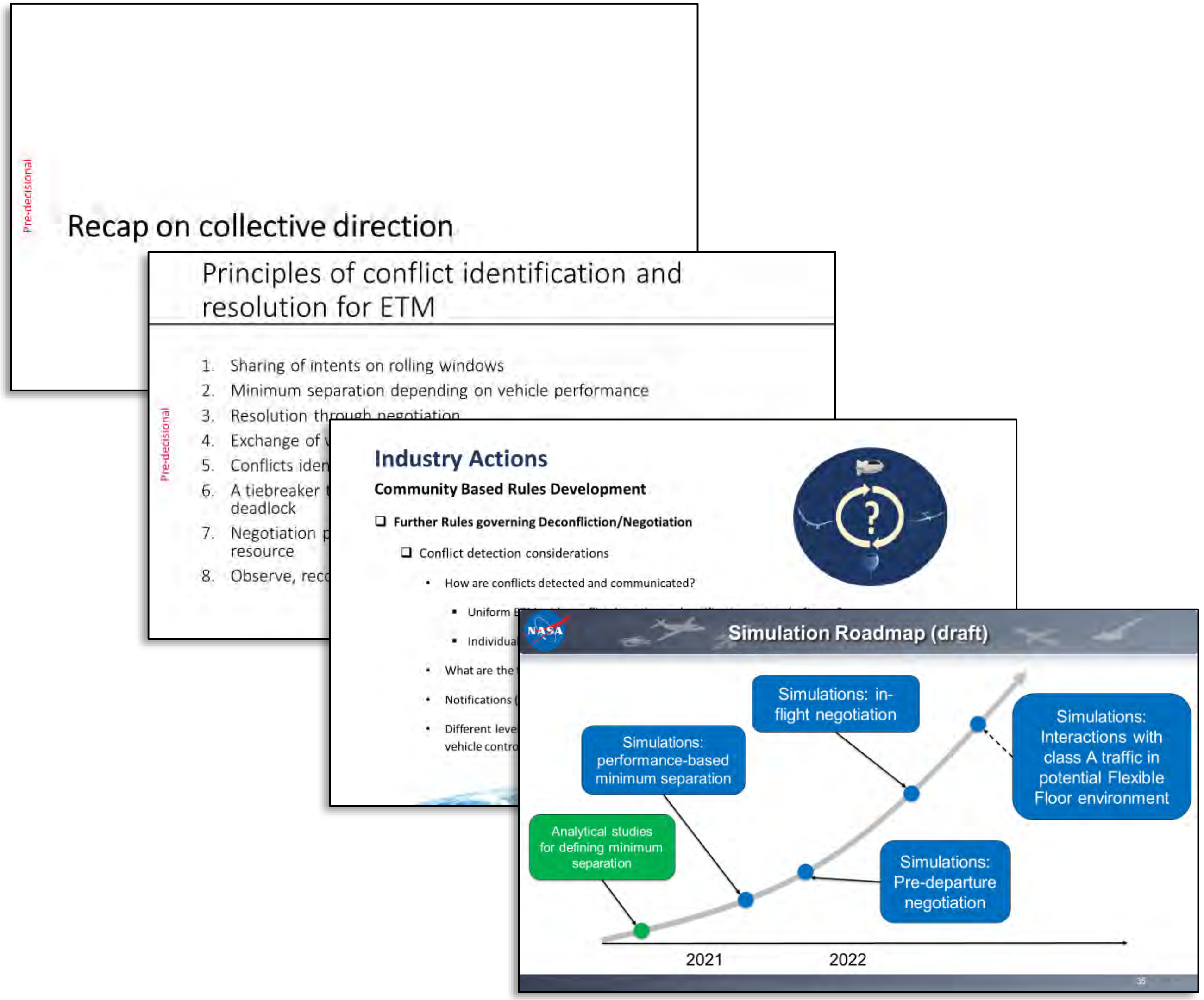
ETM: Upper E Traffic Management

December 10, 2020

Recap

Pre-decisional

- Meeting October 23
  - Recap
  - Principles
  - Actions
  - Draft Roadmap
- AIA Meeting December 2
  - Operation Intent
  - Negotiation



Agenda

- News and Updates
- Intent and Negotiation Discussion
- Use Case Walkthrough
- Modeling and Simulation Roadmap
- Wrap up

Industry Updates

News

Testing

Plans

Intent and Negotiation Discussion

Topic Items

Pre-decisional

Operation intent

-What does it mean and look like for the different platforms?

-How can/should it be represented in the cooperative environment?

-How far ahead or to what level of certainty should it be defined?

-How is it shared?

Negotiation Strategies

-Notional process

-Method (manual vs automated, digital, voice, message, …?)

-Considerations for negotiation in determining burden of maneuver (e.g., mission type/phase, maneuvering constraint, operation duration, transit vs. stationary, …?)

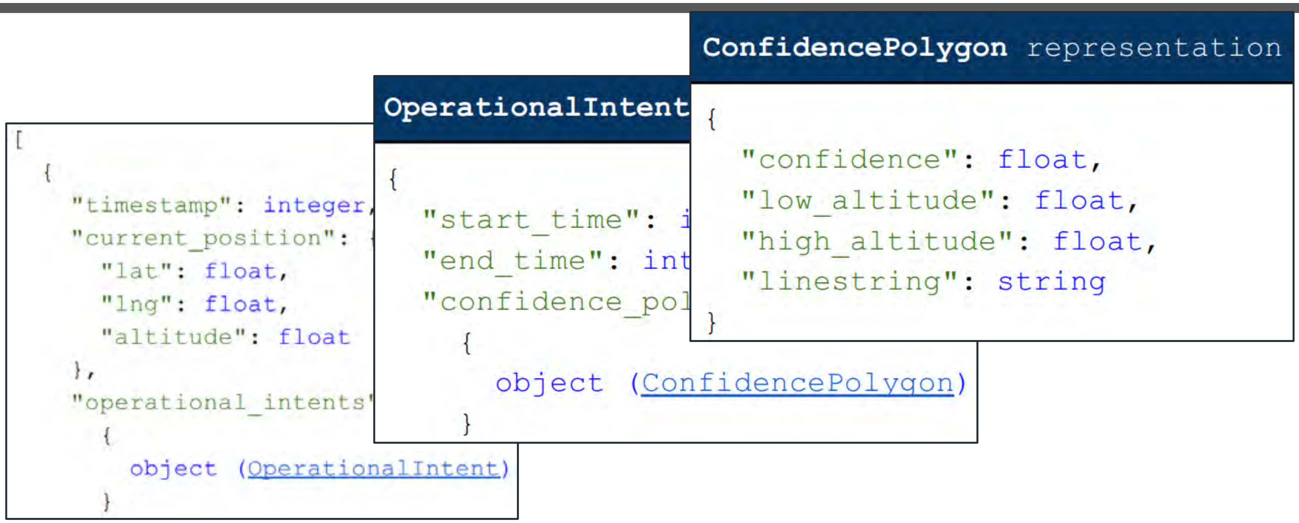
-What happens if negotiation unsuccessful?

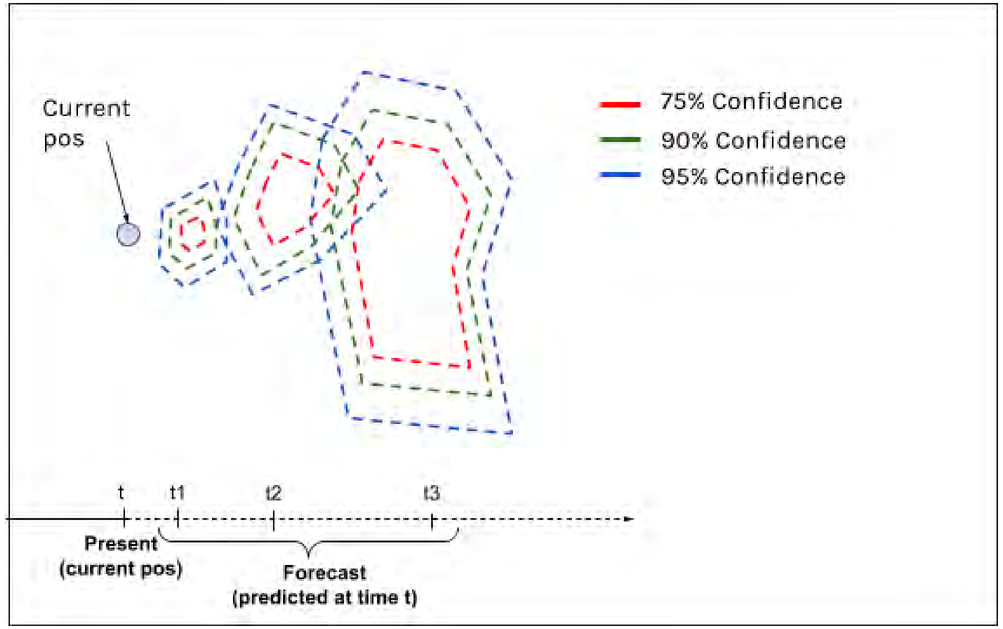
Operation Intent

Pre-decisional

What does it mean and look like for the different platforms?

- We should remain close to UTM
- An intent is a collection of 3D polygons that represent where a vehicle will be during some time segments in the future, with some level of confidence.
- There may be multiple confidence levels provided for each time segment.





Operation Intent

- How far ahead should intent be defined?
  - Long enough to identify all necessary conflicts.
- Conflicts are identified at a specified (Hardcoded timeframe for now) using a give way time Matrix.
- To what level of certainty?
  - The level of certainty must be communicated in the intent (95%, 99%, etc.) and may be multiple. Let's measure in the sim the consequences of picking one level vs. another.

