data standards must provide the ability to communicate these accuracy requirements. The determination of required execution precision must also be based on a need for the precision based upon a level of acceptable performance.

In addition to capabilities for integration with the AU, enabling TBO for the ASP is accomplished through additional ground-to-ground integration capabilities, such as:

- *Integration across Concept Components* – As ASPs adopt TBO, the integration between concept components is likely to evolve as performance needs dictate and systems get upgraded.
    - *Use of trajectory by the concept components* – Central to TBO is the sharing and managing of the Agreed Trajectory, together with the use of that trajectory. Use of the Agreed Trajectory by the components includes such activities as conformance monitoring to initiate trajectory updates, and the ensuring of situational awareness in the TBO environment given closed TBO clearances.
    - *Respect and negotiation of constraints across components* – As each component uses and modifies the Agreed Trajectory in their decision-making, constraints imposed by other concept components are shared and respected. The Agreed Trajectory may need to be revised if solutions cannot be obtained respecting established constraints.
    - *Decisions applying robustness principles* – A part of integration involves ensuring that sufficient margin is in place to allow future decisions subject to uncertainty to occur without affecting network stability.
- *Coordination between ASPs* – The extent to which decisions are coordinated and negotiated across ASPs will evolve as future standards are developed. This will impact both the Trajectory Management and ATM Configuration Management loops as described in Section 3.1.

The possible combinations of all the circumstances described above are numerous. However, the impact of each of the above can be generalized to the following:

1. *Trajectory Prediction Accuracy* – As described in Section 4.1.2.3 below, if an ASP is not able to accommodate various AU capabilities affecting prediction accuracy, the impact on trajectory prediction will be identical to the AU not having those capabilities. In addition to those impacts described in 4.1.2.3, an ASP may not be sharing a trajectory at all when there are no TBO capabilities provided by that ASP. In a mixed-mode environment, a continuum of trajectory prediction accuracy is expected (i.e., from no trajectory through the most accurate). Delivery of services, and their performance, by an ASP to an AU will be impacted by this trajectory prediction accuracy. Establishment and exchange of accuracy measures (e.g., through a Figure-of-Merit) facilitate the delivery of performance-based services.
2. *Stability of Future Decisions* – Lack of integration across Concept Components or coordination between ASPs leads to an increased impact of tactical decision-making with a corresponding reduction in the effectiveness of strategic decisions.
3. *Optimality of Agreed Trajectory* – Through trajectory negotiation with the AU, including the sharing of necessary constraints and the flow-driven development of a coordinated ATM Configuration, the Agreed Trajectory better represents the objectives of the AU and the ASPs.

An ASP will be considered to be TBO-enabled when it meets the following criteria:

- Supports both pre-departure and flight execution trajectory negotiation with so-enabled AUs
- Supports the creation and delivery of TBO clearances
- Supports the use of the aircraft-derived trajectory
- If performance needs dictate:
    - Supports the use of AU-provided trajectory parameters
    - Supports the creation and delivery of precise clearances
- Provides decisions integrated across GATMOC Components to the extent necessary for required performance outcomes
- The sharing, updating and revision of the Agreed Trajectory with relevant TBO-enabled ASPs.

The coordination between ASPs is a characteristic of the interface between ASPs and will vary based upon the performance needs of the flights operating across the boundary. For example, a boundary within cruising oceanic airspace will have different needs for coordinating/negotiating relative to a boundary near a major airport.

4.1.2.3 TRAJECTORY PREDICTION ACCURACY IMPROVEMENT

Several AU capabilities will improve the accuracy of trajectory prediction used by automation tools supporting decision-making by the various concept components. The relationship between the AU capabilities and trajectory prediction is described below.

- *Trajectory Parameter Provision* – The provision of trajectory parameters to the ASP by the AU allows ground-based ASP trajectory predictors to improve the computation of speeds and vertical speeds. For example, knowledge of climb performance parameters such as climb speed targets or predicted top-of-climb can improve climb profile assessments.
- *Aircraft Receipt and Execution of TBO Clearance* – Issuance, acceptance, loading and subsequent execution by the FMS allows for more consistent ground and aircraft intent used as input to the trajectory prediction. TBO clearances are closed clearances that do not require inferring intent for trajectory prediction.

- *Provision of aircraft-derived trajectory* – Combined with the receipt and execution of a TBO Clearance, the aircraft-trajectory provides trajectory prediction using more accurate aircraft performance models and select data items.
- *Precise clearance execution* – Where necessary, a clearance may provide specified levels of precision for execution. With precise execution, any predicted trajectory is controlled to the level of precision, ensuring a level of accuracy in the predicted trajectory.

Regardless of the AU capability, the ASP ground systems take into consideration information received from various sources to determine a predicted trajectory and the level of uncertainty or quality associated with that prediction.

Under TBO, the process of planning and re-planning involves the coordination across concept components to reach an Agreed Trajectory. However, this Agreed Trajectory can only be as accurate as the information being used, and the ability of the flight to execute it once a clearance is issued. As concept components coordinate to reach the Agreed Trajectory, each concept component must use and potentially modify candidate trajectories as described in Section 3.1.1. The benefits of trajectory accuracy, due to the mixed environment, on each concept component is described in Table 2 and illustrated in Figure 16.

Table 2 – Benefit of Trajectory Prediction Accuracy on Concept Components

Component	Benefit of Improved Trajectory Prediction Accuracy
AOM	Airspace organization can take advantage of high-precision execution to define high-capacity, high-precision airspace. In such airspace, aircraft with reduced execution precision may be excluded, or additional restrictions may be required to accommodate trajectory imprecision.
AO	Arrival (wheels-on) time estimates from trajectories are more accurate. Surface planning can rely on more accurate timing data on arrival. Smaller margins are required during planning to compensate for uncertainty on decisions resulting in more strategic (and less-costly) decision-making.
DCB	Demand prediction is more certain. Decisions to protect against demand-capacity imbalances are more accurate. This results in either a) improved mitigation, requiring less tactical intervention, or b) fewer restrictions and lost opportunity, resulting in fewer excess delays or re-routes.
TS	Incorporation of flights with improved trajectory prediction levels allows: a) reduced control to meet timing constraints, b) reduced margins to accommodate lower levels of timing uncertainty when planning to meet a time, and c) fewer delays to meet timing constraints executed using path-stretching in lieu of speed control due to the reduced margins.
CM	Improved trajectory prediction within the time horizon of separation provision leads to a reduced level of false and missed alerts resulting in: a) fewer flights being unnecessarily displaced, b) flights being displaced with smaller buffers for ensuring separation, and c) flights being displaced earlier with a smaller manoeuvre. The impact is an improvement in manoeuvre efficiency and a decrease in workload thereby improving airspace capacity. With reduced prediction uncertainty, other concept components seeking to ensure network stability by reserving margin for likely conflicts may incorporate smaller margins due to the reduced frequency and smaller magnitude of interventions.
AUO	The AU may have a higher accuracy prediction for specific input, and shares that input with other participants. Decisions on an optimum trajectory choice are better informed with knowledge of the full set of constraints affecting the flight. Choices made by the other Concept components increase the efficiency and flexibility of the flight.
SDM	Consideration of ATM System Performance will indicate a) the need for areas and times of TBO exclusivity, and b) the equitable assignment of trajectory decisions based upon the impact of capable and non-capable flights.

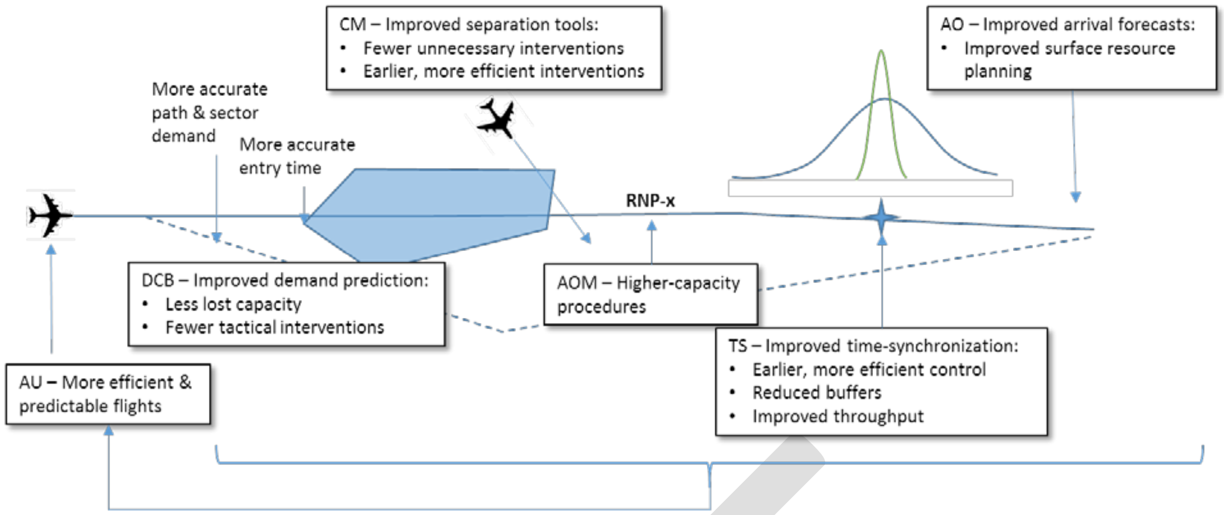


Figure 16 – Benefits of improved trajectory accuracy

4.1.3 TECHNICAL ENABLERS SUPPORT DELIVERY OF CAPABILITIES

The capabilities described previously are delivered through select combinations of technical enablers being adopted by both the AU and the ASPs. Table 3 summarizes the capabilities and the technical enablers that are either required (✓) to deliver the capability or useful for improving (↑) the performance of the capability.

While the table illustrates dependencies on technical enablers, the technical enablers on their own may not be sufficient to deliver the capability. Development of automation enhancements and training to support the processes required by the capabilities would also be required. Capabilities might also be enhanced through operational models, for example, use of an FOC would enhance the impact of negotiation for an airspace user with multiple, interacting flights.

