Tailored Arrival Manager (TAM)

Plan for ecoD 2020

ecoD-TAM General Briefing

TBFM Performance Assessment Team Meeting

May 20, 2020

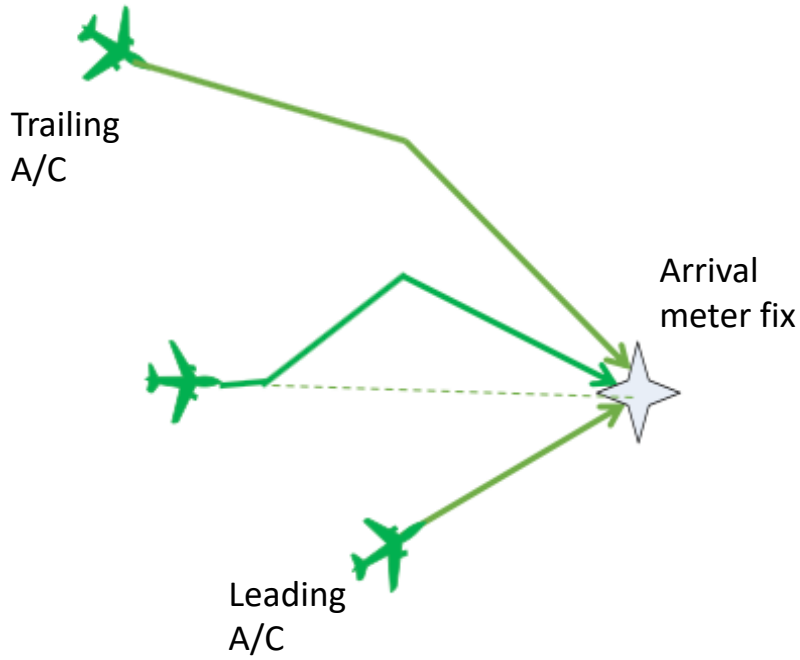
Outline

- TAM concept overview
- ecoD 2020 flight demonstration of TAM
  - Objectives
  - Scenario and procedures
  - Data collection and metrics
  - Flight route
  - Flight demo preparation (Lab Shots)
- Additional Q&A

TAM Automation: Core Features

Overall concept: Increasingly autonomous air-ground trajectory management for arrivals

- Uses NASA's AutoResolver technology to compute trajectory-based solutions that:
  - Enable fuel efficient, optimized-profile descents
  - Provide separation assurance along the entire arrival trajectory
  - Satisfy Time-Based Flow Management (TBFM) constraints for balancing demand and capacity
- Relies on digital communications for data exchange and clearance delivery
- Integrates seamlessly with existing avionics for guidance and control along the intended arrival trajectory



TAM trajectory solutions prioritize speed and path changes to minimize fuel burn and emissions

Tailored Arrival Manager (TAM)

Flight Management System (FMS)
with Data Comm Integration

1. Aircraft sends flight state and intent data to ground systems for enhancing situational awareness and maximizing the accuracy of TAM trajectory predictions

2. TAM computes an arrival trajectory solution that is conflict-free, fuel-efficient and conformant with TBFM scheduling constraints.

3. The TAM solution is delivered as a clearance instruction to the aircraft using data communications and auto-loaded into the aircraft's FMS

4. The FMS provides automated guidance and control along the TAM-intended arrival trajectory

5. TAM continuously monitors for traffic conflicts and trajectory conformance, sending corrective instructions to the aircraft as needed to ensure separation and flow management

Time Based Flow Management
(TBFM) Time Line

Top of Descent

TAM enables continuous descents at low engine power for minimum fuel consumption and emissions, even during busy traffic conditions

TAM detects and resolves conflicts and ensures that time-based metering constraints are met for maximizing throughput