Pre-decisional

Operation Intent

- For example (just with random numbers, but we can however play with those numbers and observe results)

<table>
<tr><th></th><th></th><th colspan="2">Vehicle avoided</th></tr>
<tr><td></td><td></td><td>Loon Balloon</td><td>AV HALE</td></tr>
<tr><td rowspan="2">Vehicle giving way (avoiding)</td><td>Loon Balloon</td><td>--</td><td>40min</td></tr>
<tr><td>AV HALE</td><td>10min</td><td>10min</td></tr>
</table>

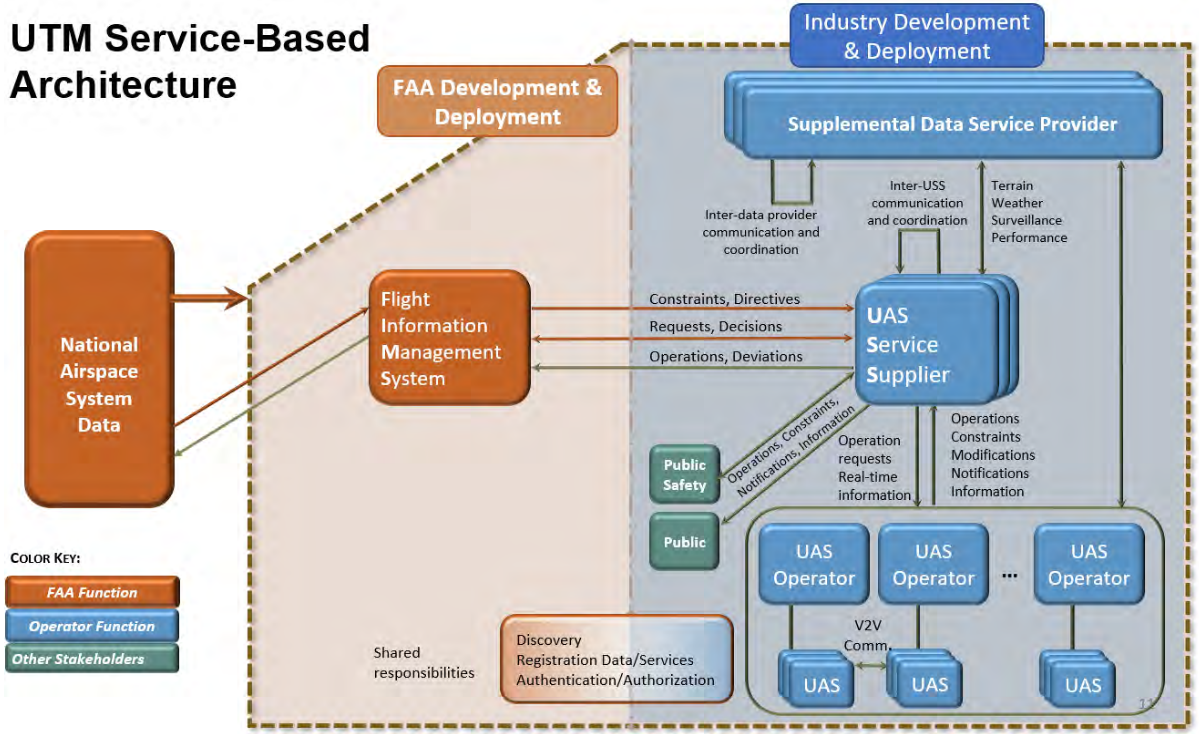
With the following rules:

- If intents overlap between 2 vehicles such that the conflict horizon is getting close to the largest avoid times in the matrix (i.e. between Loon and AV, that would be 40min). Then the conflict must be negotiated between the 2 operators. The negotiation results in assigning who needs to give way.
- Those Matrix number ultimately should be computed from some maneuverability information or vector provided by operators along with intents, which indicate in which direction and how fast a vehicle can move.
- Intents must therefore be long enough to cover the largest of the possible intersect times. They can be arbitrarily long (e.g. Loon can always provide 24h even if conflicts never get identified beyond 6h) it's just important they are at least 6h long

Operation Intent

- How is it shared?
  - Shared via web-based APIs between PSS after discovery through DSS. (For now, lets forget the DSS part and assume that the simulation is post DSS discovery).

Pre-decisional



Pre-decisional

Negotiation Strategies

Notional Process

- An overlap that is getting close to the largest of the give way times of the vehicles in conflict triggers a negotiation process with a negotiation deadline. Both players have to negotiate.
- For now, there is no need to simulate a negotiation process, let's have a random function with X% chance of win decide (to replace negotiation), and let's play around with that X% value.
- A few situations have priority:
  - Emergencies
  - Some state priority actors that chose to use their priority (i.e. equivalent to a police car with the emergency lights and siren on)
  - Situations where only one of the vehicles can maneuver should revert to 91.13 (most maneuverable needs to move). This is however last resort (lost comms, etc.) and the negotiation scheme should not allow such situation to happen.

Negotiation Strategies

Method (manual vs automated, digital, voice, message, …?)

- Method should not matter for sims. We should just assume that it happens in an allocated amount of time.
- *Desire to understand perspectives on approach and thoughts at a conceptual level*

Negotiation Strategies

Pre-decisional

Considerations for negotiation in determining burden of maneuver (e.g., mission type/phase, maneuvering constraint, operation duration, transit vs. stationary, …?)

- We should not try to simulate the negotiation process or cost of maneuvering.
- This is too complex and depends on too many factors that cannot be modeled.
- This is somewhat equivalent to modeling the cost of forcing a move on a chess player. The impact depends on the board which has an infinite amount of situations, all resulting in different outcomes some minimal, others very large. Making a model of this is likely impossible.
- Rather, let's just use random functions with different probability of win to see the impact.

Negotiation Strategies

Pre-decisional

What happens if negotiation unsuccessful?

- Such scenario is not always possible depending on what is intended by "negotiation". For example, if priority goes to the highest bidder, there is always a winner. However, if something went terribly wrong, and for some reason we are in a situation where 2 vehicles happen to be in conflict, and one of them is physically not able to move in due time, then the one that can must give way.
- Note: this does not mean that there is an option not to negotiate or to make the negotiation go stale. It should only be a last resort behavior.

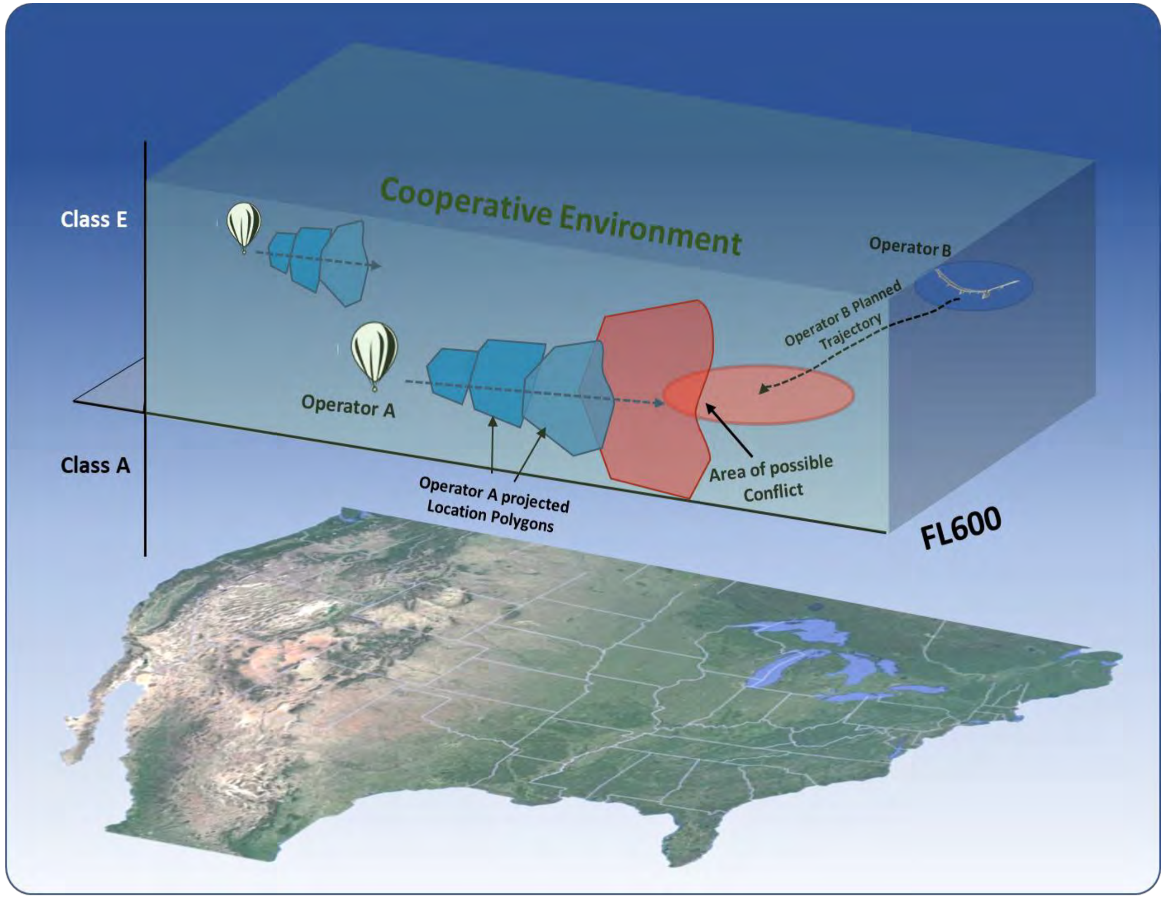
Pre-decisional

Use Case Walkthrough

Scenario 1: Balloon/Fixed Wing Planning Ahead

Pre-decisional

- HALE Balloon Operator A is operating at FL610 over the Western US and continues to forecast its flight path Southeastward across the country.
- HALE Fixed-Wing Operator B is operating over the Northeastern US and is planning its flight path at FL610 south towards the Gulf of Mexico.
- Based on current wind speed and direction, Operator A calculates the balloon will be over the central Florida in approximately 30 hours.
- Operator B calculates the fixed wing vehicle will be over central Florida in 30 hours.
- Operator A and B share and receive a rolling series of updated/extended intent information.
  - With each update, certainty of the vehicle's trajectory increases
  - Both Operators identify potential conflict
- Conflict is **not flagged** since it is still too far in the future (uncertain)



Scenario 1: Balloon/Fixed Wing Planning Ahead

Pre-decisional

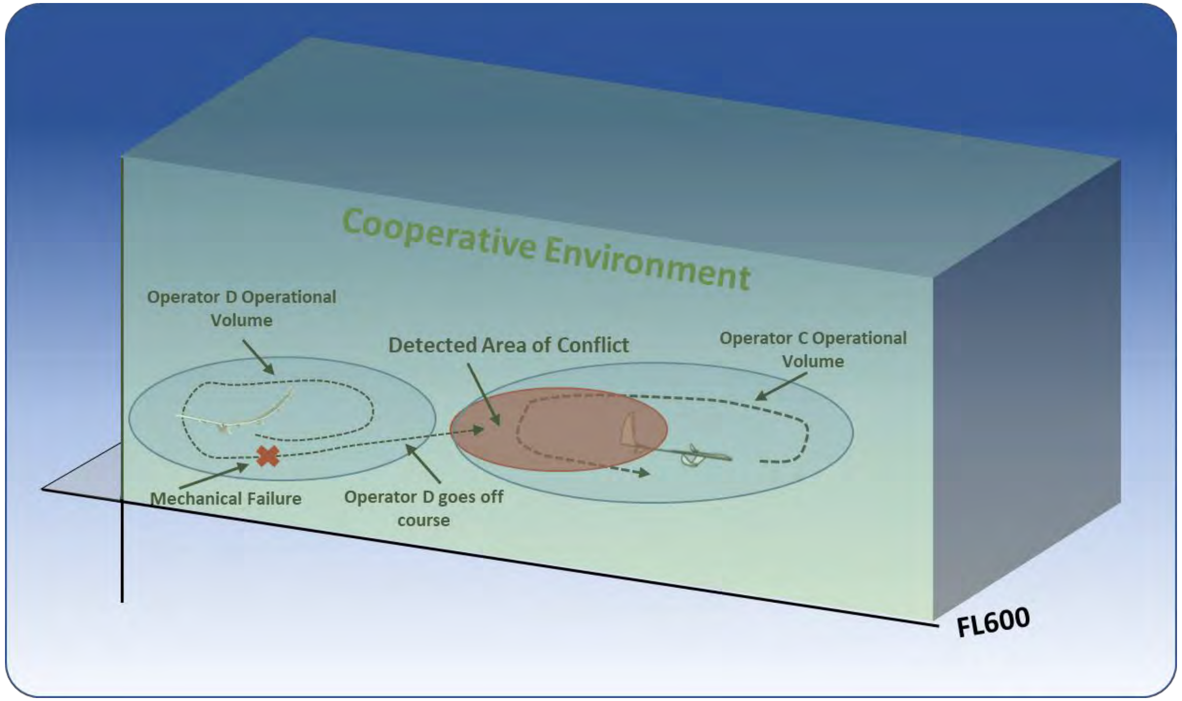
- Over time, as intent is updated on a rolling window, a conflict over Florida is identified, requiring deconfliction.
  - Conflict identification timing is determined by the exchange of operation information (e.g., intent, vehicle performance).
    - How is this exchange envisioned to be conducted?
- Outcome 1 – both Operators negotiate a resolution giving way to one another and **successfully deconflict.**
- Outcome 2 – Negotiation is **unsuccessful**, and a solution cannot be reached?.
- **Discussion:** In the collaborative environment, industry has stated that the negotiation process must occur with enough time to identify a solution, otherwise 'current right of way rules' may be instituted.