Table 3. TBO Capabilities and corresponding technical enablers

Capability	ADS-B	ADS-C	CPDLC	PBN	PBC	PBS	FMS	Connected Aircraft	FF-ICE	SWIM
Pre-Departure Trajectory Negotiation								↑	✓	✓
Flight-execution Trajectory Negotiation			↑				↑	✓	✓	✓
Trajectory Parameter Exchange								✓	✓	✓
TBO Clearances		✓	✓				✓			
Sharing of Aircraft–Derived Trajectory (ADS-C)		✓					✓			
Sharing of Aircraft-Derived Trajectory (A/G SWIM)							✓	✓	✓	✓
Precise Clearance Execution			✓	✓	↑	↑	✓			
GATMOC Component Integration									✓	✓
ASP Coordination & Negotiation									✓	✓
Trajectory Prediction Accuracy	↑	↑	↑	↑	↑	↑	↑	↑	↑	

4.2 MIXTURE OF TBO AND NON-TBO AIRSPACE USERS

The impact during planning and execution of a mixed equipage environment on the part of AUs, is described in this Section.

4.2.1 PRE-DEPARTURE PLANNING

In a TBO environment, some AUs continue to plan a flight as is done today through a flight plan message. Alternatively, AUs may have different levels of collaboration within FF-ICE. However, pre-departure planning using the flight's trajectory for Demand/Capacity Balancing, Airspace Organization and Management, Aerodrome Operations and Traffic Synchronisation continues to occur. The major impacts include:

- The AU is not collaboratively involved in these planning decisions beyond the ability to issue a change to their flight plan in accordance with constraints as they appear. Decisions continue to be made by the concept components to address demand/capacity imbalances and plan efficient and predictable flows. These decisions may result in the imposition of constraints on the flight including departure (e.g., take-off, off-block) times or routing amendments.
- The AU does not provide a trajectory corresponding to the flight plan. The result is that planning is performed using a trajectory as estimated by the ASP. The ASP-estimated trajectory is expected to be less accurate than one created and shared by the AU. The consequence of this less accurate trajectory was described previously.
    - The AU may enable improved accuracy of the ASP-estimated trajectory somewhat by providing trajectory parameters (e.g., climb/descent speeds, departure weight) pre-departure.
    - In a multi-ASP circumstance, the trajectory must either be estimated piecewise (through the collaborative sharing of trajectory prediction inputs or trajectory boundary conditions) or must be limited to the current ASP.

Other capabilities impacting the flight execution will also impact decisions during pre-departure planning. Examples of these are described below.

- A flight which is not capable of accepting and executing TBO clearances will require more ATC workload to re-route should this be required. In cases when this flight wishes to route into an area with high likelihood of re-routing, there may be circumstances where this flight is required to conservatively decide on a re-route at an earlier time, including prior to departure.
    - An area of possible convective weather activity is projected with a likelihood of occurrence. Flights not capable of accepting in-flight re-routing without unduly influence on ATC workload may be required to plan around the potential convective area.
- Where ATM System Performance requires, flights not possessing required capabilities may be excluded from certain airspace.
    - When defining an ATM Configuration based on flow, AOM may require a level of navigation precision to deliver suitable capacity.

As the Agreed Trajectory is developed for AUs engaging in pre-departure planning, a trajectory plan is developed for those flights whose corresponding AU does not engage in pre-departure planning. This trajectory plan is based upon the Filed Flight Plan with subsequent AU changes in accordance with pre-established Trajectory Management rules (Section 2.3.2); the AU is informed of the outcome and may elect to accept or not accept the outcome. This becomes the Agreed Trajectory for these flights.

The Agreed Trajectory for flights without full TBO Capabilities will be subject to larger uncertainty than those flights with full TBO Capabilities. The level of uncertainty will depend on the specific capabilities and the operational environment in which the flight is expected to operate. During planning, this level of uncertainty is considered in flight-specific decision-making by the Concept Components. In particular, the level of uncertainty will result in larger margins being required (Section 3.3.5) and the timing of decisions being less strategic.

In a mixed environment, flights of varying levels of uncertainty will interact. While the imposition of greater margins on uncertain flights may mitigate their uncertainty, this can result in these flights consuming a greater share of available capacity with resulting impact on the more capable flights. Part of the development of Trajectory Management rules must involve the development of approaches for allocation of capacity between these participants with full consideration of ATM System Performance needs.

4.2.2 EXECUTION

An Agreed Trajectory continues to be shared, managed and used as a common plan for flights that are not fully TBO Capable. In a mixed AU environment:

- Sharing with the AU is limited based upon their capability,
- Management of the trajectory information is conducted with knowledge and consideration of the trajectory accuracy and execution capabilities of the flight, and
- Use of the Agreed Trajectory as a common plan is conducted by the ASP. The AU (flight deck or FOC) may not have access to the full Agreed Trajectory.

For this last point, it is useful to consider how the Agreed Trajectory is executed as described in Figure 17 depending on the aircraft capabilities:

- For flights without CPDLC and FMS clearance loading, clearances delivered to the flight deck may need to be simplified for voice delivery and no loading into the FMS. This constrains problem resolution to a narrower set of options.
- Once delivered, the above clearances might not represent the end-to-end trajectory clearances, but deliver the Agreed Trajectory piecewise. The ground system may still contain a full Agreed Trajectory, but the flight deck avionics systems are not aware of this full agreement. The ASP must be capable of providing clearances and instructions at the appropriate times to deliver the Agreed Trajectory. Even though the clearance delivers the Agreed Trajectory piecewise (e.g., in altitude, arrival procedures), the flight deck is still provided a clearance that allows the execution of lost-communication procedures.
- Without downlink of aircraft intent, there is no monitoring of the aircraft intent via downlink. Monitoring of the conformance to the piecewise clearances is accomplished using surveillance data. Lack of look-ahead and full synchronisation between the ground and aircraft results in greater levels of uncertainty and consequences previously described.

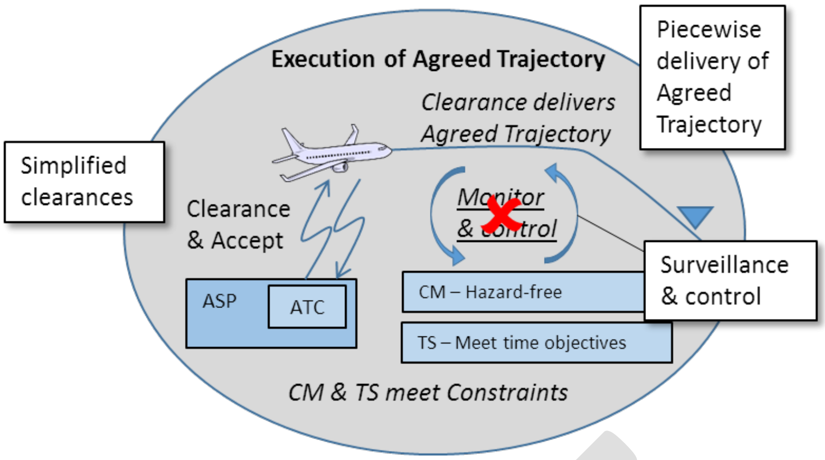


Figure 17 – Execution of the Agreed Trajectory – mixed-equipage circumstance

Much as is done today, a clearance can be provided piecewise to aircraft not appropriately equipped. An Agreed Trajectory may exist in ground automation as a result of pre-departure and flight-execution negotiation. The lateral path corresponding to that trajectory may be cleared in the same manner as a route is cleared today. The vertical and temporal profile may not be received from the flight deck, but based upon ground-based automation with its knowledge of downstream constraints and anticipated future clearances. As the flight progresses, clearances for level and speed changes are provided by ATC in such a manner as to deliver the Agreed Trajectory. For example, a planned step climb in the Agreed Trajectory should be cleared. If an ASP is unable to deliver the clearances resulting in the Agreed Trajectory, then the ASP should have negotiated a different agreement.

In a mixed environment, the treatment of constraints and tolerances continues as for the full TBO circumstance. Tolerances may require different values based on AU equipage, and not all types of constraints may be feasible within a specified level of precision (e.g., a time constraint).

In-flight re-planning is subject to the same limitations as pre-departure planning for those non–participating AUs. In addition, requirements on complex clearance delivery to the flight may limit the selection of routing choices available.

4.3 MIXTURE OF TBO AND NON-TBO ASPS

In addition to mixed AU capabilities, a mixed environment will also have combinations of ASPs with varying TBO Capabilities. As described in Section 4.1.2.2, for the ASP, these TBO capabilities include support for the AU capabilities in addition to additional ground-ground integration capabilities.

As described in Section 1.4, this mixed-environment is central to the evolutionary approach to TBO implementation, avoiding the “big-bang” case in which all must equip simultaneously. The approach allows individual ASPs to adopt capabilities as ATM System Performance needs dictate.

4.3.1 PRE-DEPARTURE PLANNING

A flight operating through multiple ASPs may expect to encounter a mix of TBO-capabilities in these various ASPs. This Section describes the impact of a flight on both upstream and downstream ASPs as it is expected to operate through airspace with reduced TBO capability as illustrated in Figure 18.

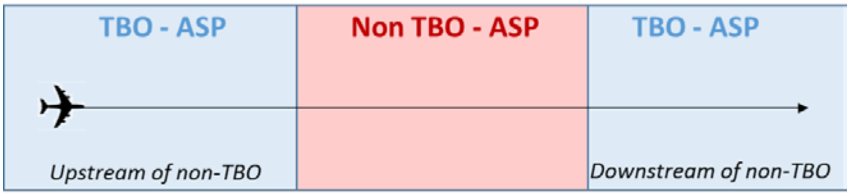


Figure 18. Flight expected to operate through mixed-mode environment

Pre-departure planning involves the collaboration of the ASPs with the AU to obtain an Agreed Trajectory that best represents the AU's objectives given known constraints. The introduction of an ASP not collaborating on pre-departure planning requires the AU, when developing a plan, to consider only the known static constraints within the non-TBO airspace when planning a flight. Since ASPs not conducting pre-departure negotiation are not likely to engage in in-flight re-planning, AUs planning through such airspace may need to take conservative decisions early should re-planning be expected.

