4 Dimensional Trajectory-based Operations (4D TBO)

4D TBO Concept of Operations Overview

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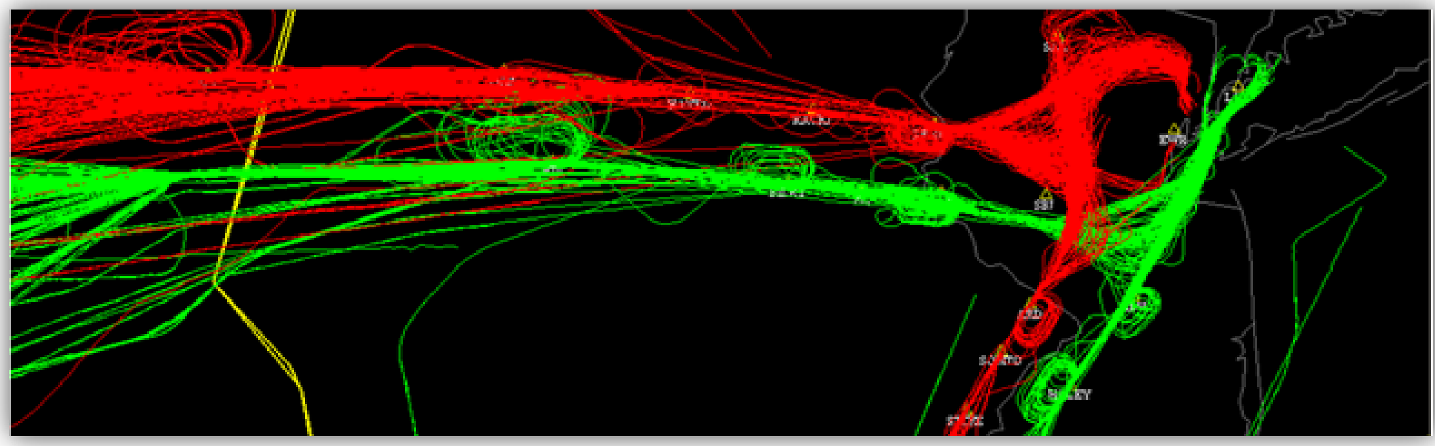
Introduction

- **The Four Dimensional Trajectory Based Operations (4D TBO) Concept represents a fundamental shift of Air Traffic Management (ATM):**
  - From control through tactical and verbally issued instructions to management of air traffic by issuing strategic clearances via data communications and voice. These clearances represent fully defined closed-loop trajectories.
  - United States: 4D TBO includes surface operations
- **The hallmark 4D TBO is the increased use of ground and airborne automation**

Introduction, Cont'd

- **The fundamental requirement of NextGen is to safely and efficiently accommodate significant increases in traffic, and to do this in airspace that is already congested, such as heavily traveled city pairs (e.g., Washington and Chicago) and near the busiest airports (i.e. New York, Atlanta, etc.).**
  - Manage all aircraft of varying capabilities using trajectories.
  - Trajectory management provides an ability to efficiently manage airspace in response to changing situations such as weather and traffic.



Qualitative Benefits of 4D Trajectory Operations

- Improvement in air traffic operations by increasing the overall predictability of traffic
- Collaborative environment: Optimal operations for airlines (aircraft using preferred routes and altitudes: pre-negotiated trajectories)
- Better service provided (due to ground-ground and air-ground interoperability)
- Improved capacity
- Reduced costs (e.g. fuel and/or time) and emissions
- Increased capacity (enroute, near airport and on the airport surface)
- Decreased workload for controllers and pilots
  - Automation assistance
    - Reduced voice communications
    - Fewer conflicts
    - Enhanced situational awareness

Today's Operations

- **Problems in busy Metroplex areas are caused by constrained airspace (adjacent airports in close proximity), convective weather, reduced-visibility, ground delays, and practices that limit capacity, throughput, and efficiency.**
  - Traffic flow and loading across ingress and egress routes and runways, are not always well-metered or balanced.
  - Noise abatement procedures, as well as wake encounter risk mitigation, tend to result in operational inefficiencies (e.g. added time or distance flown).
  - During heavy traffic or adverse weather, when executing miles-in-trail, available airspace can be underutilized.
  - The lack of an ability for stakeholders on the airport to share data, collaborate and establish a cohesive strategic plan for movement of aircraft on the surface leads to inefficient ground operations which directly affects arrival and departure flows.

Today's Operations: Pre-departure Flight Planning

In the legacy flight planning system there is limited capability for data sharing between airspace users and the ANSP and therefore solutions are developed that are ad hoc and less-than optimal.

UAL Airline Ops Center

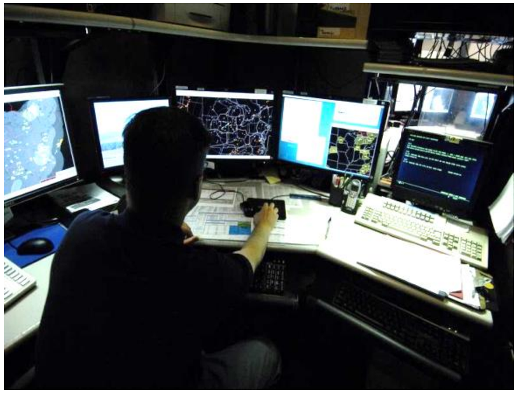
Boeing 777 Cockpit

In many cases, the entities have different sources of information (e.g. weather and traffic) which may result in significantly different views of the same situation.

The lack of data sharing from a common source and the inability to collaborate, often times result in the ANSP assigning routes that are not necessarily those preferred by the users.

Operators are forced to fly a less optimal route that may not meet their desired objectives.

FAA Command Center



ORD Traffic Management Unit

Today's Operations: Surface Operations

- **Surface operations at busy airports present numerous efficiency problems to all stakeholders from the airlines to the passengers and the ANSP.**
  - Delays which occur on the surface result in passenger inconvenience, a delay in arrival and departures, and excessive fuel burn and emissions.
  - Frequency congestion and lack of accurate and real-time predictive data to the Traffic Flow Management System (TFMS) also causes unnecessary delays and other inefficiencies that can ripple throughout the NAS.
  - Ground movements are complicated and delayed due to a lack of a means for stakeholders to perform strategic planning.
  - Information is not generally shared among all the operators and the ANSP.

Today’s Operations: Surface Operations

Airport infrastructure (e.g., runways, taxiways, aprons, gates and other parking areas) are not used efficiently thus extending engine run time and passenger time onboard the aircraft.

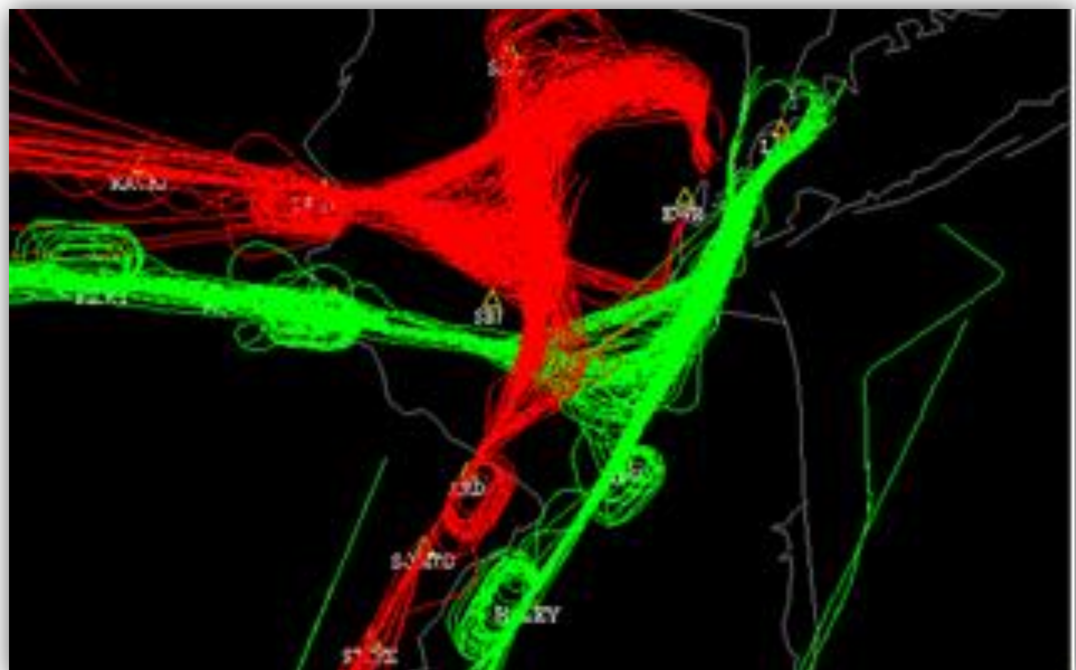
These factors are exacerbated at locations where operators perform extensive ramp tower operations without access to ATC information.

