Upper E Traffic Management

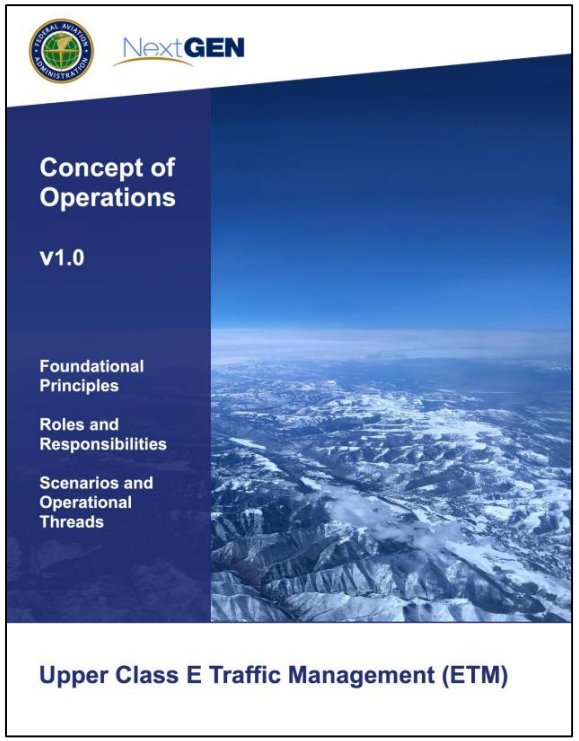
June 18, 2020

Recap

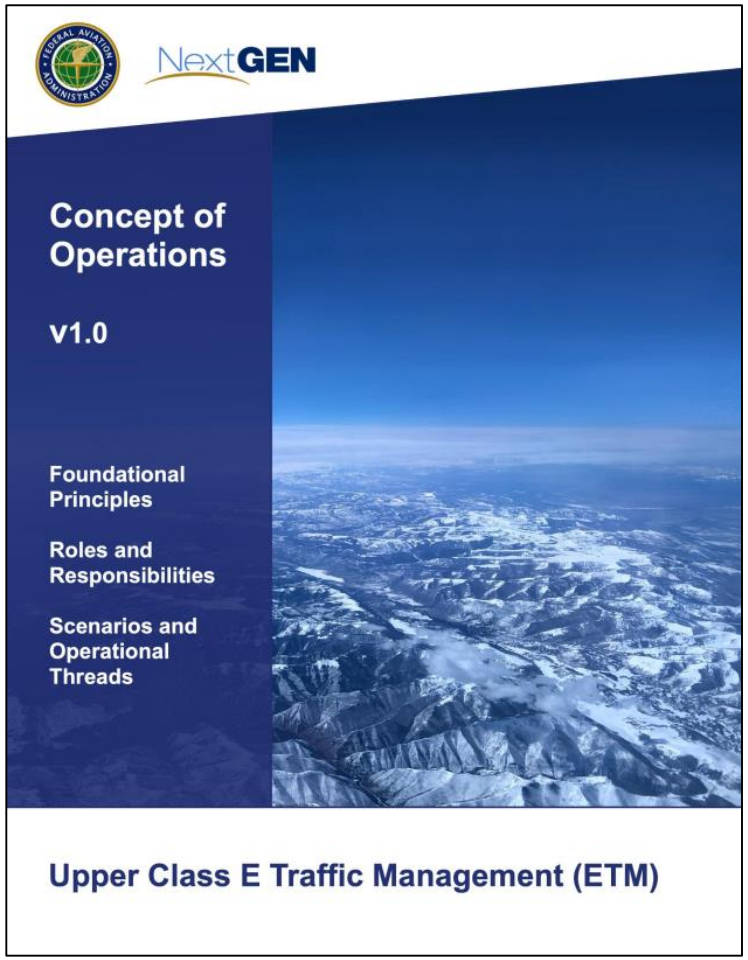
- Meeting April 24
  - UTM Briefing
  - ETM Relationship
- AIA Meeting May 19
  - Rules of the Road/Equitable Access
- ETM ConOps v1.0 Released!

Pre-decisional





ETM ConOps



- Participants
  - Operator
  - Third Party Service Suppliers
  - Air Traffic Control
  - FAA
- Airspace Management Services
  - Cooperative Separation Services
  - ATC Separation Services
- *Continued…*

Pre-decisional

ETM ConOps

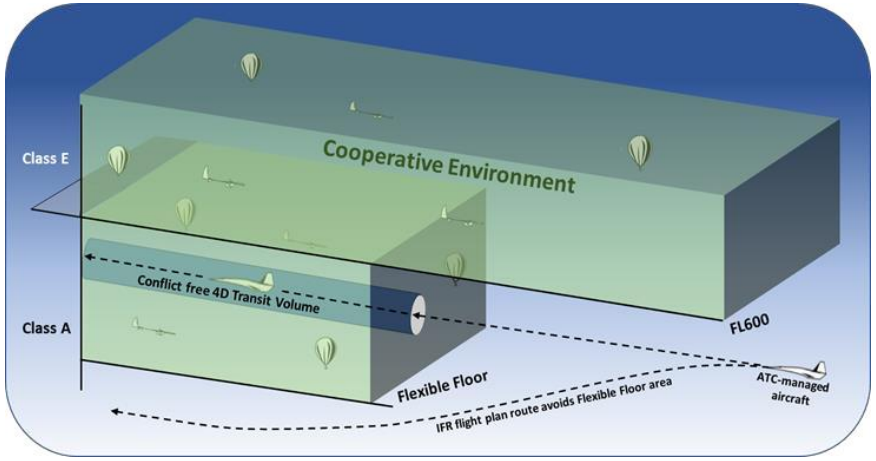


Figure 2-6. ATC-managed flight through flexible floor area

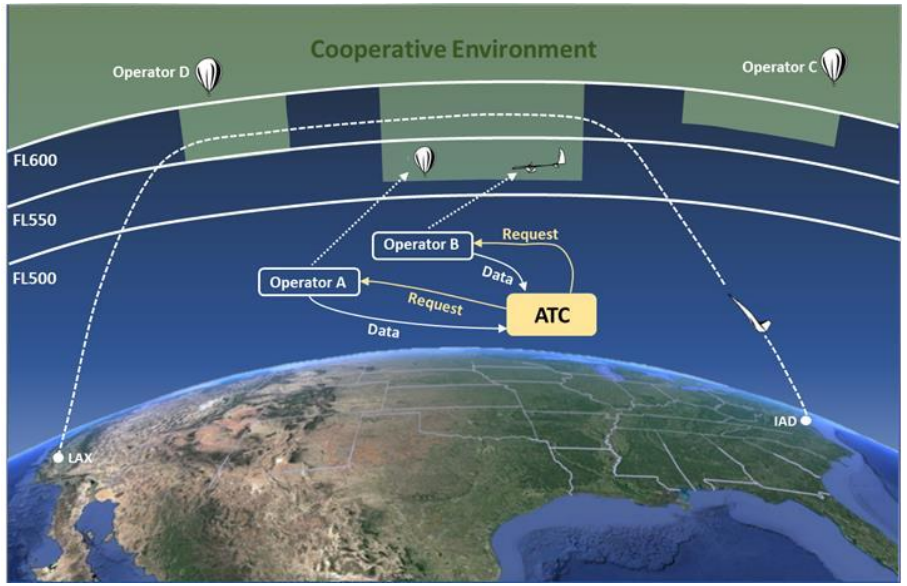


Figure 2-7. ATC information exchanges with cooperative operators

- Operations
  - Pre-Flight and Transition to Upper Class E Airspace
  - Operating Altitude WITHIN Upper Class E Airspace
  - Operating Altitude BELOW Upper Class E Airspace: Flexible Floor of Cooperative Environment
  - Descent from Upper Class E Airspace to Landing (into/through Class A airspace)
  - Contingency Management
- Equity of Airspace Usage
- Security
- ETM Implementation

Pre-decisional

Agenda

- Communications, Navigation, and Surveillance presentation and discussion
- Review and discussion of Rules of the Road/Equitable Access
- Cooperative Separation

Pre-decisional

Pre-decisional

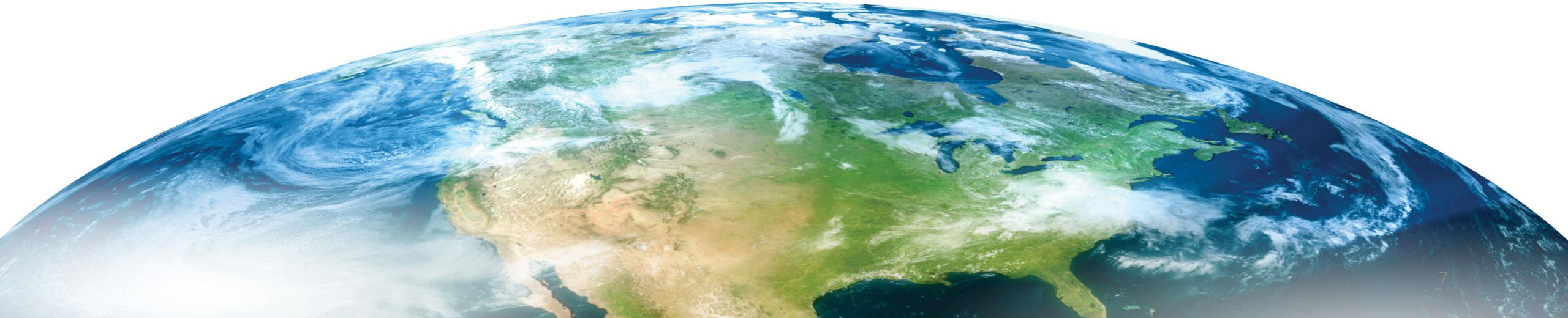
CNS

Upper Class E Traffic Management (ETM) Communication, Navigation, and Surveillance (CNS) White Paper Overview

