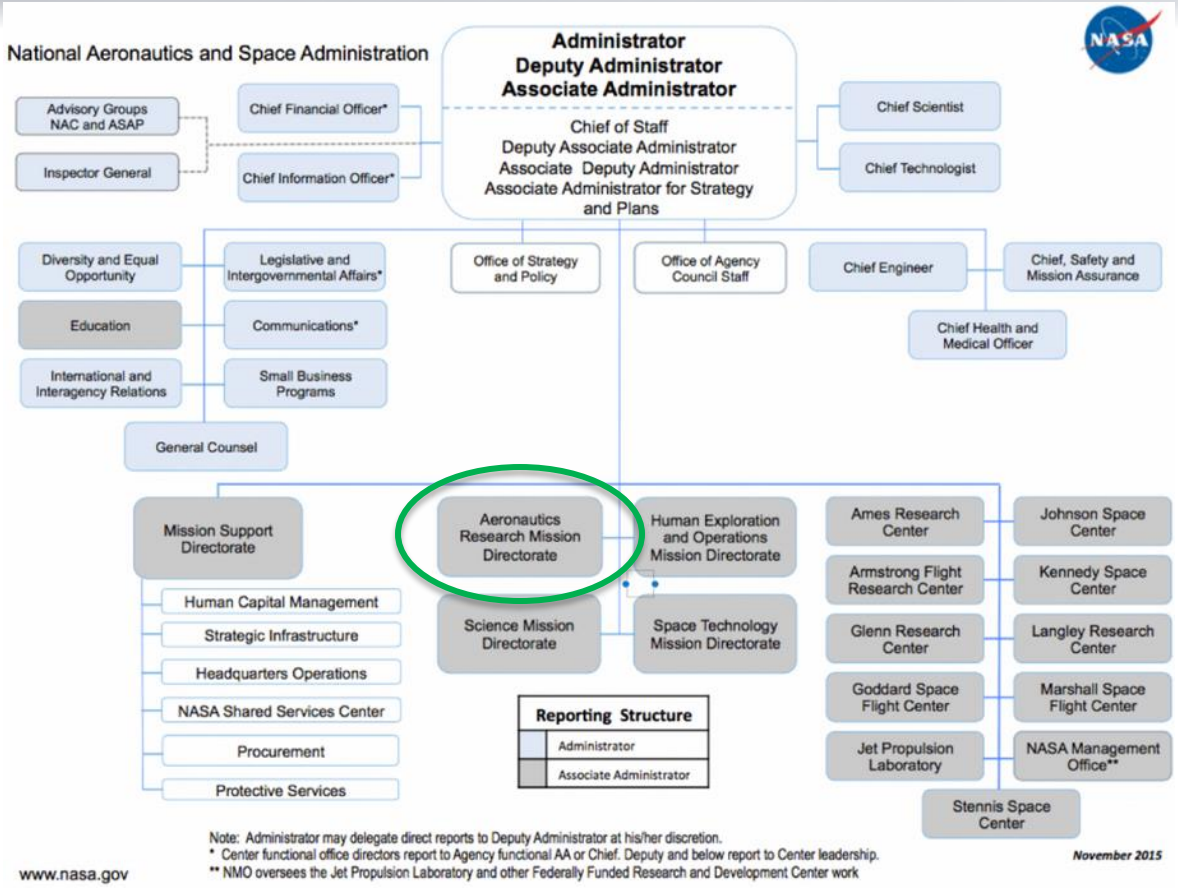
NASA ETM Modeling and Simulation
Upper E Traffic Management Meeting, December 2020

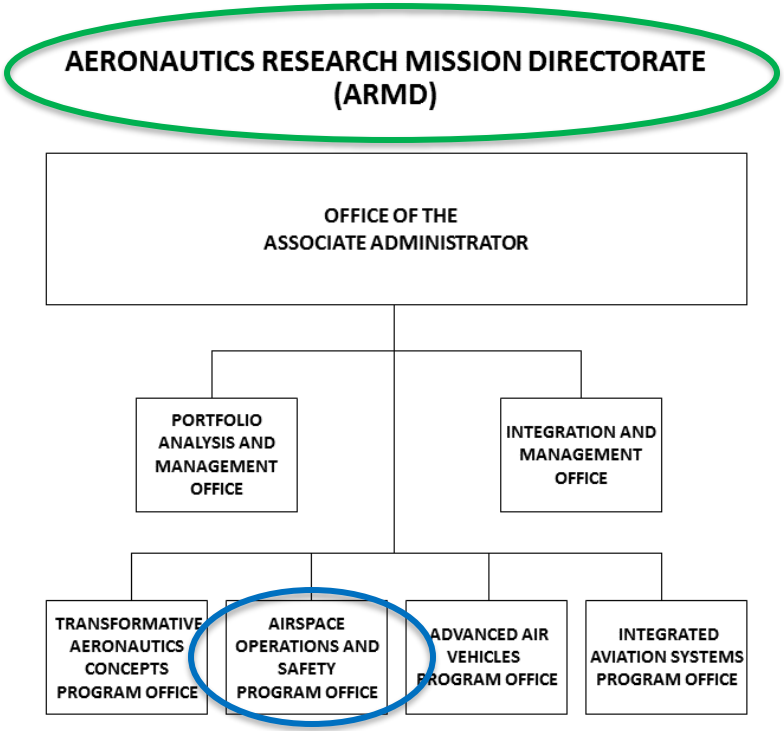
Outline

- Upper Class E Traffic Management (ETM) in NASA ARMD AOSP ATM-X Project
- ETM Modeling and Simulation Activities Prior to ATM-X Phase 2
- Next steps