The Agreed Trajectory continues to be shared, managed and used as a reference across TBO-enabled ASPs. Information relevant to TBO and known to TBO-enabled ASPs is propagated between all TBO-enabled ASPs.

While an end-to-end trajectory is developed by the AU, uncertainty in the execution of the Agreed Trajectory through non-TBO airspace is higher than for TBO airspace. As a result, the downstream ASP must consider the increased uncertainty when using this trajectory information. In a full TBO environment, the Agreed Trajectory is coordinated to ensure constraints can be met downstream with consideration of uncertainty. Approaches for developing downstream constraints that are robust to uncertainty are described in Section 3.3.5. Uncertainty may also be sufficiently large to defer decisions on some constraints.

4.3.2 EXECUTION

A flight that is expected to operate through one or more ASPs that are not TBO-enabled will be faced with trajectory alternatives as presented in Table 4 depending on the capabilities of the AU and the ASP. In the most basic case, TBO-enabled ASPs interacting with such a flight will not obtain a shared trajectory for some portion of the flight. In this case, the TBO-enabled ASPs may rely on some combination of the following:

- Present-day coordinating mechanisms for obtaining conditions at the boundaries
- Historical assessments of uncertainty for similar flights
- Information contained in the flight plan, including estimates of time
- Information obtained from TBO-enabled ASPs prior to entering the airspace controlled by the non-TBO ASP(s), in particular timing information can help inform a delayed or early flight.

The above information is combined by a TBO-enabled ASP to refine the Agreed Trajectory for a flight including an estimate of the uncertainty. TBO-enabled ASPs provide information on the Agreed Trajectory within their airspace, allowing neighbouring ASPs to use this information in predictions as well. This approach continues to be the case as more information is available based upon the combined capabilities of the ASP and the AU.

The addition of an aircraft-derived trajectory while the flight is operating within non-TBO airspace allows a downstream ASP to obtain information on the clearances provided to the flight. For example, in Figure 19, the AU provides the aircraft-derived trajectory from the cleared route prior to the downstream ASP coordinating with the upstream ASP. However, the ground intent is not included which can result in a change to the trajectory prior to exit from non-TBO airspace.

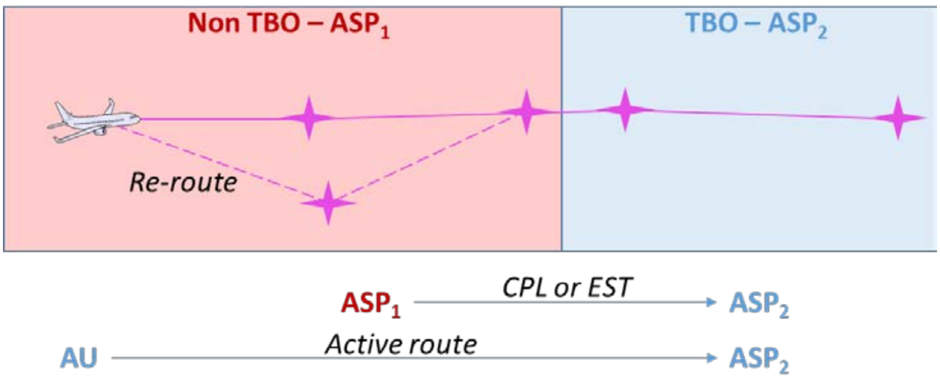


Figure 19 – Aircraft derived information can be provided earlier than estimate data in CPL or EST

As information becomes available (e.g., an Advanced Boundary Information (ABI) message is received or position information from an ADS-C contract is obtained) for a flight operating through an ASP that does not share a trajectory, downstream TBO-enabled ASPs may continue to update and, if necessary, revise the Agreed Trajectory. Coordination through present-day ATS messages is incorporated into the revision process by the TBO-enabled ASP involved in such coordination. This allows downstream trajectory decisions to continue to be coordinated with the best-known information.

For a flight through an ASP providing a trajectory with varying levels of trajectory prediction accuracy, interacting ASPs and their concept components consider the level of this trajectory prediction accuracy in their decision.

Table 4 – Trajectory alternatives in a Mixed Environment

		AU-Provided Trajectory	
		No	Yes
ASP-Provided Trajectory	No	No trajectory within the ASP. Knowledge of coordination conditions required to estimate trajectory leaving non-TBO ASP.	No ground-synchronised trajectory within the ASP. An aircraft-derived trajectory may be obtained but ground intent will not be incorporated.
	Yes	ASP provides a trajectory synchronised with ground intent and surveillance. Varying levels of prediction accuracy.	Trajectory synchronises aircraft and ground intent, compatible with full TBO environment.

Flights operating through non-TBO-enabled ASPs will continue to be cleared through such airspace as they are cleared at present, with more information on the plan being shared across TBO-enabled ASPs. For example, a flight with a planned altitude climb through non-TBO airspace will not be cleared for that climb (Figure 20) until within the non-TBO airspace. Until notified otherwise however, the Agreed Trajectory, used for planning in the downstream ASP, can incorporate that intended climb so long as it is consistent with known constraints and coordination information. In this case, the flight is operating to a clearance which requires future actions by ATC and acceptance by the flight deck to match the Agreed Trajectory.

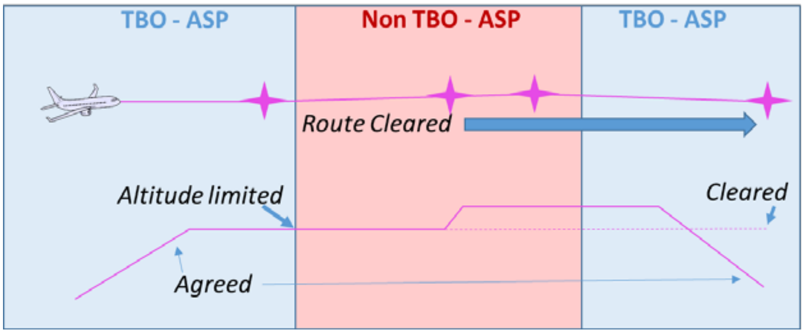


Figure 20. Agreed Trajectory not fully cleared through non-TBO ASP

When revisions to an Agreed Trajectory are required downstream of non-TBO-enabled ASP, that trajectory may be shared between TBO-enabled ASPs, and the AU, if so capable (aircraft and FOC if applicable). The AU may use this information to request a change to the clearance from ATC (see Figure 21). However, a clearance will not necessarily be granted by the ASP presently controlling the flight. Again, in this case, the flight may be operating to a Cleared Trajectory which does not match the Agreed Trajectory.

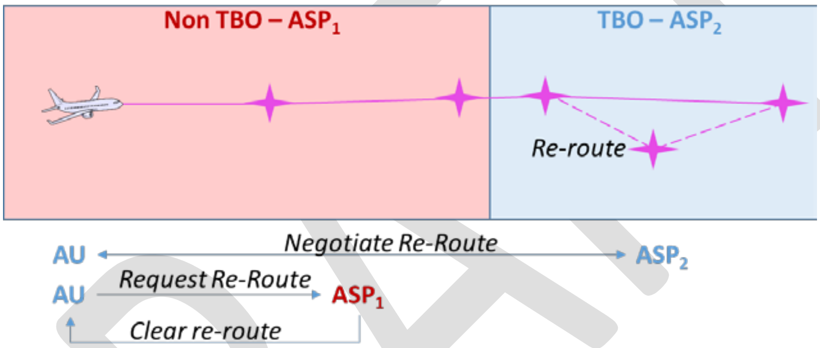


Figure 21. Negotiating a re-route in a downstream TBO-enabled ASP

During flight execution, each concept component continues using and affecting a flight's trajectory information as described in Section 3.1.1. As a flight operates through an ASP that is not TBO-enabled, the update and revision of the Agreed Trajectory is potentially limited as described previously. From the downstream ASP's perspective, TBO must deal with an inbound flight subject to the following:

- The accuracy of the trajectory prediction is reduced. This is dealt with through estimation of the accuracy of the inbound trajectory and planning to incorporate the effect of that uncertainty. Some decisions that could have been made earlier are deferred and must be made less efficiently.
- Imposition of margin to account for uncertainty. If necessary for network stability, some margin may have been applied to a decision, allowing the decision to be more stable for network efficiency at the expense of single-flight efficiency. For example, a time constraint may have built in some delay to be absorbed.
- Respect for constraints. Continual coordination between TBO-enabled ASPs allows the Agreed Trajectory to be constructed in a manner such that upstream ASPs are aware of downstream constraints when revising the Agreed Trajectory. ASPs that are not TBO-enabled may not respect those constraints and the downstream TBO-enabled ASP would only be informed during coordination. Strategies for dealing with such a circumstance include:
    - Use of aircraft-derived data for inbound flights to inform and revise the plan. These data may be received via A/G SWIM, CPDLC or ADS-C when outside of a TBO-enabled ASPs Area of Responsibility (AOR)

  - Incorporating the perturbations into uncertainty and treating them as above through deferred decisions or imposition of margin.

4.4 TRANSITION CONSIDERATIONS

The transition to full TBO is expected to occur through a significant period of operations under a mixed environment. This is necessary as TBO requires a combination of interacting capabilities delivered by:

- Each of the ASPs that interact with each flight
- The GATMOC Components as implemented by the individual ASPs
- The AU aircraft and flight crew capabilities
- The AU ground capabilities, if applicable (e.g., FOC)

With many possible combinations of interacting actors, capabilities must be delivered incrementally. However, many TBO capabilities require segments provided by different stakeholders. For example, trajectory negotiation requires both AU and ASP involvement to become operational. In such cases, transition requires an orderly synchronisation of capabilities enabling stakeholders to best deploy systems which jointly deliver capabilities.