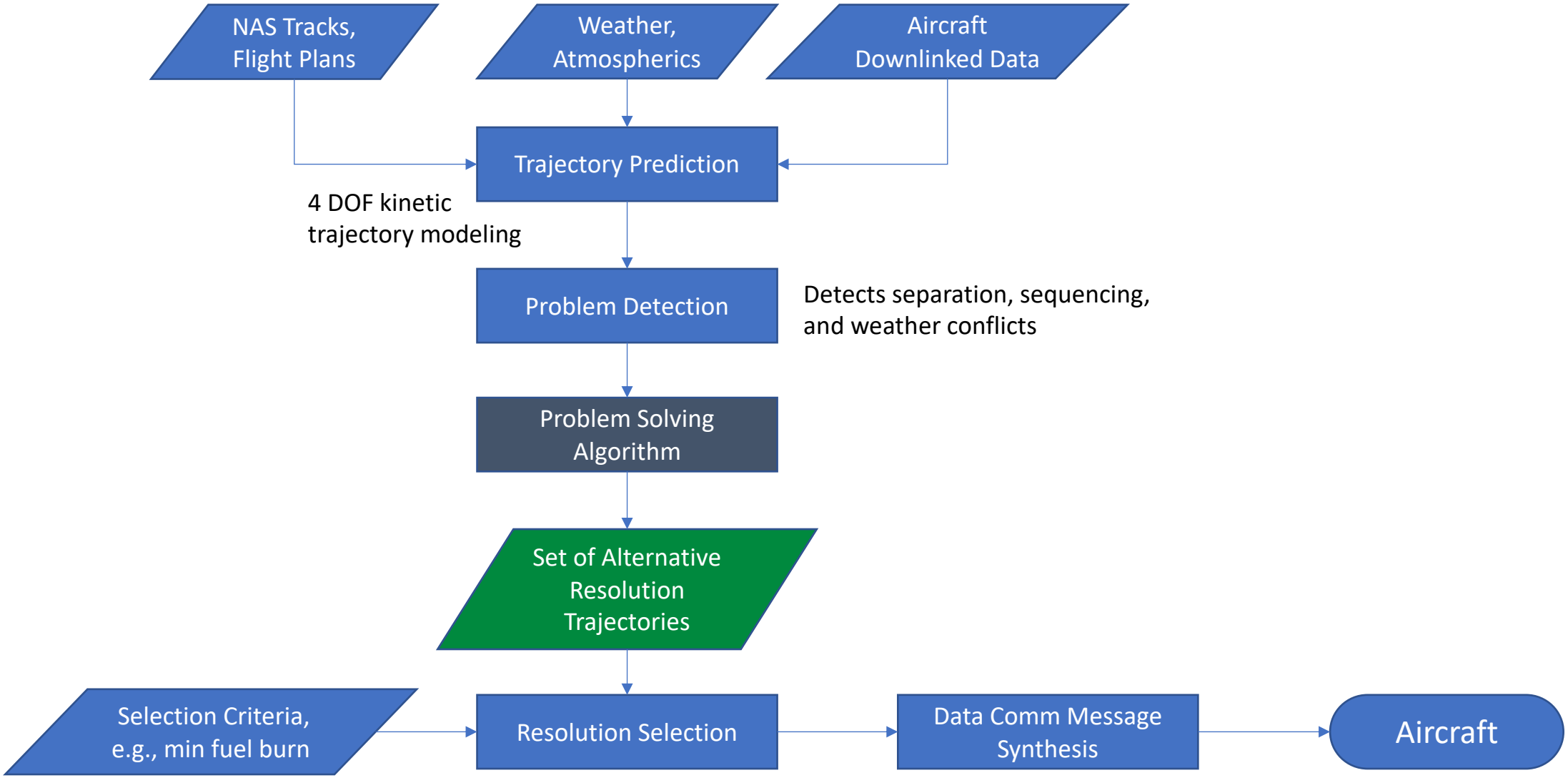
Arrival Meter Fix

TERMINAL
AIRSPACE

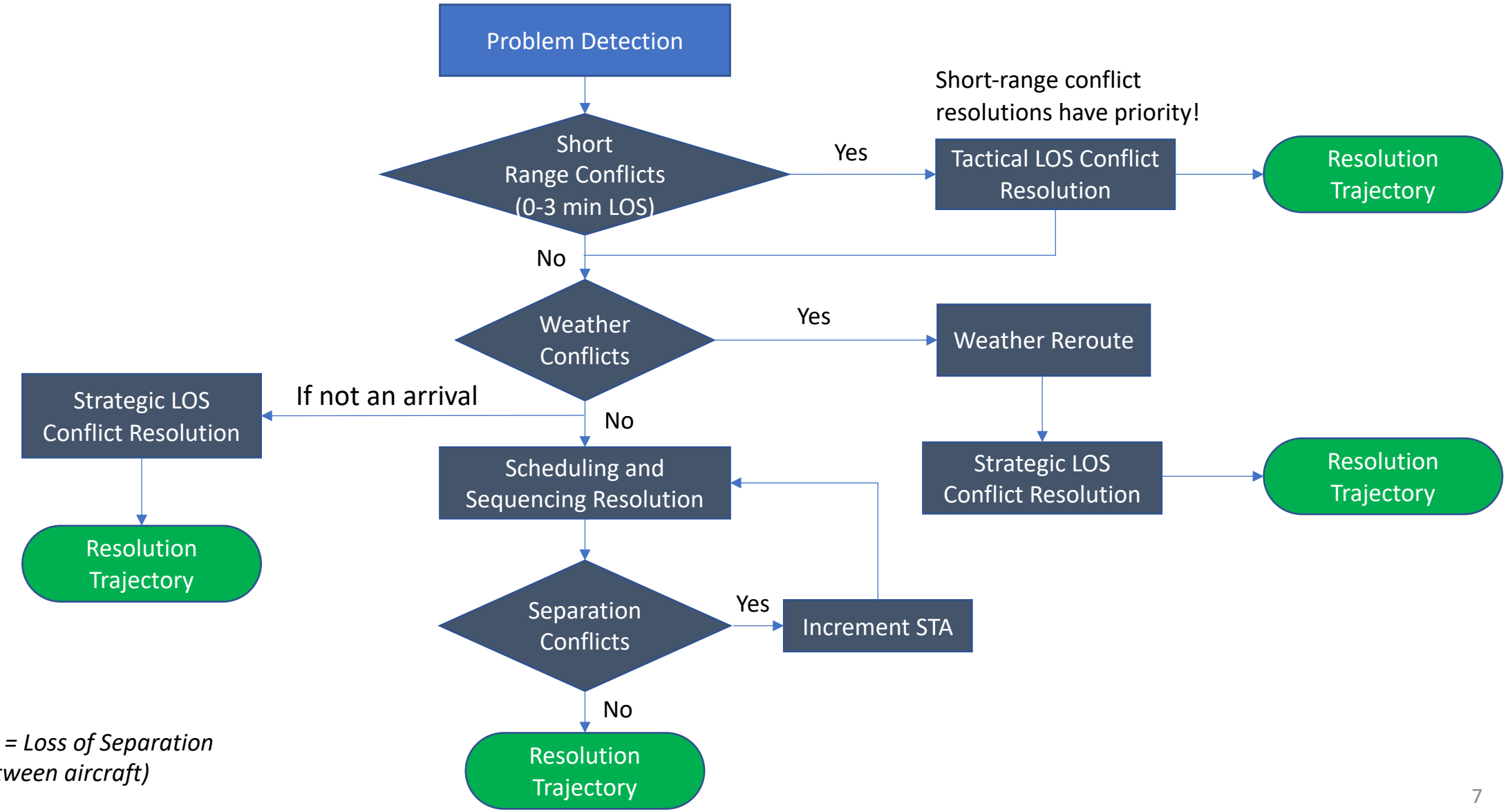
TAM's AutoResolver Algorithm

- Provides algorithmic engine for TAM trajectory-based arrival solutions
- Has been applied to a variety of NASA R&D efforts in recent years, e.g.,
  - Dynamic Weather Reroutes (DWR)
  - Urban Air Mobility (UAM)
- Solves conflicts iteratively between aircraft in en route and terminal airspace
- Designed to resolve conflicts associated with
  - Loss of Separation (LOS) between flights
  - Sequencing and scheduling
  - Weather

AutoResolver: General Solution Process



AutoResolver: Problem Resolution



LOS = Loss of Separation (between aircraft)

TAM in ecoDemonstrator 2020

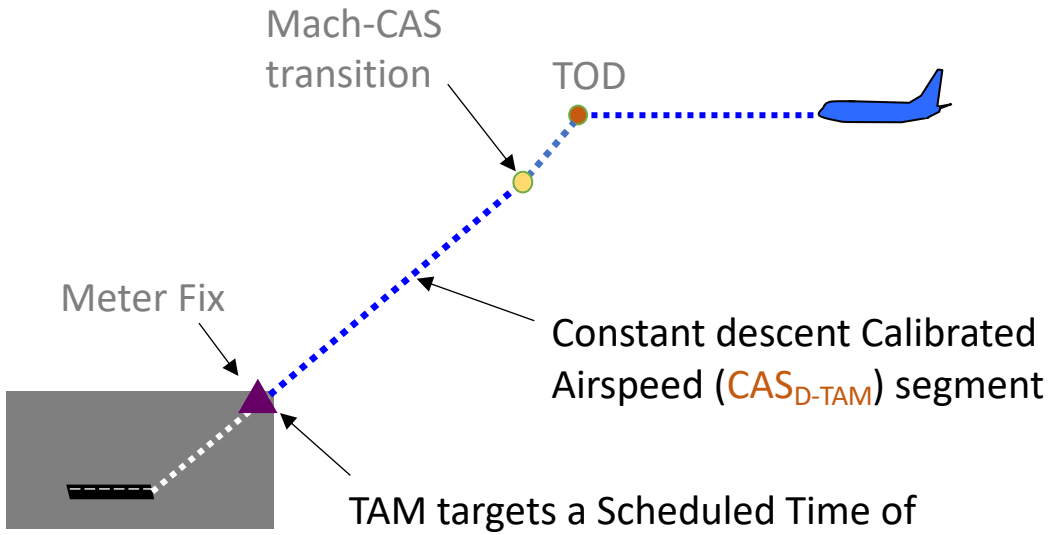
Objectives for TAM in ecoD 2020

- Demonstrate basic system integration and data exchange for trajectory-based arrival management
  - Demonstrate digital connectivity across multiple facilities and systems
  - Establish operational framework and procedures for effective collaboration with research partners (Boeing, NASA, and FAA)
- Further develop and refine TAM concept and automation
  - Demonstrate basic concept feasibility, with emphasis on required information exchange
  - Mature TAM AutoResolver algorithm
  - Assess TAM trajectory-prediction accuracy under controlled flight conditions

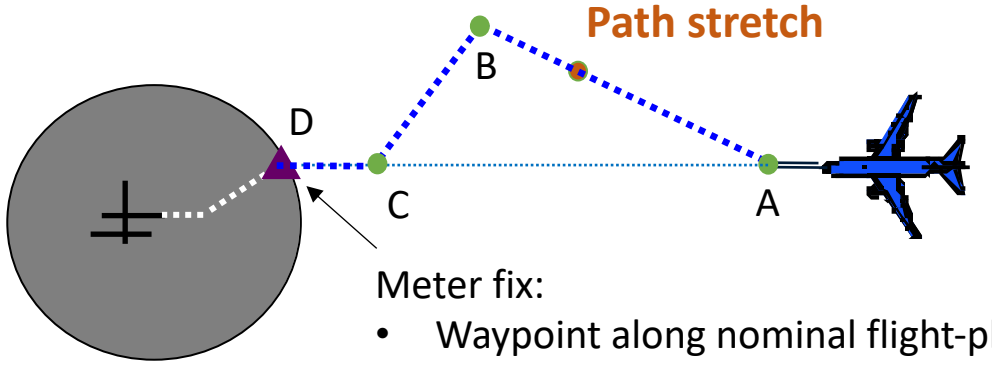
'Learn by doing' in a real-world flight environment!

TAM Advisory Output for ecoD 2020 Flight Demo

Vertical View



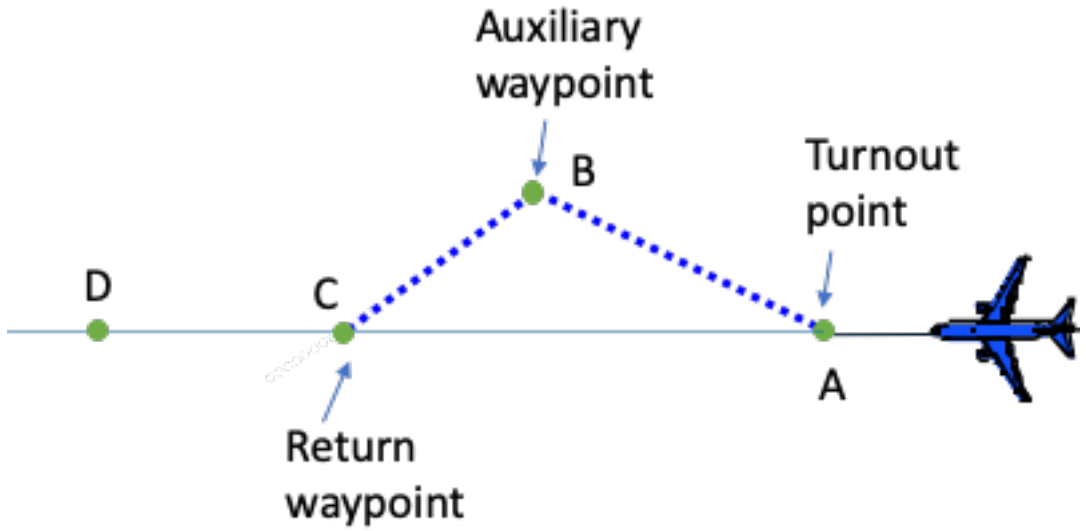
Plan View



- TAM will advise routing and descent speed for idle-thrust, VNAV PTH descent to meter fix
- Advisory elements will be data linked to flight-deck for FMS trial-plan trajectory computation but will not be flown
- For simplicity, speed advisory is limited to $CAS_{D\text{-}TAM}$. *Loading of speed advisory into FMS is not required.*