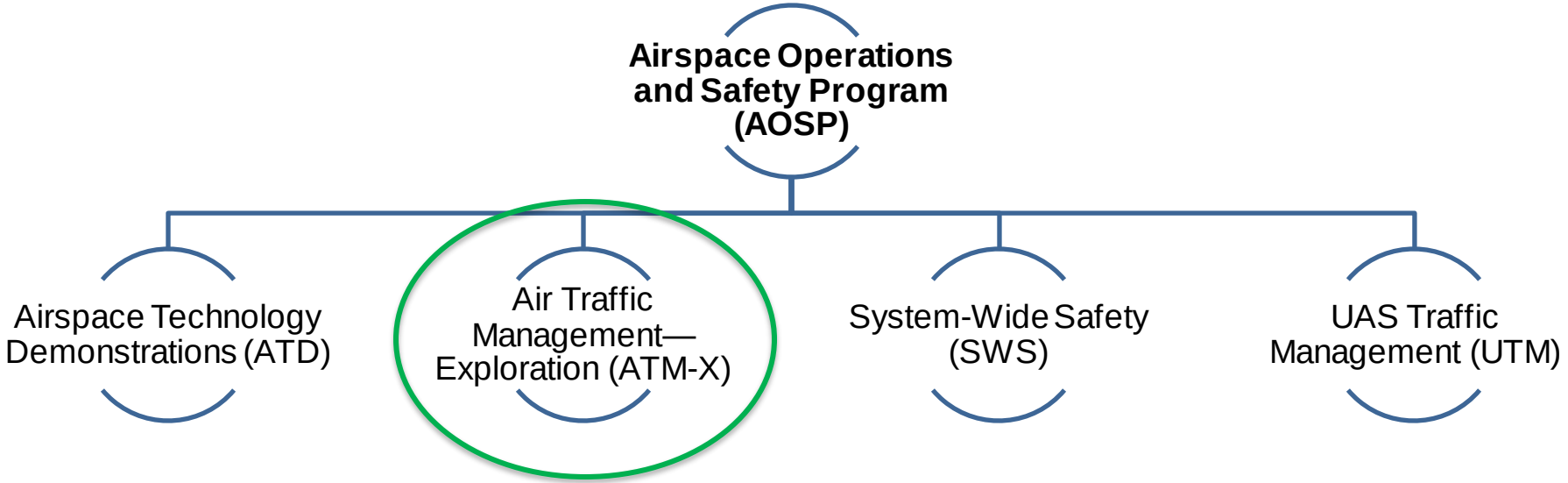
NASA Organizational Chart



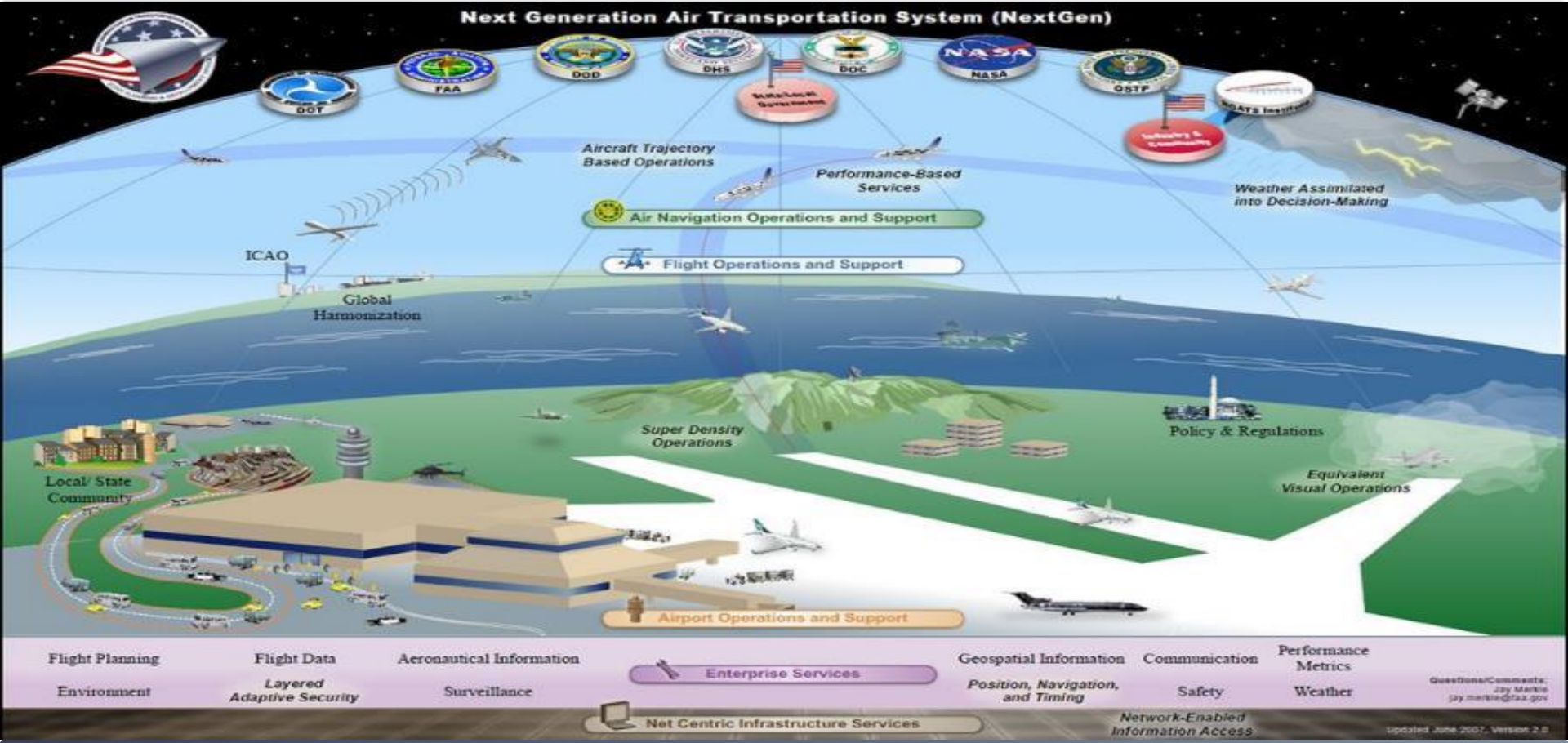
ARMD Organizational Chart



AOSP Organizational Chart



NextGen Vision for 2025



Collaborative Service-Based ATM Envisioned in the Future NAS (~2045)

ATM-X Vision and Goal

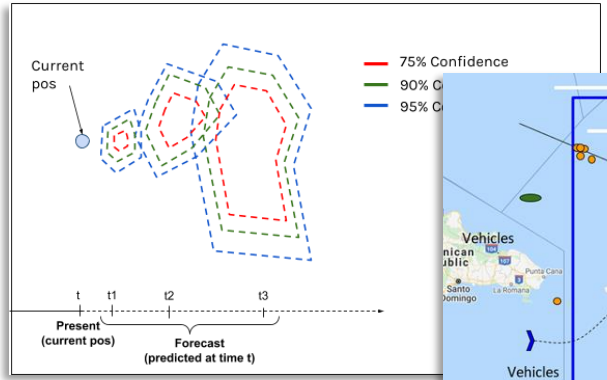
Vision: Accelerate transformation to a digitally-integrated air transportation system that enables access and increases mobility for all users