Michelle Cady

Date: June 18th, 2020

Pre-decisional

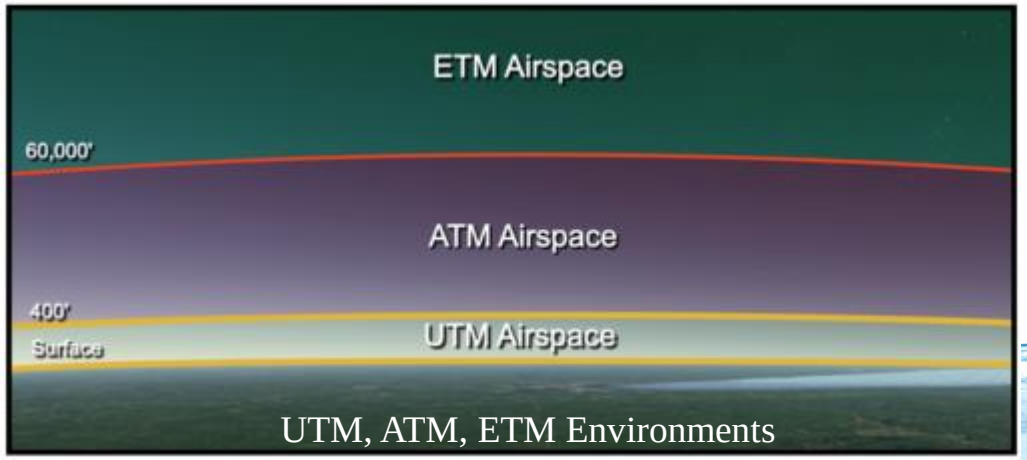


Class E – Upper Airspace Traffic Management (ETM) Overview

Pre-decisional

ETM Environment

- Airspace above Flight Level 600
- Minimal traditional ATM NAS services provided
- Minimal formal regulations for commercial ops



UTM, ATM, ETM Environments

Anticipated ETM Operators

- Unmanned Free Balloons (UFBs)
- High Altitude Long Endurance (HALE) Unmanned Aircraft Systems (UAS)
- Supersonic passenger aircraft
- Hypersonic aircraft

Communication, Navigation, & Surveillance (CNS)

- White papers assess multiple CNS technologies in the ETM environment
  - Advantages
  - Disadvantages
  - Current level of support for ETM operations
  - Potential modifications for greater ETM support

Pre-decisional



Pre-decisional

Navigation

Existing & Emerging



Navigation Overview

- "Aircraft navigation includes determining position, orientation, course and distance to the desired destination, and deviation from the desired track." (Per the 2-10 Federal Radionavigation Plan)
- Types of Navigation Systems
  - Ground-Based Navigation
  - Satellite-Based Navigation
  - Aircraft-Based Navigation

Pre-decisional



Existing Nav. Capabilities

Ground-Based Nav. Systems

- Very High Frequency (VHF) Omni-Directional Range (VOR)
- Distance Measuring Equipment (DME)
- Tactical Air Navigation System (TACAN)

Pre-decisional



Existing Nav. Capabilities
Satellite-Based Nav. Systems

- Global Navigation Satellite Systems (GNSS)
  - Operational
    - Global Positioning System (GPS) [Active - U.S. Air Force]
    - GLONASS [Active - Russian state corporation Roscosmos]
  - In Development
    - Galileo [European Union]
    - BeiDou [China]

- Space-Based Augmentation System (SBAS)



Pre-decisional

Existing Nav. Capabilities

Aircraft-Based Nav. Systems

- Inertial Navigation System (INS)

- Other Onboard Nav. Technologies
  - Altitude Equipment (Pressure/GNSS/Radar/INS)
  - Sensor Integration (Flight Management System - FMS)

Pre-decisional



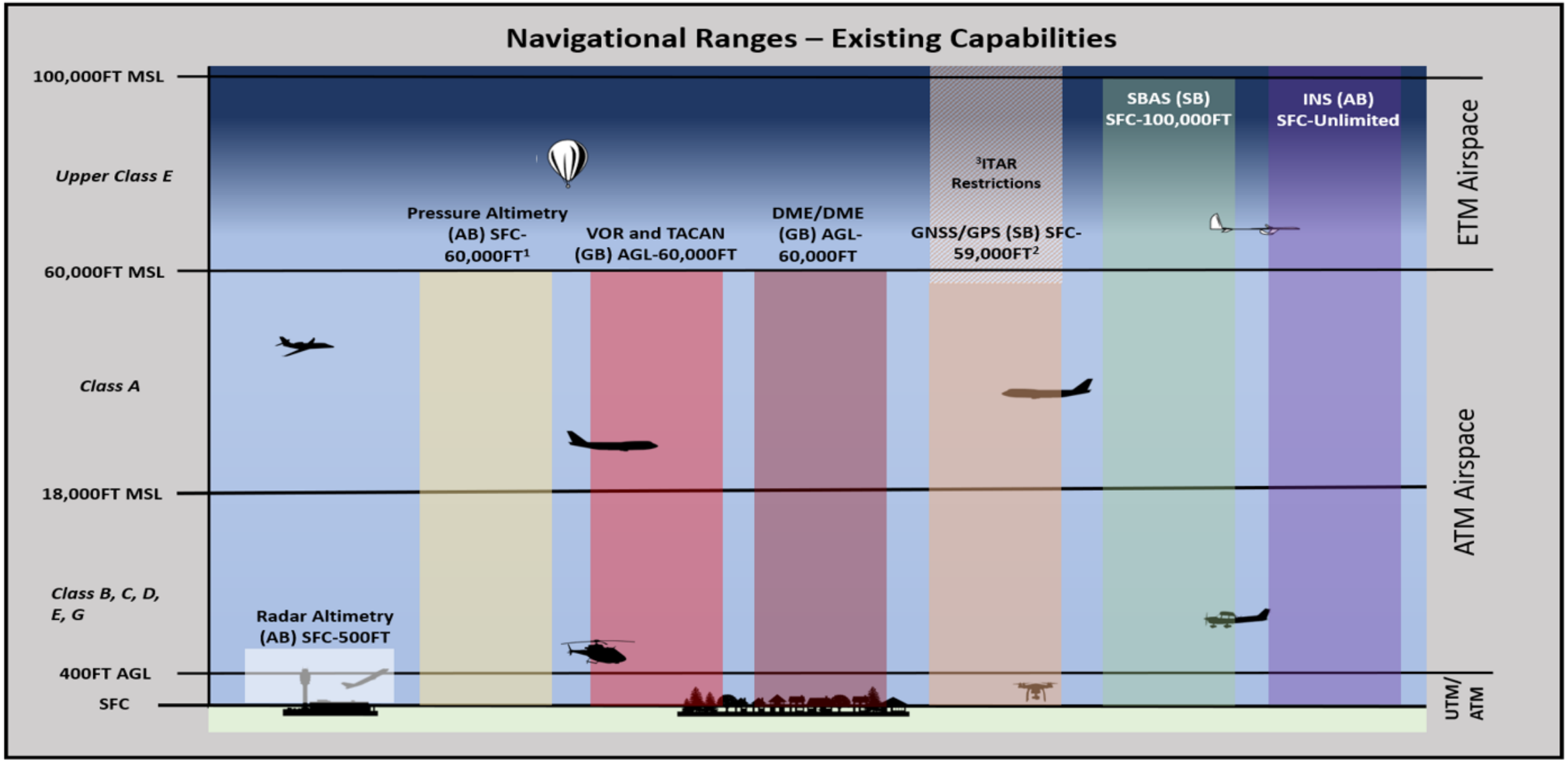
Existing Nav. Conclusions

- System that *could* be used for 2D Nav. in ETM is GNSS
  - Note – Due to previous ITAR limits (above 59,000ft and at speeds faster than 1,000 knots), many GPS receivers are disabled above FL600
    - Note: altitude restriction removed in 2016; speed limit of 1166 knots imposed
- GNSS could be utilized for third-dimension (altitude) as well
  - Note – FAA requires that operations use only pressure altimetry
  - Note – pressure-based altimeters and Air Data Computer (ADC) standards are only qualified up to 50,000ft (useful measurements to 60,000 ft)
    - High altitude barometric altimeters have been developed using extrapolated standards and are in operation up to 70,000 ft
- Other system(s) that could be used for 2D Nav. are RNAV DME/DME (RNAV computing system using 2+ DMEs to calculate a/c's location) plus INS
  - Note – DME may not have sufficient signal strength at higher Class-E altitudes, the INS could be used to fill gaps
- INS integrated with pressure altimetry may also provide altitude data

Pre-decisional

Pre-decisional

Navigational Ranges – Existing Capabilities



Navigation Type	
AB	Aircraft Based
GB	Ground Based
SB	Satellite Based

Capability Limitations
[1]Devices are not generally required to operate above 50,000 ft; however, some systems are expected to function up to 60,000 ft (e.g. business jets, Concorde)
[2]Onboard pressure altimetry devices likely not certified at altitudes greater than 50,000 feet
[3]ITAR restrictions mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (~1,200 knots)
NOTE: Expanded Service Volumes may extend VOR, DME, and TACAN capabilities beyond 60,000 ft (AGL)

Emerging Nav. Capabilities

Surveillance Position Uplink

- Multilateral (MLAT) Navigation
  - TAGS
  - Phase 2 WAM (theoretical)
- TIS-B Navigation (theoretical)