Adverse weather conditions at or near airports that result in ground delay programs, aircraft deicing, runway closures for snow removal, and other operational actions that disrupt “normal” taxiway flows and aircraft gate assignments.

Today’s Operations: Arrival / Departure

Arrivals and departures in busy Metroplex areas present some of the greatest challenges to optimizing efficiency in the NAS.

Individual flights are vectored by air traffic controllers in order to maintain traffic and weather separation as well as perform metering and merging and spacing tasks along the arrival or departure route.

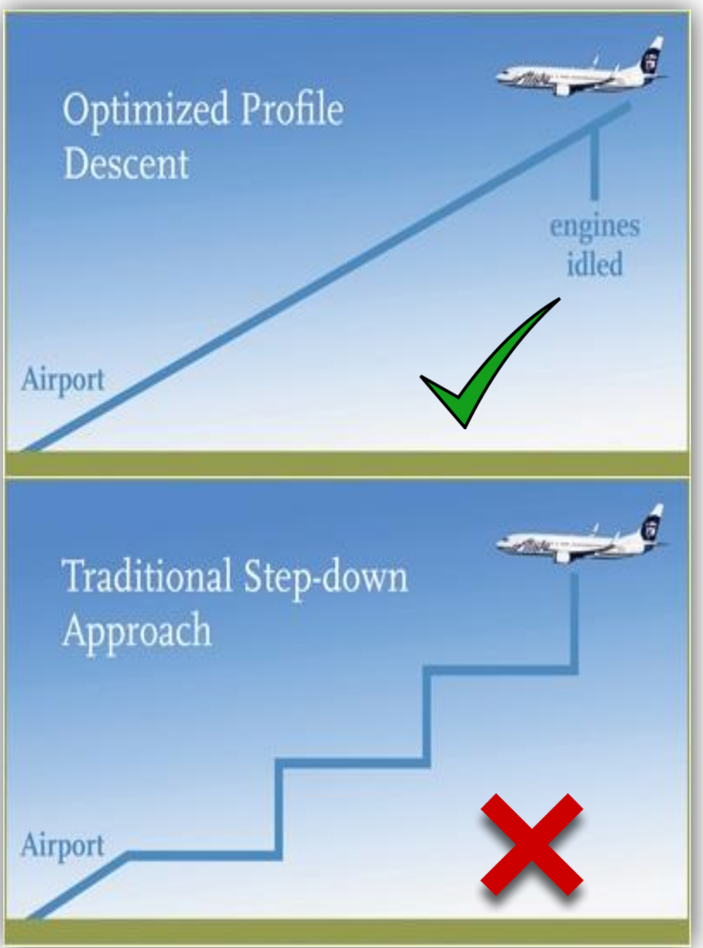


During peak periods, heavy traffic flows along egress and ingress routes coupled with the use of outdated route structures (which were constructed based on ground-based navigation aids), in many cases, do not efficiently handle present day traffic flows.

Today's Operations: Arrival / Departure

The situation is further complicated when weather becomes a factor forcing whole traffic flows to be moved to an even less efficient route.

Air traffic controllers have very few tools available to them to synchronize departure and arrival operations and therefore vector aircraft to "make the operations work". This leads to less efficient operations as well as significant workload for the controllers and flight crews.



Alaska Airlines SEA OPDs

Today's Operations: Enroute

Enroute controllers have few tools to assist them in managing traffic streams such as merging and spacing operations and re-routing entire traffic streams during weather events or other flow constraints.

- Controllers vector aircraft to maintain separation and merging traffic streams.
- When entire traffic streams need to be re-routed due to a weather event or some other constraint, many times these re-routes are pre-defined or "canned". In most cases, these canned routes are not optimized – increased fuel and emissions and added time.

Today's Operations: Enroute

The enroute system is not very flexible and cannot adapt rapidly to changing conditions. Reroutes are generally manually coordinated both on the ground and in the air.

Flight operators are unable to fully develop flight plans that respond to changing airports and airspace status in a timely manner.

On the ground, the collaboration between the ANSP and the FOC/Airspace User are accomplished verbally during periodic meetings and phone calls. Computer print-outs or hand written notes accompanied by verbal exchanges of route data preclude the use of more efficient, flight-specific reroutes tailored to operator needs.

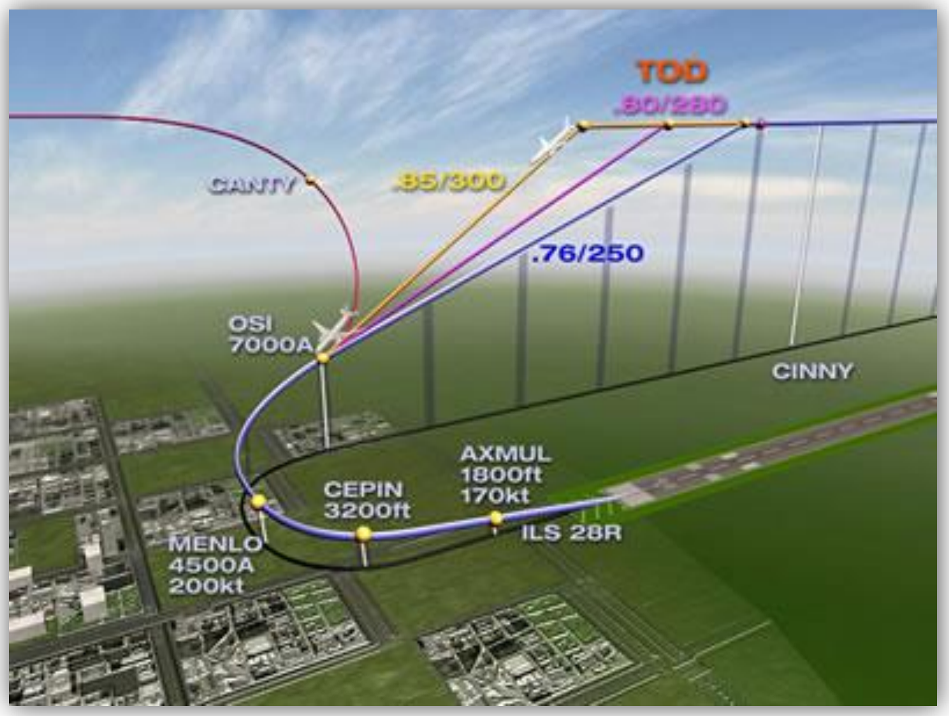
Reroutes are issued by the ANSP to the flight crews via voice communications. This method of communications makes the entire system less agile.

4D TBO Concept Assumptions

- **Precise management of an aircraft's current and future position enables increases in throughput and efficiency in the NAS.**

Concept Assumptions:

- Most aircraft in the NAS are on a 4DT
- Airspace along a route may have varying performance requirements (e.g. Communications, Navigation and Surveillance (CNS)) at a given time and/or location. Aircraft / flight crews must be able to conform to the performance requirements along the route.
- If a flight cannot adhere to performance requirements (e.g. as a result of equipment failure) the aircraft will be required to fly an alternative route or procedure



4D TBO Concept Assumptions

– Every aircraft known to the system (i.e. when a flight plan has been filed) has a 4DT which is initially derived or obtained from a flight plan and maintained in the flight object as the trajectory is revised.

– The accuracy of the trajectory is based upon the aircraft type, equipage, flight crew capabilities and many other factors.

– Trajectories generated in the future will be more accurate than those today.

– The 4DT concept advocates that improved services be made available to equipped aircraft and qualified aircrews especially in high density airspace.

– Changes to a trajectory that may occur along the flight, are managed to the extent possible, through negotiations between the FOC, flight crew and the Air Navigation Service Provider (ANSP)

4D TBO Concept Assumptions

- Most changes to the flight, excluding time critical related clearances are issued via datalink. Time critical clearances will be issued via voice depending on the situation. Some safety critical situations may require the use of voice.
- To insure the integrity of the NAS, in terms of predictability and accuracy of flight paths, negotiated trajectories must be maintained and updated at all times to reflect the latest flight plan, intent information, or clearance.
- During pre-flight, the operator and the ANSP share information (e.g. operator intent, awareness of current and predicted availability of NAS resources) resulting in the negotiated trajectory being similar to the operator's desired trajectory. The ANSP distributes the negotiated trajectory information across all stakeholders.

4D TBO Concept Assumptions

– During pre-flight, the operator and the ANSP share information (e.g. operator intent, awareness of current and predicted availability of NAS resources) resulting in the negotiated trajectory being similar to the operator's desired trajectory. The ANSP distributes the negotiated trajectory information across all stakeholders.