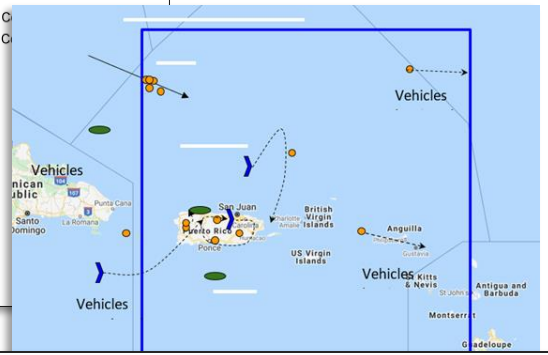
Goal: Catalyze the community to provide an all-access, safe, and efficient airspace system through innovative solutions that remove barriers

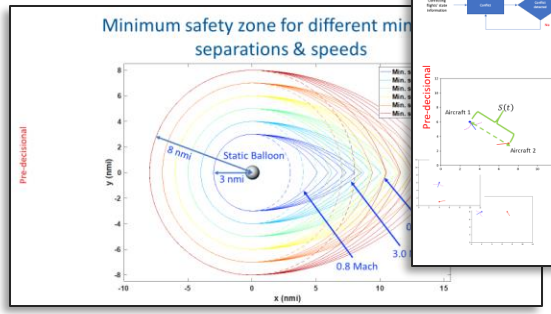
ATM-X fully supports Upper Class E Traffic Management (ETM) work

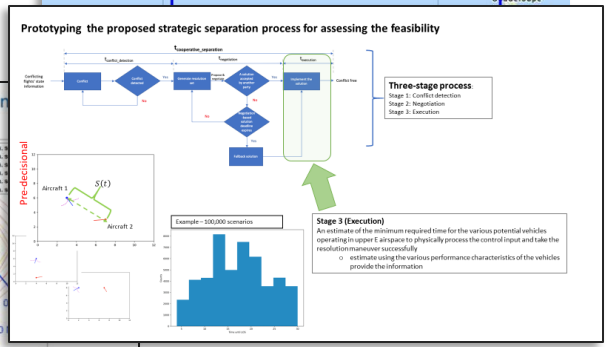
ETM Modeling and Simulation, prior to ATM-X Phase 2

- ETM Operations Modeling
  - Cooperative operation concepts and scenarios
  - Conflict identification and resolution strategies
- ETM Simulation
  - Flexible engine for Fast-time evaluation of Flight environments (Fe3)
  - High-altitude balloon dynamics