  If successful negotiation does not occur within the given time, who moves?
  - Application of right of way rules (e.g., the more maneuverable vehicle avoids the less maneuverable vehicle)
    - How does one characterize maneuverability with HALE vehicles?
  - What if both vehicles have the same maneuverability characteristics?
  - Which Operator is given priority in this situation?

Scenario 2: Fixed Wing to Fixed Wing Interaction

Pre-decisional

- HALE fixed wing Operator C and D are operating near each other in a defined area providing communication services to a hurricane devastated region.
  - Both Operators are updating their intent while operating
- HALE Fixed Wing Operator D experiences an equipment issue causing the vehicle to become non-conforming.
  - A motor fails on one of the propulsion mechanisms causing a steering issue
- Operator D accounts for the issue and updates their intent with current information; a conflict with Operator C is identified.

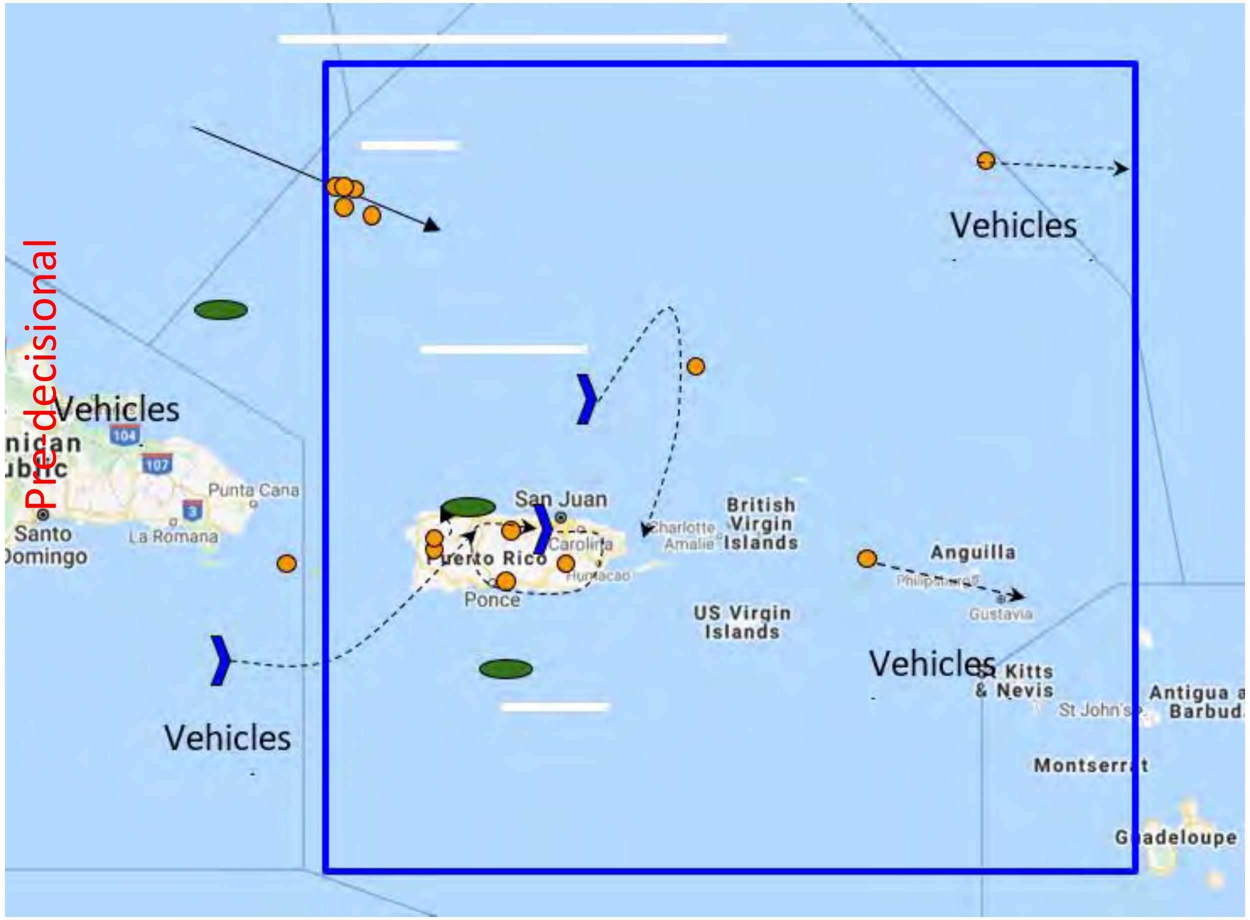


Scenario 2: Fixed Wing to Fixed Wing Interaction

Pre-decisional

- Resolution through negotiation is **not possible** as there is not enough time for both Operators to negotiate a solution.
  - It is calculated that Operator D will drift into the separation envelope of Operator C if no action is taken within a short period of time resulting in a loss of separation.
  - Operator D maintains some maneuverability despite the issue but is not able to maneuver out of the path of Operator C.
- Outcome 1 – As time permits, the conflict is resolved as Operator C gives way to Operator D (fallback mechanism) due to its limited maneuverability/ equipment issue.
- Outcome 2 – Lack of time prevents Operator C from controlling the vehicle to change course to avoid the path of Operator D, resulting in a loss of separation.
- **Discussion**: When negotiation is not viable and time restricts an Operator's maneuverability envelope (time to control/change course) to deconflict (fallback mechanism), what actions might be available as the "last resort"?

Earlier Reference Scenario: Multiple operators operating in a locally dense area for prolonged duration



- A fleet of 20 balloons and *two* fixed wing solar HALE and *Y* airships create a connectivity mesh to restore connectivity. Balloons and fixed wing aircraft would be launched from outside the mission (operational) area and ingress to the mission area at high altitude. For connectivity, each HALE will maintain a fixed orbit within a 5 km diameter circle for extended periods.
    - The volume of each operation mentioned above should be varied as an input to the simulation
- Two of the fixed wing solar HALE are occasionally redeployed to assist with ground operations.
- A cooperative military aircraft operates reconnaissance missions for a different purpose.
- Balloons ascend and descend between FL500 and FL650 to navigate with winds (about 75% of the time is spent between FL500 and FL600), HALE may occasionally go to different altitudes to optimize energy use for a few hours.
- All vehicles adapt and change their intents to meet changing mission needs. Balloons adapt their plan and altitude frequently to react to observed wind conditions. Fixed wing orbits may be shifted to react to mission requirements.