– While flights are airborne, the ANSP automation uses the negotiated trajectory to assist in strategic separation management. Strategic management of separation allows the ANSP controller to look ahead of a given flight (e.g. 20 minutes or more) and see conflicts and with the assistance of automation, devise a new trajectory for one or more of the aircrafts that will eliminate the conflict.

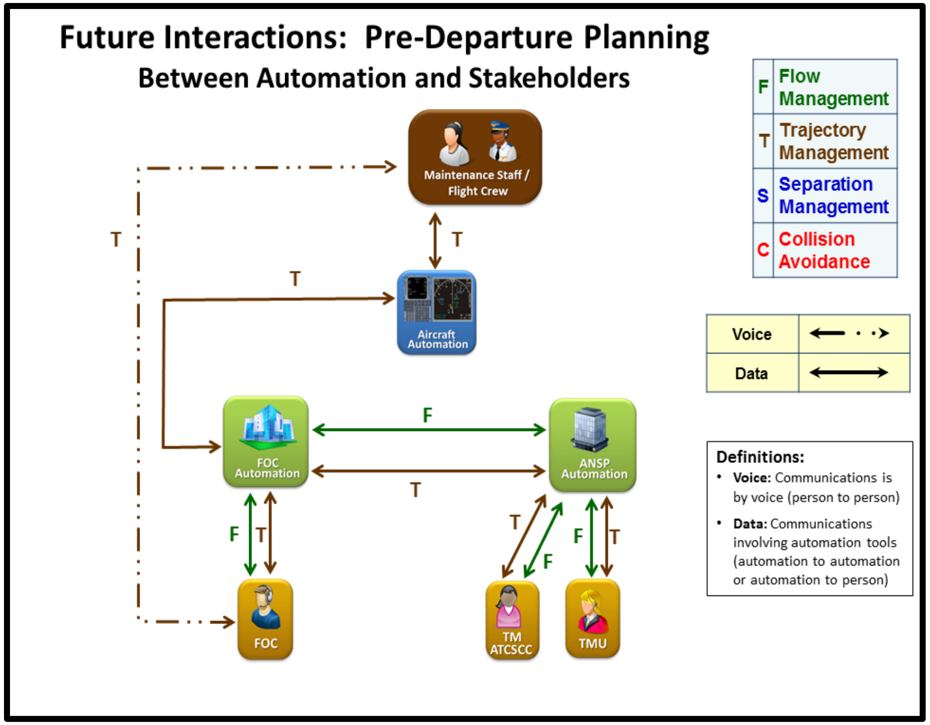
  - When required, ANSP automation will also provide air traffic controllers assistance in managing tactical separation (e.g. less than three minutes) by providing conflict detection and resolution advisories.

4D TBO Concept Assumptions

- Trajectories are aggregated by ANSP flow management automation, together with projected additional demand, to assess potential congestion problems.
  - If congestion problems exist, in most cases, the ANSP and the FOC will collaboratively evaluate alternatives.
  - When an alternative has been negotiated the ANSP will issue the clearance to the affected flight(s).
- After flight completion, the ANSP and the FOCs may perform post analysis, comparing the desired and the negotiated trajectory with the executed trajectory to determine the system performance.

Trajectory negotiation

- **Trajectory negotiation is expected to be performed through the use of automation.**
  - Data to be exchanged and the rules for decision-making must be defined.
  - It is assumed that the details of the negotiation have been established through Collaborative Decision Making (CDM) process. An example this includes the rules and protocol for conducting the negotiation between automation and the participation of the human operators.



Trajectory Negotiation

- **One of the key themes of 4DT is the collaboration and negotiation between the operators and ANSP to determine the trajectories that meet the objectives of the operators with minimal disruption to NAS operations.**
  - Collaboration between operators and the ANSP first establishes the details of the negotiation process. Once this process is established, four phases of trajectory negotiation may ensue.

Four Phases of Trajectory Negotiation

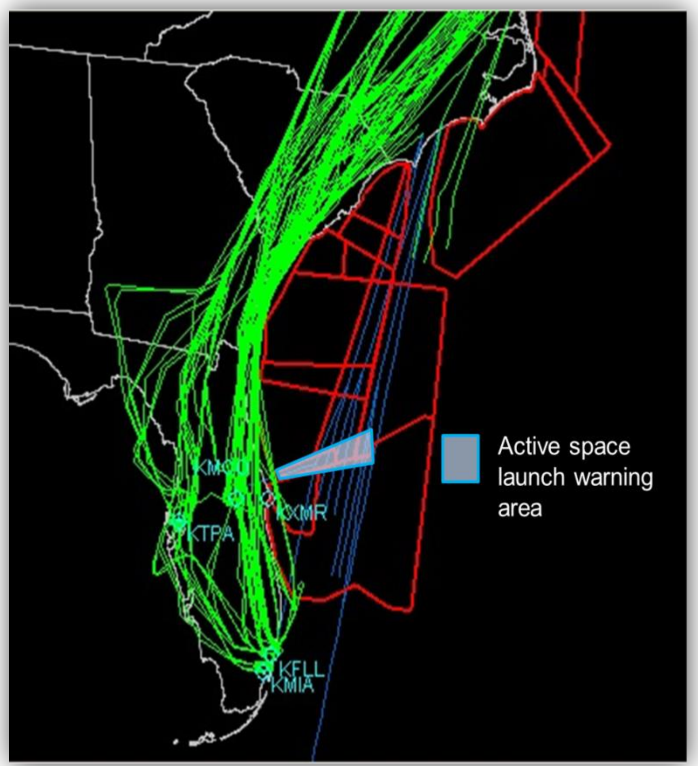
- Pre-negotiation
- Negotiation
- Agreement
- Execution

Pre-negotiation Phase

- **ANSP Perspective:** Pre-negotiation involves estimating the future state of NAS resources requiring the use of data on weather, infrastructure status, special activity airspace and staffing.
  - Demand levels are estimated through the use of available intent data, schedules and historical data.
  - The ANSP uses this information to produce a forecast of anticipated congestion which will require corrective action to mitigate.
  - The information described above is shared with aircraft operators through net-centric information sharing capabilities.
- **Operator Perspective:** This phase involves the definition of the trajectory objectives:
  - <u>Where</u> do I want to fly?
  - <u>When</u> do I want to fly?
  - <u>How</u> would I like to get there based on the known NAS constraints?
  - The FOCs/Airspace Users use shared net-centric information to assist them in determining the best trajectory that fulfills their objectives.
  - The FOC / Airspace User may submit one or possibly several prioritized desired trajectories to the ANSP.

Negotiation Phase

- **This phase begins when the FOC/Airspace User submits their TOS to the ANSP.**
  - The ANSP receives the TOS from the FOC/Airspace User via automation and determines which highest priority trajectory is feasible based on NAS constraints as defined by the CDM process.
  - The ANSP will transmit the desired trajectory selected to the FOC/Airspace User.
  - The FOC may re-negotiate the trajectory if desired



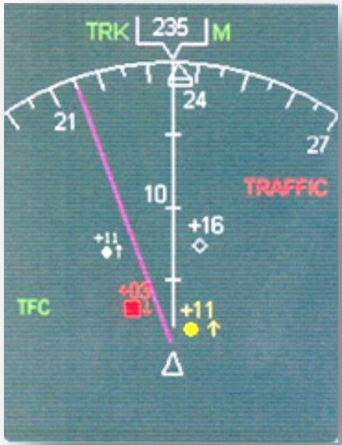
It is important that the renegotiated trajectories be performed in a timely manner to minimize NAS impacts.

Agreement Phase

- **The agreement phase is very brief and consists of the issuance by the ANSP and acceptance by the flight crew of the clearance that represents the negotiated trajectory.**
  - On rare occasion, the flight crew may not agree with the clearance that represents the negotiated trajectory.
    - Example: if convective weather is developing and the pilot-in-command (PIC) decides the routing does not safely circumvent the weather and he/she can reject the clearance.
    - The PIC rejection of the clearance will return the process back to the negotiation phase

Execution Phase

- **The flight has departed and maintains the negotiated trajectory within the trajectory constraints corresponding to the clearance.**
  - The aircraft automation will execute and in some cases monitor compliance (e.g. RNP).
  - Trajectories maintained by ground and airborne automation are updated and compared.
  - When needed, the trajectory is renegotiated.
  - When immediate action is required by the aircraft to insure safe operation is maintained (e.g., traffic collision avoidance system (TCAS) resolution advisory) the trajectory change is made without renegotiation.