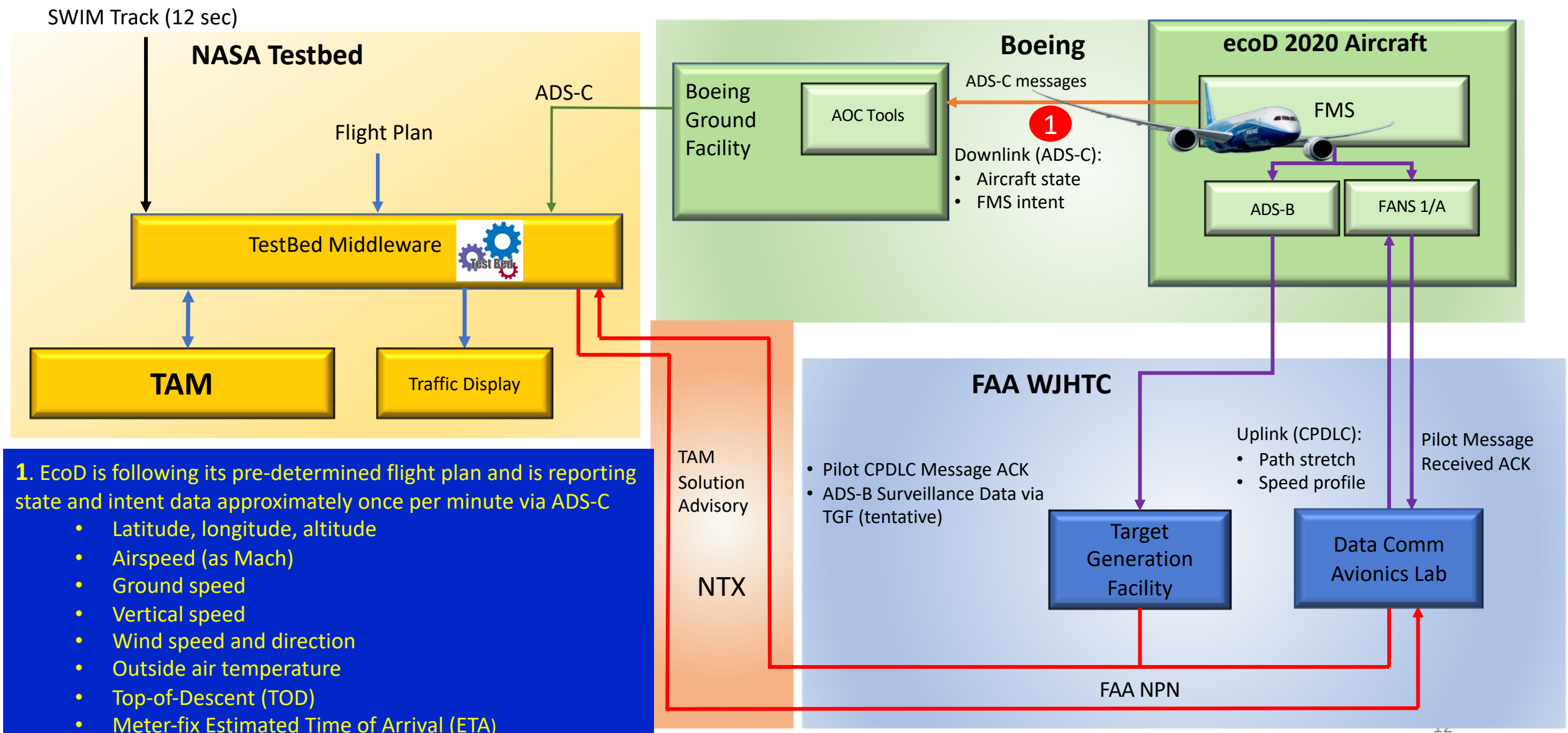
DataComm Message for TAM Advisory Uplink

FANS ID	Message Element
UM79	CLEARED TO [position] VIA [routeclearance]
UM80	CLEARED [routeclearance]
UM83	AT [position] CLEARED [routeclearance]
UM117	CONTACT [icaounitname] [frequency]
UM120	MONITOR [icaounitname] [frequency]
UM135	CONFIRM ASSIGNED ALTITUDE
UM153	ALTIMETER [altimeter]
UM159	ERROR [errorinformation]
UM160	NEXT DATA AUTHORITY [icaofacilitydesignation]
UM161	END SERVICE
UM162	SERVICE UNAVAILABLE
UM163	[icaofacilitydesignation] [tp4table]
UM166	DUE TO TRAFFIC
UM167	DUE TO AIRSPACE RESTRICTION
UM169	[freetext]
UM177	AT PILOTS DISCRETION



- Route advisory delivered via CPDLC UM79
- Speed advisory delivered via free text (appended to UM79)

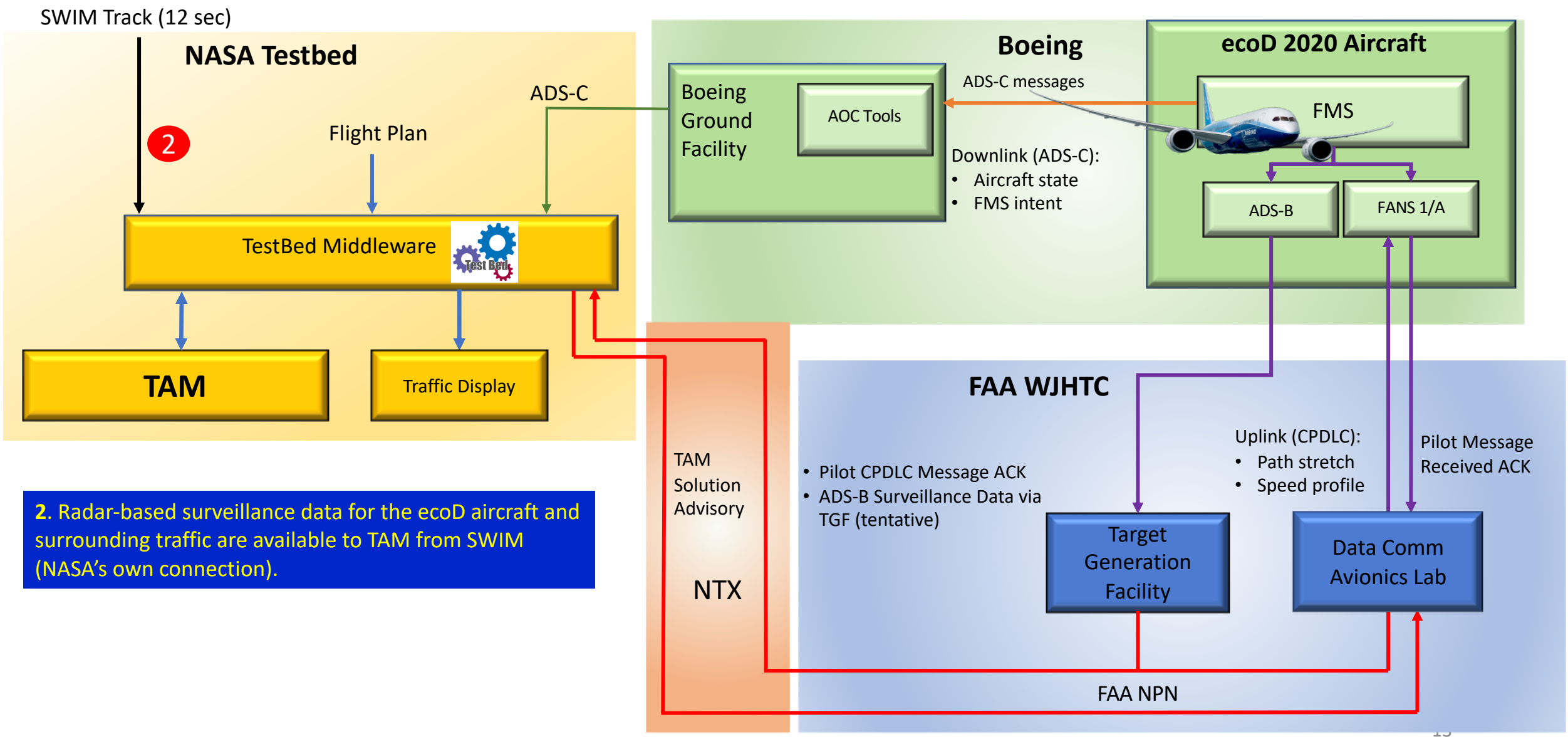
TAM ecoD 2020 Event Scenario



1. EcoD is following its pre-determined flight plan and is reporting state and intent data approximately once per minute via ADS-C