During transition, AU and ASP capabilities are structured to deliver benefits to the investing stakeholders while avoiding detriment to other stakeholders. For example, stakeholders investing in capabilities for improving prediction accuracy obtain the benefits of reduced buffers and more strategic decisions.

The evolution towards TBO across the various capabilities will occur with incremental improvements building on each other. Several perspectives may be taken to describe the transition; Table 5 describes some of the incremental implementation steps during transition. The transition is then described through the evolution of high-level capabilities: Trajectory Negotiation, Trajectory Prediction, Clearance Delivery and ATM Component Integration.

Table 5– Incremental steps during transition

Transition incremental steps	Description
Pre-departure Trajectory Negotiation	• AU-ASP ground-ground exchange • Constraint and preference information shared • Develop a shared trajectory plan
Trajectory Parameter Exchange via Ground Exchange	• AU-provided flight information via ground exchange used to improve ground trajectory accuracy
ADS-B Surveillance and speed accuracy	• Improved ground trajectory prediction
Flight-execution Trajectory Negotiation	• Negotiation of trajectory, considering preferences and constraints during flight execution • Initially may be conducted via ground-ground exchange with FOC • Flight-deck involvement possible with connected aircraft • Pre-defined PBN procedures incorporated into trajectories • More real-time constraints shared from ATM Components
Trajectory Parameter Exchange – Connected Aircraft	• AU-provided aircraft-derived parameters, possibly including an aircraft-derived trajectory • Used to improve ground trajectory accuracy and synchronise with the flight deck • The connected aircraft may include multiple approaches (e.g., A/G SWIM, FANS-1/A and ATN-B2) with impact on allowable data and accuracy
TBO Clearances (with initial CPDLC)	• Initially enables the delivery of clearances that are laterally

	closed, and loaded into the FMS • Clearances, known to automation, reliably incorporated into ground trajectory prediction • Negotiated routes may be delivered as a clearance • Pre-defined PBN procedures may be cleared after trajectory revision
Trajectory-based Ground Automation	• Automation uses increasingly accurate trajectories • Recommendations based upon trajectories create clearances delivering trajectory • Automation incorporates consideration of flight-specific performance, including prediction and control accuracy • Automation for ATM Components deployed where performance-needs dictate
Ground-Ground Trajectory Synchronisation	• Clearance and ground trajectory plans are increasingly synchronised through information sharing, coordination and algorithmic improvement • Trajectory is updated and shared across ATM Components and participating ASPs
Component integration	• ATM Components share and respect trajectory constraints in accordance with trajectory management rules • Need for revisions identified and coordinated across ATM Components and ASP boundaries, where needed
Precise Clearance Execution (CPDLC ATN B2 Final)	• Enables more precise definition and execution of clearances • Procedures developed to take advantage of increased precision where needed • Dynamically-developed PBN procedures may be provided as clearances
Air-Ground Trajectory Synchronisation (ADS-C EPP)	• Clearances, ground and aircraft-derived trajectory plans are fully synchronised • Pre-emptive conformance monitoring of aircraft-derived trajectory against clearance

4.4.1 TRAJECTORY NEGOTIATION

Trajectory negotiation is first implemented through pre-departure negotiation. The AU and ASP collaborate on the development of a shared Agreed Trajectory through ground-ground exchanges prior to ATC involvement. ATM Components publish constraints that are used by the AU to develop a plan meeting known constraints in accordance with their objectives.

Trajectory negotiation may subsequently be implemented during flight-execution allowing the AU to propose changes to the trajectory subsequent to ATC involvement. ATM Components publish more constraints, including real-time dynamic constraints, for consideration by the AU. Flight-execution trajectory negotiation may initially be implemented with ground-ground AU-ASP negotiation for those flights with FOC support. As connected aircraft emerge, negotiation can begin to involve the flight deck. Negotiation also allows the flight deck to incorporate known, evolving constraints into the aircraft-derived trajectory.

Delivery of the Agreed Trajectory is first accomplished through voice communication, limiting the options available for negotiation to those changes that can be cleared via voice. As CPDLC is deployed, more complex trajectories may be cleared, increasing the range of options for trajectory negotiation.

4.4.2 TRAJECTORY PREDICTION AND SYNCHRONISATION

The accuracy of trajectory predictions will incrementally improve, as will the synchronisation of the clearances with the trajectories computed by aircraft and ground systems. In a mixed-mode environment, the development and sharing of a figure-of-merit for prediction accuracy allows ATM Components to make trajectory-based decisions informed by the accuracy.

The initial provision of aircraft parameters and trajectory information through ground-ground exchanges between the AU and ASPs will allow some initial flight-specific tailoring of the trajectory used by existing ground automation systems. Higher accuracy surveillance data including speed information can be used to improve short-term trajectory predictions as well.

Connected aircraft may then provide ground automation systems with additional aircraft parameters more accurately known on board in addition to an aircraft-derived trajectory while ensuring accurate winds have been uploaded. The aircraft-derived information may be used by ground systems to develop increasingly accurate predictions for applications commensurate with the integrity of the data provided. Aircraft derived information may also include performance limits (e.g., on speed) allowing ground decision support tools to propose feasible solutions at the appropriate time.

Trajectory synchronisation between ground systems does not imply a single prediction for all participants. However, synchronised participants are all operating to the same plan represented in the trajectory to the level of fidelity required.   In some cases, this may require the exchange and incorporation of clearance and constraint data.

As high-integrity aircraft-derived trajectories begin to be provided, ground systems may then use these aircraft trajectories and associated data to pre-emptively verify compliance with clearances and procedures.   This provides trajectory full synchronisation between the air and ground.

4.4.3 CLEARANCES

In the early stages of TBO evolution, clearances are predominantly issued via voice. Prior to departure, the end-to-end route is typically cleared to the flight deck in accordance with the Agreed Trajectory developed during pre-departure negotiation. If so equipped, the clearance is loaded into the aircraft systems (e.g., FMS) and verified. Piecewise delivery of the Agreed Trajectory, via voice, is frequently used. Defined procedures may be cleared through instructions such as “CLIMB VIA [SID]” and “DESCEND VIA [STAR]”. Otherwise, altitude and speed changes are cleared piecewise.

When tactical actions are required, temporary heading, altitude or speed instructions are provided via voice. An open trajectory results, with some automation systems relying on inference to estimate a trajectory. The trajectory is not accurate in these circumstances.

Initial controller-pilot datalink communications (CPDLC) allow the provision of clearances to the flight that can be loaded into the FMS for execution by the flight crew. Closed clearances are easier to issue and maintain. The integration of CPDLC with ground automation systems: a) allows the ground automation systems to be aware of the clearances provided, b) permits the ground systems to develop clearances delivering trajectory-based problem resolutions, and c) allows more complex clearances to be developed and negotiated than can be cleared via voice. The initial CPDLC allows TBO clearances to be issued; however, integration with ground systems and between ASPs is required to enable clearances to fully deliver the Agreed Trajectory.

As more advanced CPDLC becomes more widely used, aircraft become capable of accepting and executing precise TBO Clearances. These include specified tolerances on performance that allow the definition of procedures tailored to the individual circumstances. Clearances can further be monitored for conformance using not just surveillance data, but the aircraft-derived trajectory provided via high-integrity links.

4.4.4 ATM COMPONENT INTEGRATION

Integration of ATM Components, within and between ASPs allows decisions to be made in a consistent manner without conflict and while minimizing unnecessary trajectory revisions.

The first level of component integration involves the publication of known constraints, allowing the AU to negotiate a trajectory, both pre-departure and during execution, considering and meeting these constraints. In this way, participants can develop a trajectory fully considering known constraints which impact the Agreed Trajectory.

Automation producing problem detection is based on known trajectories. When known, a figure-of-merit on trajectory accuracy may be applied to inform the confidence in the problem occurring. This can inform choices on when to display detected problems for intervention. As trajectory prediction accuracy improves, improvements in the figure-of-merit allow for earlier, more strategic intervention in the more certain outcome. As problems are detected and resolved, more dynamic constraints become available and are shared.

Decision support automation uses trajectories to develop recommended solutions to detected problems. Shared constraints begin to be incorporated into these recommended solutions allowing recommended solutions by one ATM Component to not create a problem to be detected by another. Not all constraints may be included, and some constraints will need to be prioritized higher than others based on safety and other performance needs. Where necessary for stability and performance, decision support systems include consideration of trajectory accuracy to ensure proposed strategic solutions are robust to tactical intervention. When available, proposed solutions are translated into clearances that can be provided by ATC to the flight using CPDLC.

The Agreed Trajectory for a flight is shared, managed and used by ATM Components across ASPs. Trajectory management rules are in place to govern the management of the trajectory including the revision and negotiation processes. Trajectory revision and negotiation uses automation in evaluating proposals for feasibility, providing constraints and, in some cases, proposing feasible alternatives.

Notification and coordination across ASP boundaries is incorporated into the trajectory sharing and revision process allowing update and revision of the Agreed Trajectory across ASP boundaries.

5 THE TECHNICAL ENVIRONMENT

The TBO Concept has been described under circumstances involving full TBO Capabilities (Section 3) and the impact of a mixed environment (Section 4). In order to deliver TBO, a technical environment, consisting of a mix of the capabilities and enablers described in Section 4, must be available across ground and airborne systems. These must further be integrated across participants to be able to deliver the collaboration necessary for the planning and execution across concept components and ASPs.

Central to TBO is the theme of sharing, managing and using trajectory information as a common plan for the flight. To enable this, TBO requires a fundamental shift from a primarily voice-based set of exchanges between participants supported by automation (Figure 22) towards a system primarily involving data exchange between interoperable systems (Figure 23). Only through data exchange, coupled with the use of that data, is it possible for automation systems to coordinate and maintain a consistent and accurate representation of the trajectory.