TCAS Alert

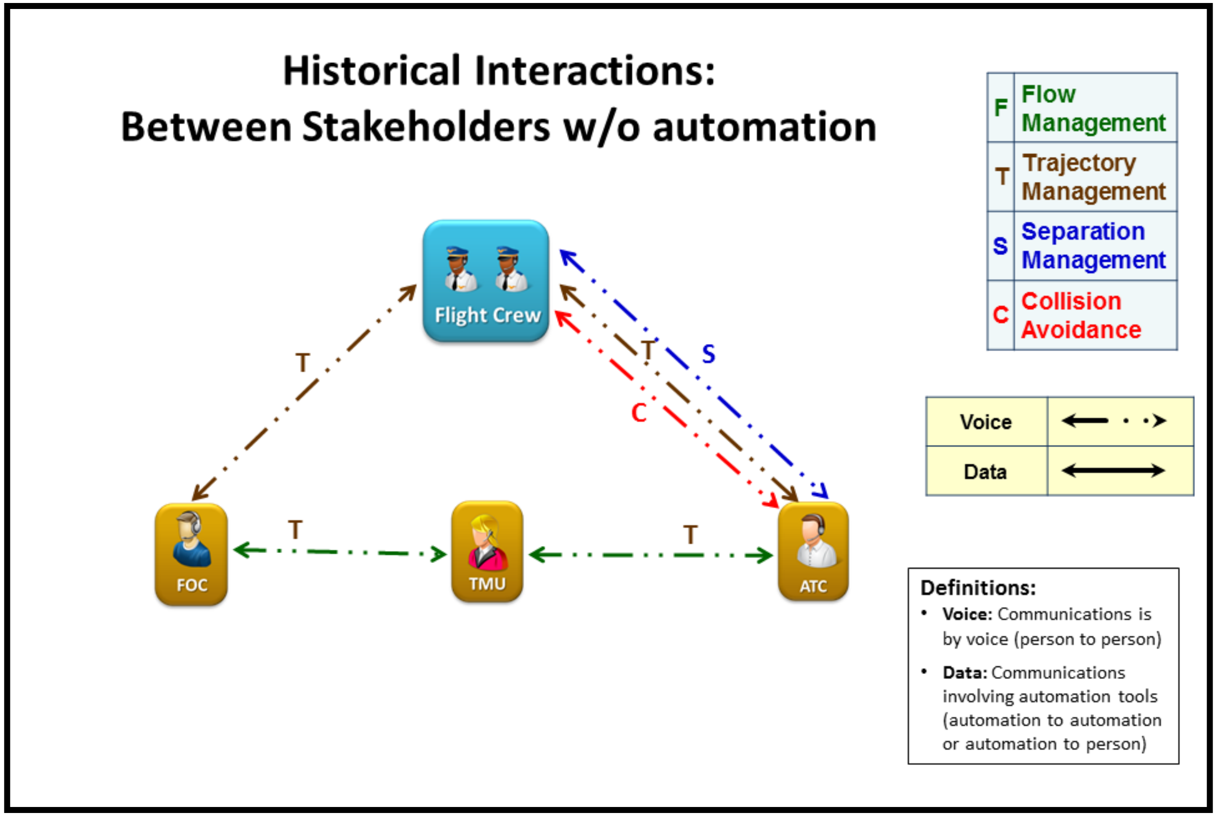
Four Distinct Elements of Air Traffic Management

- **Flow Management –** Includes information and procedures that balance flow streams into various traffic and airport areas in the effort to meet imbalances of demand and capacity. Flow management becomes very important during periods of high traffic volumes in different parts of the country or when weather, TFRs, etc. become a factor. Flow Management is strategic in nature.
- **Trajectory Management –** Trajectory management is sometimes referred to as Tactical Flow which implies the management of a given trajectory within a stream of aircraft or a flow. Trajectory management is inclusive of the management of time to a point along the route as well as horizontal and vertical position. This management could be strategic or tactical.

Four Distinct Elements of Air Traffic Management

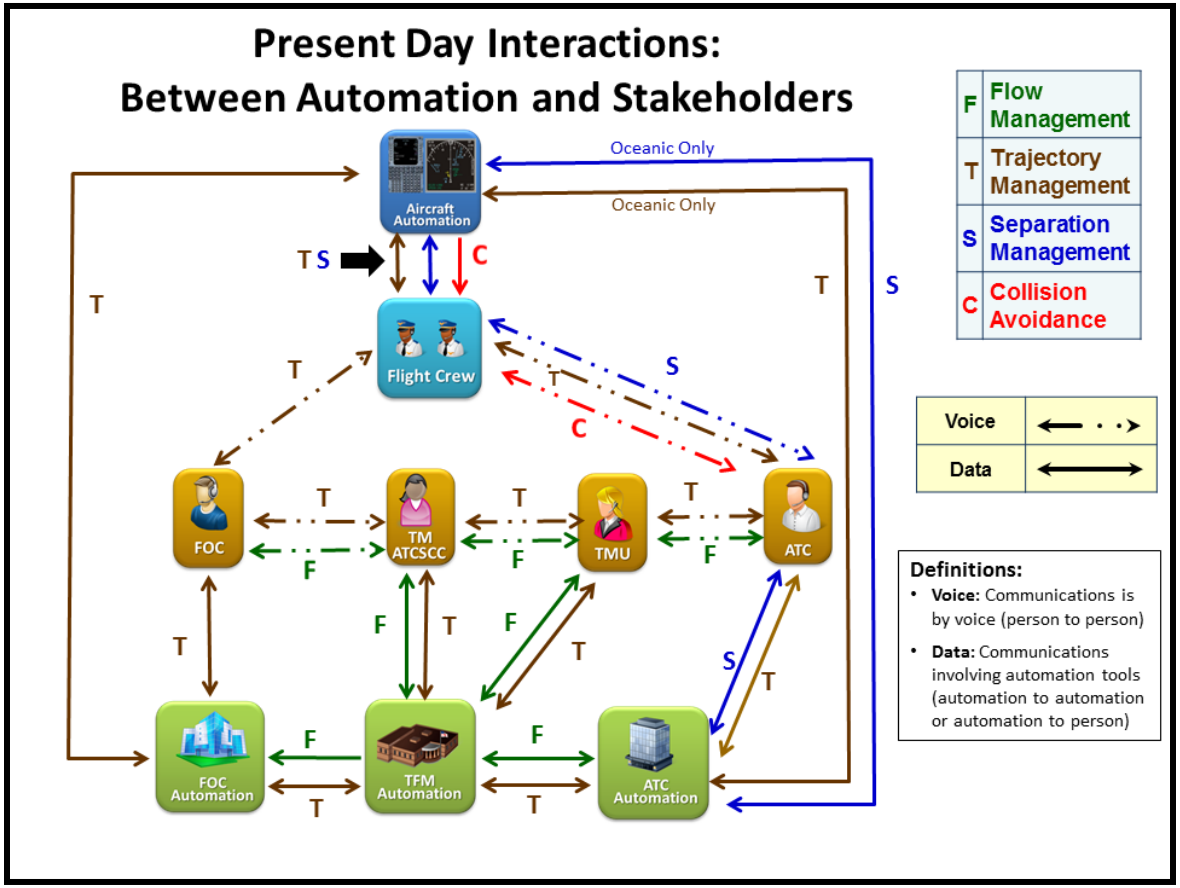
- **Separation Management -** This involves the maintenance of safe separation between aircraft or between aircraft and airspace. Separation is performed primarily by air traffic controllers and at times, by the flight crew (e.g. visual flight rule operations). Separation management is both strategic and tactical.
  - Tactical separation management is usually performed in a relatively short time span (via voice)
  - Strategic separation has a longer time horizon (e.g. 20 minutes) and is managed using 4DT. The 4DT is issued as a clearance via data communications.
- **Collision Avoidance –** Collision avoidance is a tactical operation that is performed by the pilot when an alert is received from the air traffic controller (via voice), Traffic Collision Avoidance System (TCAS), or the Airborne Collision Avoidance System (ACAS)**.** When the instruction is given to the pilot via automation, communication with air traffic control is secondary to the guidance given by the automation.