Pre-decisional

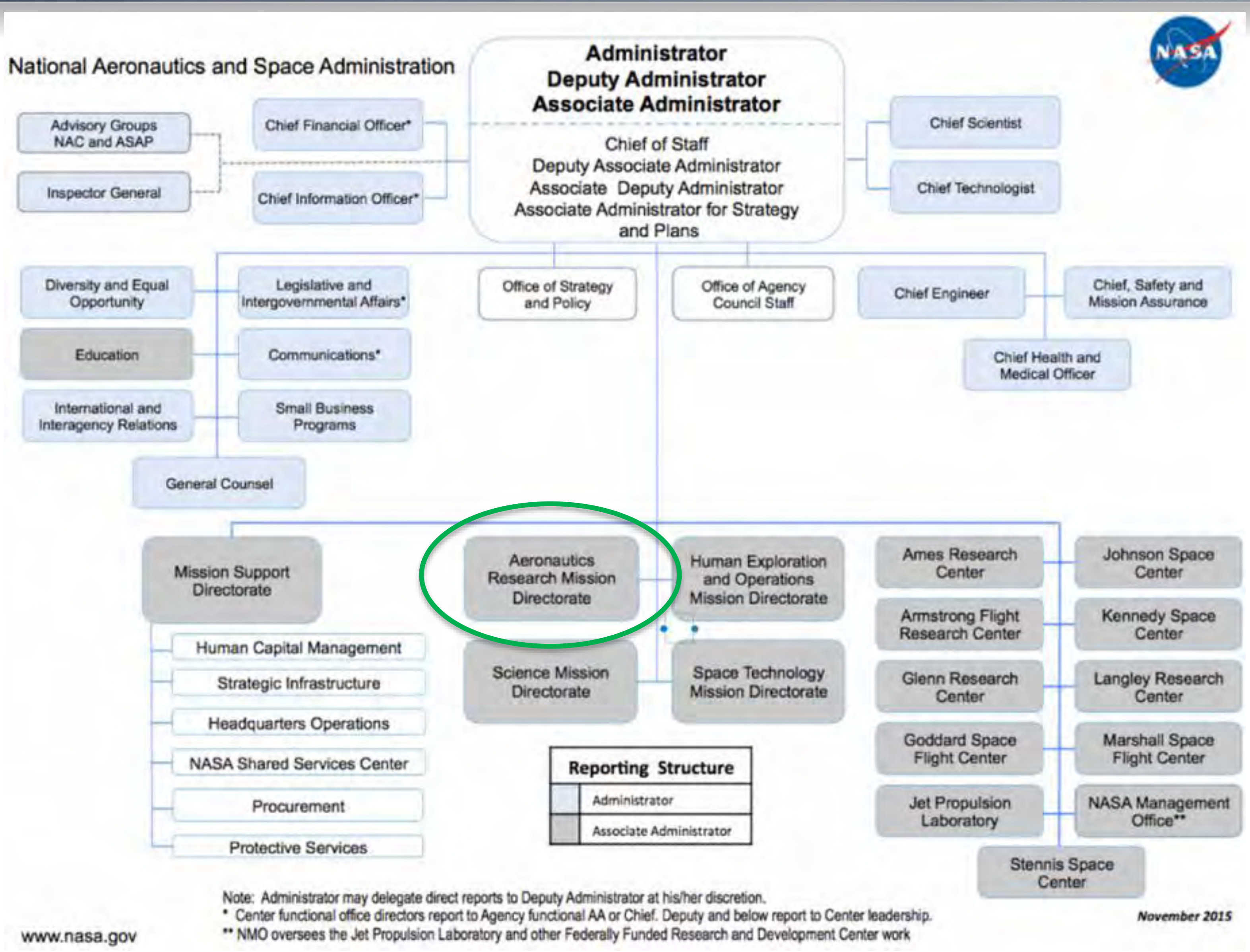
Modeling and Simulation Roadmap

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

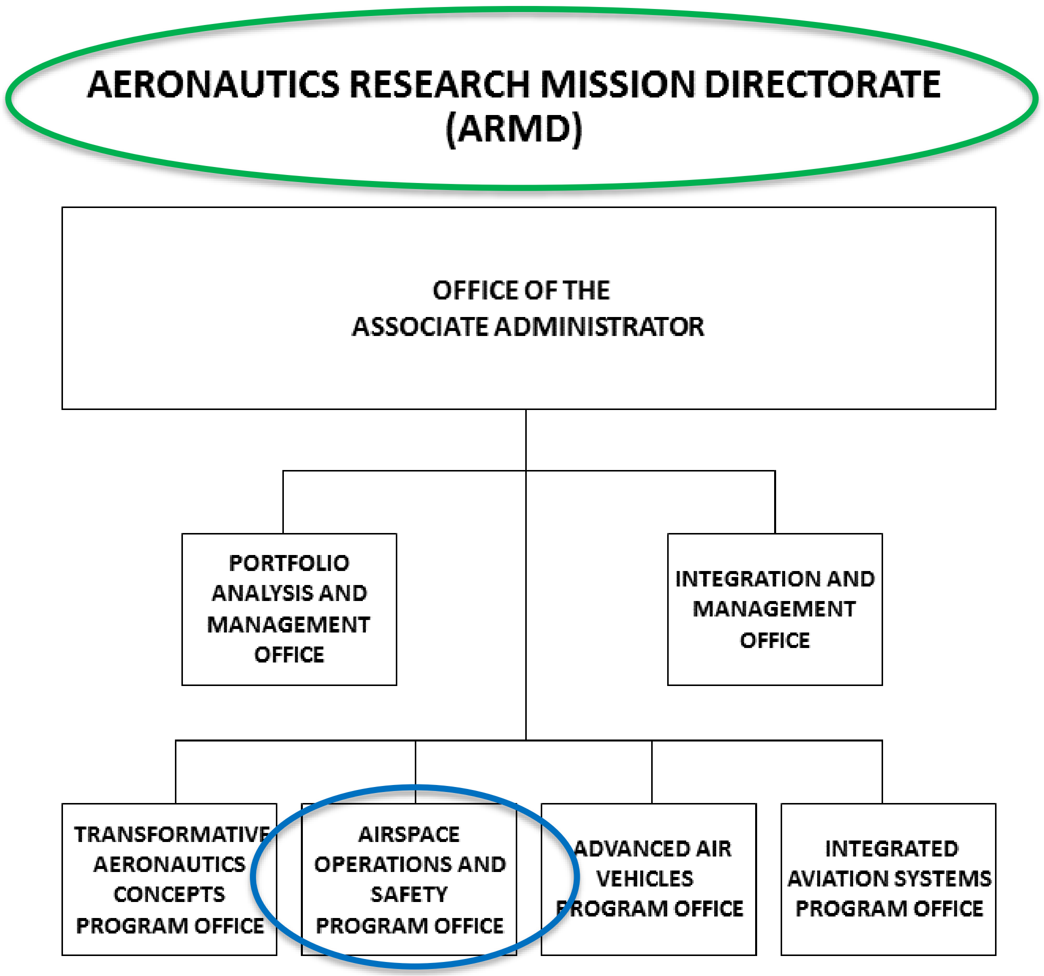
Outline

- 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

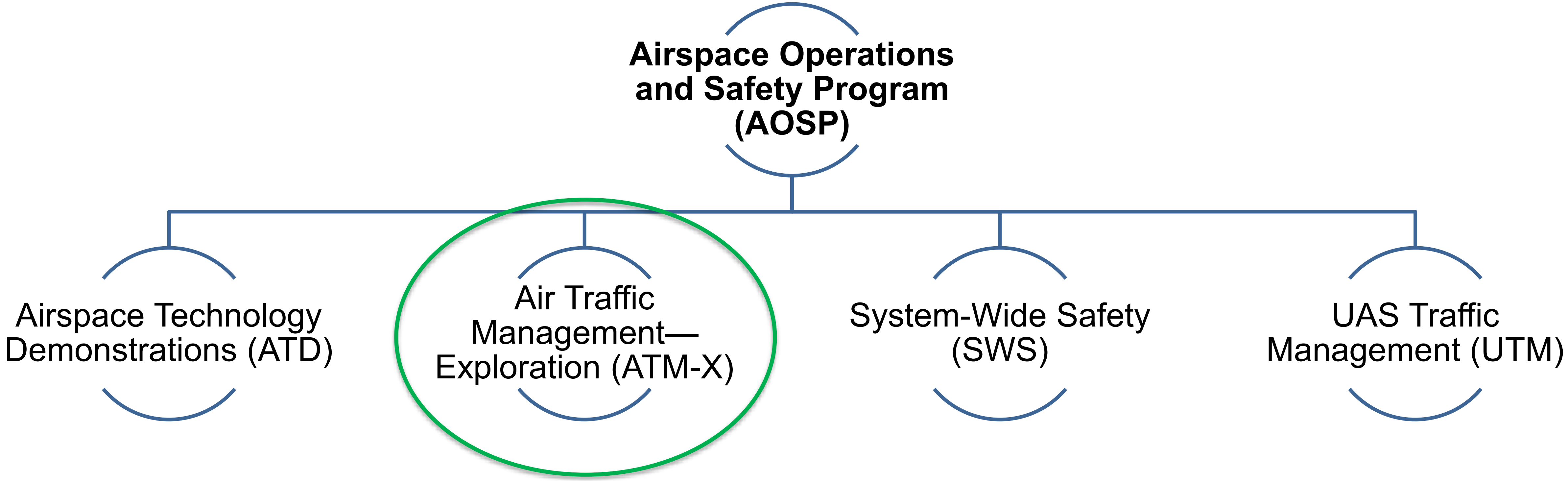
NASA Organizational Chart



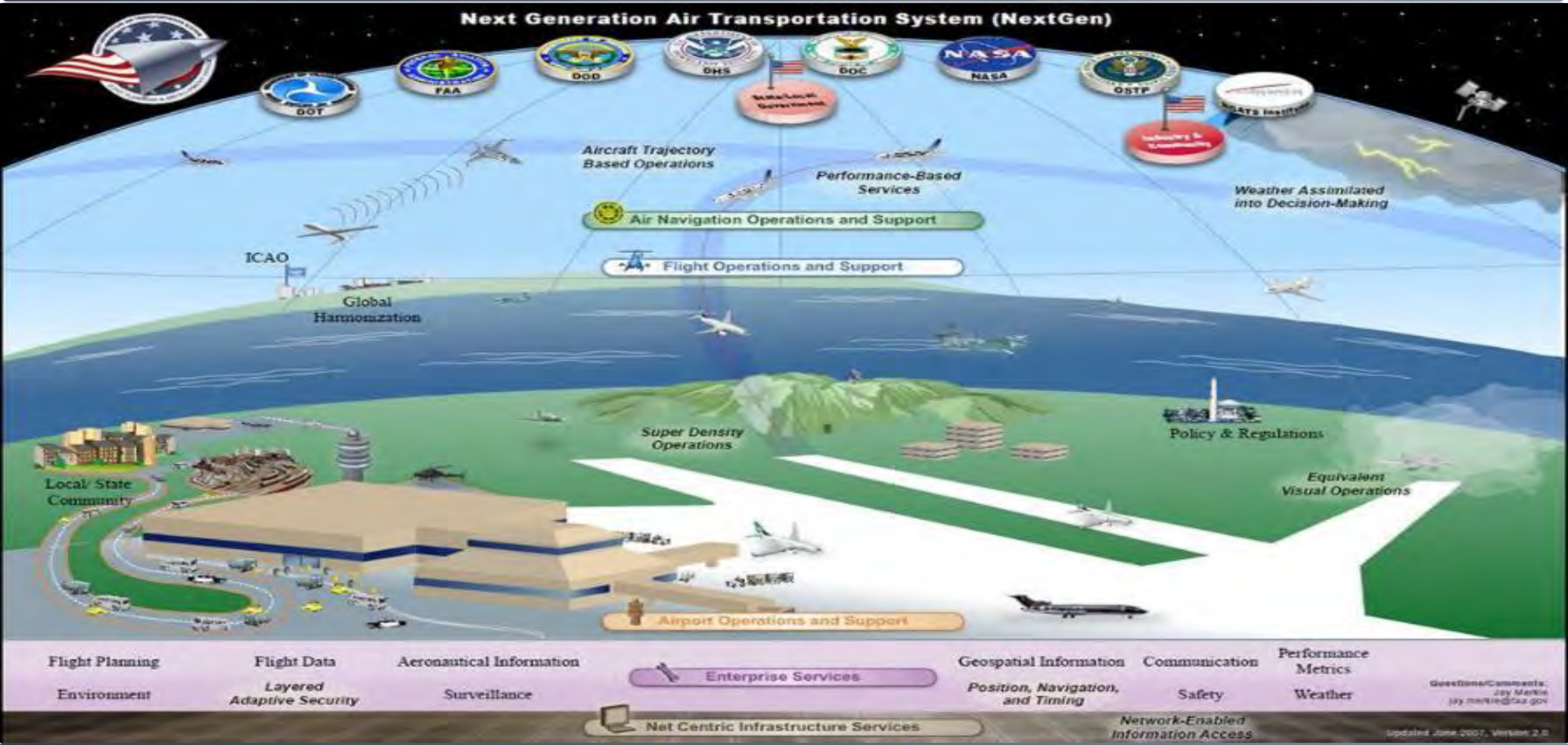
ARMD Organizational Chart



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

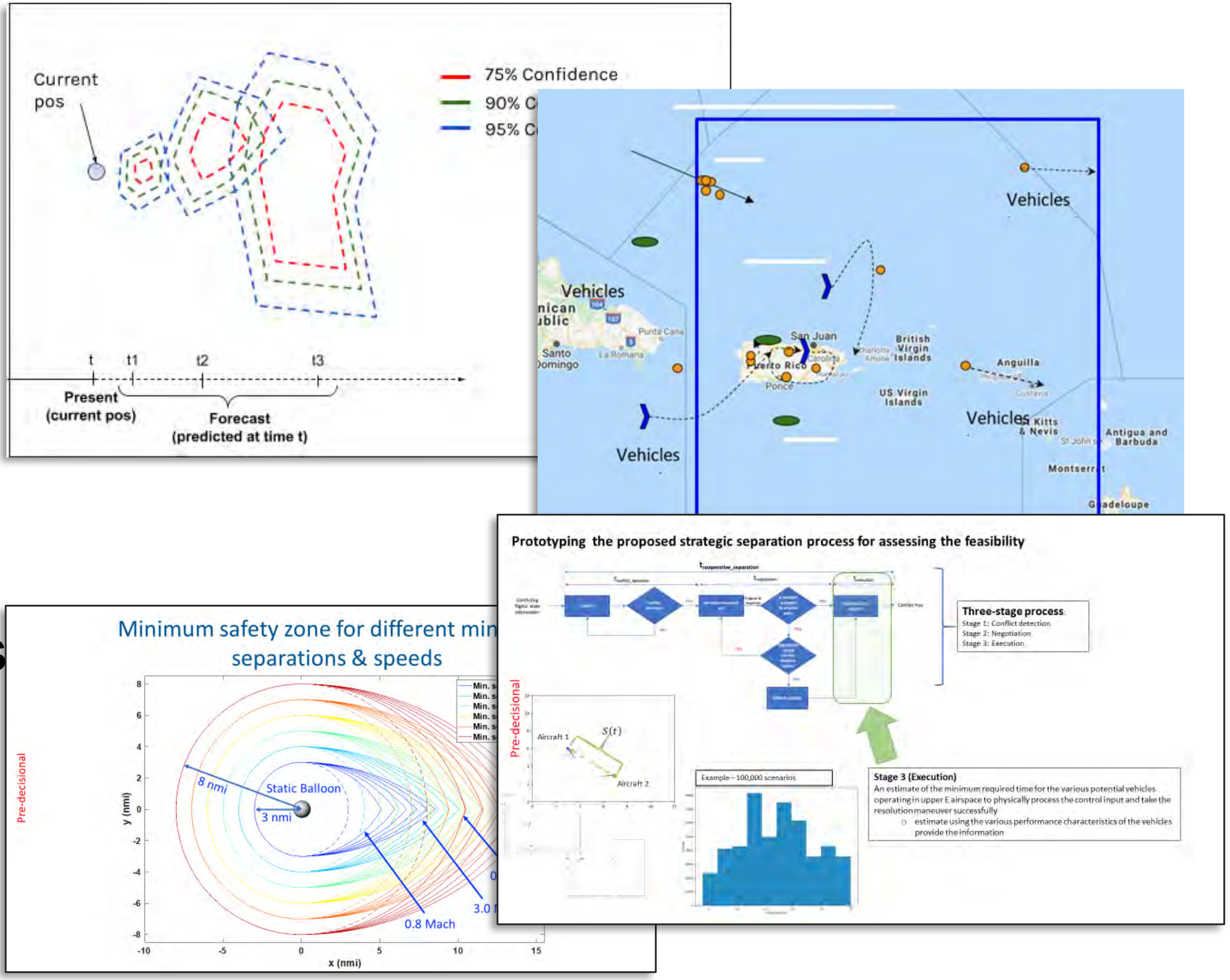
