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Managing Aircraft by Trajectory: Literature Review and Lessons Learned
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Presentation Outline

• Management by Trajectory Concept Summary
• Trajectory Management Study Summary
• Lessons Learned Regarding:
  – Stakeholder Needs and Information Sharing
  – Closed Trajectories
  – Trajectory Negotiation
  – Managing Residual Trajectory Uncertainty
  – User Preferred Routing
Management by Trajectory (MBT) Concept Summary

Key differences between ICAO TBO and MBT:

- MBT distinguishes between trajectory constraints and trajectory description
  - More explicitly identifies where user-preferences in a trajectory occur
- Trajectory negotiation process

The FAA identifies Trajectory Constraints that are required to achieve TFM objectives and conflict avoidance.

Given the Trajectory Constraints, the flight operator fully describes the trajectory that will be flown to satisfy those constraints. The Trajectory Description is sufficient to describe a 4DT but only contains elements to which, through negotiation, the flight operator commits to adhering.

Aircraft Intent more precisely describes how the aircraft expects to fly the Trajectory Description. Aircraft Intent may include details that are not included in the Trajectory Description. Aircraft Intent may change without negotiation; significant changes must be reported to the FAA.
Study focused on enabling technologies and existing concept elements that directly support MBT concept

- **Enabling technologies:**
  - CPDLC/Data Comm
  - ADS-C EPP, ADS-B
  - FMS capabilities, EFB applications
  - FAA ground systems: ERAM, TFMS, TBFM, SWIM
  - A/G SWIM and airborne internet (in-flight connectivity)

- **MBT-related concept elements**
  - Stakeholder information needs and sharing
  - Closed trajectories
  - Trajectory negotiation
  - Managing residual trajectory uncertainty
  - User preferred routing and user preferred trajectories
Study attempted to address:

- Likely reasons why previous MBT concept elements and enabling technologies have not been fully adopted
  - Technical, political, cultural, and other limitations
- Portions of previous concepts that have been adopted and the likely enablers of these adoptions
- Whether there is growing consensus, or lack thereof, about aspects of MBT concept elements

Cited 88 publications

Cited 32 web references
- e.g., aviationweek.com, aviationtoday.com
- 100+ years of Aviation Week online archive

Study publicly available at NASA NTRS website:
- Report # NASA/CR-2017-219671
- https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170009601.pdf

Example quote from Aviation Week July 14, 2003 archive:
Given other FAA priorities, nationwide deployment of CPDLC was deferred despite broad agreement in the ATC community that data link “is the key architectural enabler of almost any future envisioned air traffic management system.”
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Much of the inefficiency in today’s air transportation system can be attributed to a lack of timely and accurate exchange of information across relevant actors—Pilot, FOC, controller, traffic managers.

**Pilot**

- Lack of dynamic information hinders the pilot’s ability to improve flight efficiency.
- FMS database capacity is typically 8.2MB or less.
  - Memory limitations require that some operators carefully customize their databases based on the individual needs of their operation.
    - e.g., removing all holding patterns except those on missed approaches.
  - With the advent of PBN procedures, the demand for increased navigation database memory capacity will continue.

**Success story**

- NASA’s Traffic Aware Planner
  - EFB application with access to internet
    - Optimize trajectory requests based on dynamic information such as status of SAA and updated wind data.
FOC

- Need for causal information
  - ATC coordinator must be able to understand why changes in NAS constraints have occurred
    - Can be a challenge for the airlines to interpret an action taken by ASNP
    - May impact fleet management strategies
- Need for historical information
  - Access to a database of previous ANSP actions would make it easier for ATC coordinators to anticipate constraint changes on the NAS
    - Only CDM FOCs have access to historical information currently through the TFMS thin client applications.
- JPDO findings:
  - Rules and content for data sharing are not clearly defined
  - Lack of appreciation for and incorporation of the role of the FOC to ensure the success of the Data Comm program
Controller

- Equipment codes in flight plan describe the aircraft’s CNS equipment
  - Key piece of information because it determines aircraft capabilities and the procedures the controller must use to accommodate those capabilities
  - In the mixed equipage environment of Data Comm and ADS-B, it will become even more important
- Controller and pilot views of the weather can be different
  - Controller can trust the pilot to maneuver as necessary, but this puts the aircraft on an open trajectory
- Flight plan accurately portrays the lateral profile of the flight
  - Vertical profile is ambiguous to the controller so large buffers are used for separation.
    - If FMS trajectory prediction for top of climb and top of descent were provided, it would address some of the ambiguity
    - Remainder of the ambiguity is a result of the differences in trajectory prediction between FMS and ERAM
Traffic Managers

• Time horizon of traffic managers is much larger than that of controllers and pilots.

• Filing flight plans as early as possible (preferably the day before) provides the ANSP with an accurate picture of expected demand
  – Lessen delays that arise as a result of constraints in the NAS

• Flight planning services that are CDM participants have a direct connection to TFMS
  – Flight plans go immediately into TFMS as early intent messages
    o Ensures that a flight will be considered known demand if any TMIs are issued

• If a flight plan is not in TFMS due to late filing, any modeled TMIs will be based on incomplete information
  – TMIs will not accurately and efficiently address the imbalance that TFMS is trying to solve
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Closed Trajectories (1/3)

• A closed trajectory refers to ANSP automation, FMS, and FOC automation all having a common, shared view of the aircraft’s intended trajectory.