Information Flow: Historical (prior to 1980)



Human to Human (Little to no automation)

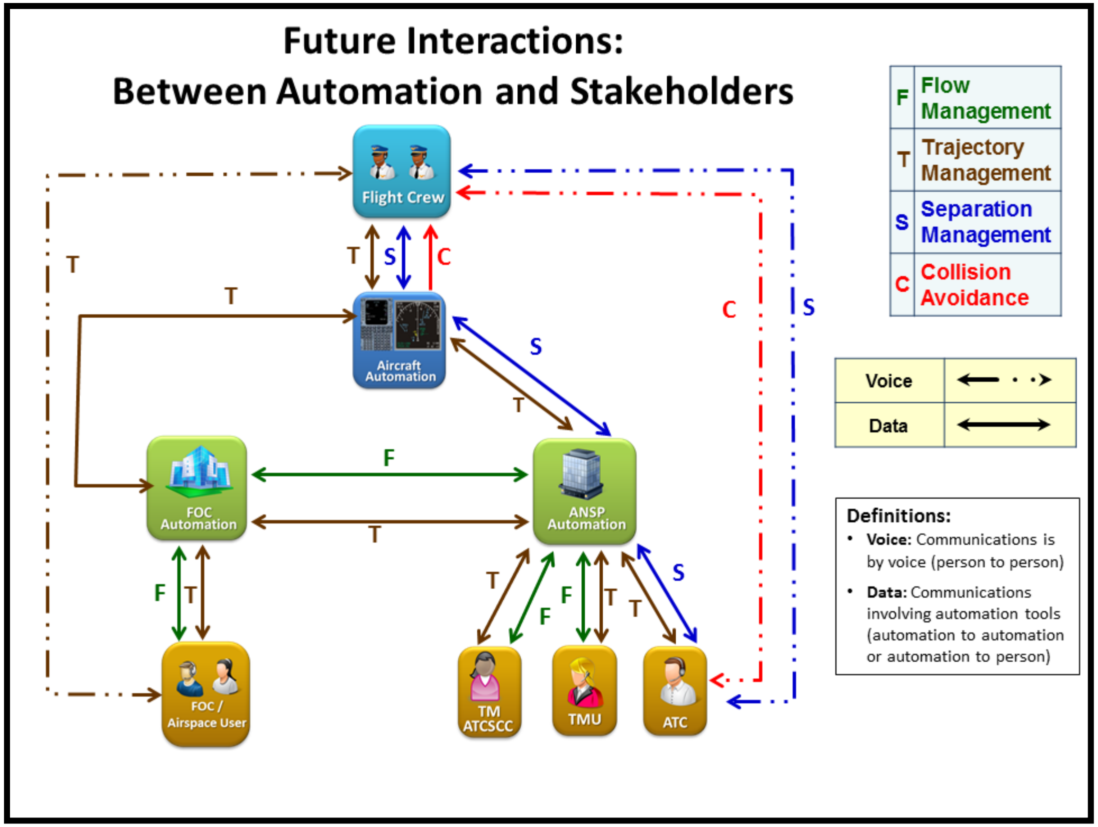
Information Flow (Today)



Person to Person (Some automation assistance)

Information Flow: Future (in support of 4D TBO)

The future is now!



Automation to Automation

Key Terms and Definitions

- **4D Trajectory -** A trajectory computed by the automation (ground and/or flight deck) that defines the flight path of an aircraft from one point to another in four dimensions (latitude, longitude, altitude and time).
- **Closed-loop Trajectory:** When the ground and aircraft automation have the same view of the projected trajectory and the trajectory is continuous (e.g. the aircraft is not on a vector or assigned an interim altitude). The air traffic controller and the flight crew also have a common view of the trajectory as represented by the clearance.
- **Open-loop Trajectory:** When the ground and aircraft automation do not have the same view of the projected trajectory and/or the trajectory is not continuous. There may be instances where the air traffic controller and the flight crew may have a common view of the clearance, but the trajectory does not reflect the clearance**.**
- **Trajectory Option Set (TOS):** A set of one or more prioritized desired trajectories that are submitted to the ANSP by the FOC/Airspace User.
- **Desired Trajectory:** A 4DT generated and requested by the operator with knowledge and consideration of NAS constraints. This is the trajectory that the operator would like to fly and is based on the three questions below.
  - Where do I want to fly?
  - When do I want to fly?
  - How would I like to get there based on the known NAS constraints?

Key Terms and Definitions (cont'd)

- **Negotiated Trajectory:** The agreed to trajectory between the operator and the ANSP that will be flown by a given flight. The intent of the negotiated trajectory is to satisfy the operator's preferences to the greatest degree possible. The negotiated trajectory is derived from the desired trajectory or a set of desired trajectories (trajectory options). The negotiated trajectory may be revised at a later time.
- **Executed Trajectory:** The trajectory that an aircraft has actually flown. The executed trajectory can differ from the negotiated trajectory due to errors in trajectory execution (e.g. unanticipated changes in the winds, flight technical errors, etc.). The executed trajectory only exists behind the aircraft, up to the current position of the aircraft.
- **Clearance:** Authorization for an aircraft to proceed under conditions specified by the ANSP which can result in the execution of either a closed or open-loop trajectory.
  - NOTE: When a decision support tool (DST) computes a trajectory, it is presented to the controller in the form of a clearance. The flight crew will load the clearance in the flight deck automation which intern creates a trajectory for aircraft execution.

Back-up Slides

4D TBO Sequences

Example: 4D TBO Arrival Concept (3D PAM)

Pre-departure Flight Planning: Airline Transport Flight 123

- The dispatcher within the FOC initiates the development a flight plan for Flight 123. The FD develops several prioritized trajectories (TOS) based on information provided by ANSP automation. The information available to the FOC is extensive but may not be inclusive of all NAS level information that may directly or indirectly affect Flight 123. Flight-specific feedback may be provided by the ANSP automation for further refinement of the TOS.
- Dispatch submits the trajectories to the ANSP automation system for approval.
- The ANSP automation analyzes the trajectories based upon the NAS-wide view of current and projected airspace constraints. The ANSP automation selects one of the desired trajectories and notifies the FOC of the selection and provides rationale for the rejection of higher priority desired trajectories.
  - NOTE: The flight dispatcher can accept the trajectory and file a flight plan or submit a new TOS.
- The dispatcher files the IFR flight plan for Flight 123. This provides the appropriate trajectory information (e.g. weight-off-wheels, etc.) to the surface CDM automation to establish the push-back time, digital taxi route and other events such as deicing sequence and time.

Pre-departure Flight Planning: Airline Transport Flight 123

- The dispatcher datalinks the flight plan that reflects the negotiated trajectory to the aircraft. The maintenance staff member autoloads the flight plan into the FMS. The maintenance staff member insures that the flight plan loads correctly and that there are no syntax errors.
  - NOTE: If the maintenance staff member has questions, he/she communicates with the FOC via datalink or voice transmission.
- The ANSP controller reviews the flight plan to ensure that flight plan meets the known needs and requirements. The ANSP determined that all needs and requirements have been met.
  - NOTE: If the ANSP determines that the flight plan needs adjustments, they will contact the FOC if required in accordance with the established CDM processes.
- The flight crew boards the aircraft and reviews the flight plan loaded in the FMS before they request their IFR clearance.
- The flight crew request their IFR clearance via CPDLC (e.g. data communications "Departure Clearance" (DCL))

Pre-departure Flight Planning: Airline Transport Flight 123

- The ANSP, having already previewed the flight plan, uplinks the IFR clearance to the flight crew
- The flight crew receives and reviews the clearance and sends a WILCO response to the ANSP.
  - NOTE: The flight crew has the option to reject the clearance and initiate the renegotiation process if required.
- The flight plan is expected to evolve towards the vision of flight information provision as described in the “Manual on Flight and Flow – Information for a Collaborative Environment”, ICAO Doc 9965, Corr.1.

SEQUENCE: Departure Taxi to a Runway and Take-off: Airline Transport Flight 123

- Prior to arrival of Flight 123, the surface CDM automation receives the estimated arrival time from a net centric capability (e.g. SWIM). Based on the estimated arrival time and projected airport conditions, the surface CDM automation develops the most efficient taxi route from the runway to the terminal in order to meet the operator’s scheduled time at the gate.
- After the aircraft’s arrival on the runway, the taxi clearance is sent to the aircraft via datalink if not already provided prior to arrival.
- The flight crew receives and executes the clearance.
- As the flight crew taxies, they monitor the ground frequency included in the clearance for additional instructions (e.g. to give way to other taxiing aircraft).
  - NOTE: Many aircraft will have a moving surface map display to aide pilots in the execution of their taxi instructions. Some aircraft will have the capability to depict the taxi route on the map. Some of these displays may include surface traffic.
  - NOTE: At smaller airports that do not have sophisticated Surface CDM tools, there will be an expectation that the aircraft will arrive at the gate within the prescribed time-window. In this case the RCs, the ANSP and the flight crew will have to move the aircraft to the gate in the most efficient way possible without the aid of Surface CDM tools.

SEQUENCE: Departure Taxi to a Runway and Take-off: Airline Transport Flight 123

- The crew of Flight 123 successfully navigates the aircraft in accordance with the taxi instructions with minimal cues and delays.
- Flight 123 arrives at the terminal gate on schedule.