Goal: Catalyze the community to provide an all-access, safe, and efficient airspace system through innovative solutions that remove barriers

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

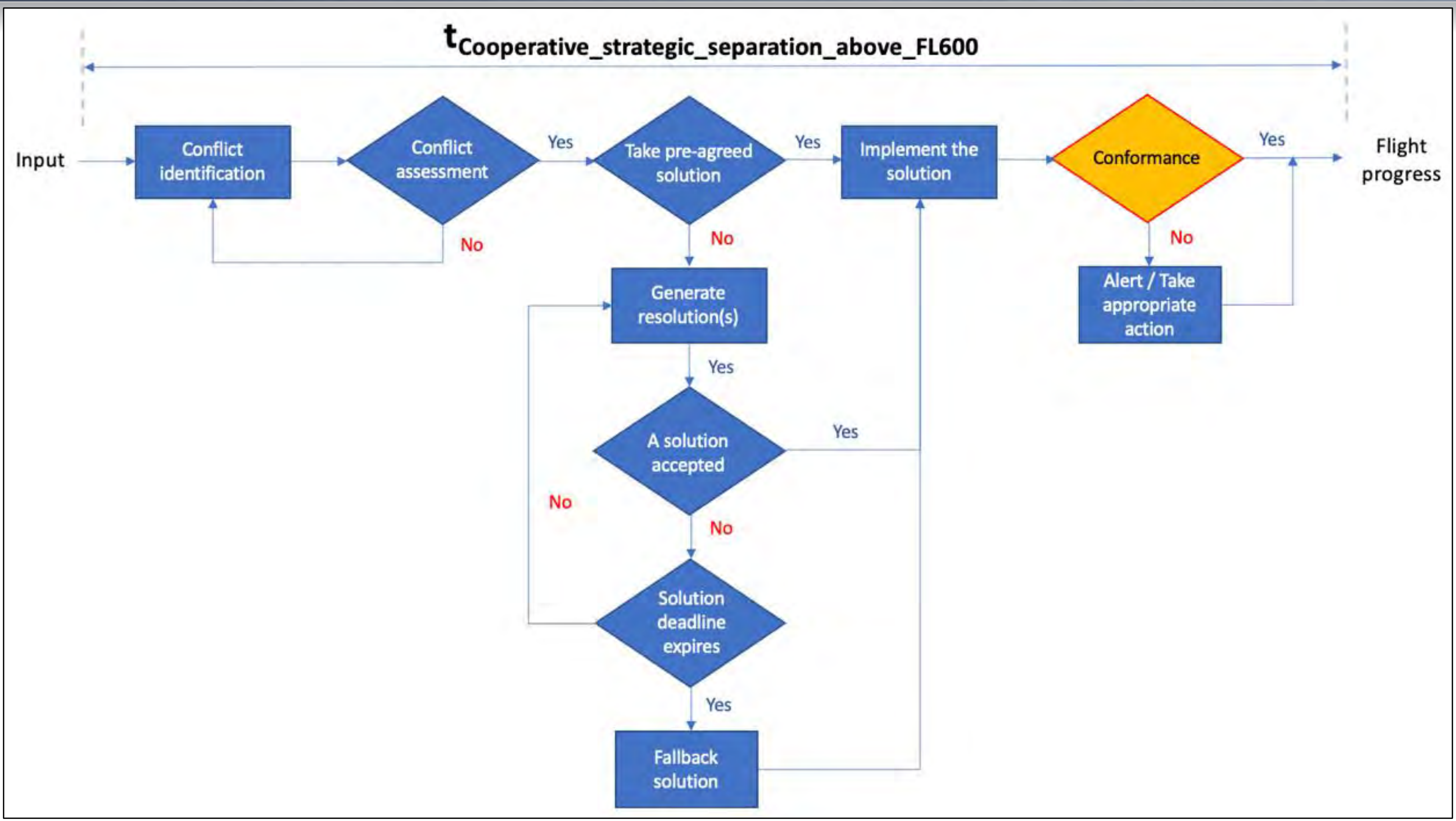
ETM Modeling and Simulation, prior to ATM-X Phase 2

- ETM Operations Modeling
  - Cooperative operation concepts and scenarios
  - Conflict identification and resolution strategies

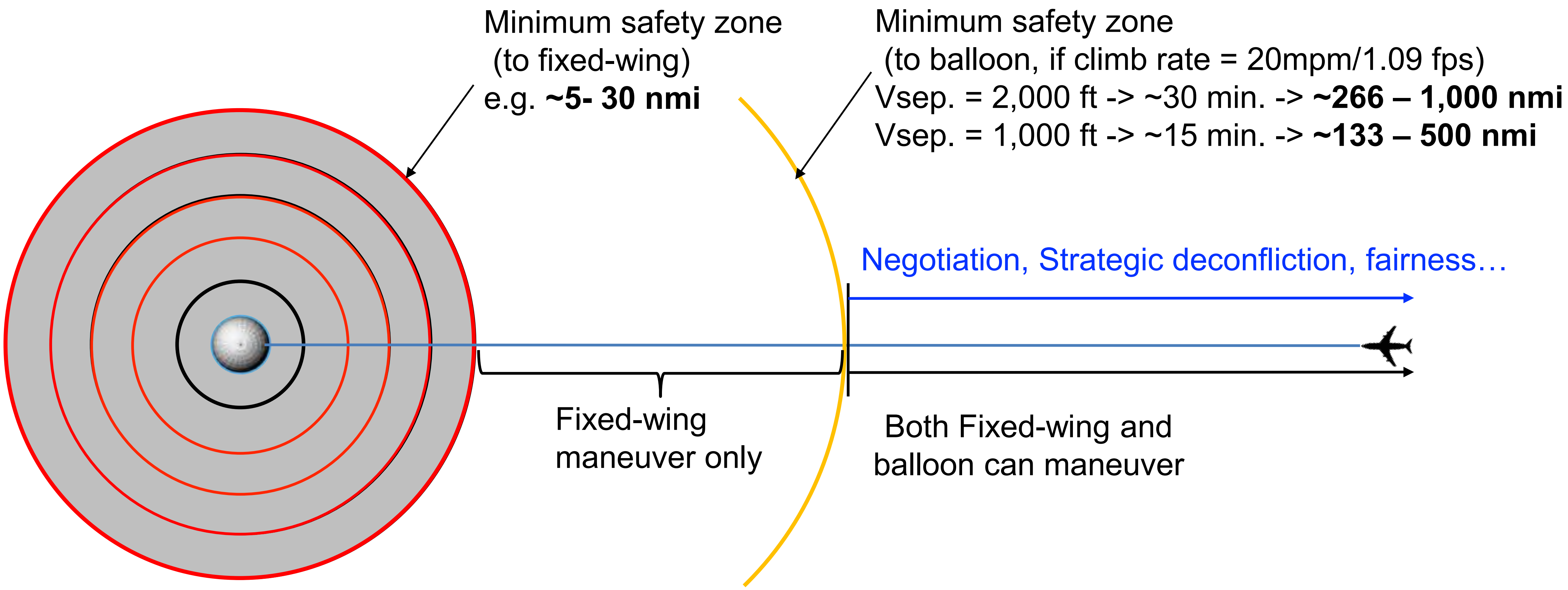
- ETM Simulation
  - Flexible engine for Fast-time evaluation of Flight environments (Fe3)
  - High-altitude balloon dynamics