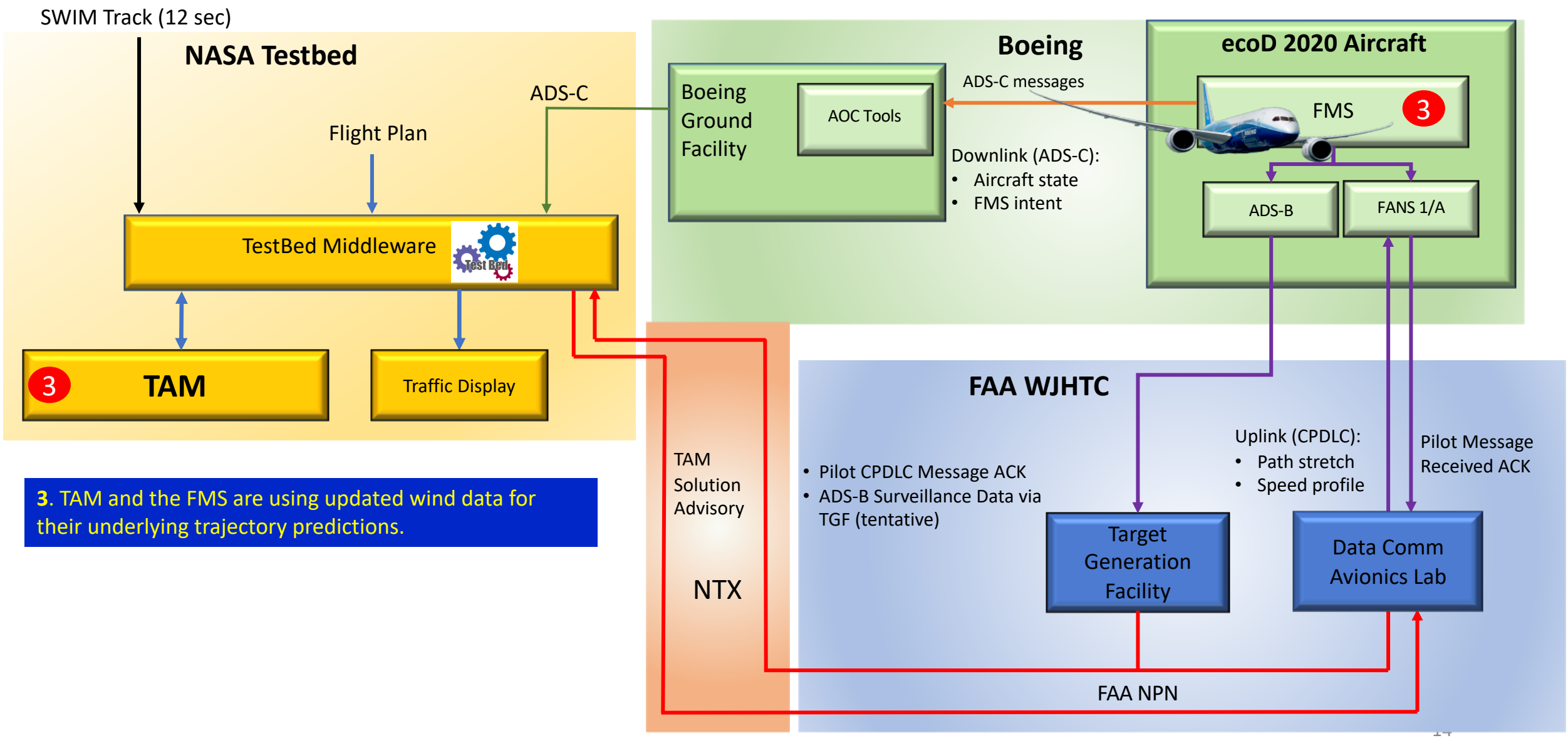
- Latitude, longitude, altitude
- Airspeed (as Mach)
- Ground speed
- Vertical speed
- Wind speed and direction
- Outside air temperature
- Top-of-Descent (TOD)
- Meter-fix Estimated Time of Arrival (ETA)

TAM ecoD 2020 Event Scenario



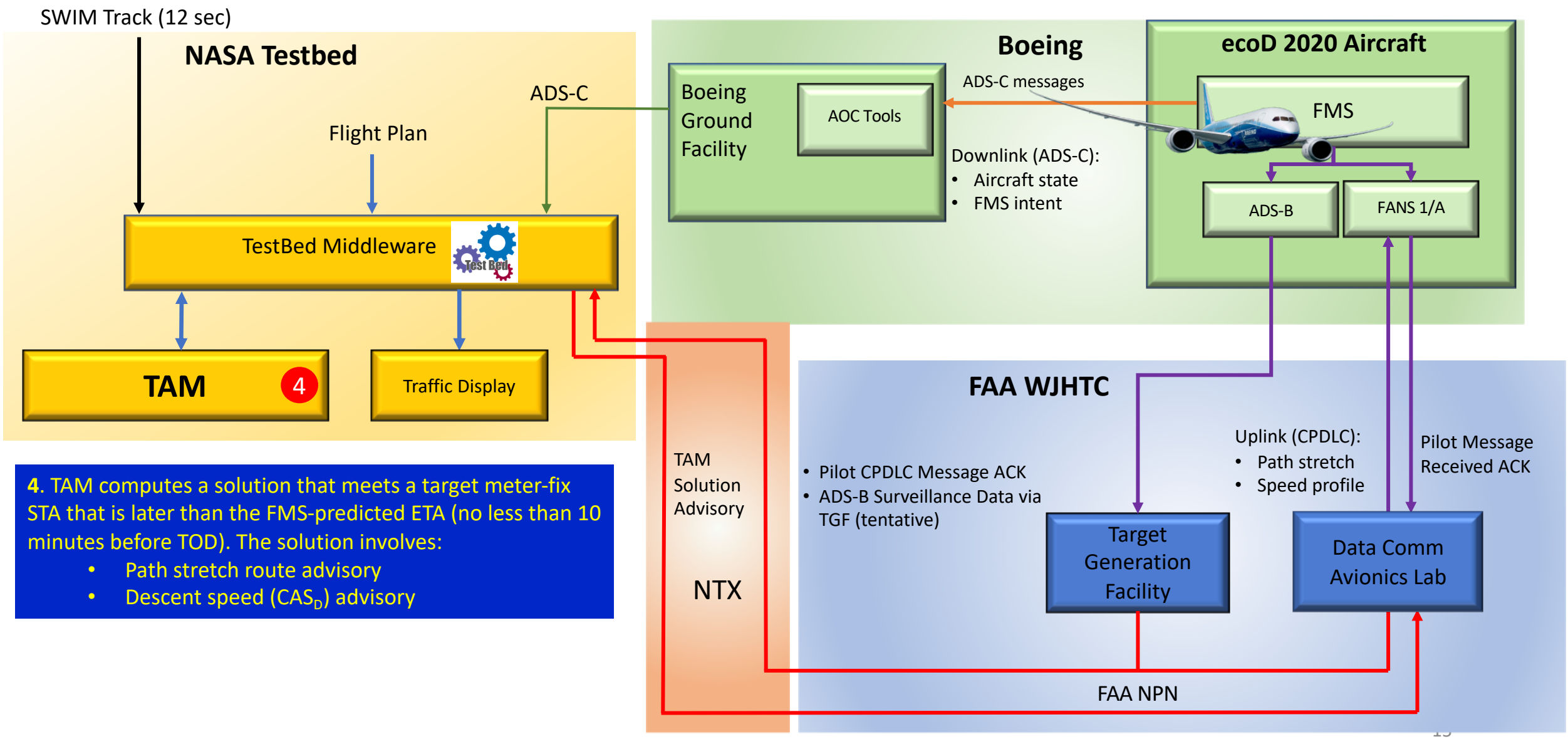
2. Radar-based surveillance data for the ecoD aircraft and surrounding traffic are available to TAM from SWIM (NASA's own connection).