SEQUENCE: Departure Taxi to a Runway and Take-off: Airline Transport Flight 123

- The Ramp Controllers (RC), FOC (including airline operations personnel at the airport) and the ANSP process Flight 123 for surface movement using the surface CDM automation. The window for aircraft push-back and the taxi route is established based on the departure runway and the current and projected demand on the airport surface.
- The airline operations personnel load the passengers on the aircraft based upon the push-back time window provided by the surface CDM automation.
- Flight 123 pushes back at the appropriate time and calls for taxi instructions to the movement area spot.
- The RC communicates the taxi instructions to the Flight 123.
  - NOTE: Datalink or Aircraft Access to SWIM may available to RCs for communication of the taxi instructions to the aircraft.
- Flight 123 executes the taxi instructions and remains in radio contact with the RC.
- Flight 123 arrives at the movement area “spot” location and requests taxi instructions from the ANSP via CPDLC.
  - NOTE: Datalink may not be available at smaller airports; therefore the taxi instructions will be communicated via voice.

SEQUENCE: Departure Taxi to a Runway and Take-off: Airline Transport Flight 123

- The ANSP communicates the taxi instructions to Flight 123 via CPDLC for execution.
- Flight 123 receives the instructions, examines them for understanding and possible errors.
- The flight crew accepts the taxi instructions and WILCOs the ANSP via CPDLC.
- Flight 123 executes the taxi instructions with minimal queue and wait time, while remaining in radio contact with the ANSP.
  - NOTE: Taxi clearances will not permit a flight to cross an active runway without positive acknowledgement. Taxi clearances have a clearance limit prior to crossing an active runway.
  - NOTE: At smaller airports that do not have sophisticated CDM tools, there is an expectation that the aircraft will arrive at the runway within the prescribed time window for departure. In this case RCs, the ANSP and the flight crew will have to move the aircraft to the runway in the most efficient way possible.
- Flight 123 arrives at the departure runway hold-short line to meet the scheduled weight-off-wheels time.
- Flight 123 receives and executes take-off clearance.

SEQUENCE: Arrival Taxi from the Runway to the Gate

- Prior to arrival of Flight 123, the surface CDM automation receives the estimated arrival time from a net centric capability (e.g. SWIM). Based on the estimated arrival time and projected airport conditions, the surface CDM automation develops the most efficient taxi route from the runway to the terminal in order to meet the operator's scheduled time at the gate.
- After the aircraft's arrival on the runway, the taxi clearance is sent to the aircraft via datalink if not already provided prior to arrival.
- The flight crew receives and executes the clearance.
- As the flight crew taxies, they monitor the ground frequency included in the clearance for additional instructions (e.g. to give way to other taxiing aircraft).
  - NOTE: Many aircraft will have a moving surface map display to aide pilots in the execution of their taxi instructions. Some aircraft will have the capability to depict the taxi route on the map. Some of these displays may include surface traffic.
  - NOTE: At smaller airports that do not have sophisticated Surface CDM tools, there will be an expectation that the aircraft will arrive at the gate within the prescribed time-window. In this case the RCs, the ANSP and the flight crew will have to move the aircraft to the gate in the most efficient way possible without the aid of Surface CDM tools.
- The crew of Flight 123 successfully navigates the aircraft in accordance with the taxi instructions with minimal cues and delays.
- Flight 123 arrives at the terminal gate on schedule.

SEQUENCE: Departures from Runway to TOA: Airline Transport Flight 123

- The use of surface CDM automation has resulted in the timely taxi of Flight 123 to the runway making an on-time weight-off-wheels departure possible. This ensures that Flight 123 will arrive at the departure meter fix and down-stream fixes including insertion into the overhead stream within the time windows defined by the 4DT.
- Flight 123 is cleared for take-off and executes the take-off roll. The weight-off-wheels time is automatically sent to Surface CDM automation at the departure and arrival airports and the ANSP automation. Sending this information updates the 4DT across automation platforms.
- The autopilot is engaged after take-off and executes the preloaded RNP Standard Instrument Departure (SID). The flight crew executes the speed schedule associated with the assigned trajectory.
  - NOTE: RNP routes will allow aircraft to operate in closer proximity and the display of these routes will provide greater situational awareness for both the flight crews and the controllers. Radio transmissions will decrease due to the clearly defined route structure and datalink, thus decreasing workload.
- Flight 123 transitions to the departure fix at the terminal / enroute airspace boundary. Flight 123 meets the desired schedule of arrival at the departure fix.

SEQUENCE: Departures from Runway to TOA: Airline Transport Flight 123

- After transitioning into the enroute airspace, the ground automation detects that Flight 123 will arrive late at the downstream merge point (MP) due to unanticipated change in the winds. The ground automation generates a speed change and associated trajectory which brings the aircraft back to conformance to the schedule. The speed change and new winds are provided to the aircraft automation. Aircraft automation creates and provides a new 4DT to ground automation, ensuring a closed 4DT.
  - NOTE: Depending upon the conditions, the automation may advise the ANSP to update the schedule rather than issue a new trajectory.
- Frequency changes are issued via datalink.
- Flight 123 proceeds as planned; the aircraft reaches cruise altitude at its assigned slot-time for insertion into the overhead stream.
  - NOTE: If a flight is not in conformance to the negotiated trajectory (meeting time, lateral or vertical position) the automation will detect the lack of conformance. If necessary, a corrective clearance may be generated by automation for the controller to issue. This clearance is reflected in an updated trajectory and is based on aircraft flight characteristics, pre-determined CDM rules, LOAs, etc.

SEQUENCE: Arrivals from TOD to the Runway

- Flight 123 is inbound to the airport. Approximately 200-250 miles out the ANSP automation computes the arrival sequence for Flight 123. The ANSP automation computes a conflict-free trajectory for the aircraft to execute well prior to TOD. This trajectory includes the expected runway, the continuous arrival path (including path stretch or shortening), a speed schedule to the runway and the approach procedure (ILS, GPS, RNP AR, etc.)
- The air traffic controller will analyze the trajectory and if he/she finds it acceptable, will transmit the clearance via datalink. If the trajectory is not acceptable, the controller will have the ability to request another trajectory from the automation or manually control the aircraft to a point where the automation can provide another trajectory.
- Flight 123 receives the clearance via data link. The flight crew then checks the clearance for errors and finds no discontinuities or errors. The flight crew transmits a Will Comply (WILCO) via datalink to the ANSP.
- The flight crew then auto-loads (ACCEPT) the clearance into the FMS for execution. The flight deck automation will send a trajectory downlink to the ANSP automation for trajectory synchronization.

SEQUENCE: Arrivals from TOD to the Runway

- When the flight crew accepted the clearance (WILCO via datalink or by voice), the ANSP will “push” the computed trajectory into the ANSP automation; amending the trajectory. Upon receipt of the downlinked trajectory by ground automation, the ground-based trajectory is synchronized with the aircraft-derived trajectory to ensure a common view is shared by the ground and flight deck automation.
- The flight crew executes the clearance in the FMS; the aircraft will fly the trajectory in the most fuel efficient manner possible. If the flight crew chooses not to accept the clearance (due to weather, syntax errors, etc.), the crew can request another clearance.
- As the aircraft flies the trajectory, the controller may issue another corrective clearance that depicts a new computed trajectory from the ANSP automation to account for traffic conflicts, metering errors, etc.
- The aircraft’s FMS will compute the appropriate TOD for the most fuel efficient descent to the runway. Some FMSs will automatically initiate the descent and other FMSs require that the pilot manually initiates the descent. In both cases, the descent will be a near idle-thrust.

SEQUENCE: Arrivals from TOD to the Runway

- As the aircraft nears the ARTCC / TRACON meter fix, the hand-off to the TRACON is automatic and the frequency change is transmitted to the flight crew well prior to the transition. The flight crew will continue the descent as planned unless the controller intervenes for traffic conflicts or other reasons.
- The air traffic controllers use merging and spacing tools to merge the arrival streams both in the enroute and terminal environments.
- Flight 123 continues the descent seamlessly into the TRACON.
- Flight 123 is capable of performing Flight Deck Interval Management (IM). After arrival in the terminal airspace, Flight 123 is instructed to maintain a set interval behind a company aircraft.
- Flight 123 continues the descent to the downwind leg of the arrival runway. The flight crew is cleared for the RNP AR approach.
- When Flight 123 touches down (weight-on-wheels), the ANSP and the Surface CDM automation will automatically receive notification and the most efficient route to the terminal gate will be computed. After Flight 123 exits the runway and contact is made with the ground controller, ground will transmit (via datalink or voice) the taxi route to the flight crew.