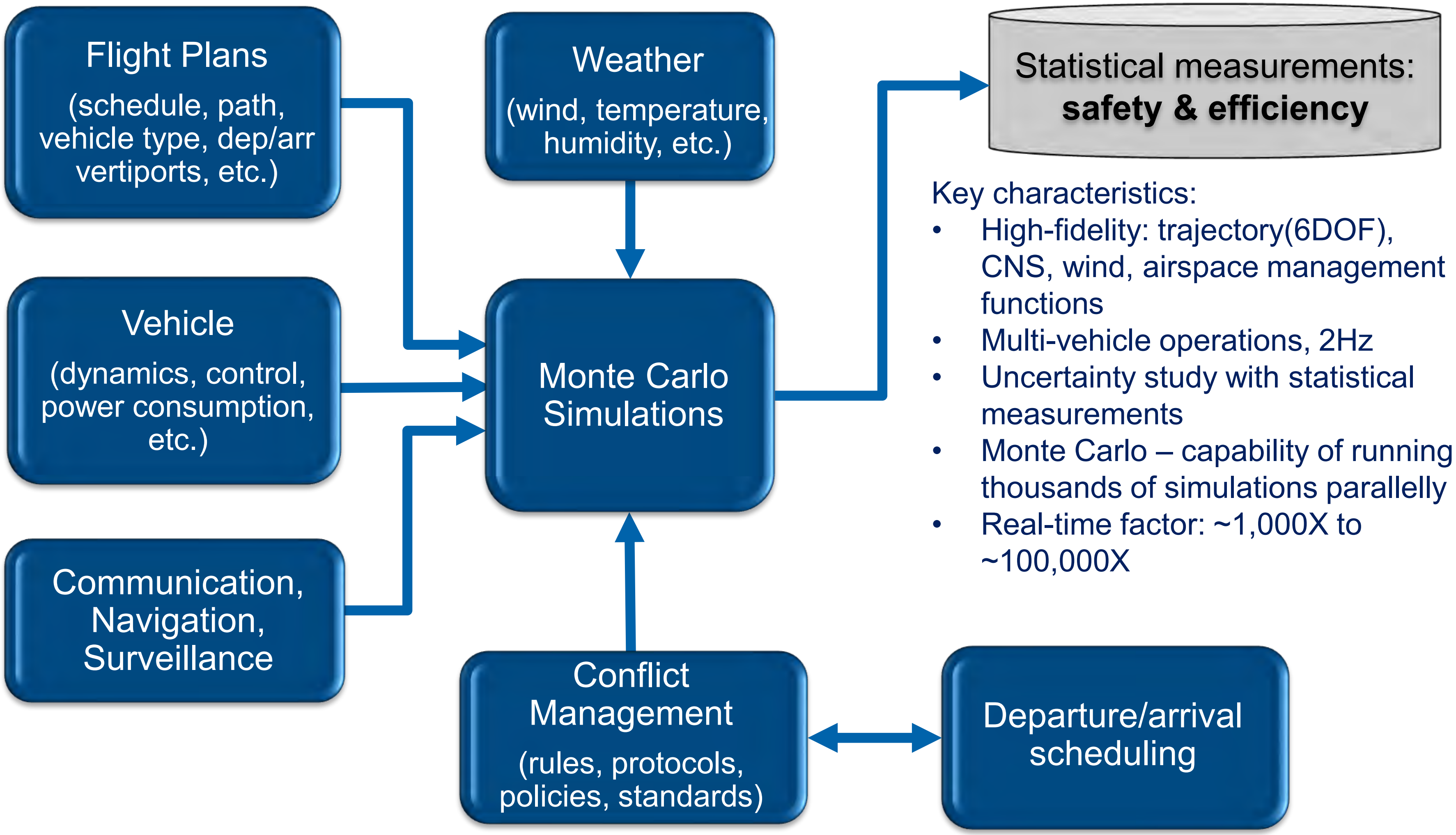
Notional cooperative separation management service processes within Upper Class E Airspace



Conflict Resolution Phases: Balloon and Fixed Wing



Fe^3 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**

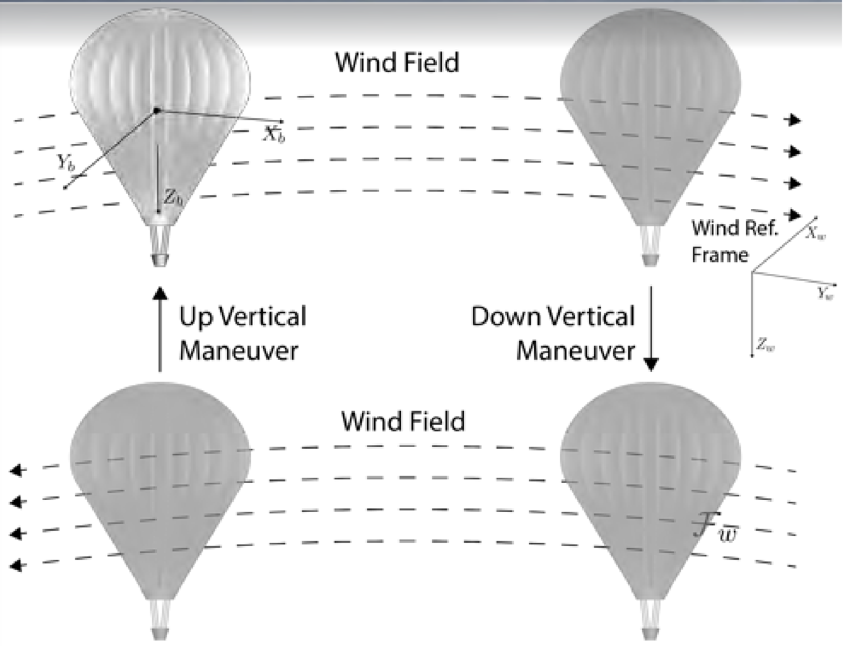
Modeling of High-Altitude Balloons

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

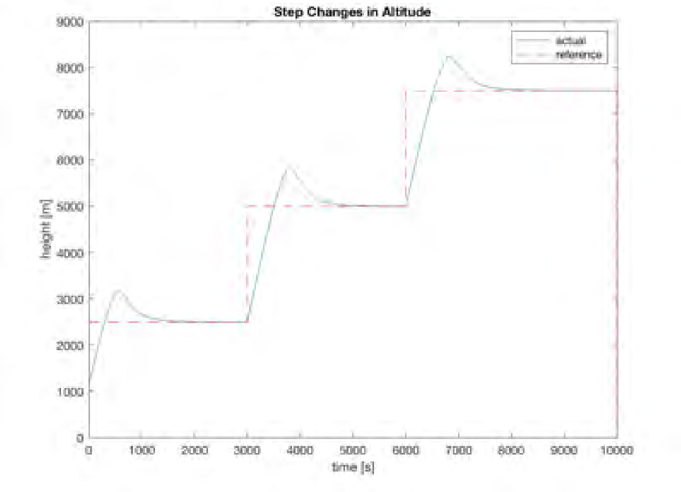
- Initial 3D model of Balloon developed
- Integrated NRLMSISE-00 (empirical, global reference atmospheric model) Implemented initial PI (proportional-integral) controller
- Performed initial tuning of drag coefficient and controller gains based on realistic balloon flight data

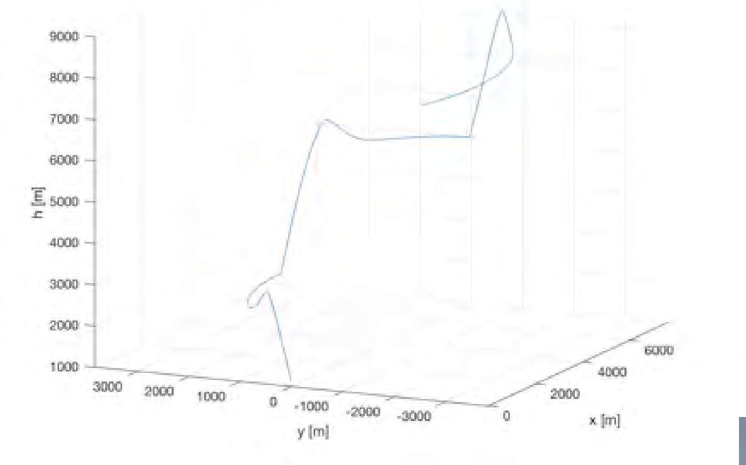


Balloon Model with Wind

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

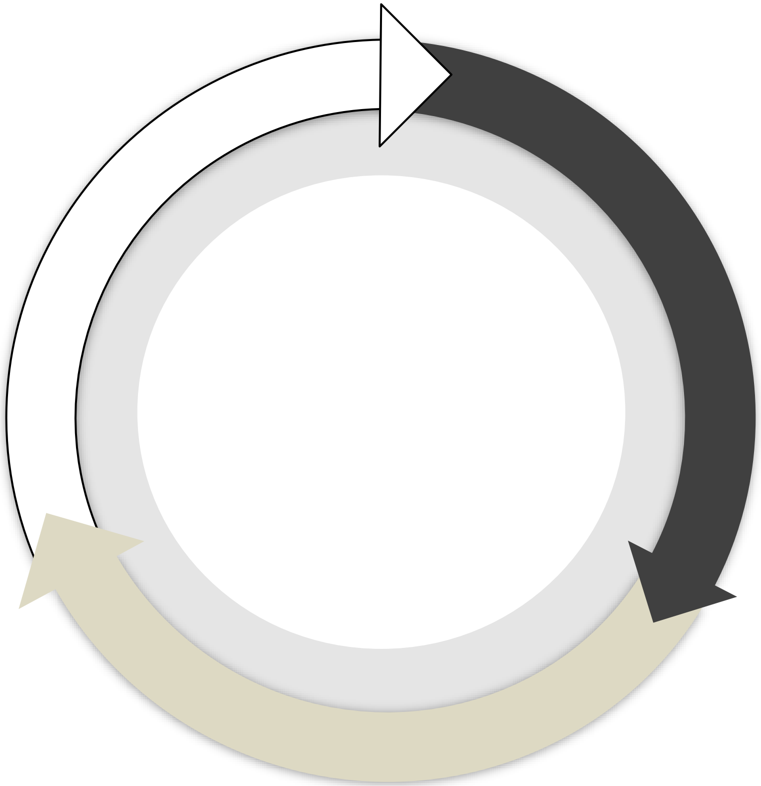
Simulation: Altitude Step Response with Wind