Pre-decisional



Emerging Nav. Capabilities

GNSS Navigation

- Multi-GNSS
  - Utilize interoperable receivers across satnav systems for global coverage

- GNSS Satellite Location and Timing (STL)
  - Employ Doppler positioning using signals from Iridium satellite constellation in low Earth orbit (LEO)

Pre-decisional



Emerging Nav. Capabilities
eLORAN

- eLORAN
  - Possible successor to LORAN-C
  - eLORAN planned to have improved accuracy, reliability, integrity and availability (upgraded transmission equip and data channel)
  - Much more resilient than GNSS (susceptible to solar storms and anti-satellite attacks)
  - Cons
    - Ceiling unknown, LORAN-C was 60,000ft
    - Land-based limits oceanic coverage
    - Vertical positioning limitation would require a/c to have different source

Pre-decisional



Emerging Nav. Capabilities

Additional Technologies

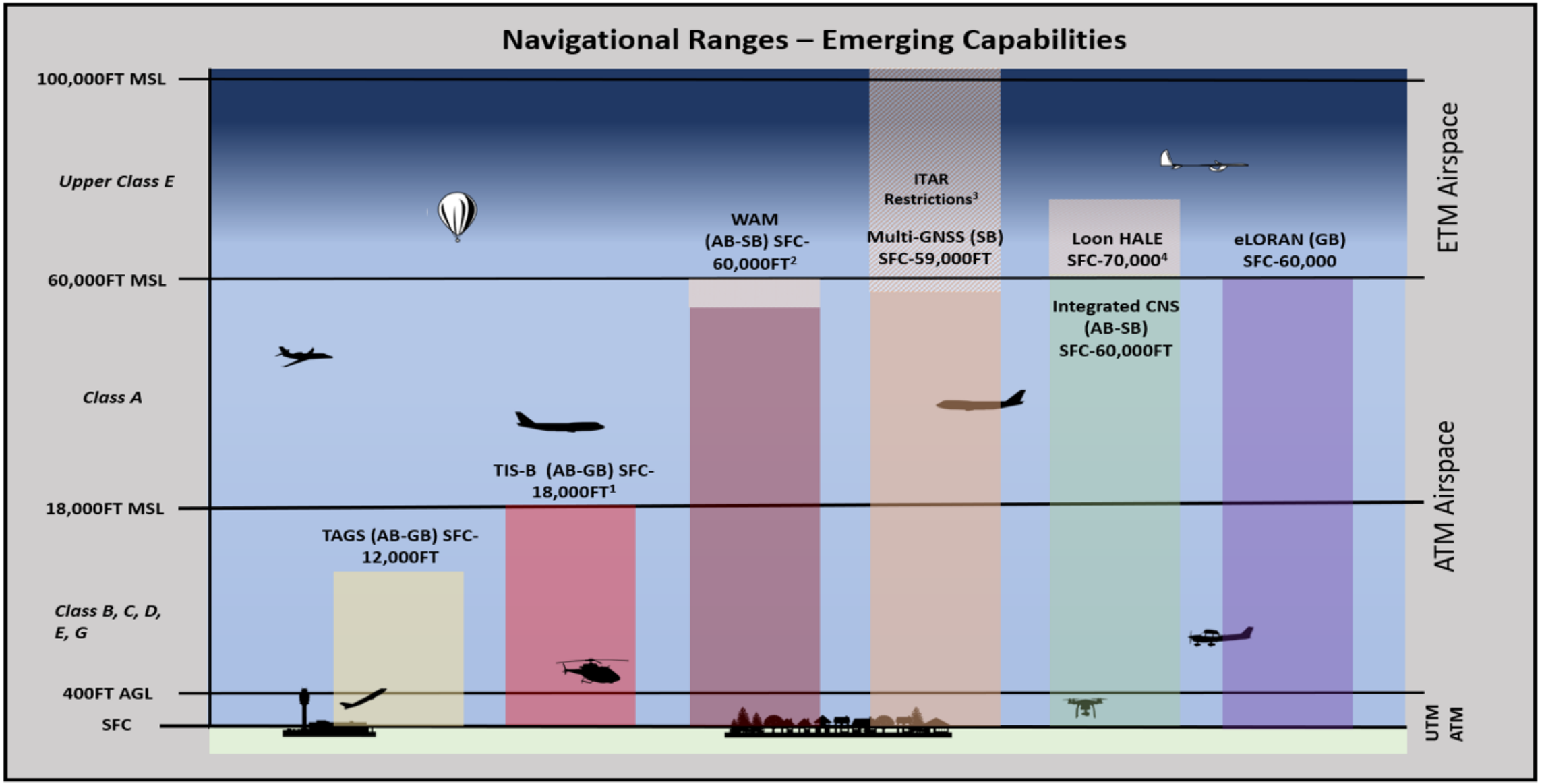
- FM time broadcasts
- DME-Sync (DME + time)
- Hybrid INS/barometric altimetry
- INS augmented with star tracker

Pre-decisional



Pre-decisional

Navigational Ranges – Emerging Capabilities



Navigation Type	
AB	Aircraft Based
GB	Ground Based
SB	Satellite Based

Capability Limitations
[1]TIS-B navigation, based on secondary surveillance radar, is hypothetical and has not been studied in detail
[2]Potential limit of 2D WAM based on pressure altimeter performance requirements (50,000 feet); 3D WAM may provide capabilities up to and beyond 60,000 ft with appropriate software changes
[3]ITAR restrictions mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (~1,200 knots)
[4]Loon has operated constellations up to 70,000 ft (pressure altimetry and ITAR restrictions aside)

Pre-decisional

Communication



Communication Technologies for Manned Aircraft

- Voice Communication
  - VHF/UHF Air-to-Ground Systems
  - High Frequency (HF) Air-to-Ground Systems
  - Satellite Voice (SATVOICE)
- Data Communication (Data Link)
  - VHF Data Link (VDL)
  - HF Data Link (HFDL)
  - Satellite Data Link (SATCOM)

Pre-decisional



Voice Communication

- VHF/UHF Air-to-Ground Systems
  - Advantages
    - Used by FAA and Industry for decades
    - Established Infrastructure
  - Disadvantages
    - Subject to interference (not a significant problem)
    - Radio Line of Sight (RLOS) between transmitter and receiver required, subject to blockage by structures, foliage and terrain
  - Changes required for Greater ETM Use
    - Increased power transmission and/or receiver sensitivity
    - Change the ground antenna radiation pattern to be more upwardly focused

Pre-decisional



Voice Communication

- High Frequency (HF) Air-to-Ground Systems
  - Advantages
    - Range of signal propagation is greater than that of VHF/UHF A/G systems
  - Disadvantages
    - HF signal is not always available due to sporadic nature of ionospheric layers
  - Changes Required for Greater ETM Use
    - New testing standards required for operation above FL700

Pre-decisional



Voice Communication

- Satellite Voice (SATVOICE)
  - Advantages
    - World-wide coverage
  - Disadvantages
    - Latency issues due to long path lengths
  - Changes Required for Greater ETM Use
    - New testing standards required for operation above FL700

Pre-decisional



Data Communications (Data Link)

- VHF Data Link (VDL)
  - Advantages
    - Enable reduced communication errors and radio frequency congestion
    - Improve capacity
    - Increase efficiency
  - Disadvantages
    - Do not allow for real time communications
    - Only available within the RF coverage volume of the ground transmitting facility
  - Changes required for Greater ETM Use
    - Necessary to specify the particular ETM service volume and expect fulfillment by the contractor/subcontractor
    - Changes to technical and procedural requirements may be necessary

Pre-decisional



Data Communications (Data Link)

- HF Data Link (HFDL)
  - Advantages
    - Distant coverage range from the ground station
    - HFDL sub-network provides communication to ATSU and AOC in intercontinental airspace
  - Disadvantages
    - Unpredictable signal reception
    - Relatively low data rate
  - Changes Required for Greater ETM Use
    - New testing standards required for operation above FL700

Pre-decisional



Data Communications (Data Link)

- Satellite Data Link (SATCOM)
  - Advantages
    - Higher data transfer rate than VDL and HFDL
    - World-wide coverage
  - Disadvantages
    - Not approved for Data Link over the domestic U.S., only in the oceanic and remote continental airspaces
    - Latency issues due to long path lengths
  - Changes for Greater ETM Use
    - New testing standards required for operation above FL700

Pre-decisional



Communication Technologies for Unmanned Aircraft

- Global Hawk
  - Command and Control (C^2) Communications
    - Communications for controlling aircraft and receiving information regarding location and condition of aircraft
  - ATC Communications
    - Global Hawk Operations Center (GHOC) to the aircraft uses Iridium satellite
    - Aircraft to ATC uses standard VHF/UHF transceiver on the aircraft or G/G VHF/UHF connection
    - Pilot to ATC communication uses phone lines

Pre-decisional



Communication Technologies for Unmanned Aircraft

- **Commercially Operated HALE Vehicle**
  - Iridium and Inmarsat connections are employed to send commands, to vehicle and downlink position, altitude, and sensor data sent from aircraft
  - Mechanisms are employed to enable communication with ANSPs:
    - Telephone notification of operations
    - Email exchanges for advance notice
    - Voice over internet protocol
    - Faxing mission sheets
    - WhatsApp communications
    - ADS-B, enabling surveillance

Pre-decisional



Performance Based Communication

- Required Communication Performance (RCP) parameters
  - RCP Transaction Time
  - RCP Expiration Time
  - RCP Continuity
  - RCP Availability
  - RCP Integrity
- RCP is only used in the oceanic and remote continental environment
  - More work is required to determine RCP use in the domestic U.S.