SEQUENCE: Enroute Operations

- Flight 123 has departed from the airport within the designated weight-off-wheels time window. The aircraft is flying a SID and is being metered into the overhead stream supported by automation.
- During the Flight's departure the aircraft traverses through the local airport TRACON airspace and transitions through multiple enroute sectors on the way to the merge point within the overhead stream. TBFM automation establishes the meter time(s) to intermediate fixes and finally the overhead stream and assists the controller in managing the aircraft to meet those times.
- Flight 123 departure has been executed without any issues and arrives in its designated slot in the overhead stream.
- Flight 123 begins the cruise phase of the flight. The flight trajectory is monitored and managed using automation that include point-in-space metering, conflict detection and resolution. Instructions are provided to the flight deck primarily through data communications. The aircraft periodically downlinks trajectory intent information for automation synchronization.

SEQUENCE: Enroute Operations

- The flight crews manage the aircraft's trajectory using flight deck automation. Flight 123 is RTA capable. The aircraft's route clearance includes RTAs to meet time at designated waypoints. These RTAs or changes in speed are occasionally updated to address downstream constraints and path stretches are occasionally issued by ground automation when a delay requirement cannot be met through speed control alone.
- Pre-departure negotiation of the flight trajectory took into account all of the known constraints along the route (e.g. TMI initiatives). Under nominal conditions, inflight changes to the flight trajectory are minimal. Flight 123 proceeds as planned.
- Predictive ground weather automation has forecast strong convective weather in the path of Flight 123's trajectory which would impact the current route clearance in one hour's time. The FOC and ANSP have been notified of the change in the forecast and the FOC and ANSP start the negotiation process.
- The ANSP has determined that the forecast strategic plan for the traffic stream that includes Flight 123 is to reroute flights away from an area approximately 250 miles down-stream from the aircraft's present location. A flow constrained area (FCA) is defined and issued to all the affected operators. Flight 123's FOC will initiate the negotiation by utilizing CTOP.

SEQUENCE: Enroute Operations

- The renegotiation phase for Flight 123 is initiated by the FOC. The FOC analyzes all of the NAS information available from the ANSP and other sources and compares that information with the company's objectives to determine a prioritized TOS. This analysis is performed by the dispatcher in the FOC using automation.
- The prioritized TOS are sent to the ANSP to determine if any of the TOS will be accepted.
- The ANSP notifies the FOC of Flight 123 that the priority #1 trajectory in the TOS is acceptable and the FOC requests that the flight plan representing the trajectory be amended.
- The FOC notifies Flight 123 to expect a flight plan revision from the ANSP. Flight 123 acknowledges the notification and WILCOs the plan.
- The ANSP has notified the other affected FOCs of the proposed plan. The affected FOCs successfully negotiate their new trajectories and contact their flights to notify them of the impending reroute. If any of the flight crews have an issue, they will be addressed through their FOC.
- The ANSP sends the revised clearance to Flight 123 and the other affected aircraft via data link. The Flight 123's flight crew reviews the revision and finds the revision acceptable.

SEQUENCE: Enroute Operations

- The flight crew auto-loads the revised clearance into the aircraft's FMS resulting in the agreed-to trajectory. Flight 123 WILCOs the ANSP.
- The revised clearance is loaded into the ground automation by the controller or automatically by virtue of the "WILCO" response. Flight 123 downlinks a trajectory to the ground automation for synchronization. The other affected flights do the same.
- Flight 123 uneventfully executes the revised trajectory.
- At about 250 to 300 miles from the destination airport, Meter Points (MPs) are used to merge traffic streams and to perform adjacent center metering in order to minimize choke points and absorb some delay needed for merging arrival streams in the upper airspace before the aircraft reaches TOD.
- Approximately 20 to 30 minutes before the aircraft reaches TOD, the expected runway, the fully defined RNAV route to the runway and the arrival procedure is calculated by the ground automation. The route contains the transitions, the lateral path including path stretching and shortening to support metering, and the speed schedule.
- The automation presents the trajectory to the controller with a clearance to send to Flight 123.

SEQUENCE: Enroute Operations

- The ANSP controller reviews the clearance for potential errors and has determined that clearance is fine and sends it to the Flight 123 via datalink.
- The flight crew reviews the clearance and determines that there are no issues or syntax errors and loads the clearance in the FMS and executes.
- When Flight 123 is 15 minutes before TOD, the ANSP advises Flight 123 to expect a runway and route change due to a convective cell that has stalled in the path of the flight.
- The Metroplex airspace demand is high due to the fact that it is the peak arrival period for the area. Special integrated arrival and departure procedures are in place, where arrival and departure traffic are being transitioned to alternative arrival and departure gates. Routes through these gates are bi-directional and require added containment for Flight 123 and other flights affected by the weather. A dynamic RNP route is uplinked to Flight 123 and other affected aircraft.
- Flight 123 and the other affected aircraft receive their individual reroutes. The reroutes contain the new lateral path, altitude, speed schedule and new metering points.

SEQUENCE: Enroute Operations

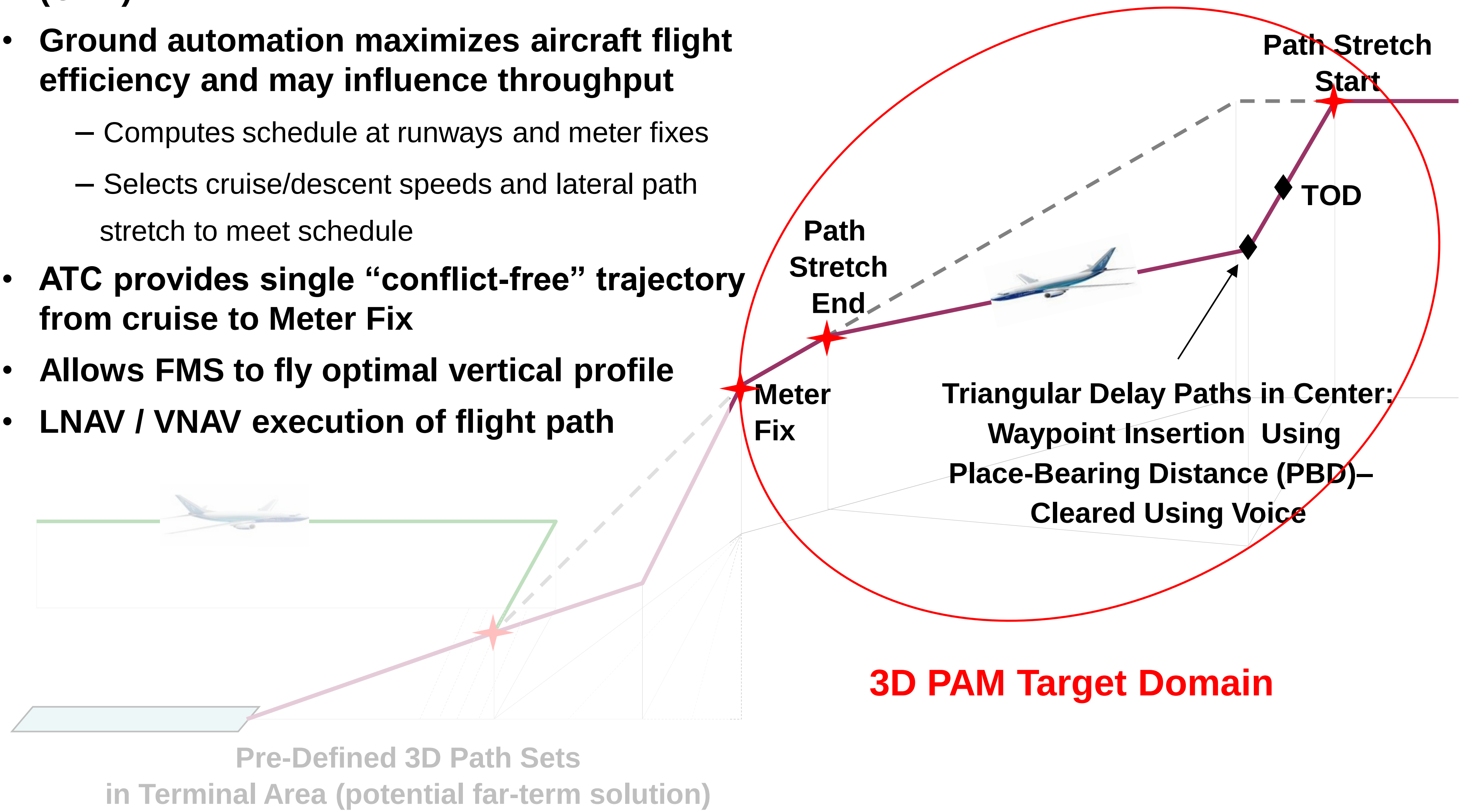
- Flight 123 checks over the revision and finds the revision acceptable and sends a “WILCO” to the ANSP The flight crew auto-loads the revised flight plan into the aircraft’s FMS. The aircraft then downloads a trajectory. The same process is untaken by the other affected flights.
- The dynamic RNP route change is executed by Flight 123 and the other affected flights.
- Flight 123 eventually reaches the TOD point as defined by the aircraft’s FMS. At TOD, Flight 123 automatically starts its descent. The flight crew and the ANSP monitors the descent and makes adjustments as needed (e.g. speed, etc.)
- The TOD signifies the end of the enroute phase