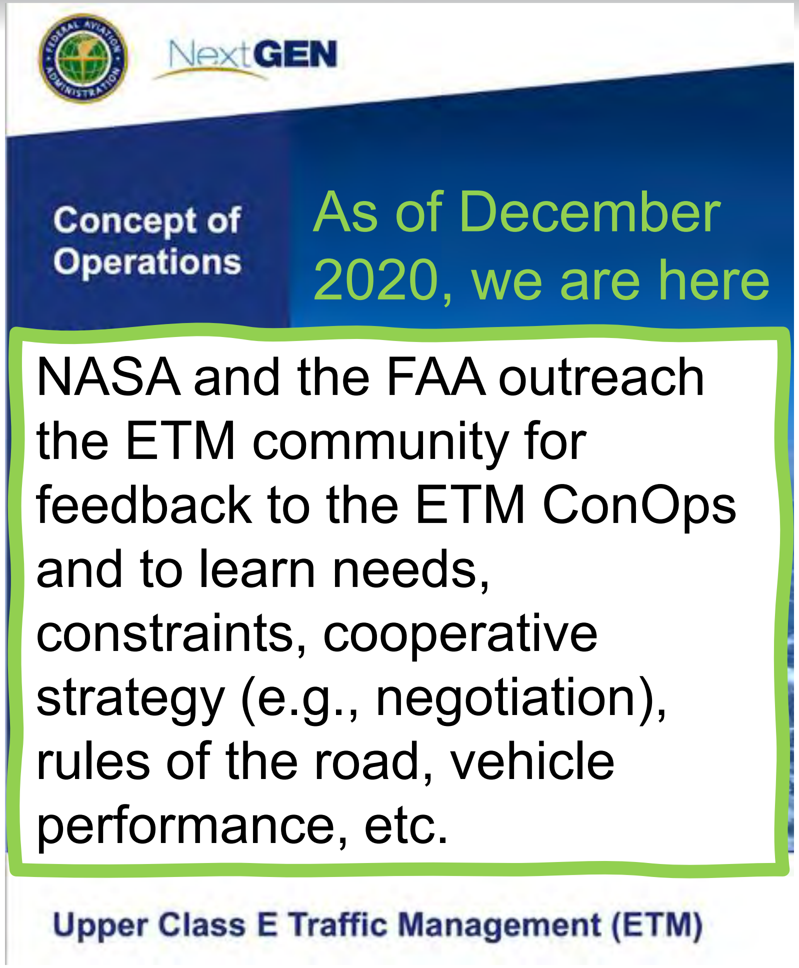




ETM Modeling and Simulation in ATM-X Phase 2

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

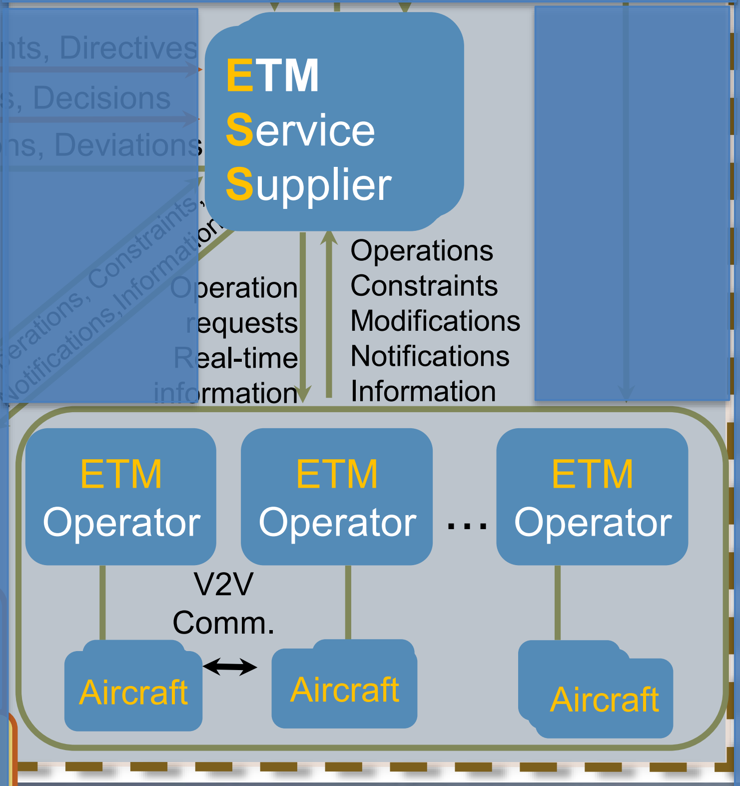




NASA models performances and services with the community input (e.g., negotiation process), builds scenarios informed by the FAA and the community to reflect the needs and constraints, and conduct simulations to assess the efficacy of the services

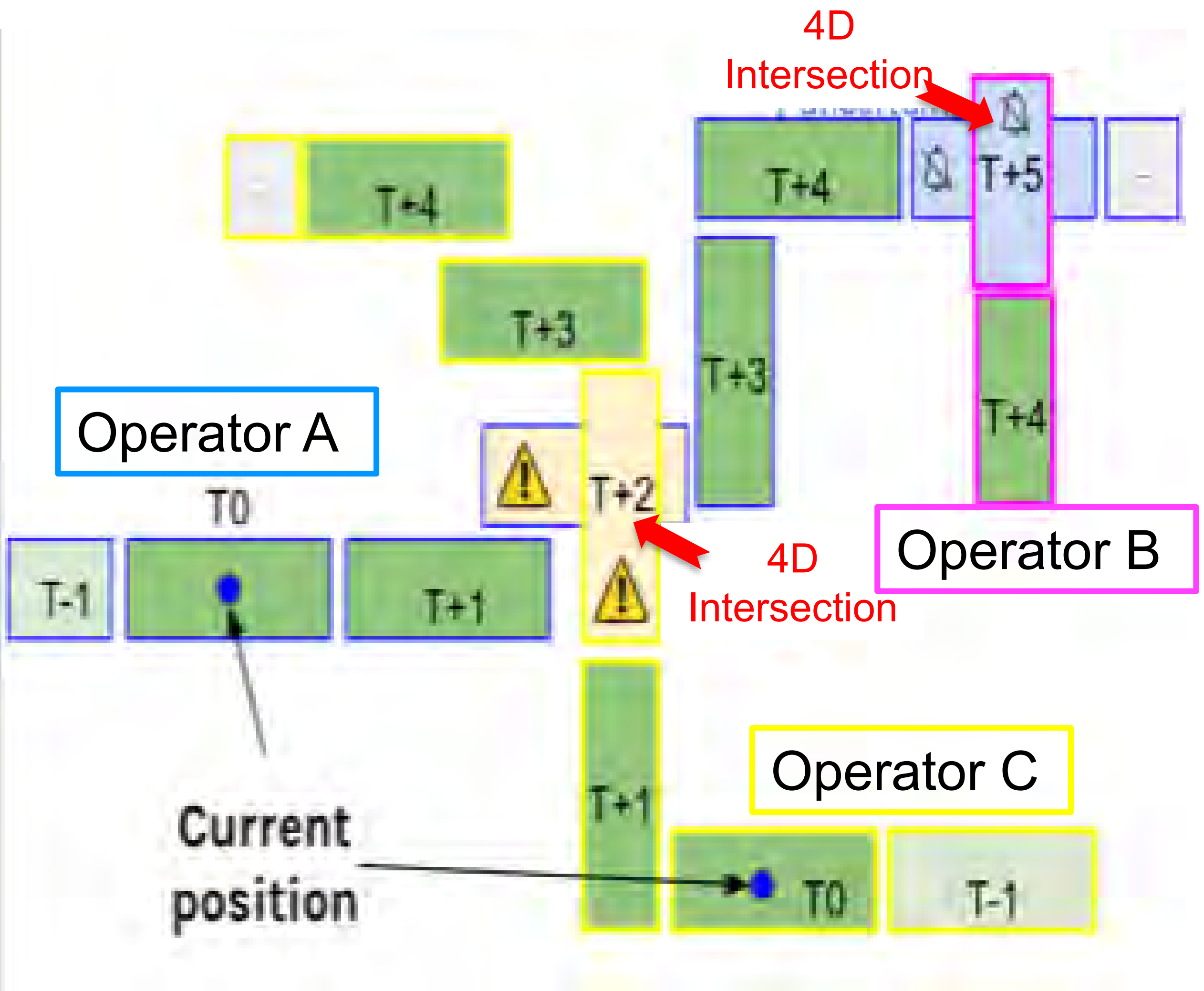
Introducing ETM Services Supplier (ESS)

- 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



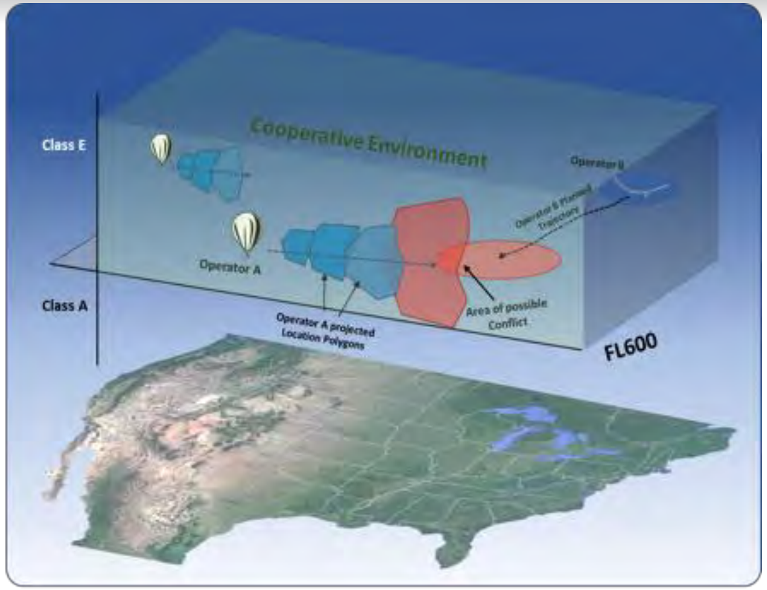
Initial ETM Service: Conflict Identification and Notification

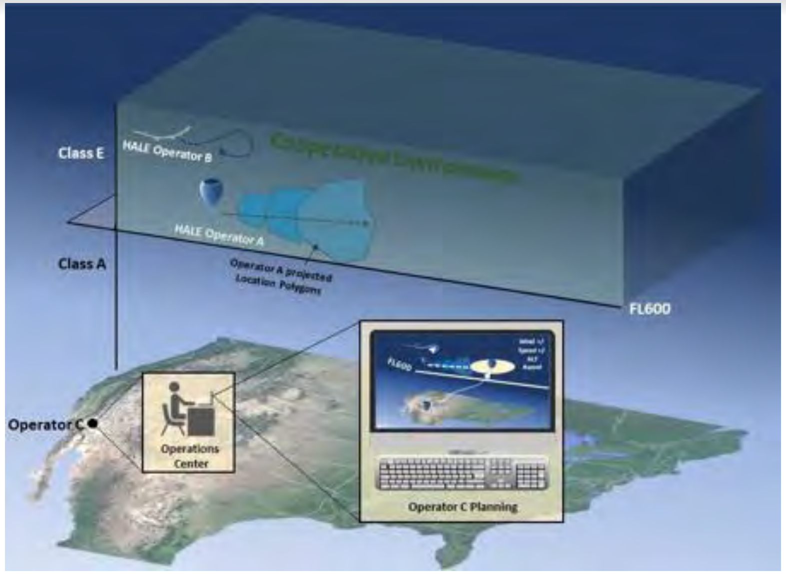
- ETM participants to submit operational intent to ESS
  - Operational intent should be standardized
  - Single or multiple ESSs could serve the NAS; the latter requires inter-ESS discovery, communications, and synchronization
- With the operational intents, ESS in position to identify 4D intersection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

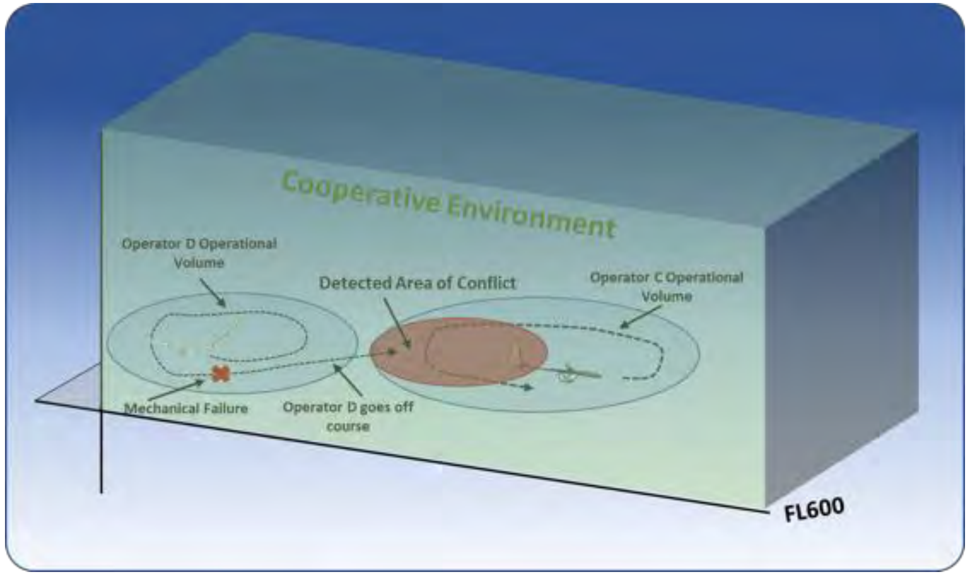


Understanding Cooperative Strategy with industry Input

- 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

Modeling/data collection:
- **Vehicle Model**
- **Communication, navigation, and surveillance**
- Wind