Pre-decisional



Communication Capabilities Conclusion

- Voice Communications
  - VHF/UHF Air-to-Ground (A/G) *could* be used at the lower elevations of the ETM environment, as is. The elevation of coverage in the ETM environment could be increased by making relatively simple changes to the antennas and radios.
  - HF could be used in the ETM environment
  - SATVOICE could be used in the ETM environment with an upper limit on the speed of the aircraft

Pre-decisional



Communication Capabilities Conclusion (cont'd)

- Data Communications
  - VDL *could* be used at the lower elevations of the ETM environment.
    - VDL is contracted out, so it would be a matter of making VDL a contractual requirement
  - HFDL *could* be used in the ETM environment
  - SATCOM could be used in the ETM environment with an upper limit on the speed of the aircraft
    - Advantage: Highest data transfer rate
  - RCP needs to be approved for use in the ATM environment before use in ETM environment

Pre-decisional



Pre-decisional

Surveillance



Surveillance Overview

- Ground Based Surveillance
  - Radar
  - Wide Area Multilateration (WAM)
- Aircraft Provided Surveillance
  - Automatic Dependent Surveillance-Broadcast (ADS-B)
  - Automatic Dependent Surveillance-Contract (ADS-C)

Pre-decisional



Ground Based Surveillance

- Radar
  - Advantages
    - Used for decades by FAA and Industry
    - Less susceptible to jamming or spoofing in comparison to Global Navigation Satellite System (GNSS) based surveillance
    - Data spatially and temporally correlated with ADS-B for use in STARS, ERAM and systems that support traffic flow management and collaborative decision making

Pre-decisional



Ground Based Surveillance

- Radar (cont'd)
  - Disadvantages
    - Errors increase with range and can be significantly greater than those associated with GNSS based surveillance sources
    - Velocity errors can be significant, especially when aircraft are turning (radar lag)
    - Surveillance constrained due to limitations of commercial barometric altimeter systems
    - Coverage of oceanic airspace limited to coastal regions and areas surrounding select islands
    - High procurement and maintenance costs
  - Changes for Greater ETM Use
    - Software (tracker and display) modifications to enable some ARSR installations to provide surveillance up to 100,000 ft; potentially lower ETM coverage with software change to ASR installations

Pre-decisional



Ground Based Surveillance

- **Wide Area Multilateration (WAM)**
  - Advantages
    - Provides accurate surveillance in regions that preclude radar deployment
    - Phase 2 corrects pressure altitude with weather forecast data
  - Disadvantages
    - Commercial pressure altimeters limit vertical and horizontal position estimates
    - Horizontal position accuracy values not guaranteed at higher altitudes
    - Coverage represents a fraction of total area surveilled by radar and ADS-B
  - Changes for Greater ETM Use
    - Phase 1 WAM not acceptable to ETM operations due to low ceiling
    - Phase 2 limited to systems configurations and pressure altimeter constraints; effective for lower Class E (FL600)

Pre-decisional



Aircraft Provided Surveillance

- Automatic Dependent Surveillance-Broadcast (ADS-B)
  - Advantages
    - International adoption of 1090ES technology
    - Augmentation of space-based technology offers potential for worldwide surveillance coverage
    - Ultimate surveillance coverage
  - Disadvantages
    - Limited oceanic surveillance
    - Update rates are reduced in high 1090 MHz interference environments that occur in dense airspace
    - ITAR restrictions apply
    - Commercial altimeter limitations above FL600 affects pressure altitude reported through 1090ES and UAT

Pre-decisional



Aircraft Provided Surveillance

- Automatic Dependent Surveillance-Broadcast (ADS-B)
  - Changes for Greater ETM Use
    - Revision to ITAR GPS receiver restrictions
    - Several peripheral systems may require change to enhance ADS-B
    - Data fusion, automation, and traffic flow management systems may require software changes to enable additional inputs and operational use of information
    - Dependent on continued development of version 3 standards

Pre-decisional



Aircraft Provided Surveillance

- Automatic Dependent Surveillance-Contract (ADS-C)
  - Advantages
    - Provides surveillance in oceanic and remote continental regions
  - Disadvantages
    - Not used or approved for tactical separation of aircraft
    - Susceptible to jamming and spoofing
  - Changes for Greater ETM Use
    - Modifications to air data computer standards and commercial barometric altimeter technology may be required
    - Continuous availability of absolute geometric altitude may be required
    - SATCOM service provides may have to reconfigure systems
    - Tracking and automation systems used by ANSPs may require software changes
    - Operators may have to consider greater service provider fees

Pre-decisional



Surveillance Capabilities Conclusion

- Two vertical dimension options for surveillance of ETM airspace:
  - Transition from pressure altitude to geometric altitude surveillance at FL600
  - Pressure altitude reporting to FL600, a mixture of pressure and geometric altitude surveillance between FL600 and FL800 (e.g., high altitude systems), and a reliance on geometric altitude above FL800.

Pre-decisional



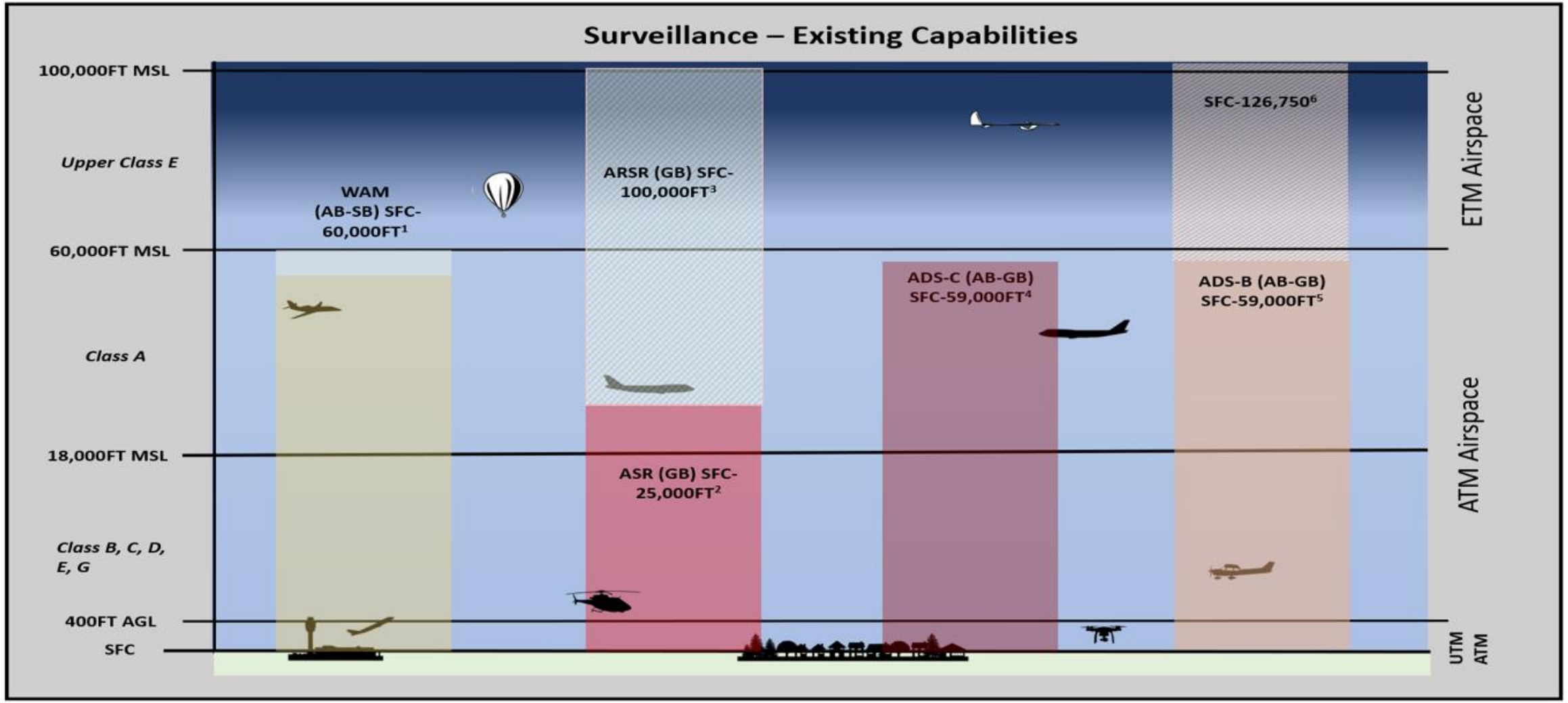
Surveillance Capabilities Conclusion (cont'd)

- Low-resiliency construct
  - Surveillance for most ETM vehicles over land and coastal areas would be provided by v.3 ADS-B transmitted to an extended SBS network
  - Enhanced ADS-C *could* provide surveillance for supersonic passenger flights in oceanic airspace
  - Operator provided telemetry routed to the SDI and v.3 ADS-B *could* provide surveillance for space operations
- High-resiliency construct
  - Adds surveillance sources to low resiliency option
  - Space-based ADS-B would provide additional GPS dependent coverage of supersonic and space operations in oceanic airspace

Pre-decisional



Pre-decisional



Navigation Type	
AB	Aircraft Based
GB	Ground Based
SB	Satellite Based

Capability Limitations
[1]Potential limit of 2D WAM based on pressure altimeter performance requirements (50,000 feet); 3D WAM Phase 2 may provide capabilities up to and beyond 60,000 ft with appropriate software changes
[2]ASR software (e.g. Terminal Automation) coverage limited up to 25,000 ft
[3]Some ARSR installations provide coverage up to 100,000 ft; however, all SSRs are dependent on pressure altitude that is unreliable above 60,000 ft
[4]Extant ADS-C installations (primarily in air transport category aircraft) are subject to previously published ITAR restrictions that prevent GPS output of latitude, longitude, and velocity above altitudes of 59,000 ft
[5]Installations adhering to previously published ITAR restrictions
[6]1090ES format limits altitude to 126,750 ft, horizontal velocity to 4,086 kts, and vertical rate to 32,608 fpm; UAT format limits altitude to 101,337 ft and vertical rate to 32,608 fpm - vehicles traveling more than 600 m/s shall be subject to current ITAR restrictions

Integrated Communication, Navigation, and Surveillance (CNS)

Pre-decisional

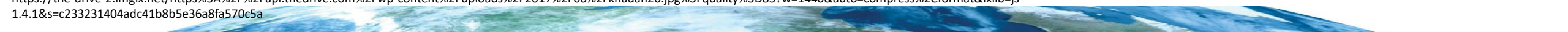


Examples

- Ex 1. HALE, fixed wing RQ-4 Global Hawk
  - Pre-programmed mission trajectories/waypoints executed by autopilot (classified but known that it utilizes GPS and INS nav. capabilities)
  - Or Remote Pilot in Command (RPIC) can use comm.