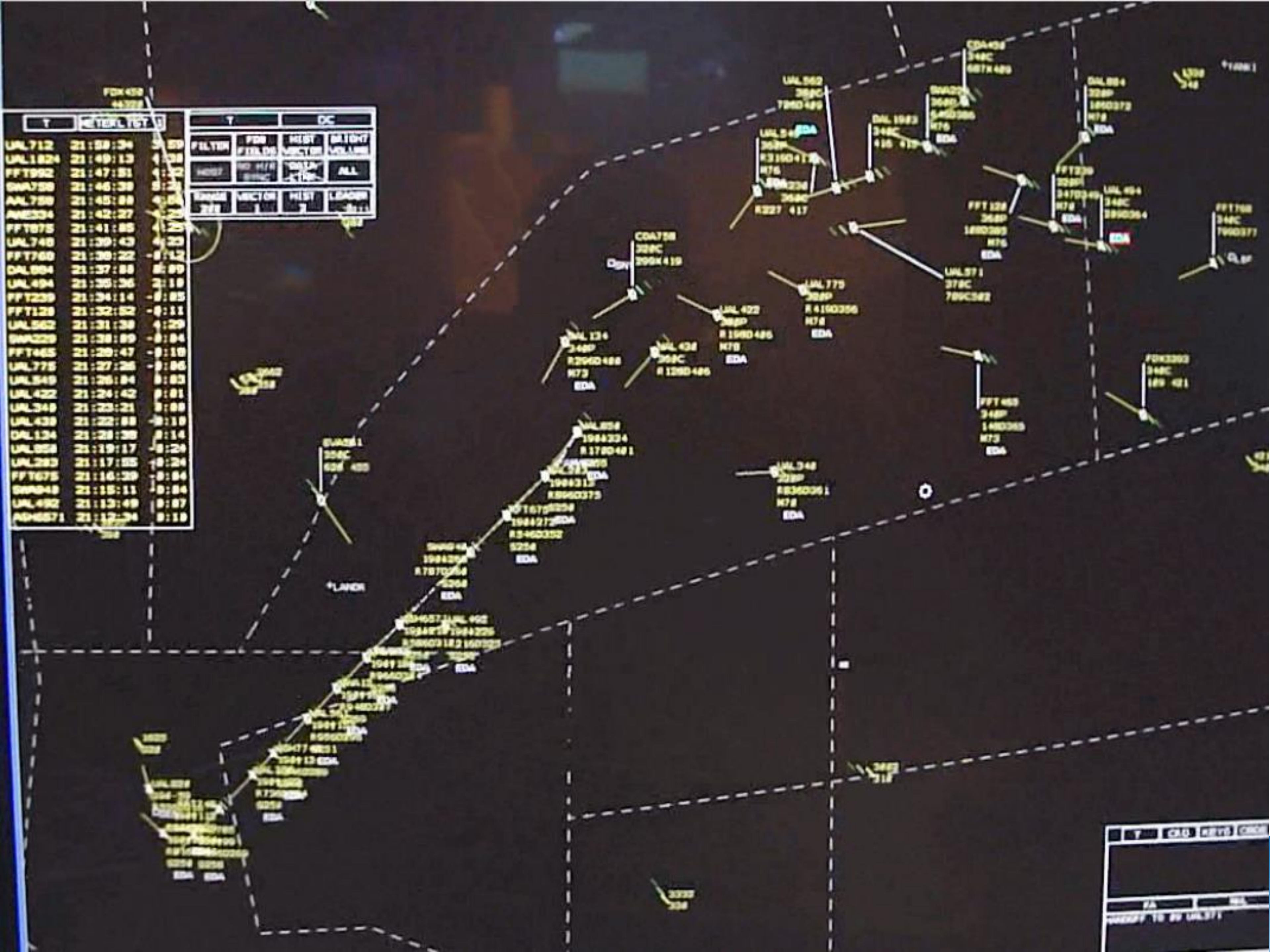
3D Path Arrival Management Concept

(Example of 4D TBO Arrival Operation)

3D Paths in Arrival Management - Overview

- **Works off a RNAV or RNAV-like “backbone” (OPD)**
- **Ground automation maximizes aircraft flight efficiency and may influence throughput**
  – Computes schedule at runways and meter fixes
  – Selects cruise/descent speeds and lateral path stretch to meet schedule
- **ATC provides single “conflict-free” trajectory from cruise to Meter Fix**
- **Allows FMS to fly optimal vertical profile**
- **LNAV / VNAV execution of flight path**





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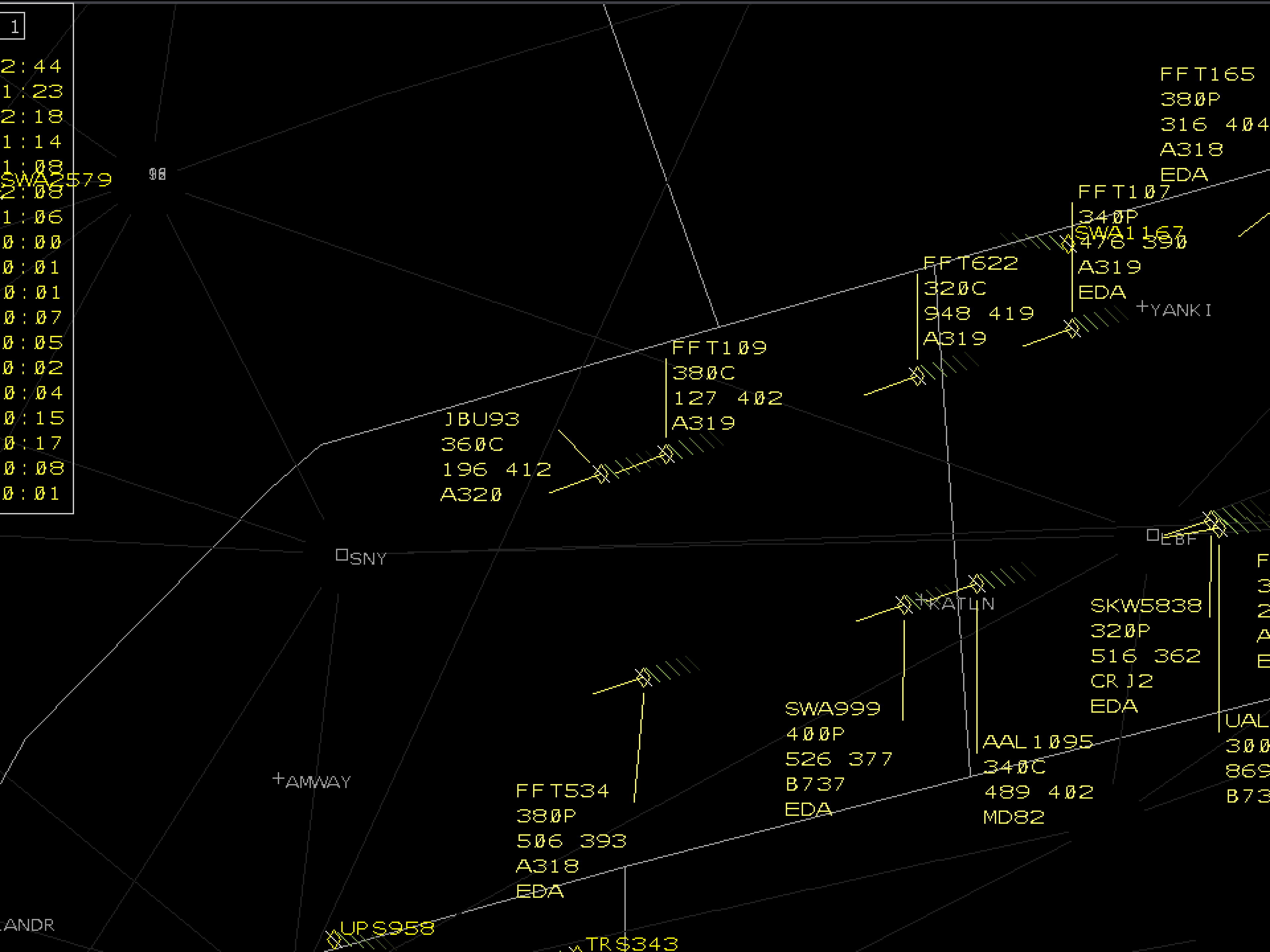
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