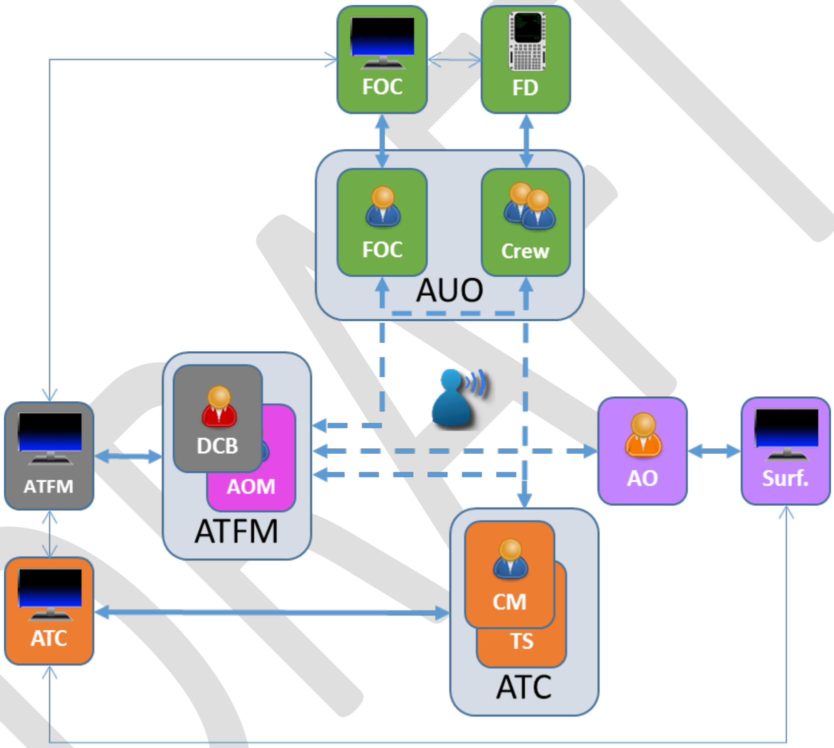


Figure 22 – Present-day, primarily voice-based interactions between participants

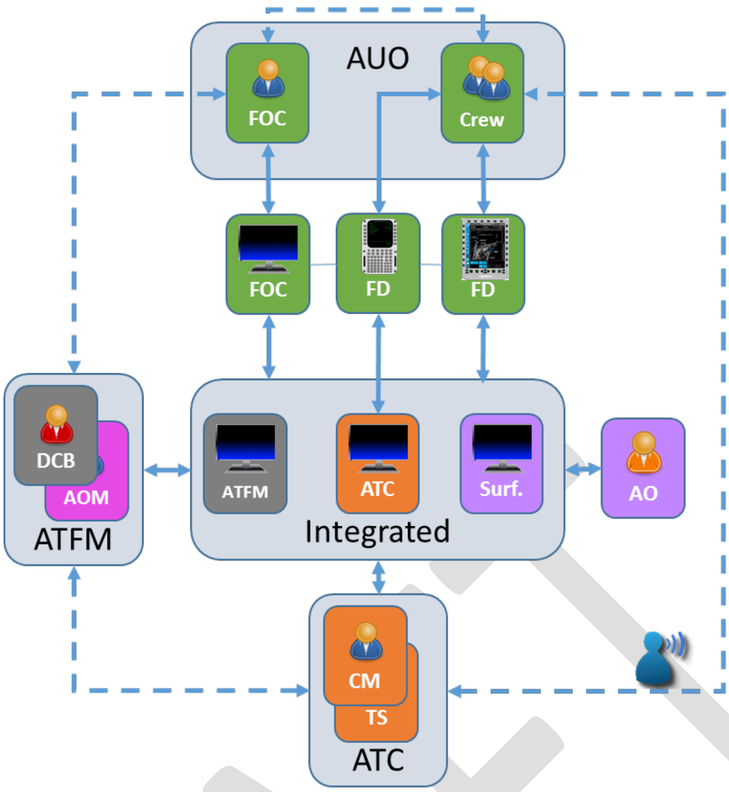


Figure 23 – Under TBO, shift towards data exchange allowing the sharing, managing and use of the 4DT

5.1 GROUND SYSTEMS

Enabling the sharing of trajectory information requires connectivity and common standards for exchange. Global SWIM (see ICAO Doc. 10039) provides the connectivity and common standards for the exchange of such information. A path for implementation is described in the SWIM thread of the Aviation System Block Upgrades (ASBU) found in the Global Air Navigation Plan (GANP, ICAO Doc. 9750).

Layered upon SWIM, standards for the exchange of data in a manner allowing for interoperability across the various participants are required. These require standards for the data that are shared both for the Agreed Trajectory and for the supporting data that is used in arriving at trajectory solutions. As articulated in ICAO Document 9965, "Manual on Flight and Flow – Information for a Collaborative Environment", these information domains include flight data, aeronautical data and weather data. Standards for data exchanges in these domains must be defined and implemented within ground systems in order to support the data sharing necessary for TBO.

With data standards defined, another layer atop the data standards involves the definition of the services that are supported using the data. What these services do is provide the standardization of the behaviour, indicating how the data is to be provided and used by the various participants within the ATM System. ICAO provisions are expected to be defined pertaining to FF-ICE, Digital ATM Information and Meteorological Information as contained in the FICE, DATM and AMET ASBU threads respectively. Standardization at the level of these services provides the necessary standards for the management of trajectory and related information.

The layering of SWIM standards, data standards and service standards is illustrated in Figure 24 below. Ground automation systems exchanging, consuming and producing the information and services would be expected to comply with these standards in a TBO Environment. Compatibility at this level is necessary for systems delivering the concept components to effectively collaborate on trajectory updates and revisions. The layered description in Figure 24 should also be considered to include the ability of aircraft to participate through Air/Ground SWIM.

While standardization is expected at the service level for those that are globally applicable, additional services may also be defined in support of local or regional TBO needs and capabilities.

At the level of management of the trajectory, Section 2.3.2 already discussed the need for Rules for Trajectory Management which must be collaboratively developed and embodied into the automation systems that are maintaining the trajectory data. These include incorporating rules on data ownership and requirements on the automation with regards to trajectory updates and revisions. For example, the appropriate automation system might be required to create and publish a trajectory update upon detection of anticipated tolerance violation.

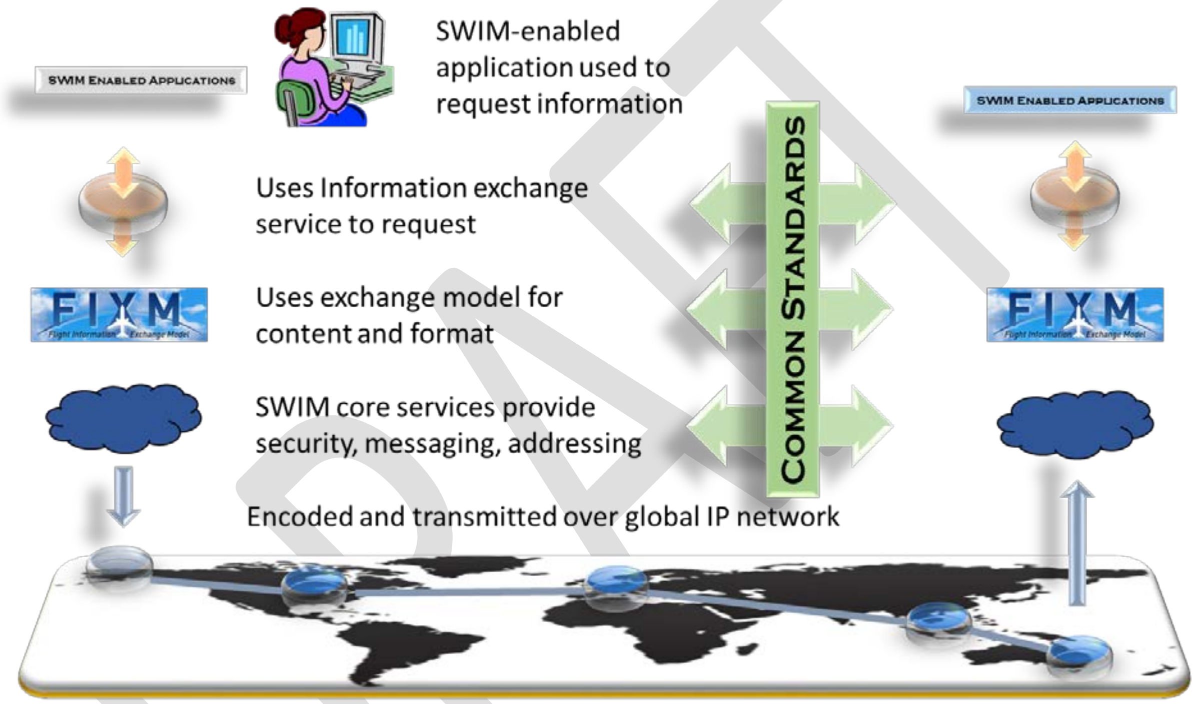


Figure 24 – Layering of Network, SWIM, data and service-level standards [From ICAO Doc. 10039]

Section 3.1 describes the use and modification of trajectories by each Concept Component. Ground systems implementing these components must be capable of:

- Using the shared trajectory to conduct their functions as described in Section 3.1.1
- Taking into consideration applicable constraints required to meet objectives of other participants
- Creating and sharing actions with a predictable modification to the trajectory
- Express constraints resulting from those actions allowing other components to take these into consideration
- Take into account robustness of proposed solutions considering known uncertainty, particularly for the mixed environment

The above apply for any trajectory negotiation or trajectory revision.

For trajectory negotiation, AU ground systems also collaborate through the layered service delivery shown in Figure 24. As envisioned in the FF-ICE Concept, the AU obtains meteorological, aeronautical, flight and flow data as input to the development of trajectories during negotiation.