- Ex 2. Loon HALE telecomm. balloons
  - Control ingests wind forecast data to chart trajectory
  - ADS-B sends position to control. When in position, comm. transmits bladder command to change alt.
  - Uses multi-GNSS (GPS and Iridium) positioning and calibrated pressure alt.

Pre-decisional



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Pre-decisional

Draft Rules of the Road/ Equitable Access

Draft Rules of the Road/Equitable Access

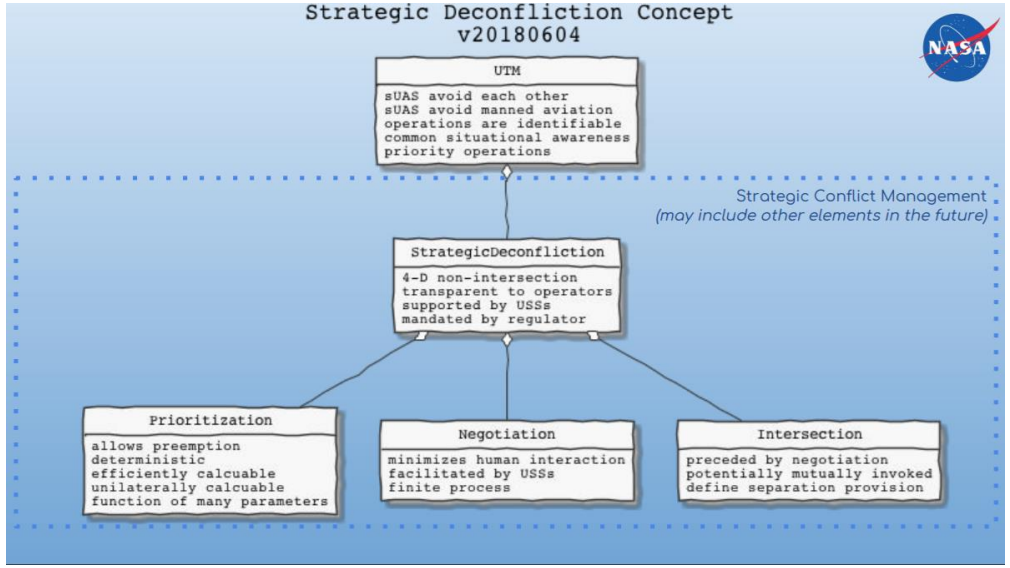
- Equitable access to the airspace only becomes an issue when the demand for the finite airspace is such that multiple operators compete for the airspace.
  - Therefore, a first necessity and priority is to ensure that the systems, rules and standards in place are designed to **maximize the use of airspace efficiency**
  - A consequence of the above is that we must **only** negotiate and resolve the conflicts that need to be resolved and negotiated
- Change of intents and re-planning will be frequent in the stratosphere: Inappropriate conflict identification and overly long conflict identification timing are likely to be a major source of non-equitable access.
  - For example an operator may negotiate or have priority to access an airspace (and reserve it), in a way that prevents others from accessing it, but that may decide not to use the airspace after re-planning

Pre-decisional

Rules of the Road/Equitable Access

- Missions and constraints in the stratosphere will be complex. The cost of "moving out of the way" will widely differ based on circumstances, missions, and timing.
- Negotiation will likely be a preferred strategy (over static and simplistic rule) to ensure fairness, and ensure that the variety of constraints, mission objectives, etc. are taken into account.

Pre-decisional



From UAS Service Supplier Specification

- Strategic Deconfliction needs an allowance for negotiating deconfliction of UTM operations. The Negotiation scheme:
  - *[UTM-CM.45] MUST minimize direct human interaction.*
  - *[UTM-CM.50] MUST be facilitated via USSs.*
  - *[UTM-CM.55] MUST be a finite process.*

https://utm.arc.nasa.gov/docs/2018-UTM-Strategic-Deconfliction-Final-Report.pdf

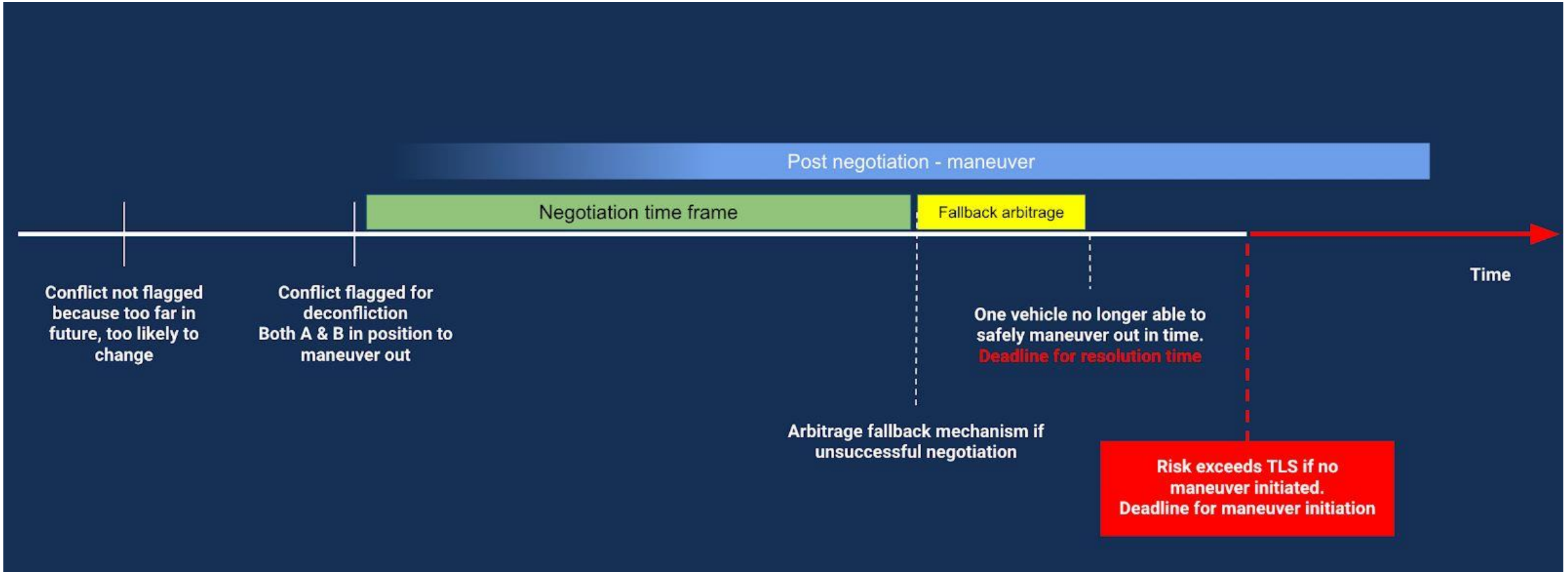
Rules of the Road/Equitable Access

- Negotiation of conflict resolution can take 2 forms:
  - **Pre-agreed bilateral agreement between 2 operators** on how a conflict should be resolved. (This may be a set of rules, or framework agreed bilaterally for who has priority in given conditions)
  - **Ad hoc - negotiations (automated or manual)**. Provided that:
    - The negotiation time (whether automated or manual) is taken into account in the logic for identifying conflicts.
    - There is a fallback solution in case negotiations do not yield to an outcome on-time
- At this stage of the development, we **do not want to over-design priority rules** (there is so much we do not know). We rather want to promote negotiation, have simple fall-back solutions, and ensure we can iterate quickly, monitor results and evolve our framework to learn from our learnings.

Pre-decisional

Rules of the Road/Equitable Access

Pre-decisional



Rules of the Road/Equitable Access

- The definition of equity is actually quite complex and will need research. At this stage of low density, where equitable access issues are unlikely we argue the following:
  - Conflicts should be identified (flagged) at a stage where BOTH vehicles in conflict are still in a position to be able to give way to the other (except for absolute 0 maneuverability vehicles - e.g.balloon with no altitude control).
  - The risk-based conflict identification approach should take into account the performance of each vehicle to ensure flagging of the conflict is done accordingly.
  - Negotiation should yield a solution before either of the vehicles involved is in a position where it can no-longer give way to the other vehicle.
  - In situations where negotiations are stale, operators may resort to an arbitrage method. With the following properties:
    - The output of the arbitrage method cannot be known in advance by the operators in conflict (so as to not influence negotiations)
    - Unless there is a safety concern (which should not be the case if conflict identification was done properly) - the arbitrage method should give equal chance to either vehicle (50/50)
    - The arbitrage method is a standard that does not need a 3rd party decider (consider “rock paper scissors” “standard” used between kids to decide who gets the last piece of dessert).