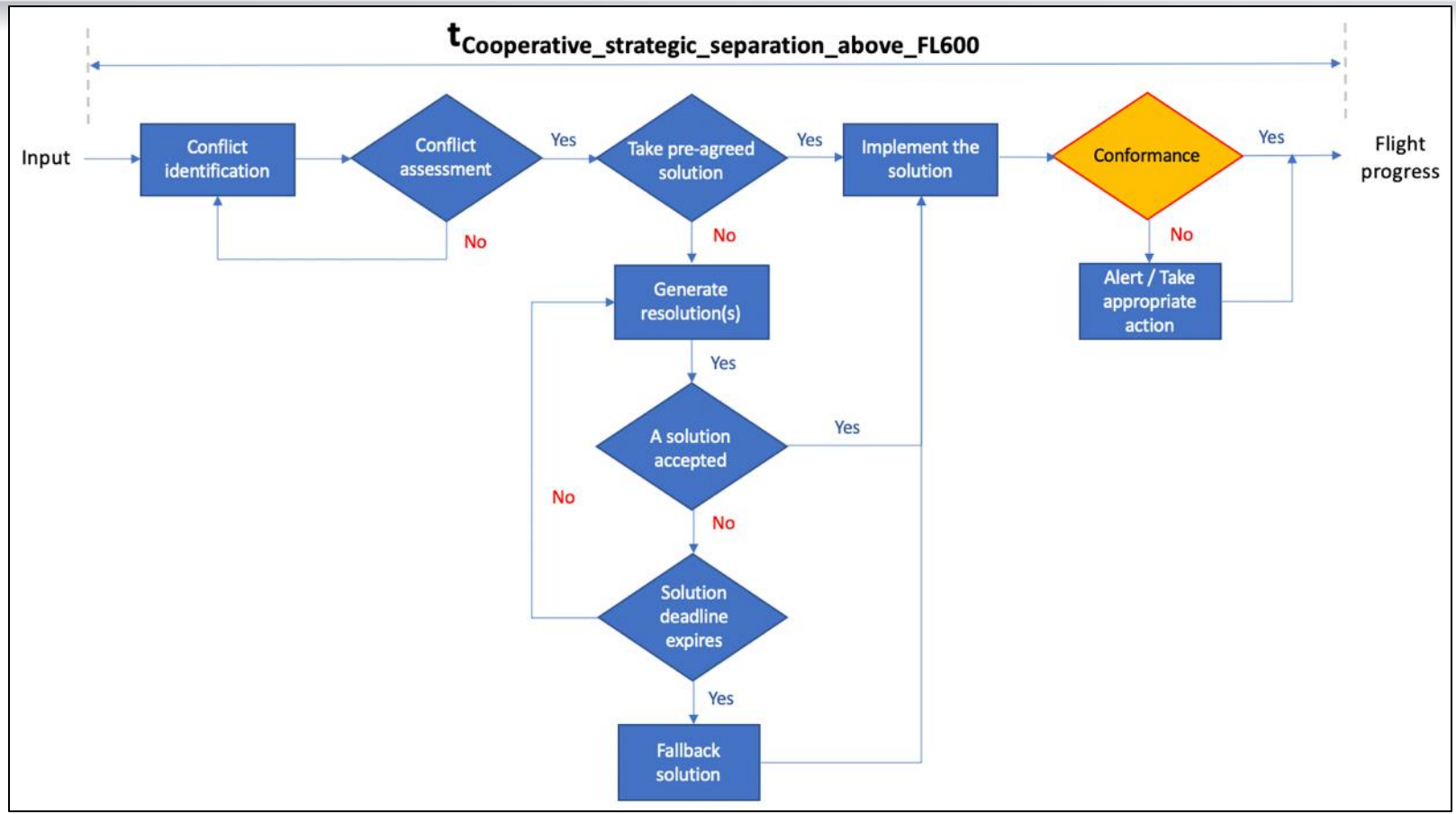




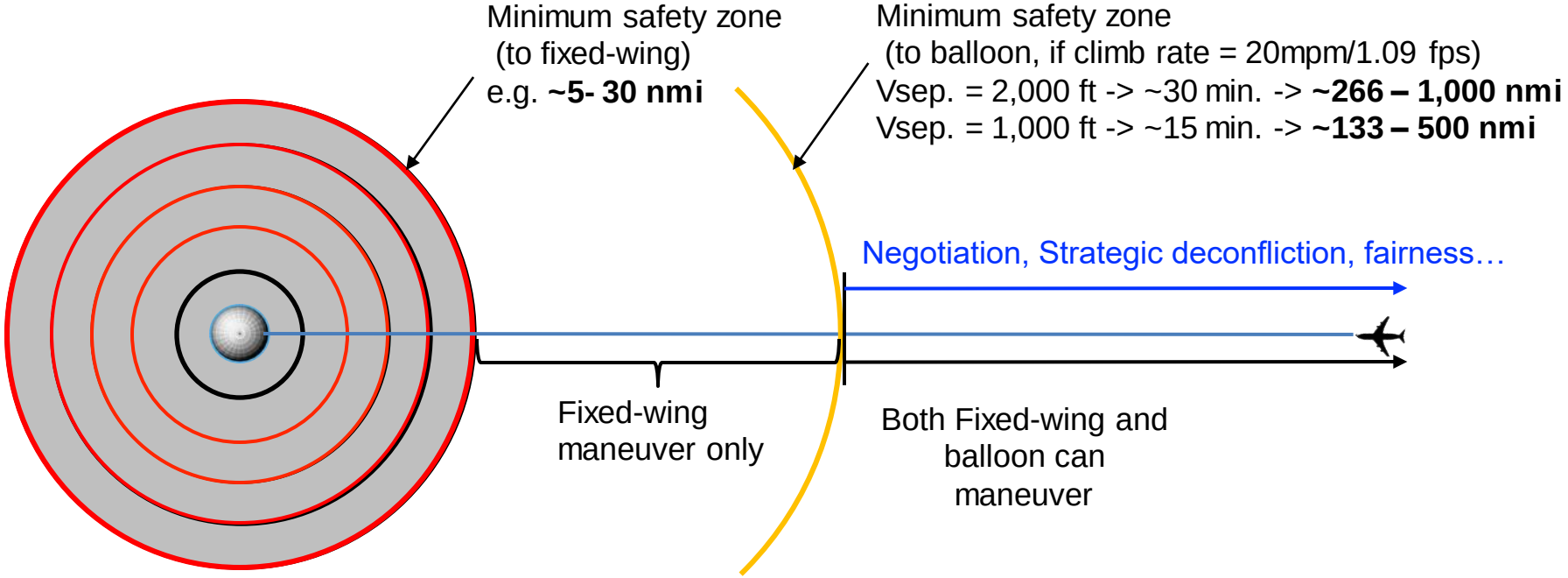




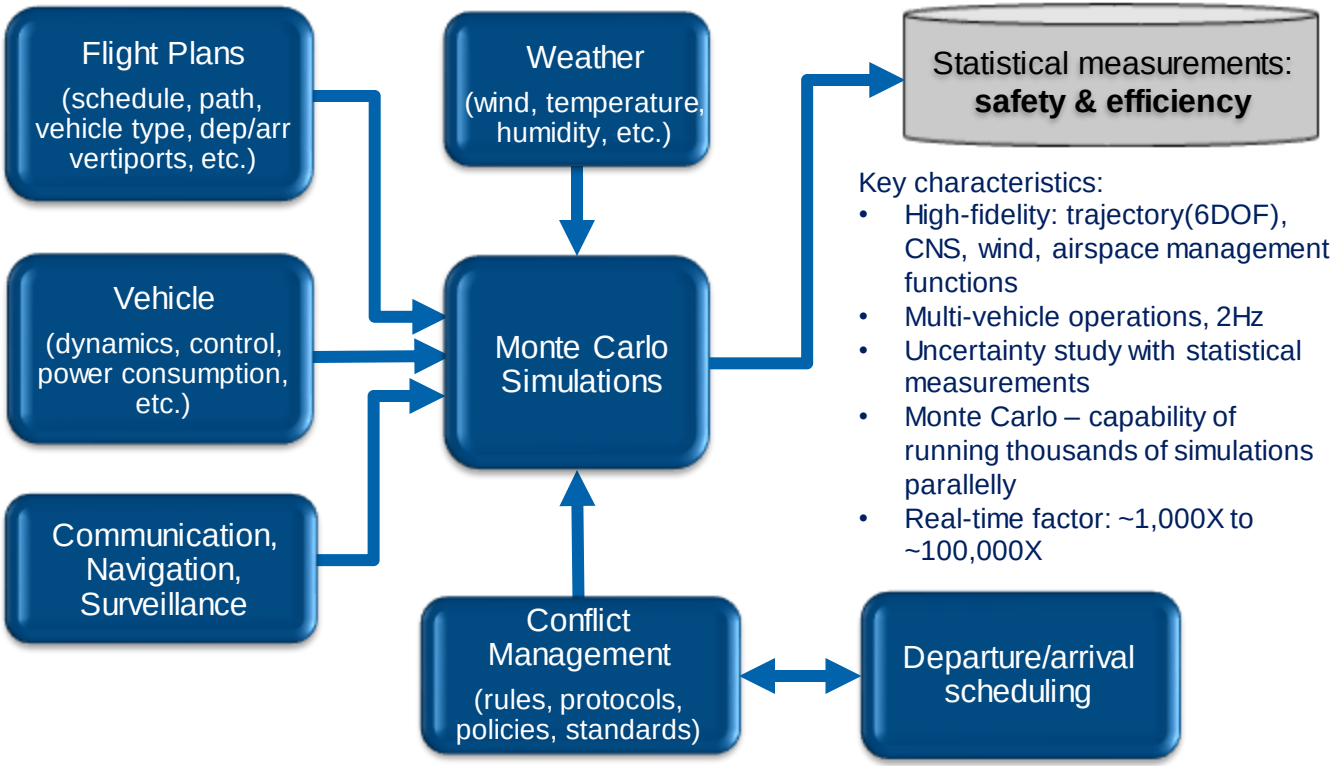
Notional cooperative separation management service processes within Upper Class E Airspace