With trajectory revision and negotiation occurring between participants from different organizations with mixed capabilities, information quality and timeliness must be considered. As described in Section 4.1.2.3, the quality of trajectory prediction should be estimated, ideally based upon known sources, quality of input and conditions under which the predicted trajectory was generated. This trajectory quality can be shared across trusted parties through a figure-of-merit (FOM) and incorporated into robust decision-making.

At a minimum, the coordination and negotiation of trajectories across participants requires that they provide operationally acceptable and feasible trajectories and associated constraints during negotiation and revision.

Obtaining a trajectory prediction is necessary to be able to share an Agreed Trajectory and to evaluate the actions from each Concept Component. ASP ground systems operating in a mixed environment will need to obtain and integrate data from a variety of sources to conduct this trajectory prediction. This includes:

- Integrating AU-provided trajectory parameters (e.g. via SWIM)
- Incorporating AU-provided aircraft-derived trajectories (e.g., via SWIM or ADS-C)
- Considering constraints provided by various concept components
- Ensuring that the clearances will deliver the Agreed Trajectory
- Updating the Agreed Trajectory based upon comparison with trajectory update requirements (e.g., through use of ADS-B and ADS-C)

Execution of the Agreed Trajectory requires an ability for the ground system to create and provide clearances to the flight that result in the execution of the Agreed Trajectory within tolerances. For end-to-end clearances providing a full trajectory, these are constructed for delivery via CPDLC with loading into the FMS. The appropriate clearance limit must be developed based on downstream capabilities. Verification of compliance with the delivered clearance can be pro-active through comparison of a down-linked aircraft-derived trajectory (e.g., via ADS-C).

Monitoring and alerting of flight conformance to delivered clearances require consideration that clearances may have been provided upstream allowing planned manoeuvres in speed and altitude. Appropriate Human-Machine Interfaces ensure situational awareness of these clearances.

5.2 AIRBORNE SYSTEMS

In the mixed environment supported by TBO, some aircraft will have a minimum level of equipage. These flights may have additional restrictions placed upon them; for example, due to their inability to execute procedures with required navigation performance. However, the concept components continue to make decisions on these flights that are trajectory-based, with full consideration of the higher level of uncertainty from the predicted trajectory.

Some connected aircraft will have access to services provided through SWIM. However, while inter-operable with the full set of standards illustrated in Figure 24, the air-ground solution may need to be tailored for air-ground performance requirements. Through these services, the aircraft becomes a more active participant in trajectory negotiation. TBO also accommodates different levels of participation by the FOC in trajectory negotiation. The ICAO *Manual on System-Wide Information Management (SWIM) Concept* (Doc. 10039) provides additional details on aircraft SWIM connectivity including architectural alternatives.

As described in Section 3, TBO seeks to maintain an Agreed Trajectory that is delivered during execution within performance bounds. Practically this implies that clearances seek to deliver the Agreed Trajectory and that the trajectory being executed is monitored to ensure precision. This is accomplished through:

- Use of closed clearances
- Clearances with required levels of delivery accuracy tailored to the circumstances
- Verification of clearance input and execution
- Downlink of aircraft-derived trajectory and parameters for improved prediction

To deliver the above, with the ground system environment described in 5.1, aircraft systems include the Flight Management System (FMS), Controller-Pilot Data Link Communications (CPDLC), downlink of aircraft-derived trajectory and parameters (e.g., via ADS-C), and precise clearance delivery (e.g., PBN and RTA) where appropriate.

Flight Management Systems

For aircraft equipped with an FMS, the aircraft FMS maintains a trajectory prediction based upon the loaded route including constraints. The FMS also takes into account many additional parameters such as aircraft performance, commercial parameters, sensor data, and meteorological information. The trajectory computed by the FMS provides input to the flight's vertical and lateral guidance functions. With appropriate mode selection the aircraft executes to deliver this trajectory. Uncertainty on the predicted trajectory remains with mode selection an important contributor to the character of that uncertainty (e.g., time or vertical error). Another important contributor to aircraft-derived trajectory uncertainty is the accuracy and fidelity of the meteorological data (e.g., winds) used by the FMS.

When a closed clearance is loaded and executed, with accurate environmental data, the trajectory computed by the FMS matches that which is executed as a result of the closed clearance with LNAV/VNAV engaged. Open clearances imposed after a closed clearance was issued will result in discrepancies between the executed and aircraft-derived trajectory. When deviations due to open-clearances are sufficiently large, no aircraft-derived trajectory will be produced.

Controller-Pilot Data Link Communications (CPDLC)

To ensure consistency between air and ground trajectory predictions, the clearance (including constraints) that shape the Agreed Trajectory needs to be efficiently loaded in the FMS. This can be done through CPDLC. The use of CPDLC is preferred over voice communication due to the length and complexity of an end-to-end closed clearance. Through the use of select loadable clearances, the clearance provided via CPDLC can be loaded into the FMS with the flight crew accepting the clearance and executing it. By loading the clearance into the FMS, the aircraft-derived trajectory can be computed based upon that clearance.

As the FMS executes the end-to-end clearance, the set of altitude and speed constraints provided with the clearance are incorporated into the plan. The clearance may also include requested step climbs for the flight. If a tactical altitude clearance is provided which limits the altitude, the flight respects (e.g., via Mode Control Panel input) the altitude limit; however, the downlinked trajectory will continue to provide the aircraft intent as loaded into the FMS.

Downlink of Aircraft-Derived Trajectory and Parameters

Once an end-to-end clearance has been issued, accepted and is being executed by the flight, the aircraft-derived trajectory can be downlinked to the ground systems. This downlink helps ensure that the trajectory being executed to by the flight, based upon the clearance, is sufficiently consistent with the ground-based trajectory that was used by the various concept components to meet their objectives. This trajectory can then be incorporated into an update to the Agreed Trajectory. Should large discrepancies arise, a trajectory revision may need to be initiated. If the discrepancy indicates the clearance is not expected to be conformed to, ATC must be notified by automation.

Such a downlinked trajectory prediction shall not be interpreted as a contract but rather as intent. It reflects the future trajectory predicted by the aircraft systems, taking into account any cleared constraints. The trajectory actually flown may differ from the intended flight trajectory, due to the intrinsic flight operations uncertainties. Note however that cleared trajectory constraints must be complied with (e.g. cross a certain point at a certain time or a certain altitude/flight level).

The downlinked trajectory prediction does not represent a perfect trajectory prediction, but rather the trajectory predicted by the FMS, given the constraints, intent and additional parameters that are known to the FMS. When so engaged, the lateral, vertical and RTA guidance functions will seek to control to the lateral, vertical (descent only) and temporal (i.e., time target) solution computed by the FMS. These may allow, in certain dimensions, delivery of a trajectory within specified precision:

- In the lateral (2D) dimension, adherence of the aircraft's current position is bound by the RNP specification the aircraft flies to.
- Adherence in the time dimension is not guaranteed to any specific accuracy unless the aircraft is flying to a time trajectory constraint, which specifies tolerance at the waypoint to which the constraint is allocated. On the trajectory, up to that constraint the uncertainty may be different.
- In a level segment of the downlinked trajectory prediction, the standard vertical adherence values apply. For a downlinked trajectory prediction segment where an aircraft is either climbing or descending, potential deviations from the vertical profile are not bound by any specific value unless the aircraft is flying to an altitude trajectory constraint. In other words, the actual altitude deviation from the predicted trajectory up to the constraint position and after the constraint position is "uncertain".

6 REFERENCES

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2. ICAO Doc 9882, AN/467, ATM System Requirements Supporting the Global Air Traffic Management Operational Concept

3. ICAO Doc 9965, AN/483, Manual on Flight and Flow – Information for a Collaborative Environment (FF-ICE)

4. ICAO Doc 9750, AN/963, Global Air Navigation Plan for CNS/ATM Systems

5. ICAO Doc 10039, AN/511, Manual on System Wide Information Management (SWIM) Concept

6. ICAO Doc 4444, ATM/501, Procedures for Air Navigation Services

7. ICAO Circular 335, AN/194, ATM Service Delivery Management (ATM SDM)

8. ICAO Draft Version 2, Remotely Piloted Aircraft System (RPAS) Concept of Operations for International IFR Operations, September 2016

9. ICAO Doc 9869, 2nd Edition, Performance-Based Communications and Surveillance (PBCS) Manual, Advanced Unedited, 2016

10. ICAO Doc 9613 AN/937, Performance Based Navigation (PBN) Manual, 4th Edition, 2013

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12. ICAO, Global Operational Data Link Document, 2nd Edition, 2013

APPENDIX A REMOTELY-PILOTED AIRCRAFT SYSTEMS (RPAS)

When considering the impact on TBO operations stemming from the inclusion of RPAS, the differences exhibited by RPAS from conventional aircraft must first be considered. These include:

- Performance differences in the areas of:
    - Communication – Unlike navigation and surveillance, the communications architecture of an RPAS exhibits differences with manned aircraft that must be considered. Communications performance must be defined for the RPAS and established so as to result in the same outcomes as for manned aircraft.
    - Navigation – RPAS would be expected to meet the same standards for navigation that are required of other aircraft. There is nothing fundamental about an RPAS that would alter their ability to do so.
    - Surveillance – Similar to navigation, RPAS would be expected to meet the same standards for surveillance as other aircraft. Some have argued additional challenges emanating from significantly higher density of RPAS; however, this is a result of allowing the higher density to occur, not inherent to an RPAS.
- Impact of a lost-link. Specific procedures must be described for dealing with lost links based upon the combined ASP and aircraft capabilities.
- Lack of see-and-avoid capabilities. Some RPAS operations may be geo-fenced within airspace volumes.

A.1 COMMUNICATION PERFORMANCE

Communication of instructions from ATC to the aircraft, and acknowledgement of those instructions are essential for ATC-provided separation. The performance attributes associated with such communications are one consideration in the determination of the separation criteria (e.g., a factor leading to differences between oceanic and radar separations). RPAS operating under TBO operations would be expected to meet the same performance requirements on communication as conventional, manned aircraft.