Pre-decisional

Pre-decisional

Cooperative Separation

Dr. Hyo-sang Yoo

Objective:

- Develop a pair-wise cooperative negotiation approach to “tactically” separate aircraft via intent sharing with preference

Motivation:

- In order for vehicles within ETM airspace to be safely operating, the vehicles must remain “conflict-free” from other aircraft

Background:

- Practical realization of safe and equitable access to the ETM airspace relies greatly on effective and efficient separation management among the vehicles
- Inappropriate conflict identification and resolution may result in inefficient use of the airspace results in inequitable access to the airspace
- ETM operations may move away from centralized command-and-control system between pilots and air traffic controllers, to a distributed system that allows operators to choose their own preferred route operation
- Such decentralized operation may enable the operators to be responsible for deconflicting their vehicles with other operators’ vehicles
- Without involvement of the centralized authority, the conflict between a pair of the vehicles could be resolved via the pair-wise cooperative negotiation approach via intent sharing with preference

Approach:

- Develop a notional model representing a process of cooperative negotiation between operators for a conflict-involved pair of aircraft
- Develop and prototype any necessary tools to assess feasibility of the overall framework, which can provide general lessons that we can adopt and evolve from
- Conduct an analysis to determine any necessary requirements to enable the proposed negotiation approach to be operational
- Examine the feasibility of the proposed approach using simulation capability

Pre-decisional

Initial assumptions for operations

Pre-decisional

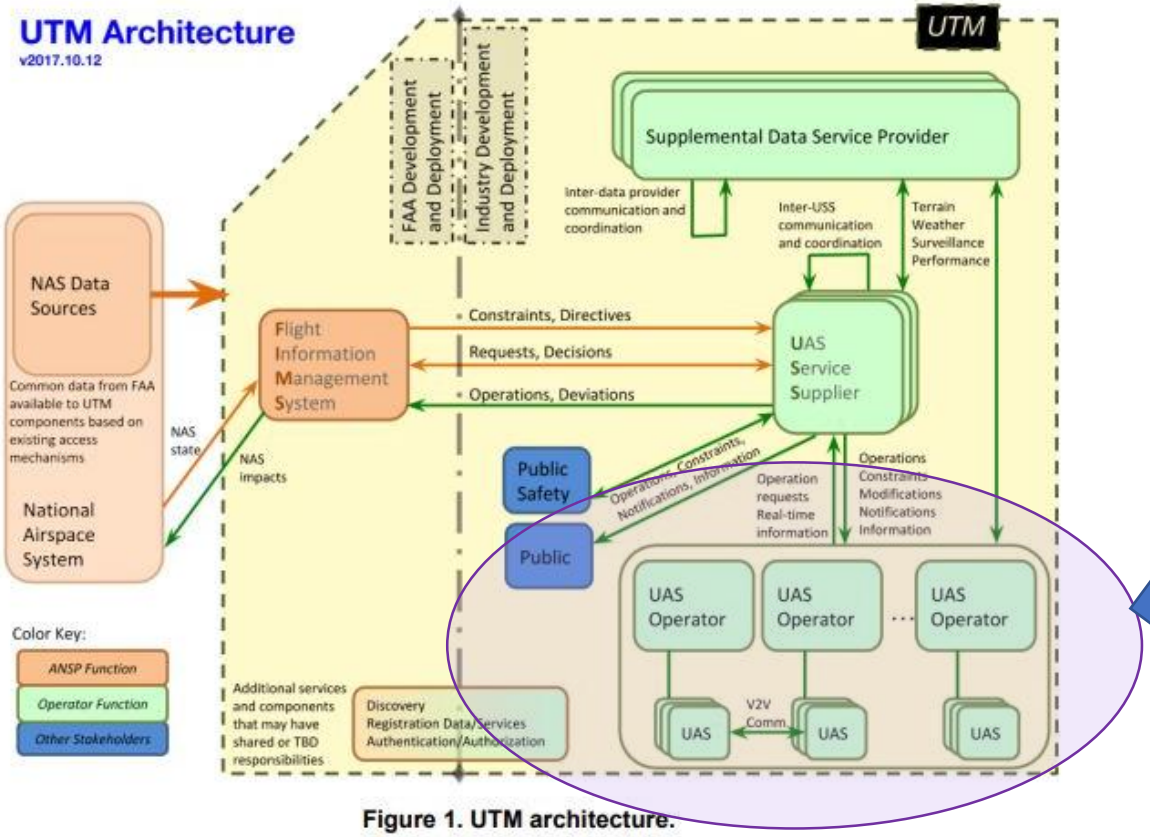


Figure 1. UTM architecture.

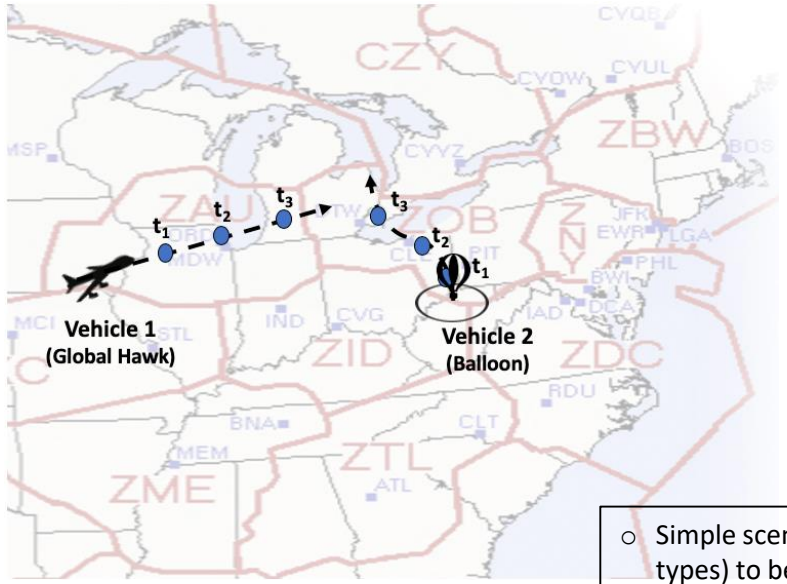
- In ETM operations above FL600, vehicle to vehicle interaction will be cooperatively coordinated and managed by operators themselves
- Operator shares accurate, timely flight information to other operators
- When conflicts are detected, Operators are responsible for de-conflicting the involved vehicles to ensure separation is maintained

Cruise Phase Scenario

Airspace above Cleveland Air Route Traffic Control Center (ZOB)

- One of the busiest Air Route Traffic Control Center (ARTCC) overseeing portions of Maryland, Michigan, New York, Ohio, Pennsylvania, West Virginia, and Ontario (Canada)
- "One in four rural residents say access to high-speed internet is a major problem in their area[1]"
- About 20% of the United States Household has no broadband internet subscription and 2,987,661 (out of total 69,141,968) households in the U.S. states within ZOB ARTCC have **no** internet access at all[2]
- Assumption: Multiple HALE vehicles are providing aerial wireless network services to the areas within the ZOB center

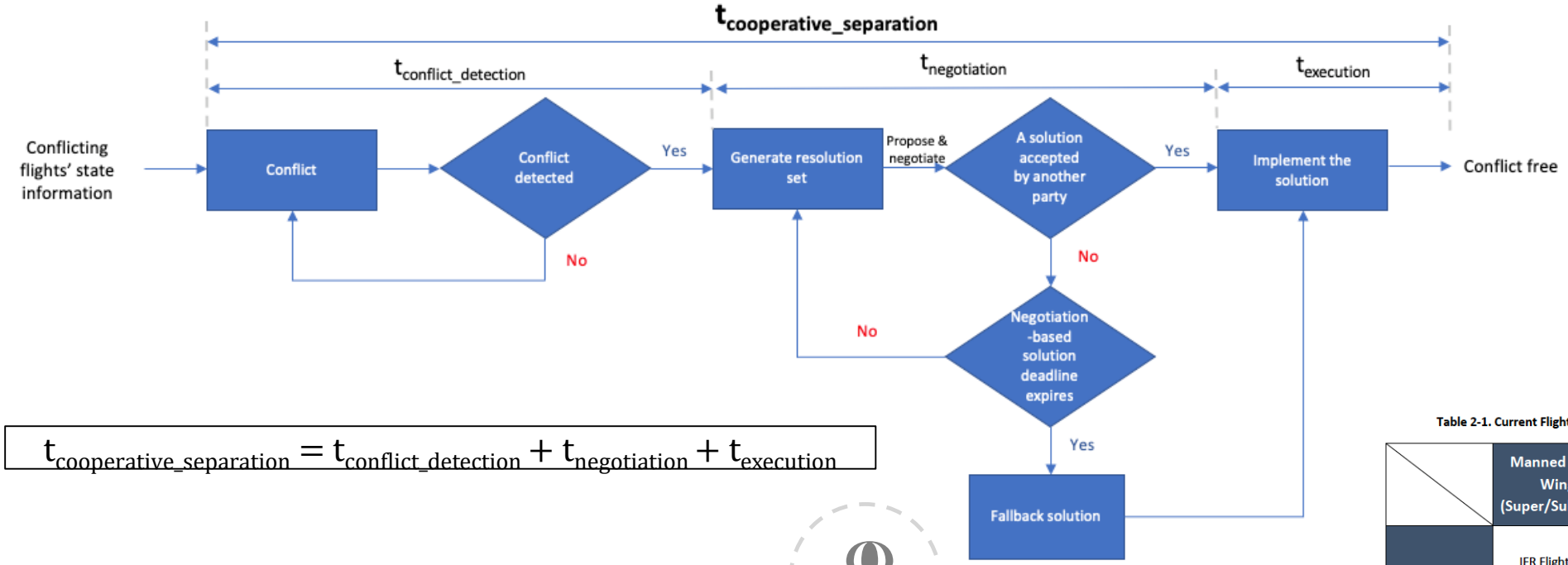
Pre-decisional



- Simple scenario (only two or three vehicle types) to begin with
- Traffic density may increase to moderate level for the experiment purpose