TAM ecoD 2020 Event Scenario



3. TAM and the FMS are using updated wind data for their underlying trajectory predictions.

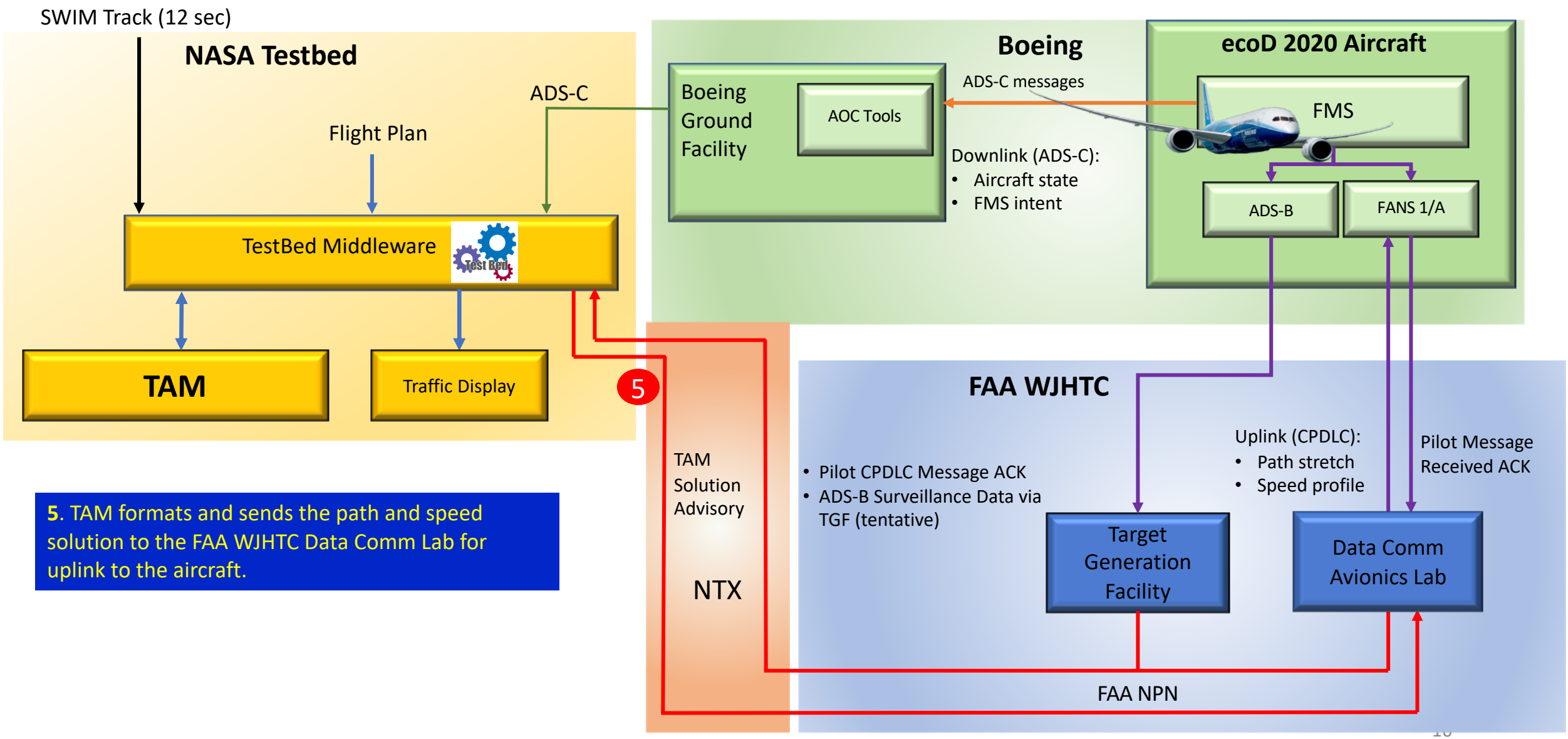
TAM ecoD 2020 Event Scenario



4. TAM computes a solution that meets a target meter-fix STA that is later than the FMS-predicted ETA (no less than 10 minutes before TOD). The solution involves:

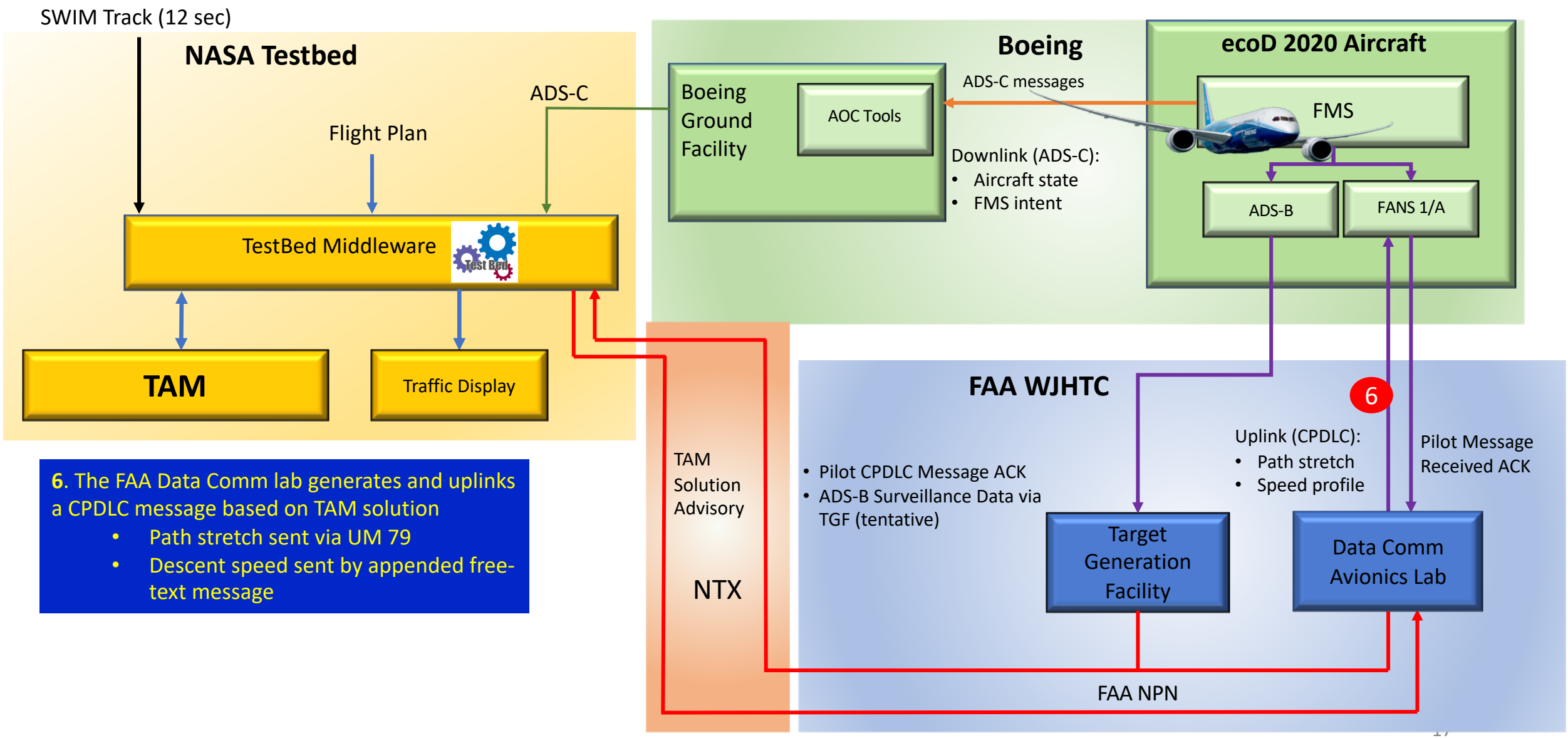
- Path stretch route advisory
- Descent speed (CAS_D) advisory

