*International Civil Aviation Organization*

**MIDANPIRG/20 and RASG-MID/10 Meetings**

***(Muscat, Oman, 14 – 17 May 2023)***

**Agenda Item 2.2: Update from States and International Organization**

# USE OF CONNECTED AIRCRAFT (CA) FOR EXCHANGE OF REFERENCE AIRCRAFT TRAJECTORY INFORMATION

*(Presented by the United States)*

**EXECUTIVE SUMMARY**

Connected Aircraft (CA) provides the capability for aircraft to connect to the full range of Air Traffic Management (ATM) information exchange. As connectivity grows more ubiquitous, the CA aircraft, in combination with a global System Wide Information Management (SWIM) provides an opportunity for global connectivity between any ATM participants and the aircraft. In turn, this supports full aircraft participation in Flight and Flow-Information for a Collaborative Environment (FF-ICE) and Trajectory-Based Operations (TBO).

CA supports and improves both TBO and FF-ICE by enabling additional information exchange between aircraft and ground, particularly trajectory information known more precisely by a flight (e.g., its state and intent). In addition, CA brings more situational awareness to the flight crew regarding the ATM environment they are operating in, increases their ability to efficiently absorb and apply such information through applications on the Electronic Flight Bag (EFB), and allows them to participate in trajectory negotiations.

Estimates show that CA equipage levels will reach a critical mass of 50% in 5-8 years in the United States. This is a significant equipage level which warrants further research and consideration of CA concepts.

| | |
|---|---|
| *Strategic Objectives:* | This information paper relates to the Strategic Objective of Air Navigation Capacity and Efficiency |
| *Financial Implications:* | Not Applicable |
| *References:* | ICAO Doc. 9854 - *Global ATM Operational Concept*<br>ICAO Doc. 9965 - *Manual on Flight and Flow-Information for a Collaborative Environment (FF-ICE)*<br>ICAO Doc. 10130 - *Global Trajectory-Based Operations (TBO) Concept* |

## 1. INTRODUCTION

1.1 Building on the *Global ATM Operational Concept* (ICAO Doc. 9854), the *Manual on Flight and Flow-Information for a Collaborative Environment (FF-ICE)* (ICAO Doc. 9965) and the

*Global Trajectory-Based Operations (TBO) Concept* (ICAO Doc. 10130) all support the following core principles related to trajectories:

- **Share it**: Sharing of trajectory information eventually leading to a common view as the Agreed Trajectory
- **Manage it**: Managing trajectory information using Collaborative Decision Making (CDM)
- **Use it**: 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

1.2 As a part of Global SWIM (see ICAO Doc. 10039) Connected Aircraft (CA) supports and improves both TBO and FF-ICE by enabling additional information exchanges between aircraft and ground, ensuring all participants are operating with the same consistent information. The CA allows information known only to a flight to be shared with Air Traffic Management (ATM) systems. This reduces the need for ground systems to assume or model flight data which can lead to errors and subsequent inefficiencies. Additionally, CA brings more situational awareness to the flight crew of the ATM environment they are operating in, increases their ability to efficiently absorb and apply such information through capabilities such as the Electronic Flight Bag (EFB), and allows them to participate in trajectory negotiations.

1.3 Ultimately, CA provides the capability for aircraft to connect to the full range of ATM information exchange for reaching a common plan across decisions as illustrated in Figure 1. By also leveraging a wider range of connectivity options and Global SWIM, CA leads to a more ubiquitous and flexible system enabling the connection of any ATM system participant to the aircraft anywhere on the globe.


**Figure 1. CA Information Sharing for TBO**

## 2. DISCUSSION

2.1 Decades of prior research, including simulations, laboratory studies, and flight tests, have shown that the following categories (see Table 1) of aircraft information help improve ground trajectory predictions, essential for TBO.

**Table 1. Aircraft Information**

| Type | Examples |
|---|---|
| **Current State** | Position, Altitudes, Speeds, Weights |

| | |
|---|---|
| **Future Intent** | Flight Management System (FMS) Aircraft Trajectory Prediction Data (such as provided by Automatic Dependent Surveillance – Contract Extended Projected Profile (ADS-C EPP)) |
| **Guidance Modes** | Lateral, Vertical, Speed |
| **Guidance Settings** | Cost Index, De-rate settings, Altitude Window, Speed Window, Heading Window |
| **Performance Limits** | User Preferred Speed Limits, Maximum Cruise Altitude, Minimum Calibrated Air Speed |

2.2 CA provides a means to expedite the provision of such data, by leveraging capabilities to more cost-effectively access and provide such data given the existing fleet. In addition, the CA provides greater flexibility to allow legacy aircraft to balance the cost of provision with benefits while allowing new value propositions to emerge beyond what is currently described by international standards, for example the Extended Projected Profile (EPP). Such CA capabilities will be available on an expedited timeline for a wider set of aircraft than would be available by awaiting the deployment of the EPP through ATN-B2 ADS-C on its own.