Conflict Resolution Phases: Balloon and Fixed Wing



Fe³ Simulation Diagram



Key characteristics:

- High-fidelity: trajectory(6DOF), CNS, wind, airspace management functions
- Multi-vehicle operations, 2Hz
- Uncertainty study with statistical measurements
- Monte Carlo – capability of running thousands of simulations parallelly
- Real-time factor: ~1,000X to ~100,000X

***Fe³ - Flexible engine for Fast-time evaluation of Flight environments**

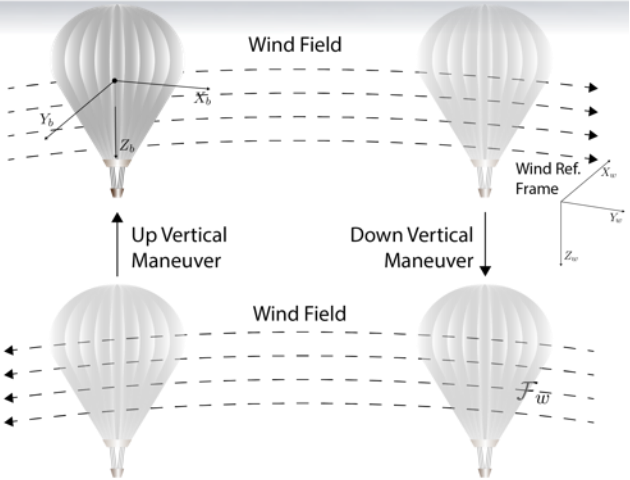
Modeling of High-Altitude Balloons

Challenge: Balloon dynamics are fundamentally different from conventional aviation vehicles (e.g fixed-wing type)

- Highly dependent on upper-E atmospheric properties
- Highly susceptible to wind
- Vertical control only

Status

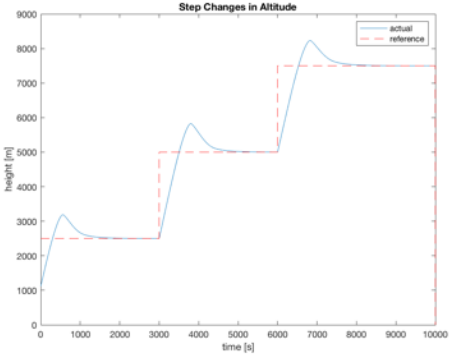
- Initial 3D model of Balloon developed
- Integrated NRLMSISE-00 (empirical, global reference atmospheric model) Implemented initial PI (proportional-integral) controller
- Performed initial tuning of drag coefficient and controller gains based on realistic balloon flight data

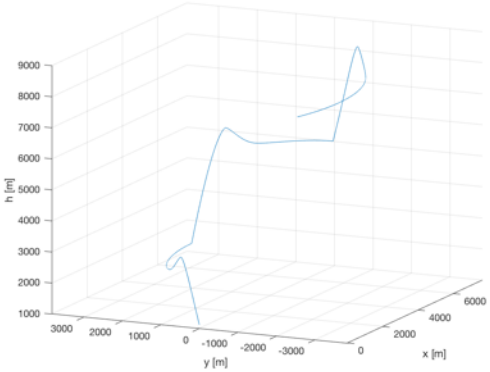


Balloon Model with Wind

$$\begin{cases} \frac{d}{dt}\left((m_b+\eta m_a)v_x\right) = -\frac{\bar{q}A_bC_d}{\|\vec{V}_{rel}^{(e)}\|}v_{rx} \\ \frac{d}{dt}\left((m_b+\eta m_a)v_y\right) = -\frac{\bar{q}A_bC_d}{\|\vec{V}_{rel}^{(e)}\|}v_{ry} \\ \frac{d}{dt}\left((m_b+\eta m_a)v_z\right) = -\frac{\bar{q}A_bC_d}{\|\vec{V}_{rel}^{(e)}\|}v_{rz} + (m_a-m_b)\,g \\ \dot{x}=v_x;\ \dot{y}=v_y;\ \dot{z}=v_z \\ \vec{V}_{rel}^{(e)} = v_{rx}\vec{i}+v_{ry}\vec{j}+v_{rz}\vec{k} \\ v_{rs}=v_s-\zeta_s;\ \ \bar{q}=\frac{1}{2}\rho\|\vec{V}_{rel}^{(e)}\|^2 \end{cases}$$

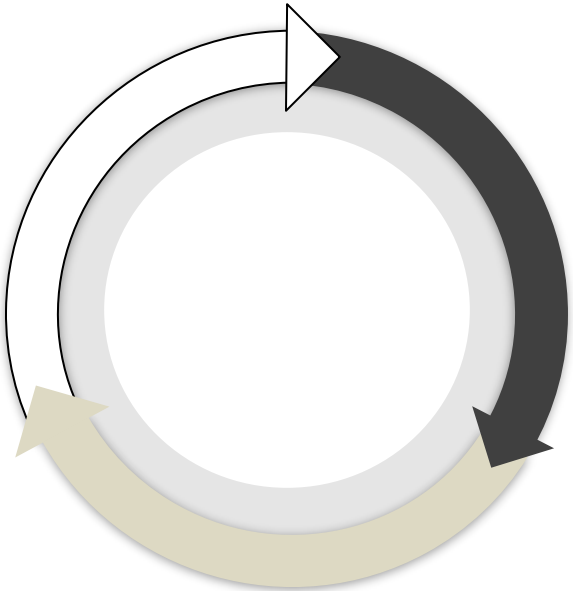
Simulation: Altitude Step Response with Wind



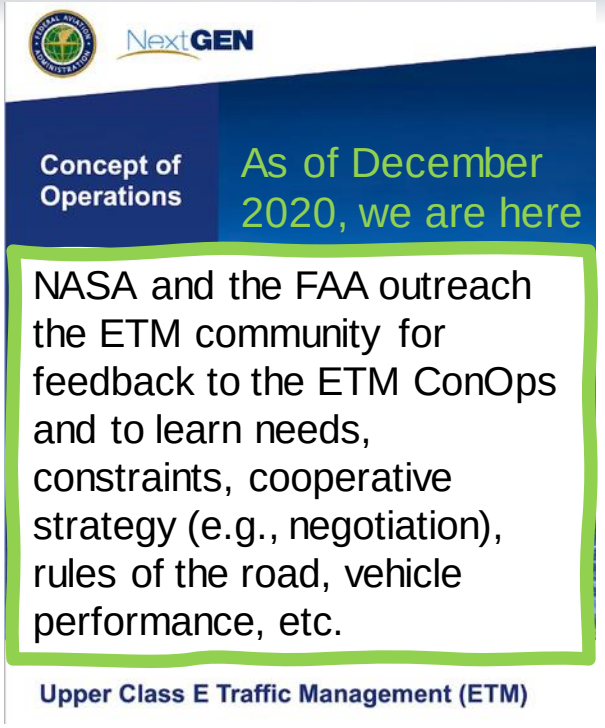


ETM Modeling and Simulation in ATM-X Phase 2

NASA provides the assessment results and research output such as services architecture and requirements to the community and the FAA for ETM ConOps Maturation