TAM ecoD 2020 Event Scenario



5. TAM formats and sends the path and speed solution to the FAA WJHTC Data Comm Lab for uplink to the aircraft.

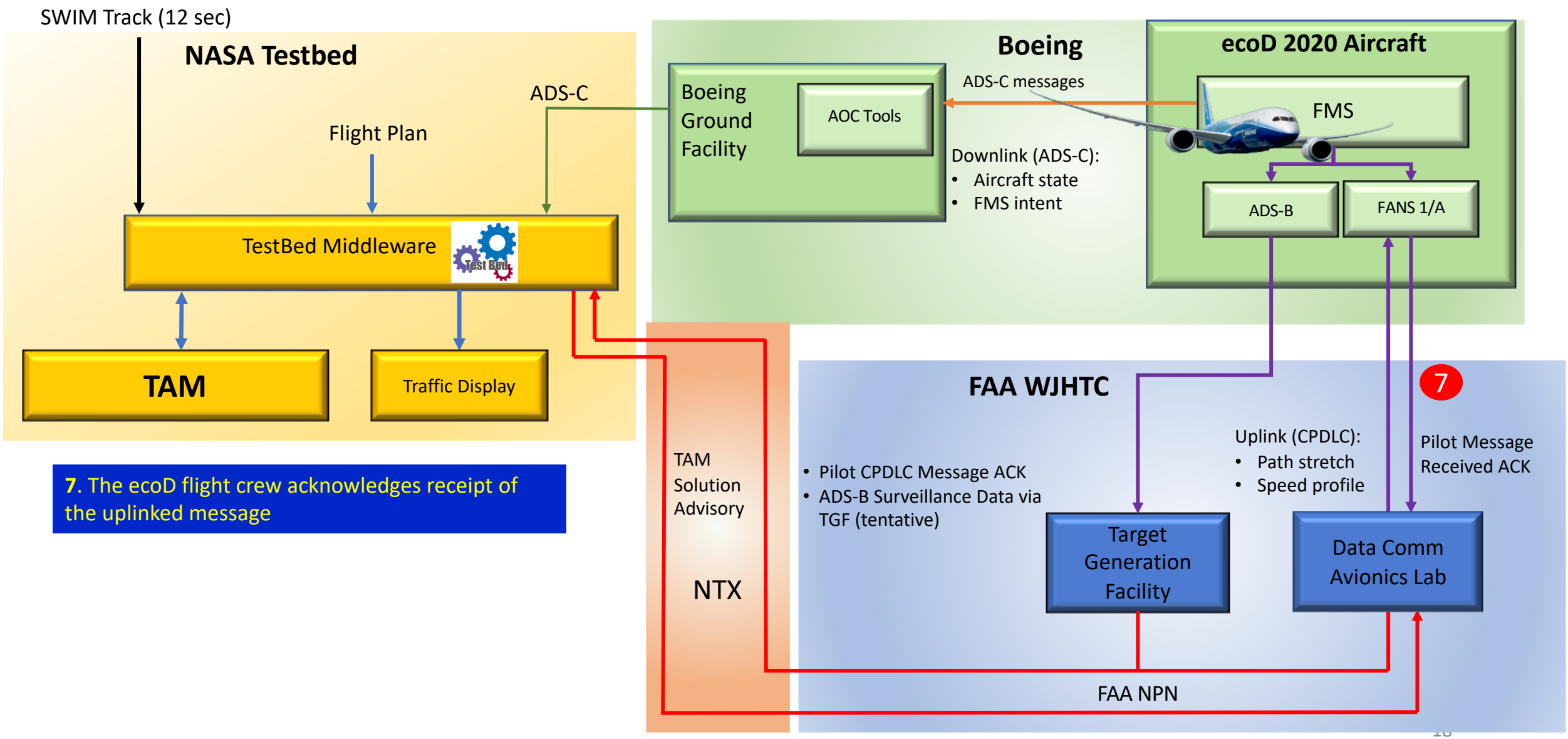
TAM ecoD 2020 Event Scenario



6. The FAA Data Comm lab generates and uplinks a CPDLC message based on TAM solution

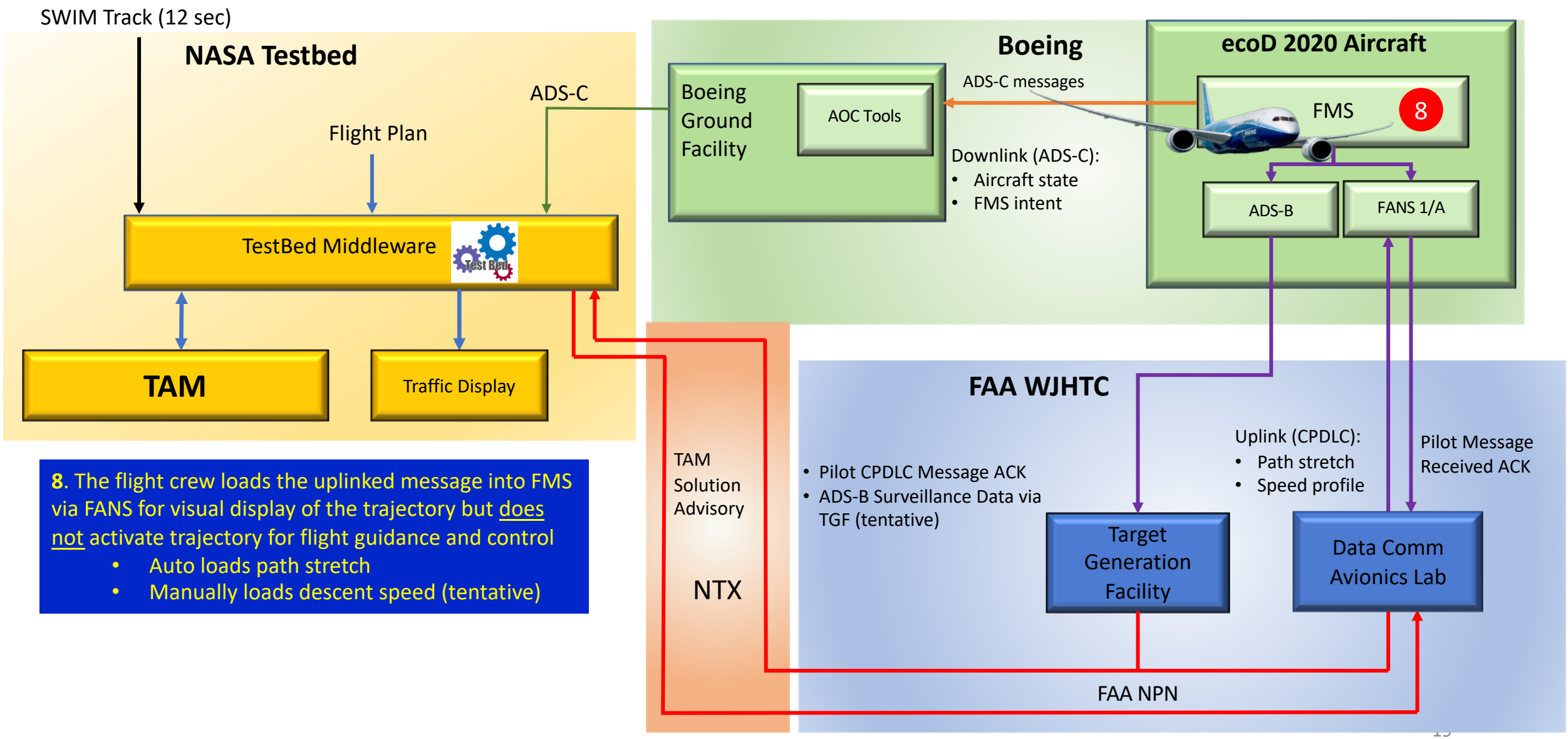
- Path stretch sent via UM 79
- Descent speed sent by appended free-text message