[1] https://www.pewsocialtrends.org/2018/05/22/what-unites-and-divides-urban-suburban-and-rural-communities
[2] 2018 Data from U.S. Census Bureau

Notional model of pair-wise cooperative negotiation process for deconfliction

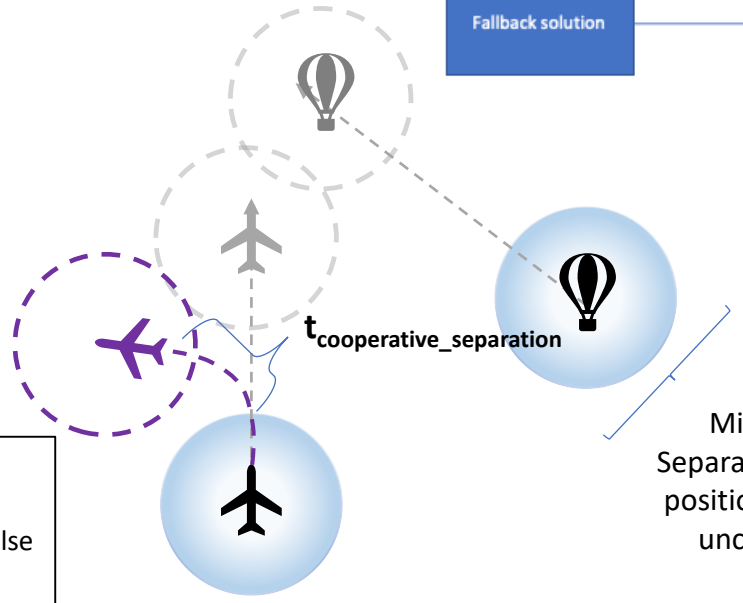


Pre-decisional

$$t_{cooperative_separation} = t_{conflict_detection} + t_{negotiation} + t_{execution}$$

$$t_{Conflict} > t_{cooperative_separation}$$





Minimum Separation due to positioning error uncertainty

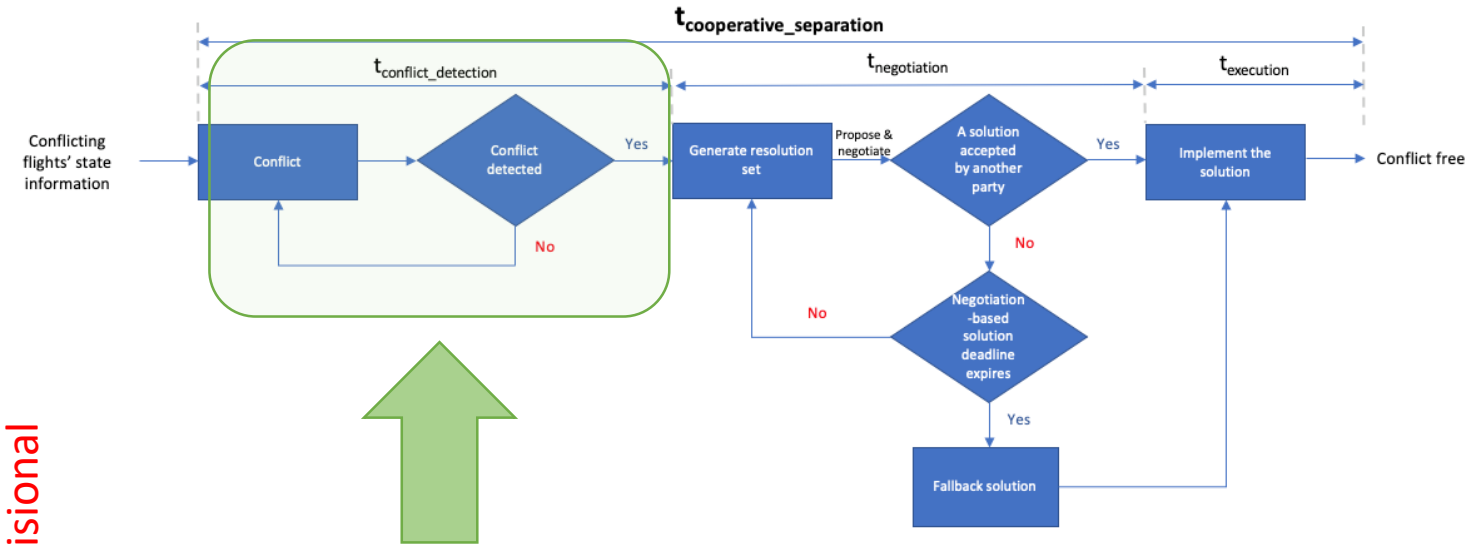
Time until conflict ($t_{Conflict}$) needs to be greater that $t_{cooperative_separation}$, in order to ensure the safe separation of vehicles. However, too large time horizon may result in greater false detection rate due to increase in uncertainty. Also, it may lead to inefficient use of the airspace.

Table 2-1. Current Flight Planning, Notification, & Authorization Requirements by Vehicle Type

	Manned Fixed Wing (Super/Subsonic)	High Speed Unmanned Fixed Wing	HALE Unmanned Fixed Wing	Balloon (HALE & Short Endurance)	HALE Airship
Flight Plan	IFR Flight Plan Filed (6 - 24 hours*) in advance (per 7110.65 9-2-15a) *supersonic only	IFR Flight Plan filed 1 to 2 hours in advance. Covers route between airport and SUA	Filed as required based on national regulation	Unable due to trajectory uncertainty	IFR Flight Plan 24 hours prior

- **Challenges in pre-flight coordination separation**
- **Uncertainty in trajectory increases significantly in relation to time horizon, which may lead to inefficient use of airspace**

Prototyping the proposed strategic separation process for assessing the feasibility

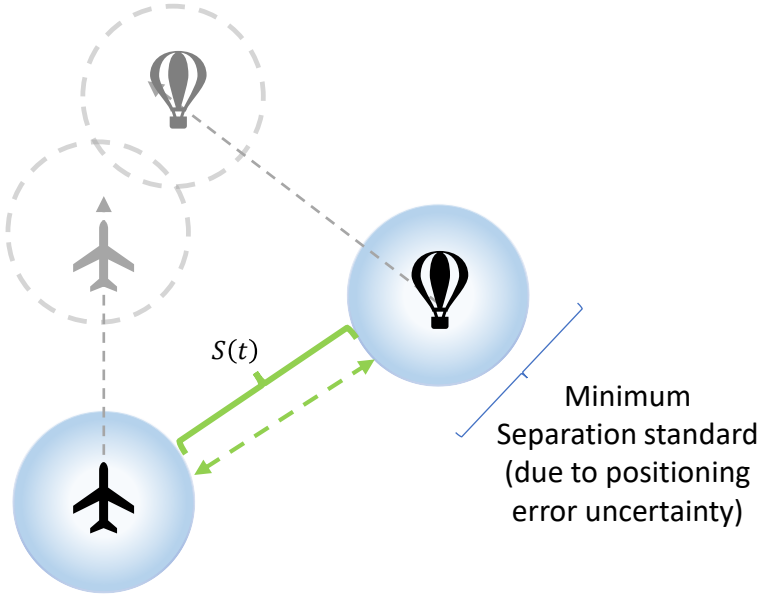


Three-stage process:
Stage 1: Conflict detection
Stage 2: Negotiation
Stage 3: Execution

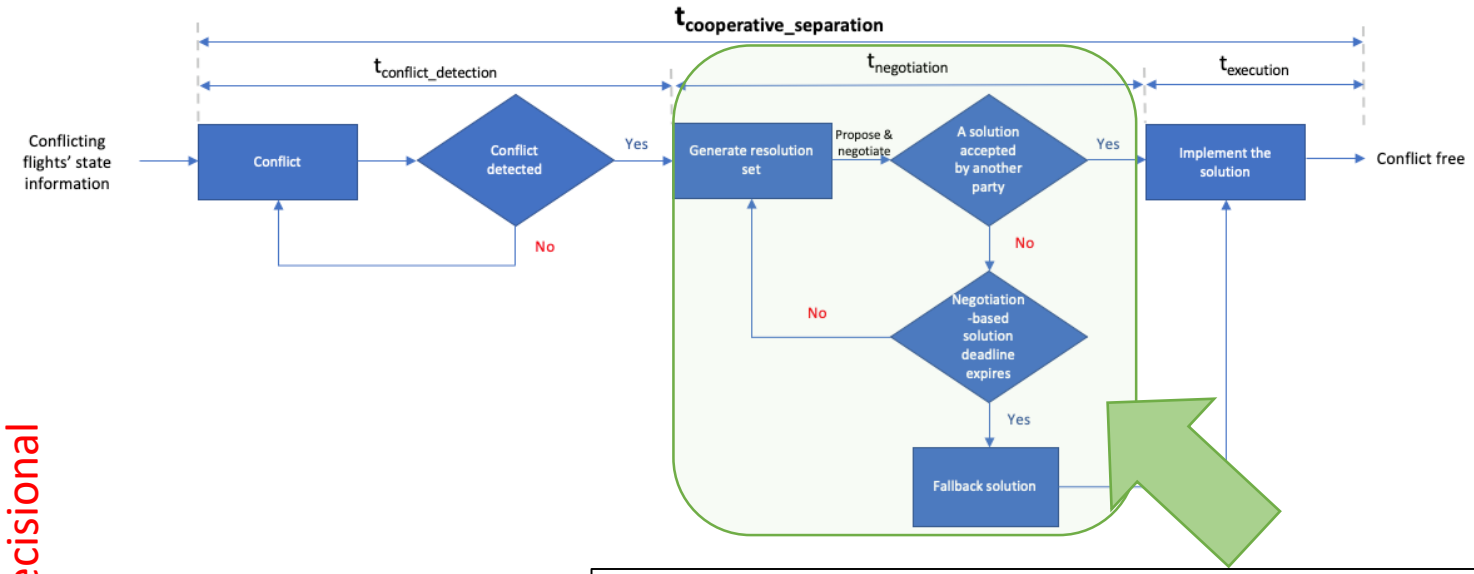
Pre-decisional

Stage 1 (Conflict detection)