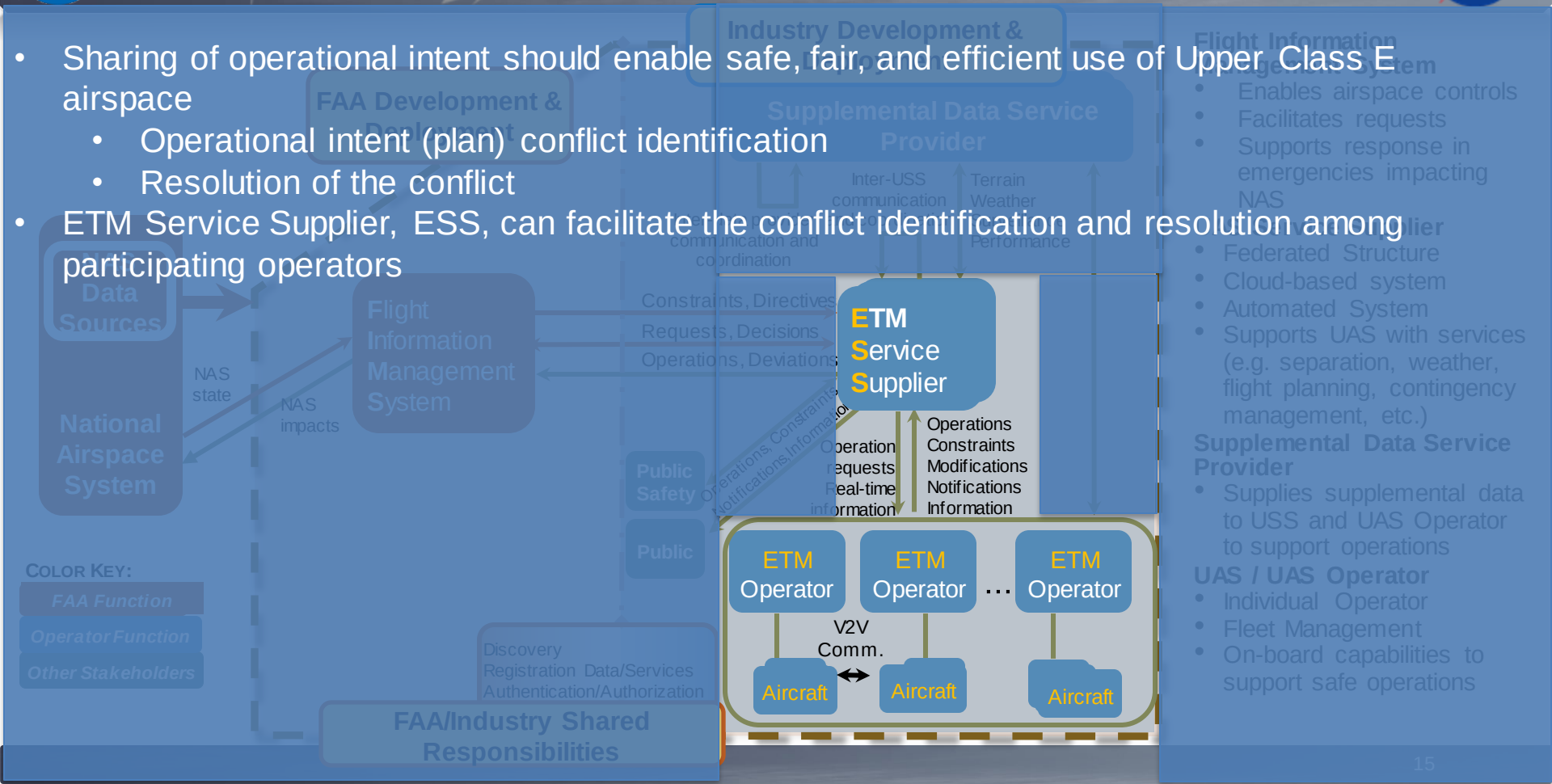


NASA models performances and services with the community input (e.g., negotiation process), builds scenarios informed by the FAA and the community to reflect the needs and constraints, and conduct simulations to assess the efficacy of the services



Introducing ETM Services Supplier (ESS)

- Sharing of operational intent should enable safe, fair, and efficient use of Upper Class E airspace
  - Operational intent (plan) conflict identification
  - Resolution of the conflict
- ETM Service Supplier, ESS, can facilitate the conflict identification and resolution among participating operators



Flight Information Management System
- Enables airspace controls
- Facilitates requests
- Supports response in emergencies impacting NAS