Analytical studies

Simulations: performance-based minimum separation

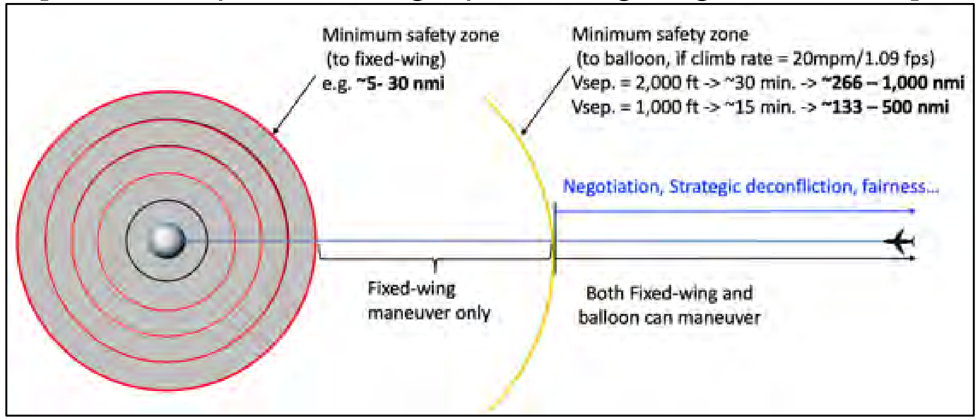
Negotiation/coordination models
- Intent sharing: format, rate, accuracy
- Methods (content/format):
  - Rules of road or agreements
  - Manuel/Automated (option sets)
  - Auction
- Communication
  - Response time
  - Latency
  - Accuracy

Multiple Aerial Vehicle Simulations

Scenarios

Research Questions to be addressed by simulations

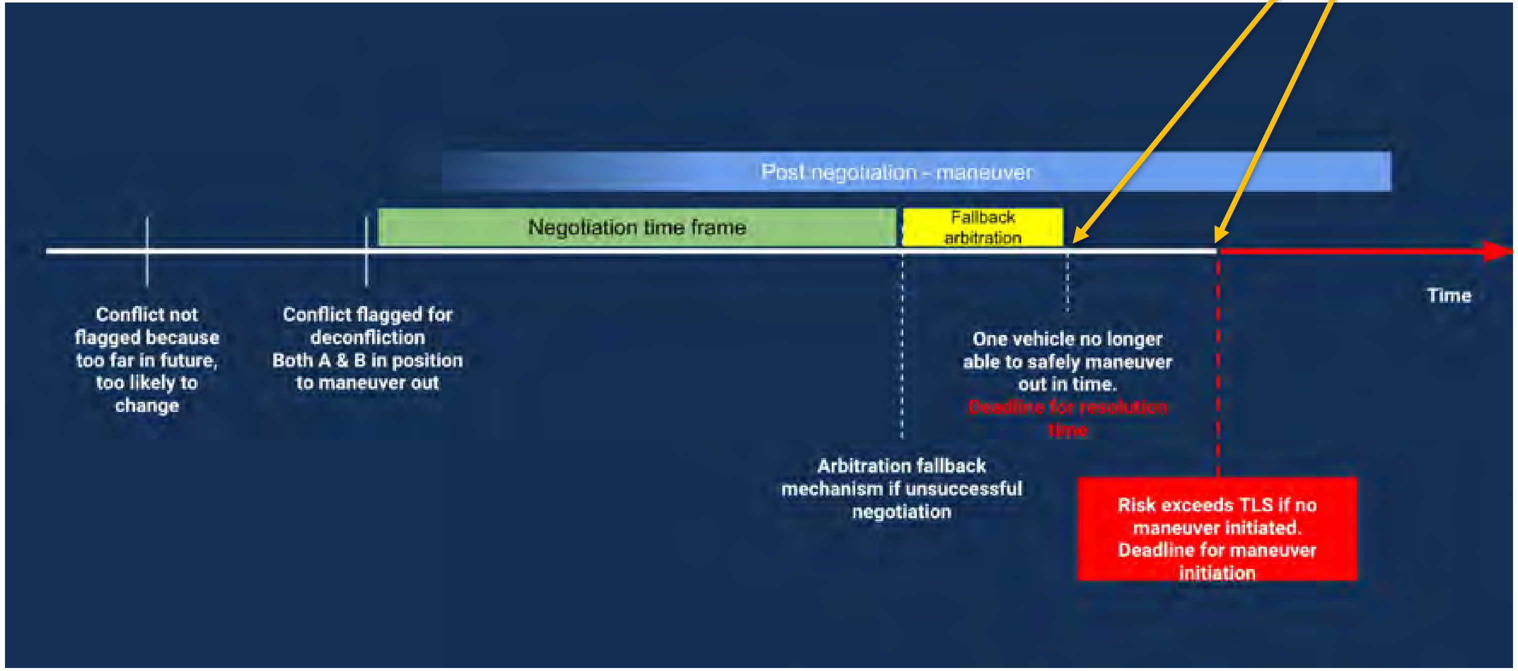
[Plot from previous tag-up meeting Aug. 27th, 2020]

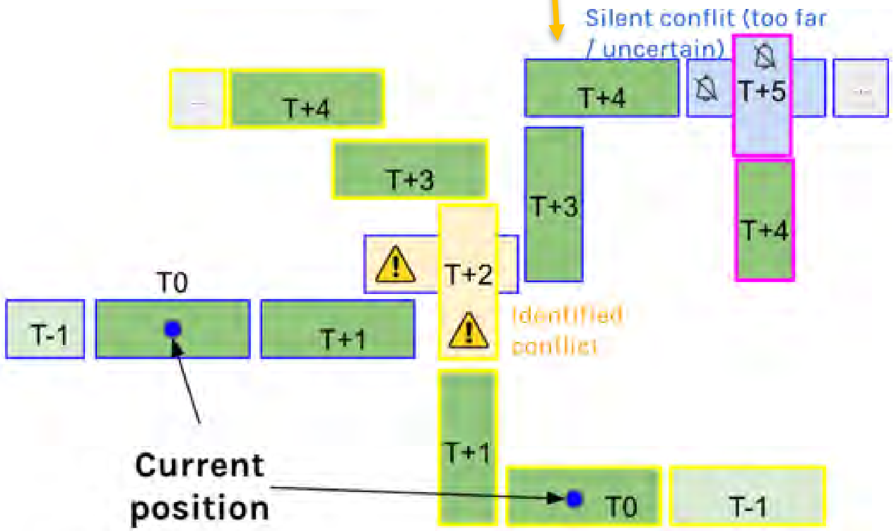


1 Timing and spatial boundaries for conflict resolution and negotiation

2 Size or duration of "rolling intent window"

3 CNS requirements



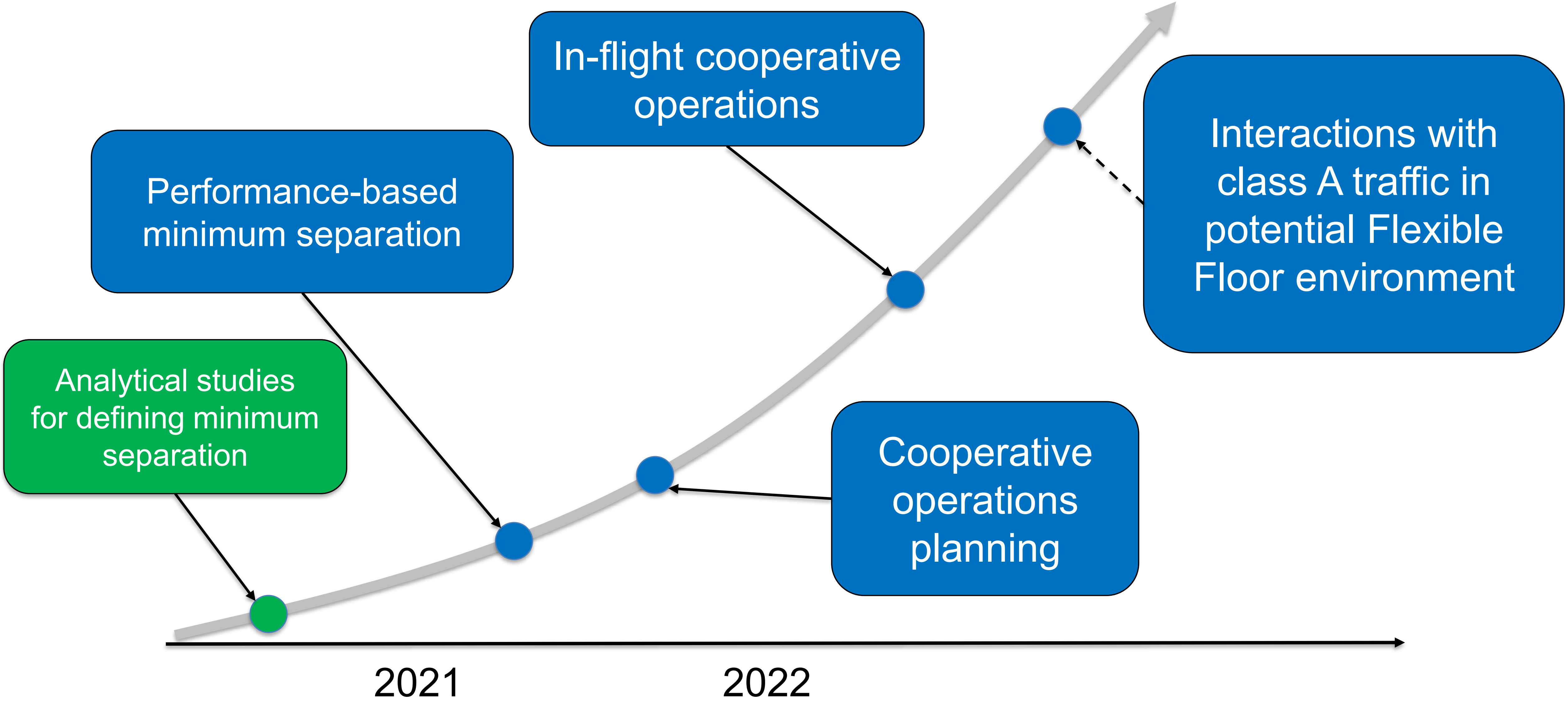


Research Questions to be addressed by simulations (cont'd)

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



Wrap up

Pre-decisional

Questions?

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