1. Conflict detection:
   - A simple pairwise, constant-velocity based on the initial heading of the vehicle logic can be used as a start
2. Minimum separation due to positioning error
   - Guideline for the minimum separation due to positioning errors uncertainty based on CNS information we are gathering
   - Sensitivity analysis to see the impact of the minimum separation vs lookahead time and how it affects the airspace efficiency
3. Estimate of the total amount of time needed for this stage:
   - It is determined by the surveillance system that operators choose to use to monitor their vehicles, update rate of the intent sharing and the operators' information processing time to detect the conflict



Prototyping the proposed strategic separation process for assessing the feasibility



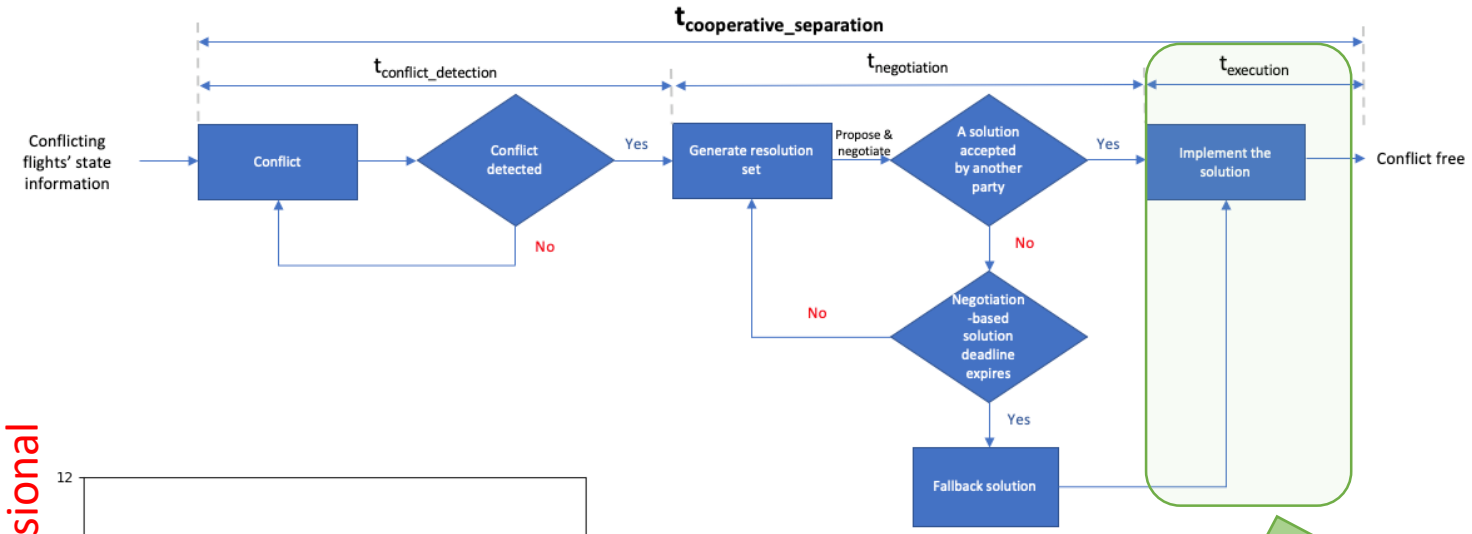
Three-stage process:
Stage 1: Conflict detection
Stage 2: Negotiation
Stage 3: Execution

Pre-decisional

Stage 2 (Negotiation)

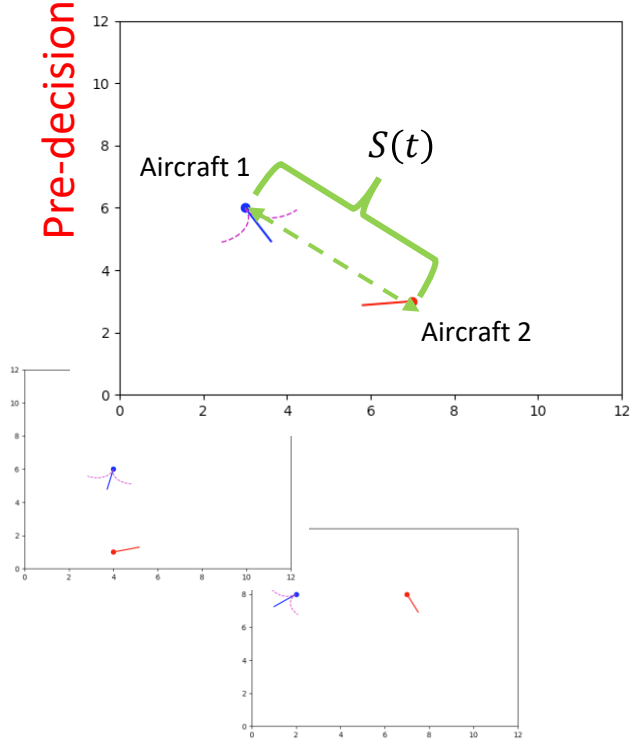
1. A representative way of generating resolution set with preference:
    - For a fixed-wing aircraft, resolutions set with cost for each resolution option
        - left turn, right turn, climb, descent, speed up, speed down, and combination of left & right turn, speed up & down
        - A simple representative algorithm for returning to the original course after resolution
    - For balloon, two resolution set with cost for each option
        - Climb and descent
        - A simple representative algorithm to return to the original altitude
    - Choose a general cost function to represent the preference for each option
2. A representative logic for selecting the resolution option based on the negotiation
3. A logic for fallback
    - Simple rule-based approach to choose the option that provides the minimum total cost of the resolution options submitted by both operators involved in the conflict
4. An estimate of the total amount of time needed for the negotiation
    - An initial guideline for the negotiation protocol can be developed to help estimate the potential time it may take to complete the negotiation

Prototyping the proposed strategic separation process for assessing the feasibility

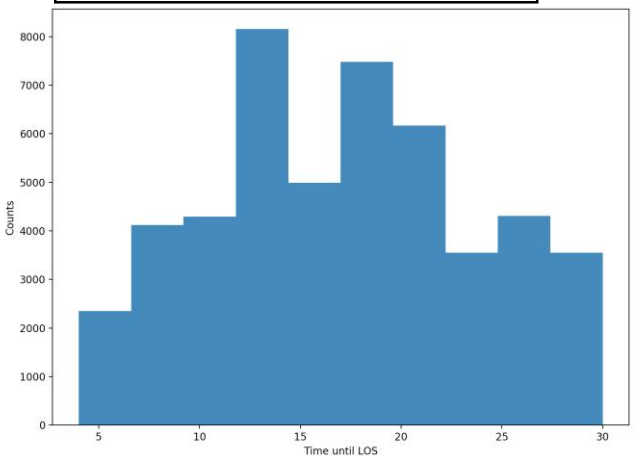


Three-stage process:
Stage 1: Conflict detection
Stage 2: Negotiation
Stage 3: Execution

Pre-decisional



Example – 100,000 scenarios



Stage 3 (Execution)
An estimate of the minimum required time for the various potential vehicles operating in upper E airspace to physically process the control input and take the resolution maneuver successfully

- estimate using the various performance characteristics of the vehicles provide the information

Simulation platform: AutoSim - architecture and functions

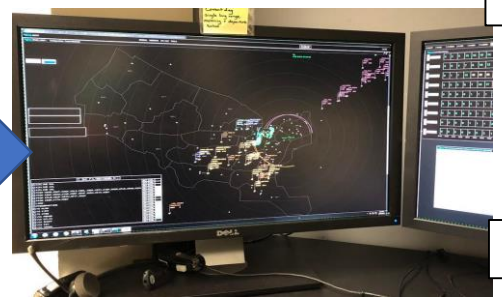
TCP/IP communication

Server

Clients

Pre-decisional

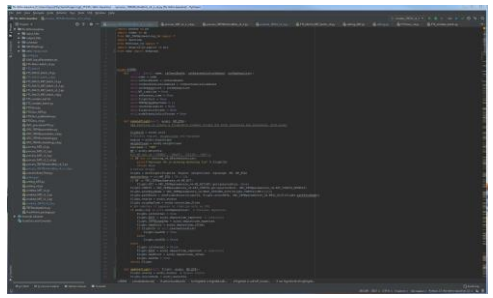
- Traffic Scenario
- Wind file (for environment and trajectory) – may not include for the initial simulation to control the experiment



- Aircraft state information

- Conflict resolution maneuver

Autosim



- Identify the pairs of aircraft with conflict
- Generate conflict resolution set for the conflict detected aircraft
- Negotiation strategy
- Data collection

Pre-decisional

Questions?

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