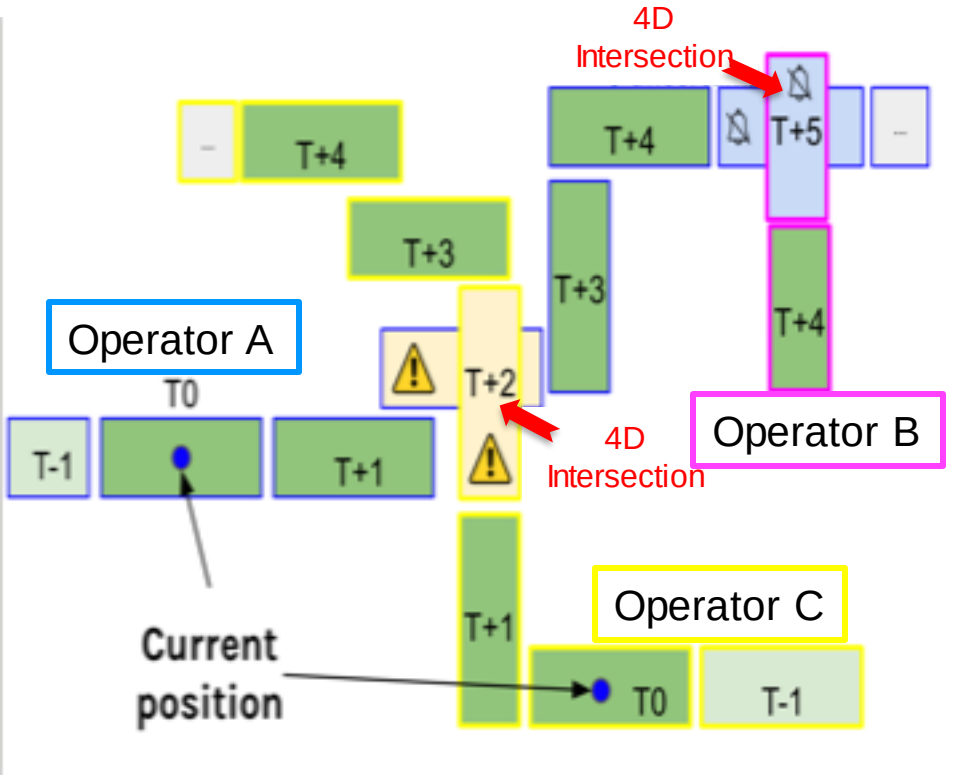
ESS
- Federated Structure
- Cloud-based system
- Automated System
- Supports UAS with services (e.g. separation, weather, flight planning, contingency management, etc.)

Supplemental Data Service Provider
- Supplies supplemental data to USS and UAS Operator to support operations

UAS / UAS Operator
- Individual Operator
- Fleet Management
- On-board capabilities to support safe operations

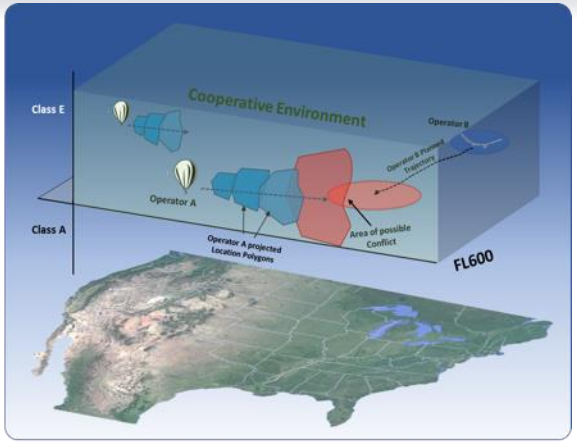
Initial ETM Service: Conflict Identification and Notification

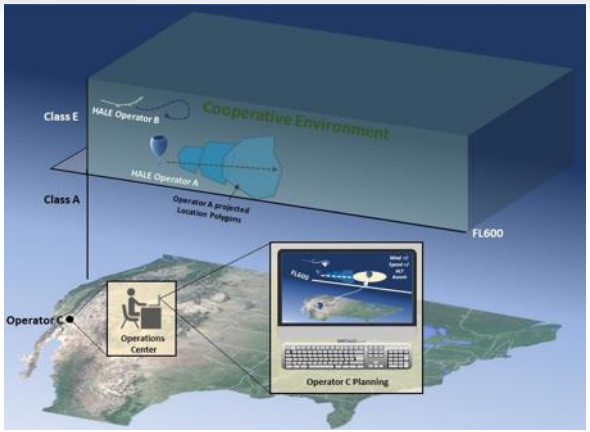
- ETM participants to submit operational intent to ESS
  - Operational intent should be standardized
  - Single or multiple ESSs could serve the NAS; the latter requires inter-ESS discovery, communications, and synchronization
- With the operational intents, ESS in position to identify 4D intersection of operational intent and inform the operators
  - It is possible that 4D intersection to not to be identified as a conflict