*2.3 CA Use Cases*

2.3.1 There are three basic use cases of trajectory provision that can be supported by CA and make use of aircraft-derived trajectory information:

- Updates to the trajectory predicted by the FMS, corresponding to the active route, allowing air and ground systems to be aligned, yielding an improved trajectory in ground systems. This corresponds to the use case applicable to the ADS-C EPP.
- Trajectory negotiation involving an exchange of trajectory planning information upon request by the airspace user. This allows all participants to reach a consistent agreement on the trajectory plan including how it is to meet constraints.
- Automated synchronization of a trajectory prior to issuance of an ATC instruction to ensure the ATC instruction will meet its objective.

2.3.2 Trajectory negotiation involves the provision of a proposed trial trajectory from the airspace user (AU), while meeting constraints provided by the various ATM Service Providers (ASP). Negotiation allows an agreement on the Trajectory to be reached that is the best plan for the AU, given any constraints needed by the ASP to manage system performance. This negotiation provides the common plan required by TBO.

2.3.3 Automated synchronization provides a forward-looking, value-added use case for CA. When the ASP wants to provide an instruction to the flight, being able to assess the impact of that instruction on the trajectory is useful to evaluate the consequence of the instruction. Without information from the aircraft, ground-based systems rely on the assumption that the provision of a new clearance will not result in the change in some other aircraft intent parameters. This can be a flawed assumption resulting in an instruction that does not meet the objective. Yet being able to make such an assessment accurate requires additional information from the flight deck, which CA could be used to supply.

2.3.4 It is cumbersome to leverage the secondary (inactive) flight plan available on some FMSs to derive intent for trial planning, especially when dealing with multiple plan options. Additionally, there are currently no mechanisms to make such secondary plan intent information available from the FMS. This limits the ability of current avionics to supply the data required for the trial planning use case described above. With some adaptation, possible today, CA can provide the required capability.

2.3.5 CA concepts are currently being evaluated to potentially provide such information to allow ground systems to estimate the aircraft intent for a proposed plan. Figure 2 illustrates two example paths for obtaining trial plan intent. An EFB application could host identical software from the FMS and generate trial plan intent based on synchronizing information ingested from the FMS and other avionics. Alternatively, the full operational capability (FOC) might provide the capability. By synchronizing settings and the aircraft state, the same trajectory that would be predicted by the FMS can be provided by the EFB.

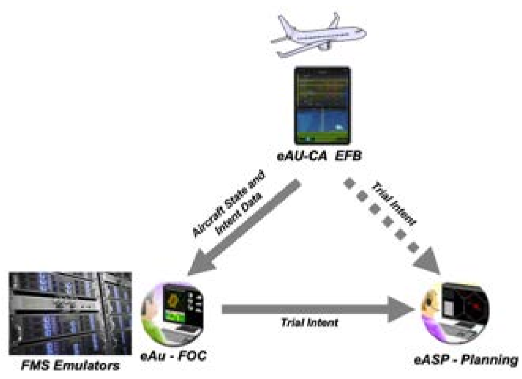


**Figure 2. Trial Plan Intent**

*2.4 CA Data Access and Capabilities*

2.4.1 Leveraging data from CA requires far less commitment from aircraft owners and operators. Aircraft equipped with the latest FMS models such as the GE Connected FMS (CFMS), Garmin Flight Stream or the Honeywell Boeing 787 FMS provide ready access to data which can be easily processed by mobile devices for uses such as trajectory predictions, either on the device itself or by packaging and forwarding to ground systems via Internet Protocol (IP). For aircraft with older FMSs, Aircraft Interface Devices (AID) as illustrated in Figure 3 below offer a cost-effective mechanism to access data.