The Performance-Based Communication and Surveillance (PBCS) Manual, describes the RCP Type as illustrated in Figure A-1. It is expected that the RCP allocation would also reflect an example for RPAS through a Remote Pilot Station (RPS) such as shown in Figure A-2. In this example, ground-ground communication from ATC to the Remote Pilot Station (RPS), and any required time to translate that communication for transmission to the aircraft would be included for the RPAS case. In general, the timing allocations would have to be aligned with the specific communications architecture.

The total time for an instruction to be issued by ATC, for that instruction to begin to be executed by the aircraft, and for ATC to receive confirmation must be identical to the performance of the manned aircraft operating in the same airspace under the same separation rules. Additional requirements on availability, continuity, and integrity must also be met. Further, an RPAS must be capable of receiving the same set of instructions, presumably expressed in accordance with data link message sets or through ground-to-ground communication standards.

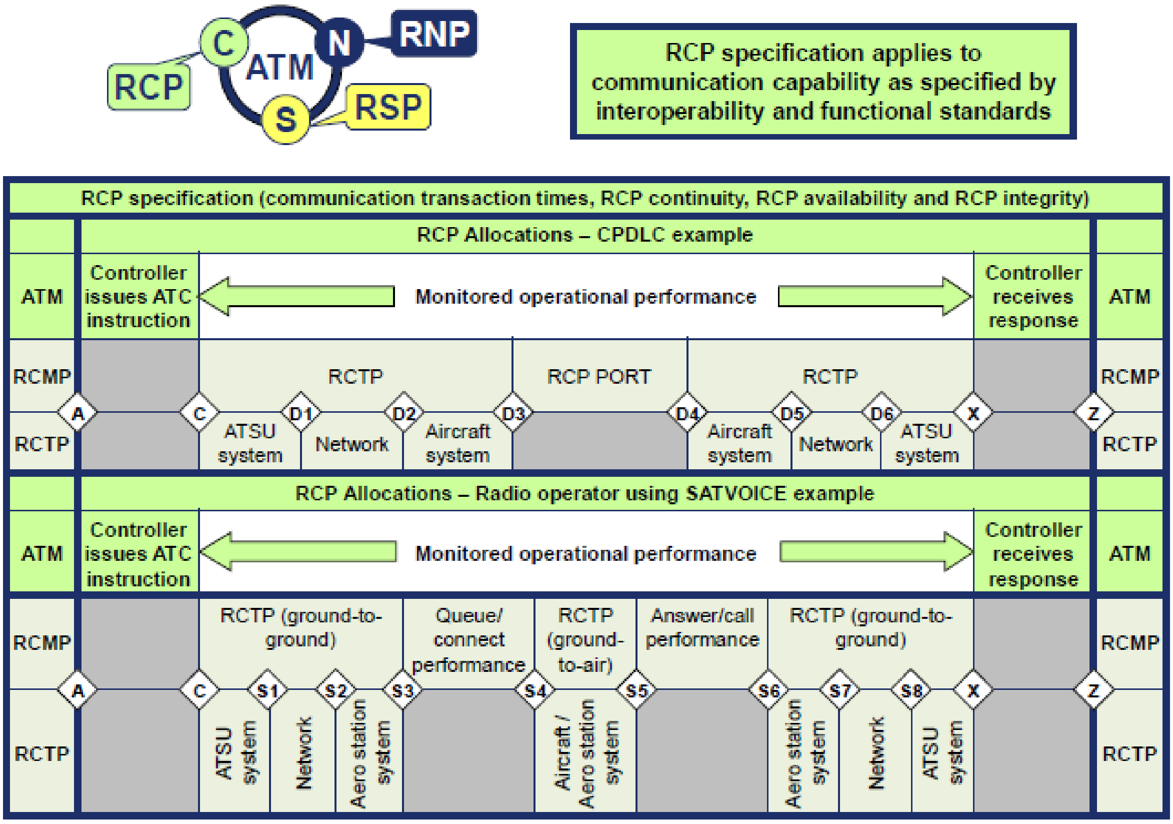

Figure A-1. Transaction times for RCP Type (from Doc 9869)

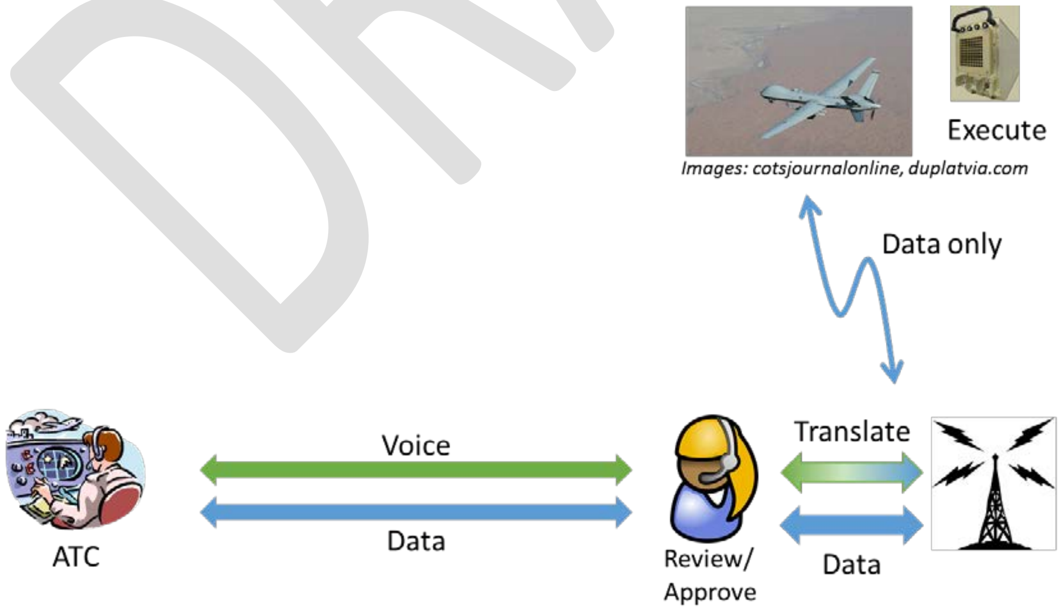

Figure A-2. Information flow for ATC instructions

A.2 LOST-LINK IMPACT

In a TBO environment, the behaviour of a conventional manned aircraft in a lost communication scenario involves the flight continuing with a full end-to-end clearance in accordance with the Agreed Trajectory. If a clearance was issued to a clearance limit, then the flight operates to the clearance limit and follows lost-communications procedures beyond the clearance until arrival (wheels-on).

For RPAS, the ability to follow the above depends on whether the RPAS is capable of landing at the destination with a lost link and if the AU and ASP both agree. The various cases are described below:

- A full trajectory has been cleared end-to-end.
    - Flights with the ability to land at the planned destination and which have an agreement to continue in the event of a lost-link will continue along the agreed trajectory with no possibility of a trajectory revision.
    - Other flights must have defined contingency trajectories prior to execution. Contingency trajectories must be revised together with any revision to the agreed trajectory. In the event of a lost-link, the flight continues on the next contingency trajectory with no possibility of a trajectory revision as long as the link is down.
- The flight has been provided a partial clearance to a clearance limit.
    - Flights with the ability and agreement to continue and land at the planned destination continue along the clearance to the clearance limit. A contingency trajectory had previously been defined, and agreed to, to the destination consistent with lost communication procedures. The flight continues on the contingency trajectory.
    - Other flights follow the same process as described for the end-to-end clearance.

In all cases, other aircraft are separated from the aircraft having experienced the lost-link.

Figure A-3 illustrates contingency trajectories to an alternate airport together with the impact that a revision may have on contingency trajectories. When revisions occur:

- Contingency trajectories must be unambiguous and known to the aircraft. Transactions involving a change to the contingency trajectories must be atomic.
- New contingency plans must be included as part of the negotiation process and agreed to.

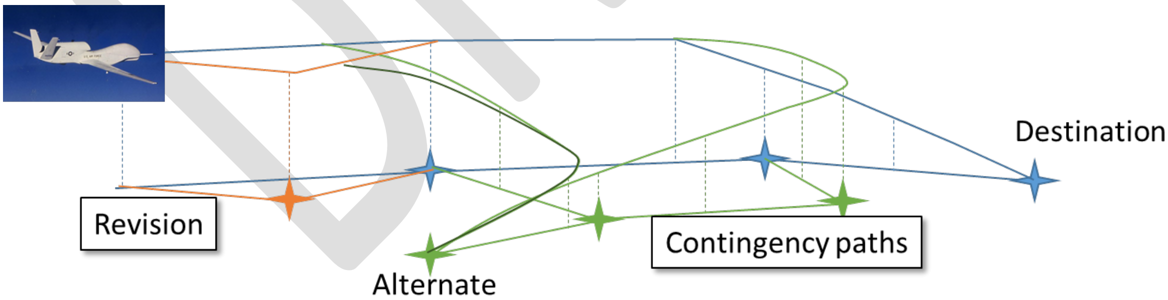

Figure A-3. Contingency paths and their revision

A.3 VOLUME-OF-AIRSPACE OPERATIONS

Some RPAS may be geo-fenced to operate within a volume of airspace. This airspace may be dynamic, but indicated and shared to both AUs and ASPs. However, individual flight operations within the volume may not be shared or indicate to ATC.

TBO operations would, in general, be segregated from such airspace volumes. Transit of the volume may be permitted with an indication that the transiting aircraft has been warned of the hazard.

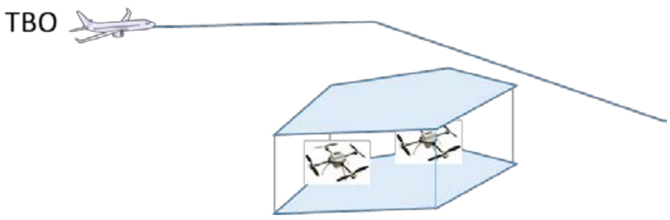

Figure A-4. Volume-of-airspace operations for geo-fenced RPAS

APPENDIX B – TBO AND THE CONCEPT COMPONENTS

This Appendix provides a summary of each of the GATMOC Components and describes how each component uses and affects the trajectory.