• Closed trajectories enable accurate evaluation of the paths of multiple aircraft for the purpose of CD&R and flow management
  – Reduces the need for downstream controller intervention

• Closed trajectory clearance:
  – Any controller-issued clearance that ensures the updated trajectory is closed (e.g., a route amendment)

• Open trajectory refers to aircraft no longer flying a shared view between the aircraft and ground automation
  – e.g., aircraft flying based on selected heading, speed, or altitude in the mode control panel
    o Overrides the FMS trajectory
Closed Trajectories (2/3)

Closed Trajectory Clearances Issued by Voice Communication

• In the en route cruise environment, the most common closed trajectory clearance issued by voice is the direct-to clearance
  – One or more waypoints in the flight plan are skipped and the aircraft flies direct to the waypoint stated in the clearance

• Other commonly used closed trajectory clearances STARs and IAPs
  – Can identify both the lateral and vertical profile and can be stored in the FMS navigation database

• For trajectories that must absorb delay via path stretching (to meet STA)
  – NASA developed method for voice-issued Efficient Descent Advisor (EDA) clearances
    o Ensures path stretch maneuver is initiated sufficiently downstream to provide pilot with sufficient time to enter path stretch waypoint into FMS
    o Closed trajectory is maintained
Closed Trajectories (3/3)

- Open trajectory clearances exacerbate the trajectory uncertainty in the system

- Closed trajectories provide trajectory predictability
  - Enables controllers to use longer look-ahead, closed trajectory clearances
  - Which further improves trajectory predictability

- However, there is clearly cultural resistance to automated conflict resolution advisories

- One negative impact is not knowing what set of technologies, procedures, and cultural changes will be the tipping point that moves the NAS towards widespread use of closed trajectories
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Current system is not very conducive to trajectory negotiation.

- Voice communication of complex reroutes is impractical for widespread use in the NAS
- Pilot or FOC negotiating the trajectory does not have complete visibility into static (e.g., SOPs and LOAs) and real-time ANSP constraints

Some users have gone to great length to incorporate unpublished ANSP constraints into their flight planning automation

- e.g., UPS found that for their operations, it was most efficient to file their flights in line with what the ANSP was least likely to cancel.
  - Due to the nature of traffic patterns in the NAS, flights in the Northeast corridor mainly use flight plans based on fixed-route constraints
  - Flights in the western part of the country typically use more wind-optimal routing
Trajectory Negotiation (2/2)

• Roadblocks to Adopting Trajectory Negotiation
  – FMS capabilities do not support proposing a new trajectory, only to propose a flight-optimal way to achieve the given flight plan.
  – EFB applications to support trajectory negotiation do not currently exist
    o These applications will likely get developed when sufficient enablers are in place
      ▪ Air carrier industry lack of interest in applications to leverage CTOP is a cautionary tale for trajectory negotiation participation
        » Provides similar types of benefits as trajectory negotiation

• Implications for MBT
  – Trajectory negotiation is one of the MBT benefits that allows users to see direct, tangible benefits across the fleet or for individual flights
    o It will be difficult to make realistic estimates of user participation for trajectory negotiation, which will have a direct bearing on benefits
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Managing Residual Trajectory Uncertainty

Description: The uncertainty that remains after incorporating:

- Closed trajectories
- Trajectory synchronization between automation systems

• Weather and TFM uncertainty will continue to be major contributors
• Implications for MBT
  - Lateral and temporal trajectory constraints are seen as the interface between TFM and MBT
    - Validity of these constraints in addressing demand/capacity imbalances in the presence of weather will likely be degraded
    - MBT can provide flexibility and agility when the constraints are updated to mitigate to some extent the initial inefficiencies
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In domestic US operations, UPRs are limited to non-restrictive routing (NRR) airspace at and above FL 350

- User-preferred routes between specific fixes described by pitch (entry into) and catch (exit out of) fixes
  - Pitch points indicate an end of departure procedures or preferred IFR routings where a flight can begin a segment of NRR
  - Catch point indicates where a flight ends a segment of NRR and joins published arrival procedures or preferred IFR routing
- Leverages Navigational Reference System (NRS) grid of alpha-numeric waypoints
  - e.g., KG78K, KP90G, KP09A
  - Lack of acceptability of NRS for various human factors reasons
Roadblocks to Adopting UPR

- Controller complexity and traffic density in eastern US will continue to prevent the use of UPRs in that region.
- No research has been performed to identify the traffic level threshold where UPR requests should be accepted or rejected.
- FMS database capacity limitations impact UPR flight planning capabilities and potential airborne rerouting.
- Human factors issues associated with the NRS grid can tip the scale towards denying UPRs.
- Many SOPs/LOAs contain trajectory constraints that are unknown to the navigation databases used by the FMS and FOC flight planning applications
  - which can result in flight plans getting amended to support ANSP needs
Questions?