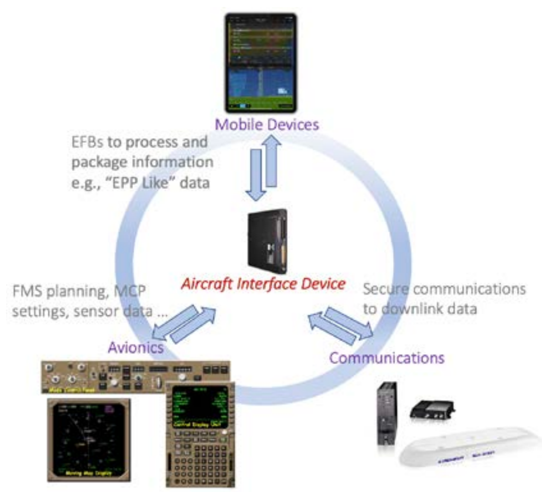


**Figure 3. Aircraft Data Access**

2.4.2 Information can come from various types of avionics and sensors, some currently accessible or easily tapped, while others more challenging and requiring stronger justification for cost of access. Avionics that can provide data include the FMS, Navigation Display (ND), Mode Control Panel

(MCP), Control Display Unit (CDU), Air Data Computer (ADC), Communications Management Unit (CMU) to name a few.

2.4.3 The Navigation Display (ND) that is common to most transport aircraft could be leveraged to extract important lateral path, wind forecast and estimated time of arrival (ETA) data. If a time, speed, or vertical constraint were active in the avionics, that data is also available.

2.4.4 The MCP provides outputs that describe the state of the aircraft guidance systems. Data from this source can extract upcoming vertical clearances, if an aircraft is flying a vector, when the aircraft is using the flight plan from the FMS and what control modes the aircraft is using to navigate. This data can be used with the ND data to build a higher fidelity picture of the trajectory, particularly with short time horizons.

2.4.5 Finally, there is opportunity to access the ACARS communications bus via the AID that could also provide data to improve trajectory predictions. This data could range from aircraft performance data currently used by aircraft dispatchers to a full trajectory prediction by the FMS such as the ARINC 702A intent message depending on the FMS type. Such a bi-directional mechanism through ACARS also allows information to be sent to the FMS such as forecast winds, flight plan changes, etc.

2.4.6 Table 2 below provides an initial assessment of the availability of aircraft information from Table 1.

**Table 2. Aircraft Information Availability**

| Type | Availability |
|---|---|
| **Current State** | **High degree of availability:** Assume basic data an avionics interface device can collect from typical aircraft data buses. |
| **Future Intent** | **Medium degree of availability**: Some avionics provide this now e.g. ARINC 702-A Intent output. Emerging capabilities, such as Connected FMS, will enable higher availability. |
| **Guidance Modes** | **High degree of availability**: Assume basic data an avionics interface device can collect from typical aircraft data buses. |
| **Guidance Settings** | **Low degree of availability**: Limited avionics provide now, however, emerging capabilities, such as Connected FMS, will enable greater availability. |
| **Performance Limits** | **Low degree of availability**: Limited avionics provide now, however, emerging capabilities, such as Connected FMS, will enable greater availability. |

2.4.7 EFB with Avionics Connectivity brings additional display, computing power and ability to exchange two-way data with certified/installed avionics. Over the past two decades, EFBs have been fully adopted by US airlines, and are now in use at a near-100% rate. Originally, these EFBs were either installed avionics, or portable purpose-built devices intended for use on aircraft. Installed EFBs often had two-way connectivity with other avionics systems to allow for sharing of information between the devices, supporting applications such as aircraft performance and weight and balance computations. Portable purpose-built EFB systems were often installed with "read only" single direction integration with installed avionics systems. These installations often included an ARINC 429 converter that allowed the portable EFB to have access to avionics generated data, such as aircraft position, air/ground sensors and other data, but the portable EFB could not send information to the aircraft systems. The creation of the tablet-style personal computing device (e.g., the Apple iPad) and other similar lower cost devices have led to today's US Air Transport fleet having nearly-ubiquitous equipage between portable and installed EFBs.

2.4.8 To complement the proliferation of both installed and portable EFB devices, system architectures have evolved to enhance the creation, sharing and transfer of aircraft data. Components that have enabled these architectures include the AID, wireless cellular connectivity, Bluetooth connectivity, and wired connections. AIDs have become more common in US Air Transport fleets over the last decade because they provide security between certified avionics systems and non-certified, often portable EFBs, while still allowing for sharing of information between these systems without the need for hard-wired connections between individual components.