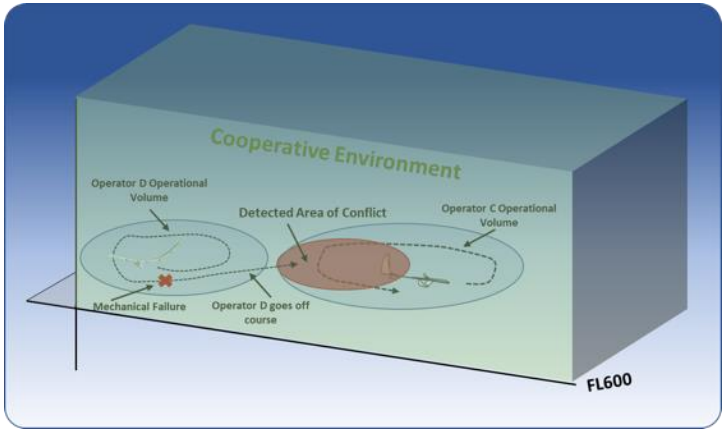


Understanding Cooperative Strategy with industry Input

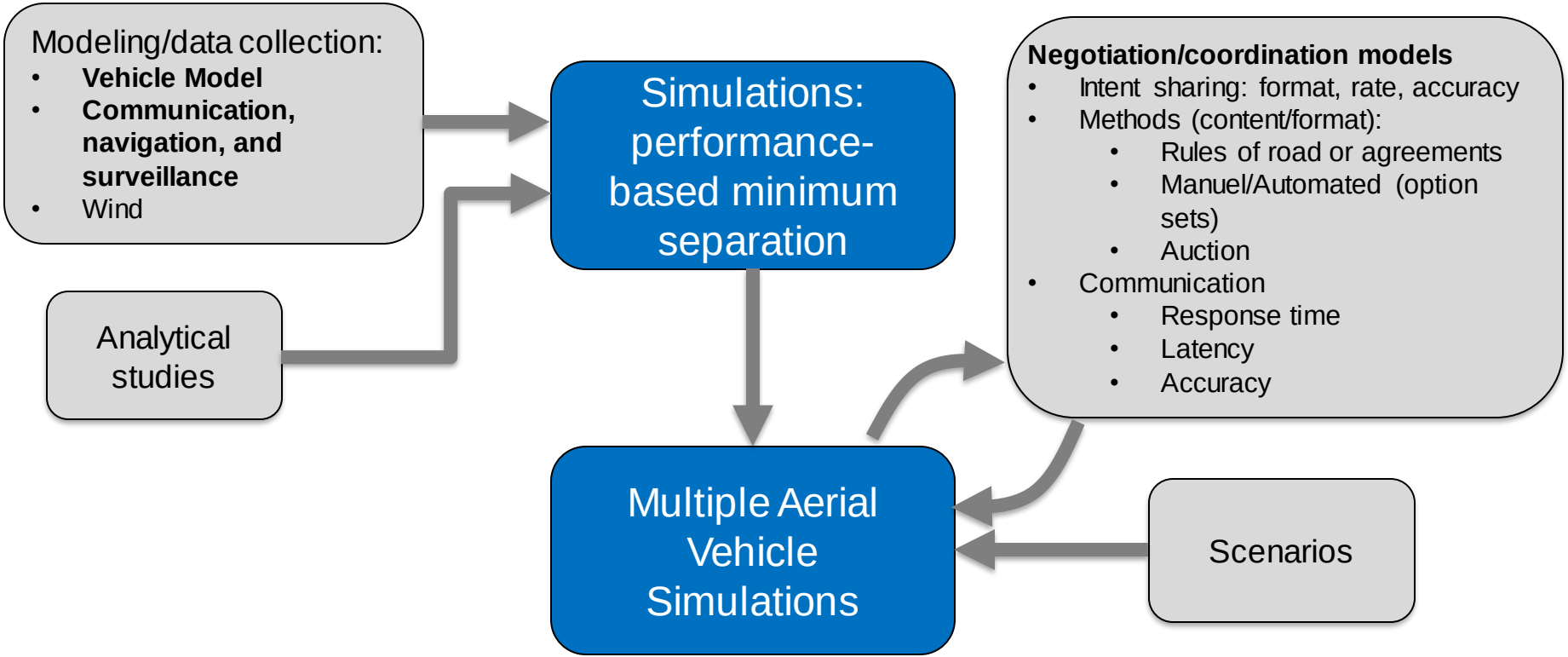
- Three scenarios developed to facilitate discussion and gather the industry input
  - ESS policy on identifying 4D intersection as a conflict
  - Operator response to the identified conflict
    - Agreements
    - Negotiations
    - Rules of the road
- NASA also engaging with the ETM community members in 1:1 setting
  - Mission needs and constraints
  - Vehicle performance
  - Timeline





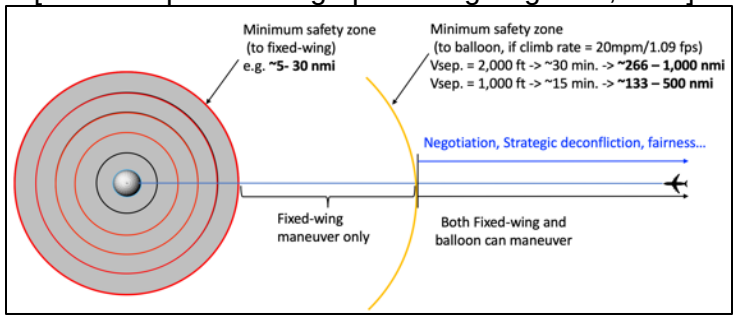


Modeling and Simulation Development



Research Questions to be addressed by simulations

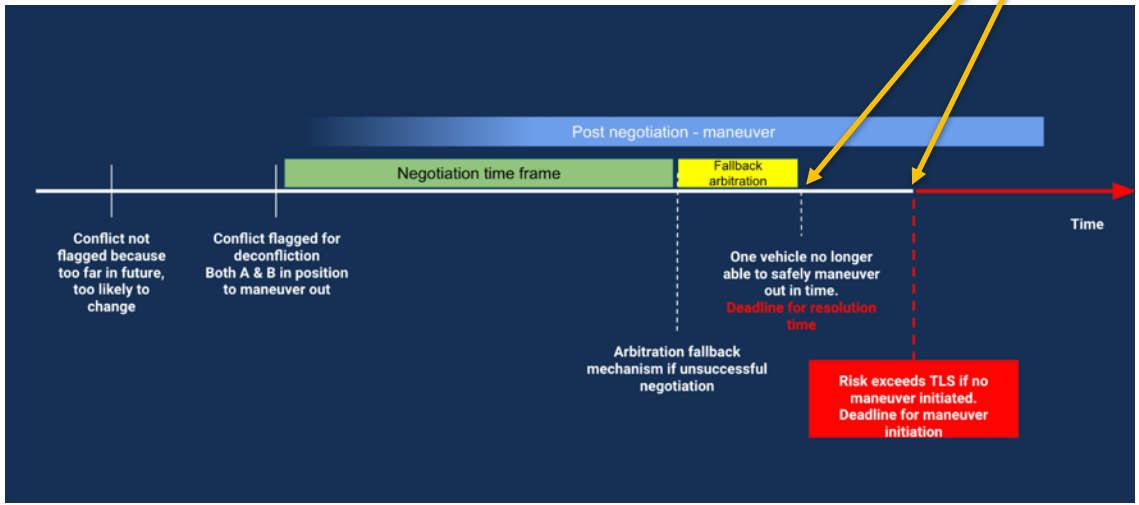
[Plot from previous tag-up meeting Aug. 27th, 2020]

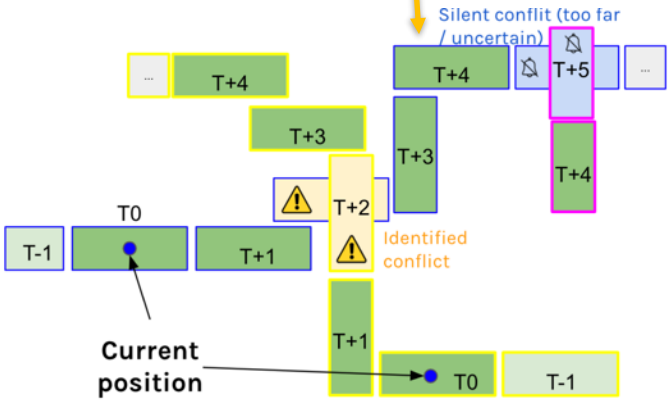


1. Timing and spatial boundaries for conflict resolution and negotiation

2. Size or duration of "rolling intent window"

3. CNS requirements





Research Questions to be addressed by simulations (cont'd)

For both pre-departure and in-flight, identify negotiation/coordination model(s) that are **safe, efficient, fair,** secure, and scalable:

- Intent sharing: content, format, rate, accuracy, and responsibility
- Methods:
  - Rules of road or predefined agreements
  - Manual/Automated (option sets)
  - Auction
- Communication: response time, latency, and accuracy
- Metrics: efficiency and fairness

Modeling and Simulation Timeline