TAM ecoD 2020 Event Scenario



7. The ecoD flight crew acknowledges receipt of the uplinked message

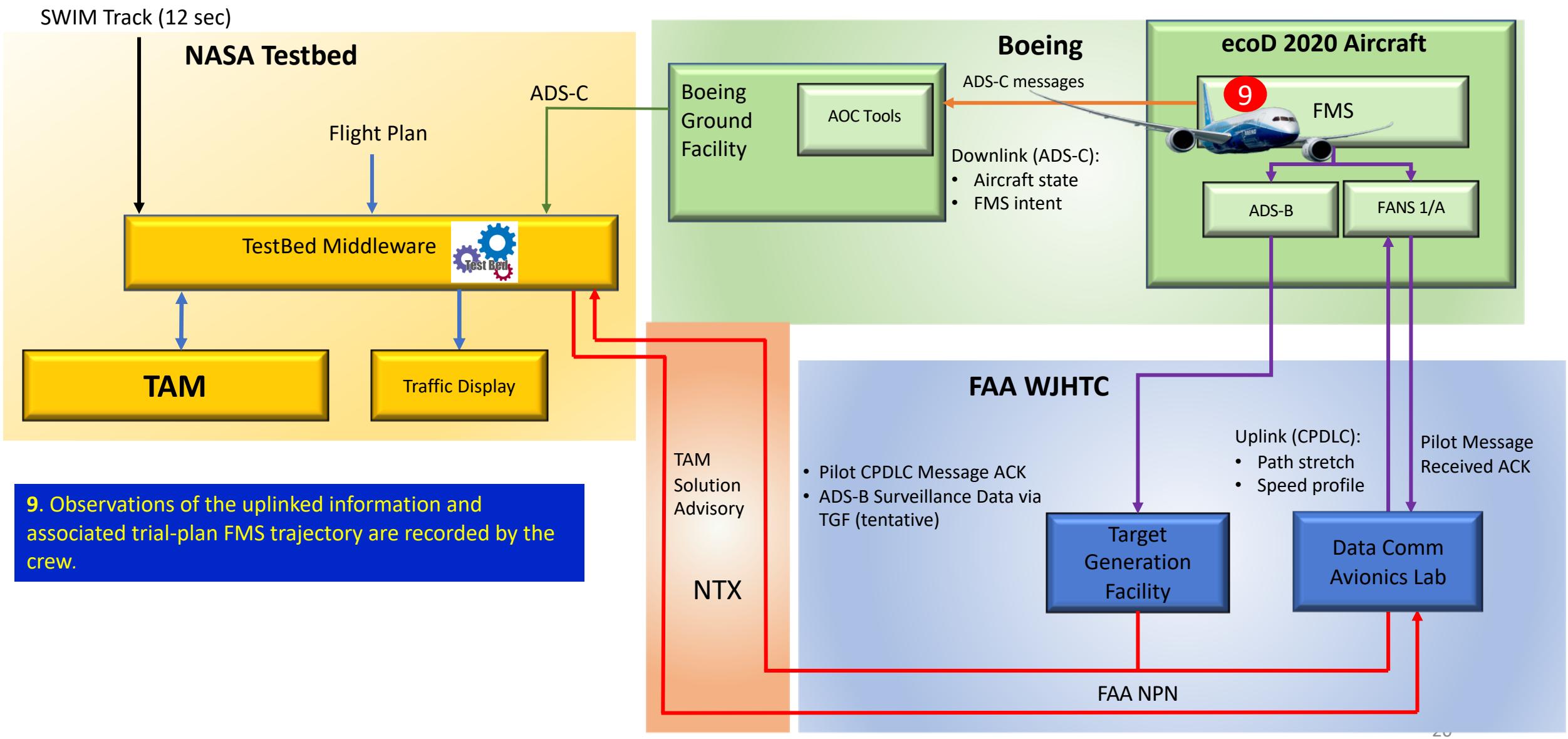
TAM ecoD 2020 Event Scenario



8. The flight crew loads the uplinked message into FMS via FANS for visual display of the trajectory but <u>does not</u> activate trajectory for flight guidance and control

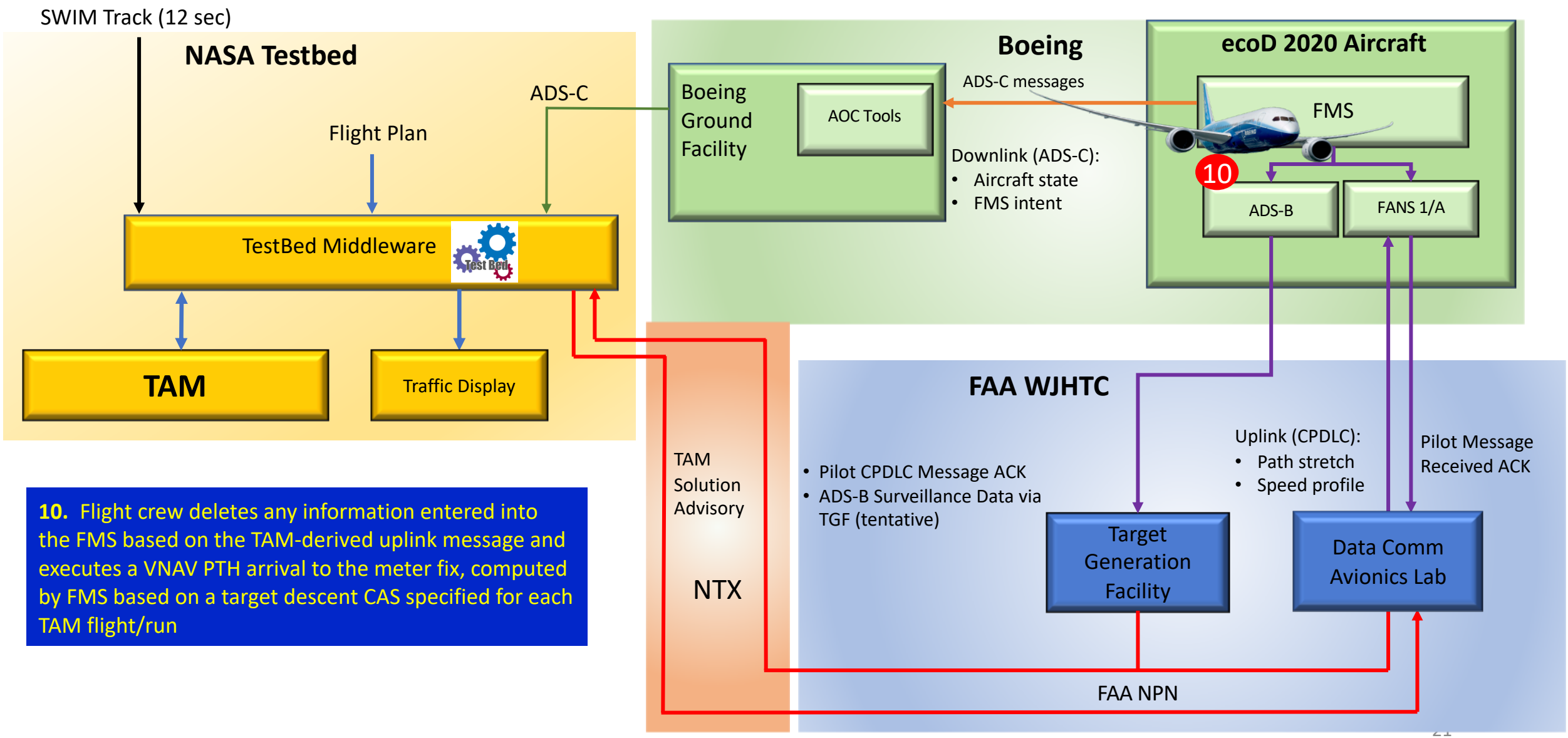
- Auto loads path stretch
- Manually loads descent speed (tentative)

TAM ecoD 2020 Event Scenario



9. Observations of the uplinked information and associated trial-plan FMS trajectory are recorded by the crew.

TAM ecoD 2020 Event Scenario



10. Flight crew deletes any information entered into the FMS based on the TAM-derived uplink message and executes a VNAV PTH arrival to the meter fix, computed by FMS based on a target descent CAS specified for each TAM flight/run

Data Collection

Data Type	Source	Update Rate	Comments
ADS-C-derived data	Boeing	Every 64 sec	Includes TOD and meter fix ETA derived from ADS-C intent reports
ADS-B-derived data	FAA TGF	Every second (1Hz)	Requires no action from Boeing. Pending further testing and approval from FAA
Radar-derived track data	NASA existing FAA SWIM feed	Every 12 sec	
Flight plan messages	NASA existing FAA SWIM feed	Prior to flight and upon controller-entered FP amendments	
Atmospheric data	NASA RAP data from Sherlock	13 km grid, hourly forecasts	
Pilot questionnaire	Boeing via NASA-developed form	During and/or post flight	Content and logistics to be determined
Onboard Test Director questionnaire	Boeing via NASA-developed form	During and/or post flight	Content and logistics to be determined
Visual documentation of TAM solution on flight deck	Boeing ecoD flight crew	At minimum, upon receiving and loading TAM solution sent via data comm	Photographs at a minimum, supplemented by video feed if possible, e.g., GoPro camera

Test Matrix and Data Analysis

Notional test matrix for ecoD 2020 TAM scenarios

Run #	Nominal Descent CAS (knots)	Meter Fix Delay (minutes)
1	250	2
2	250	4
3	250	6
4	270	2
5	270	4
6	270	6
7	340	2
8	340	4
9	340	6

DRAFT

- Independent variables:
  - **Nominal descent CAS:** specified on Test Cards for FMS VNAV PTH configuration by flight crew
  - **Metering delay:** affects size of path-stretch solution computed by AutoResolver
- Dependent variables reflect accuracy of underlying TAM predictions:
  - **ETA at meter fix**
  - **TOD location**