B.1 AIRSPACE ORGANISATION AND MANAGEMENT (AOM)

AOM organizes and manages the airspace portion of the ATM configuration. Several principles applicable to AOM as described in ICAO Doc 9854 have important consequences for TBO. These principles include:

- Flexible management of airspace based upon services demanded
- Dynamic flight trajectories accommodated whenever practicable
- Coordinated planning and management between adjacent areas minimizes operational constraints
- Airspace organization facilitates the seamless handling of flights and optimum flight trajectories gate-to-gate
- Designated airspace exists but does not permanently preclude mixed usage/mixed equipage operations

As individual flight trajectories are not precisely defined until closer to departure, the organization and pre-tactical management of airspace is largely based upon anticipated flows. Other information such as winds, outages, military airspace requirements are also considered. Where anticipated flows indicate the possibility of accommodating dynamic flight trajectories, airspace is organized to accommodate these as practicable. As trajectories become known closer to operations, the aggregation of these trajectories into flows permits a refinement of the ATM Configuration based upon services demanded.

Refinement of the ATM Configuration requires collaboration. AOM collaborates between adjacent areas, Aerodrome Operations and Demand and Capacity Balancing to ensure a seamless and efficient ATM Configuration consistent with resources deployed to meet demand. While the airspace is managed flexibly, this flexibility is balanced against stability and lead time necessary for predictable and efficient operations.

AOM impacts trajectories via the ATM configuration which may impose constraints upon flights and their trajectories. These constraints potentially include: routing requirements, performance requirements (e.g. on CNS), designated airspace, and use of defined procedures. As describes in the Manual on Flight and Flow – Information for a Collaborative Environment (ICAO Doc 9965, Section 3.5), AOM dynamically updates Aeronautical Information which constrains other Concept Components when defining the trajectory.

B.2 AERODROME OPERATIONS (AO)

Aerodrome Operations plan for and provide the aerodrome infrastructure and surface operations to the ATM System. Integration of Aerodrome Operations with other concept components occurs through ATM Configuration Management and Trajectory Management. For ATM Configuration Management, AO collaborates on the selection and timing of runway configuration based in part upon anticipated departure / arrival flows and their surface needs (e.g. desirable taxi flows).

During planning and re-planning of the trajectory, the expected ATM Configuration, including runway configuration, constrains possible trajectory choices in terms of departure and arrival paths.

Trajectory Management involves the collaboration of AO with other concept components in the update and revision of the trajectory. On departure, updates to the shared trajectory are expected as a result of surface events affecting the expected take-off time. For flights with time constraints, when the change in take-off time results in a time constraint not being met, a trajectory revision is required. Revisions are also required for runway re-assignments.

On arrival, AO collaborates in the planning and trajectory revisions for arrival paths and timing. Trajectory updates are provided to AO, to inform on changes to timing of arrival events.

Under some circumstances, timing constraints are required on departure. In this case, AO collaborates with AUO in the planning and execution of the taxi-path, to meet the take-off time within required constraints. This taxi-path may be cleared to the flight and shared locally, but does not necessitate the sharing of the full taxi-path across all participants.

B.3 DEMAND AND CAPACITY BALANCING (DCB)

Demand and Capacity Balancing operates, using CDM principles, within three time frames:

- Strategic – Optimization of assets for improved ATM Performance (e.g., throughput)
- Pre-Tactical – Deployment of assets, resource allocation, airspace organization and modification of planned trajectories
- Tactical – Demand Management through trajectory changes and airspace adjustment

The use and modification of trajectories is focused in the pre-tactical and tactical stages. As DCB evaluates demand, shared trajectories are used as input, informing Trajectory Management directly and flows for ATM Configuration Management. DCB considers the uncertainty in trajectory data; for example, statistical demand and capacity estimation might be applied.

As previously described, DCB collaborates with AOM and AO for ATM Configuration. DCB evaluates the demand and capacity of feasible ATM Configurations coordinated with AOM and AO.

DCB affects the trajectory through the imposition of flight-specific path (e.g., routing or altitude) or timing modifications beyond those that may be generally imposed through ATM configuration. For example, ATM Configuration may restrict categories of flights from operating in certain airspace within a specified time window. On the other hand, DCB may impose flight-specific target times on flights operating within defined airspace due to demand and capacity limitations.

DCB participates in trajectory planning and re-planning in collaboration with AUO to revise the Agreed Trajectory in such a way as to balance demand and capacity. DCB must consider uncertainty and leave sufficient flexibility for future tactical decisions to ensure a robust, performant solution.

B.4 TRAFFIC SYNCHRONISATION (TS)

Traffic Synchronisation (TS) focuses on the adjustment of individual trajectories in the time dimension to allow for a “safe, orderly and efficient flow of air traffic”. TS uses and modifies trajectories during planning, re-planning and execution.

During planning and re-planning, TS uses trajectories to identify the need for the modification of timing to ensure orderly flow. This includes the application of time constraints on the trajectory with appropriate bounds to account for uncertainty and perturbations. AUO is informed of necessary constraints and may initiate a re-planning of this and other flights, to yield a preferable outcome. For example, in accordance with collaboratively-agreed rules, an AU may elect to assign necessary delay to one flight in lieu of another.

When a controlled time has been determined and placed on a trajectory, during execution TS ensures that the controlled time is met through the issuance of one or more control instructions to the flight. Trajectory uncertainty and perturbation is considered in decisions regarding when and how frequently to control the flight.

B.5 CONFLICT MANAGEMENT (CM)

Conflict Management consists of three layers:

- Strategic conflict management occurs through a combination of AOM, DCB and TS all acting to ensure that their decisions simultaneously do not create new conflicts, but also reduce the likelihood of future actions necessary for separation provision.
- Separation provision occurs during flight execution by modifying and executing a flight's trajectory to avoid a hazard projected to conflict within a specified horizon.
- Collision avoidance is independent of separation provision and is only activated when separation provision has been compromised. Collision avoidance occurs within shorter conflict horizons than separation provision. At a minimum, TBO must be resilient subsequent to collision avoidance actions.

For strategic conflict management, as trajectory solutions are developed and coordinated across AOM, DCB and TS these must:

- Respect any constraints imposed for separation provision within the conflict horizon, or coordinate any trajectory modifications within the conflict horizon and area of responsibility with the designated separator.
- Consider trajectory uncertainty to ensure future actions for separation provision are not likely to adversely affect ATM System Performance. Methods include:
    - Managing the likelihood of conflict occurrence from planned trajectories
    - Provision of sufficient margin in a trajectory to allow, if necessary, separation provision with minimum impact

With successful strategic conflict management, the frequency of separation provision actions should be minimized. Separation provision uses an updated trajectory to evaluate for conflicts with hazards. This updated trajectory must reflect the known aircraft state, must reflect clearances to the flight, and may be updated with higher frequency than the shared trajectory as greater accuracy is required for separation provision than other concept components.

In the event of a detected conflict, separation provision will provide a clearance which modifies the trajectory of one or more flights to resolve the conflict subject to meeting known constraints if possible. Other concept components, as part of the trajectory information, have provided constraints necessary for meeting their objectives. Furthermore, margin has been built into the trajectory to allow likely conflict resolution manoeuvres to meet these constraints. When shared constraints cannot be met, the separation provision clearance may still be provided, but a trajectory revision is initiated.

Clearances provided for conflict management are expected to be closed, allowing a trajectory to be computed and shared. Under certain exceptions, an open clearance may be required, this circumstance is described further in (Section 3.3.1).

B.6 AIRSPACE USER OPERATIONS (AUO)

Airspace User Operations are involved during planning, re-planning and execution of a flight. Knowledge of the planned ATM Configuration, meteorological forecasts, equipment outages, and other information is used by the AU to compute a trajectory meeting known ATM System constraints while best meeting the AU's objectives. As the ATM Configuration is modified by AOM and DCB, the AU-provided trajectory may respond with a revision.

Throughout planning and re-planning, AU-provided trajectories are subject to constraints specific to the flight stemming from other components (e.g., AOM, DCB, TS). Since the AU is involved as the trajectory is being coordinated, the AU may propose preferred alternatives during trajectory revision in accordance with collaboratively agreed rules for trajectory management (see Section 2.3.2).

The AU operates the flight in accordance with clearances provided to and accepted by the flight deck. These clearances are provided by ATC in such a manner as to deliver the Agreed Trajectory (Section 3.3.1). During aircraft execution, AUO may trigger a trajectory revision for re-planning purposes. The AU may also provide information on trajectory preferences for other concept components to incorporate in their decisions.

B.7 ATM SERVICE DELIVERY MANAGEMENT (SDM)

As stipulated in ICAO Document 9854:

> "The ATM service delivery management function will manage the balance and consolidation of the decisions of the various other processes/services, as well as the time horizon at which, and the conditions under which, these decisions are made."

Under TBO, GATMOC Components interact, using and modifying trajectories as a central mechanism for coordinating and meeting their objectives. As described above, ATM SDM manages these interactions. This will be achieved in part through the application of rules for Trajectory Management (Section 2.3.2) which are collaboratively agreed to. In part, SDM is the process of establishing and applying these rules.

When faced with uncertainty, many decisions across concept components must first determine whether an action must be taken now, by one component or later by another. The deferring of a decision, or coping with uncertainty for robustness, might also need to be accompanied with the deliberate incorporation of margin. Some examples include:

- DCB might defer action regarding a demand/capacity imbalance that is uncertain to occur in favor of later action
- TS may incorporate thrust and speed margin on descent for robustness against separation management action
- AOM may impose airspace structures early versus the expected impact of trajectory-specific tactical DCB measures necessary due to anticipated flows

SDM considers the ATM System performance impact of the above types of decisions.