2.4.9 Another advantage of the AID is that it provides operators flexibility by allowing EFB hardware to be updated through replacement, without necessarily requiring any changes to the aircraft wiring or interfaces. Some manufacturers now offer wireless connectivity via Bluetooth technology between avionics and portable EFB systems which further reduces or eliminates the need for any aircraft modifications to enable EFB and avionics integration. Cellular technology, satellite connectivity and other networks have proliferated to the point where aircraft information exchange between the aircraft and ground to support EFB and avionics applications are available for all aircraft suitably equipped.

*2.5 Current and Anticipated CA Equipage in the United States*

2.5.1 Figure 5 below is a range of equipage estimates for the United States Air Transport Fleet based on current 2022 fleet equipage estimates, the FAA fleet forecast, and the predicted behaviors of nine of the largest US fleet airline operators. Equipage refers to connectivity between aircraft avionics and EFB. The dark blue line indicates the natural curve (aircraft already equipped or will come standard). The light blue line adds forward fit and retrofit assumptions.

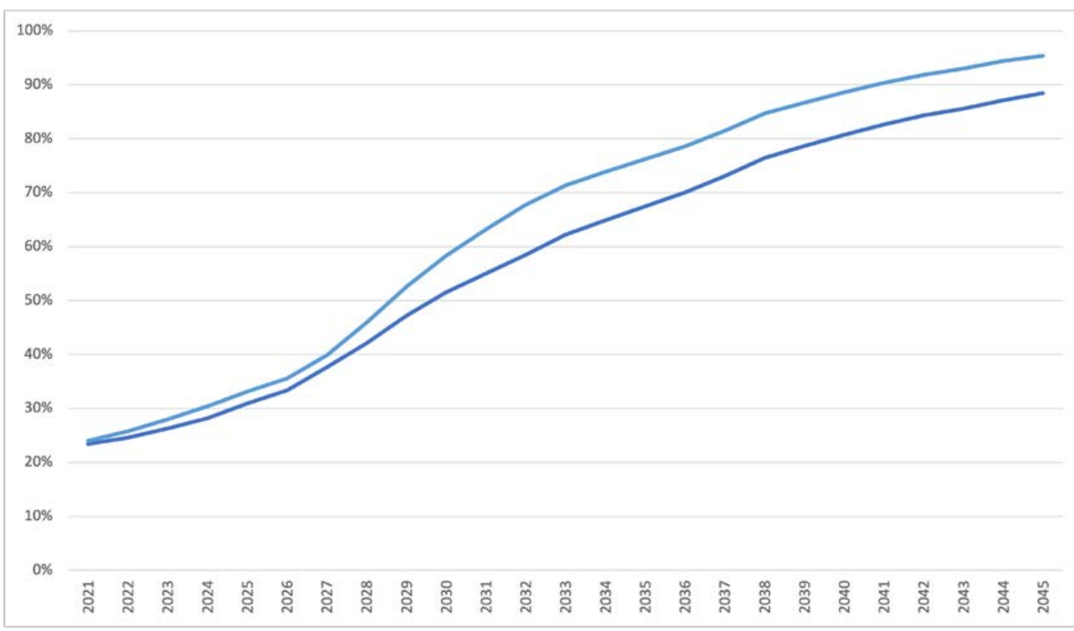


**Figure 5. Connected Aircraft Equipage Forecast in the United States**

2.5.2 It is expected that two-way connectivity between EFB and aircraft avionics through forward fit and retrofit equipage will become the dominant equipage model over the coming years. It is also worth noting that industry has expressed that this equipage is occurring due to expected operator or manufacturer internal benefits/business case, rather than on any planned operational enhancements from Air Traffic Management initiatives. This is important to understand because – without regard to any additional benefits from TBO or other initiatives - there is a likelihood that US Air Transport fleet equipage for EFB with two-way connectivity will continue to occur and will very likely become the default standard new aircraft configuration by the mid to late 2030s.

## 3. CONCLUSIONS

3.1 Current trends indicate that equipage levels for two-way connectivity between the EFB and aircraft avionics will become prevalent by 2028-2030. Such connectivity provides the foundation necessary to leverage CA for providing aircraft-derived trajectory information on a natural equipage timeline. Further, such an approach for providing EPP-like data also enables the delivery of a variety of additional capabilities of use to TBO.

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