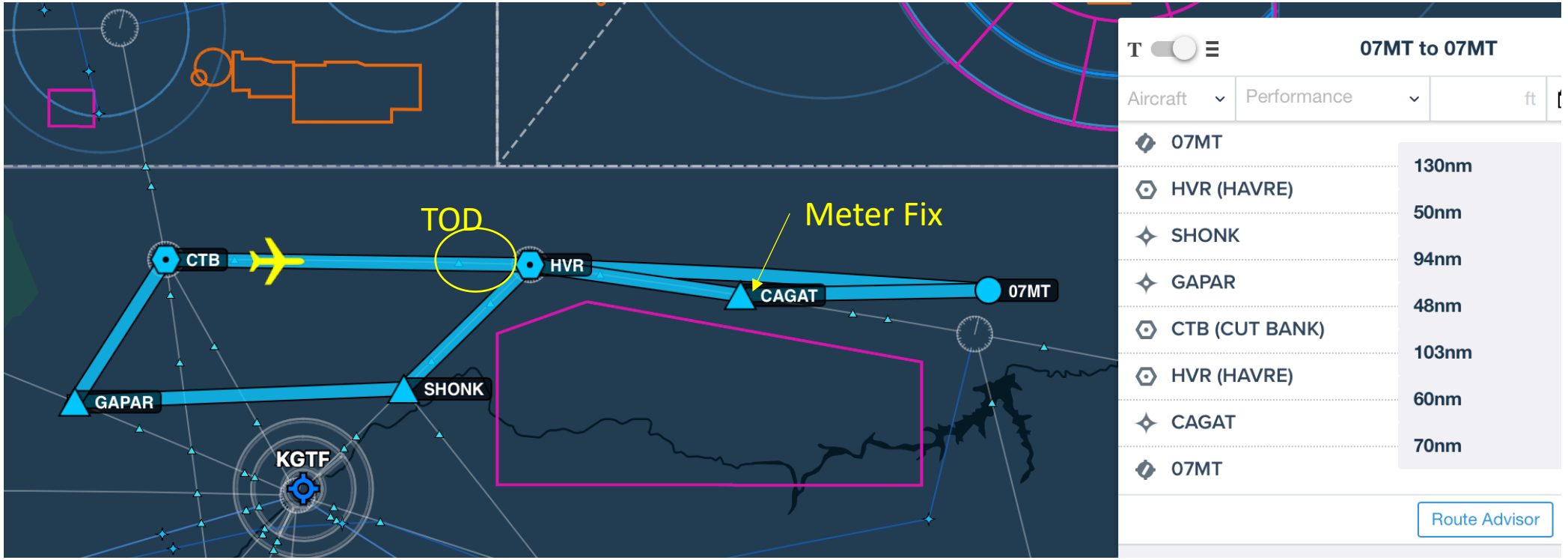
Nominal Flight Route Possibilities for TAM Scenarios

Moses Lake, WA Scenario

- Cruise alt = FL360
- Cruise speed = 480 KTAS (approximately)

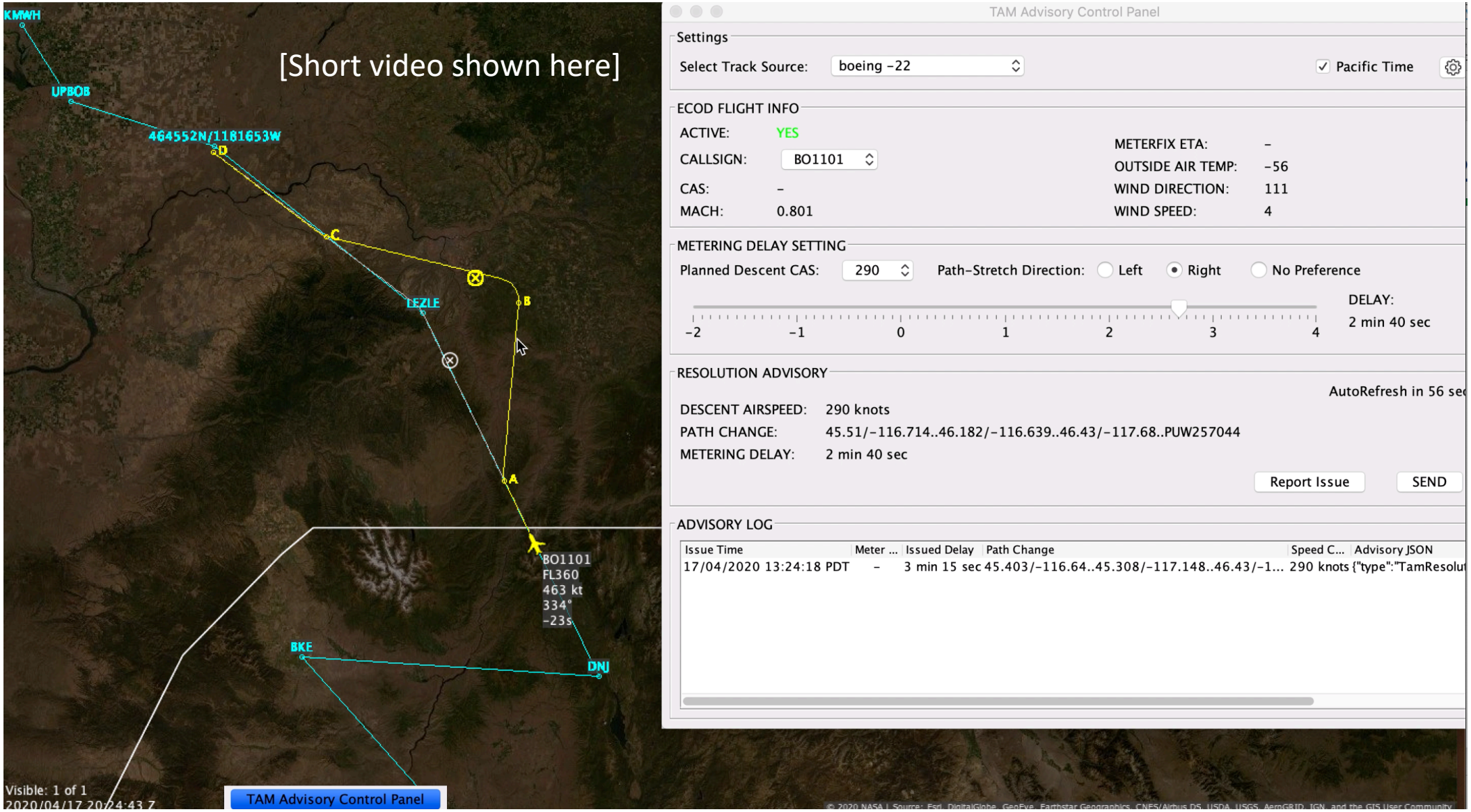
Nominal Flight Route Possibilities for TAM Scenarios

Glasgow, MT Scenario



- Cruise alt = FL390
- Cruise speed = 480 KTAS (approximately)

TAM System Operation for ecoD 2020



Flight Demo Preparation: Completed Lab Shots

- **TAM 1**: Acquired flight track and other data from FAA Cockpit Simulator Facility (CSF) for use testing TAM automation
- **TAM 2**: Tested route clearance delivery and data comm integration with FMS
- **TAM 3**: Tested delivery of ADS-C derived data to TAM
- **TAM 4**: End-to-end system test that included computation and delivery of TAM advisory to Boeing 777 avionics bench via FAA Data Comm Avionics Lab (DCAL)

FAA CSF B737 Cab

TAM route clearance on B777 Nav Display – Boeing IASL

NASA TestBed Lab

TAM Lab Shot Schedule for ecoD 2020

Name	Date	Partners Involved	Test Objective
TAM 1	Aug 7, 2019	NASA, FAA	Acquire aircraft state and intent data from FAA B737 cab to test data interfaces and TAM functions
TAM 2	Oct 24–31, 2019	NASA, FAA	Send a TAM solution to FAA Data Comm lab for CPDLC message formulation and Test Bench integration
TAM 3	Dec 10, 2019	NASA, Boeing	Exercise downlink of aircraft state and intent data from Boeing B737 cab/bench via ADS-C
TAM 4A	Feb 20, 2020	NASA, FAA, Boeing	Exercise all data exchanges (ADS-C downlink and CPDLC uplink) between TAM and Boeing bench
TAM 4B	Mar 4, 2020	NASA, FAA, Boeing	Completion of TAM 4A objectives
TAM 5A	May 6 2020	NASA, FAA, Boeing	Exercise end-to-end TAM scenario with focus on contingencies involving air/ground events
TAM 6	May 2020	NASA, FAA, Boeing	Exercise end-to-end TAM scenario with focus on flight crew procedures
TAM 7	Jun 2020	NASA, FAA, Boeing	Exercise end-to-end TAM scenario (repeat of previous tests with any required mods)
TAM 8	Jun 2020	NASA, FAA, Boeing	Exercise end-to-end TAM scenario (repeat of previous tests with any required mods)
TAM 9	Jul 2020	NASA, FAA, Boeing	Test of data communications with aircraft on dock
TAM 10	Jul/Aug 2020	NASA, FAA, Boeing	Test of data communications with aircraft in flight (tentative)

Additional Q&A

1. Any feedback related to proposed routing options, KMWH vs 07MT?
2. When should VNAV PTH descent get programmed in FMC for each TAM flight?
3. Any concerns with keeping aircraft in VNAV PTH mode from TOD to meter fix (~14000 ft)?
4. What planned descent CAS range is suitable for B787 VNAV descent?
5. Any significant differences in B787 FANS 1/A operation compared to B772 and B737 Max?
6. How and when are updated wind data loaded into FMC for descent planning?
7. When should aircraft log on to data comm (KACY)?
8. Any concerns with loading, observing, but not executing TAM solution?
9. Any constraints or best practices for observing TAM solution on flight deck displays via photo/video?
10. Any recommendations for filling out pilot questionnaire for TAM?
11. Any recommendations on pilot questionnaire content?