Notes for NSF Proposal and Experiments

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If our hypothesis is that lane-based airways offers advantages to urban air mobility regulators as well as operators, then what would you measure, and what experiments would be run to measure it, and what parameters are used, and how do they impact the measures (e.g., airway volume, speed, etc.).

It would be good to have a set of:

1. Hypothesis
2. Proposed solution
3. Performance measures for judging solution
4. Testing to obtain measures (or to validate model)

For things like lane-based paths, roundabouts, takeoff-landing (also for contingencies and communication).

0.1 Thesis

The lane-based approach provides operators with privacy and computability, and provides airspace regulators with the ability to plan for demand/capacity balancing, contingency sites, and infrastructure investment.

Experiments

- What is the required density of communication and GPS infrastructure to support a given lane-based airspace structure? How should they be oriented relative to the airspace?
  - Performance measures include, latency, connection stability (how many dropped packets)
  - How does altitude affect these measures?
  - We will create a three-dimensional link-loss calculator to aid airspace regulators in infrastructure planning
- What is the required density of radar infrastructure to support a given lane-based airspace structure? How should they be oriented relative to the airspace?

  - Performance measures include latency and covariance
  - We will design a recommended solution for airspace regulators in infrastructure planning

- We will evaluate software that functions as an order-preserving distributed ledger for "seat" reservation, similar to Project Wings' InterUSS platform. Rather than a grid representation of the airspace, as they use now, the seats are organized by airway segments to facilitate the lane-based approach.
  - Performance measures include latency

- Practical control issues related to the airspace design will be evaluated:
  - Minimum time-headway required for human operators - that is the flexibility in time that the schduling system should allot for human operators. We will then determine the theoretical expected capacity of the airways based on these measures to aid airspace regulators in demand/capacity balancing.
  - The ability of operators to stay within a lane, given the environmental conditions, will be evaluated to determine safe lane spacing.
  - Lane entry and exit profiles will be evaluated to determine how well they clear the space-headway required by UAVs utilizing the same airway.

- Contingency planning
  - After evaluating entry and exit profiles, we will determine a recommended density of contingency areas for emergency landings, based on the airway structure.
  - We will evaluate the speed with which a lane can be evacuated (all UAVs heading to the same contingency area), to aid airspace planners with infrastructure planning

0.2 NASA's Current Approach

Based on Sprint 2 data and currently published API. The current approach to strategic deconfliction: First, each USS defines geographic areas and times for which they are providing services. A USS can define multiple and disjoint areas, and each area is called a USS instance. Intersecting USS instances form a local USS network (LUN). Inside the LUN, USSs are required to share operational information with all other USSs.

Some downsides to the current approach:

1. Privacy: Operations must share their flight plan inside a LUN.

2. Computability: New operations must check intersection with all other operations inside a LUN.

3. Transportation planning: Not clear how to examine demand/capacity balancing. Operation density may be spread out or focused, but is not sufficient to describe the probability that tactical avoidance will be needed. For state/emergency operations, vast swaths of airspace may need to be reserved because we cannot predict the flight paths of operations in the future.

4. Infrastructure planning: Contingency plans are operation dependent, can't define them as part of the infrastructure because it would be difficult to predict where flights would go. Also, determining ideal locations for radio, radar, and gps towers is more complex.

Benefits to the current approach

1. Flight paths can be any shape

Other notes

- Google's Project Wing implemented a distributed ledger called InterUSS for determining when USS instances intersect. They are providing this as a service to USSs.

Operation Definition in the v4 Spec (NASA's current approach, this is what must be shared)

- <u>GUFI</u>: globally unique flight identifier
- <u>USS name</u>: identity of the USS
- <u>Submit time</u>: Time that this operation was first announced to the USS network (in the LUN)
- <u>Update time</u>: Time that this operation was updated
- <u>UAS registrations</u>: registration data for the vehicle(s) used in the operation
- <u>FAA rule</u>
  - PART 107: The operation follows FAA rule 107. Submission of such operations is mandatory
  - PART 107X: In general, operations are 107X if they are doing something that would require a waiver under current 107 rules. Submission of such operations is mandatory.
  - PART 101E: Submission of 101E would be required if operation is within 5 statute miles of an airport. Optional otherwise.

  - OTHER: Placeholder for other types of operations

- State: Current state of the operation
  - PROPOSED: This operation is not yet ACCEPTED. It may be awaiting information from the operator, it may be in conflict with another ACCEPTED or ACTIVATED operation and undergoing a negotiation process, or for some other reason it is not yet able to be declared ACCEPTED.
  - ACCEPTED: This operation has been deemed ACCEPTED by the supporting USS. This implies that the operation meets the requirements for operating in the airspace based on the type of operation submitted.
  - ACTIVATED: This operation is active. The transition from ACCEPTED to ACTIVATED is not an announced transition. The transition is implied based on the submitted start time of the operation (i.e. the effective time begin of the first OperationVolume). Note that an ACTIVATED operation is not necessarily airborne, but is assumed to be "using" the OperationVolumes that it has announced.
  - CLOSED: This operation is closed. It is not airborne and will not become airborne again. If the UAS and the crew will fly again, it would need to be as a new operation. A USS may announce the closure of any operation, but is not required to announce unless the operation was ROGUE or NONCONFORMING.
  - NONCONFORMING: See USS Specification for requirements to transition to this state.
  - ROGUE: See USS Specification for requirements to transition to this state.

- Contact: contact info for this operation

- Controller location: Location of the operation controller

- Contingency plans: An array of ContingencyPlans wherein this operation may land if needed/required during operation. Aids in planning and communication during the execution of a contingency. An Operation MUST have least one Contingency Plan (CP) per Operation Volume

- Operation volumes: The actual geographical information for the operation. A note on "intersection": Note 2: All of the terms "crosses", "within", "touches" imply intersection. I can track down a source for this definition (probably OGC), but for now, you can see it illustrated in the description for PostGIS intersection: `https://postgis.net/docs/ST_Intersects.html`
  - Effective time begin: Earliest time the operation will use the operation volume

- Effective time end: Latest time the operation will done with the operation volume
- Line of sight: Boolean, whether or not it is VLOS
- Max Altitude: The maximum altitude for this operation in this operation volume. In WGS84 using feet units
- Min Altitude: The minimum altitude for this operation in this operation volume. In WGS84 using feet units
- Ordinal: This integer represents the ordering of the operation volume within the set of operation volumes
- Flight geography: Geojson array of array of Points. Points are pairs of longitude latitude values. If a third element is provided for altitude, it is silently ignored. For Polygon, the first and last long-lat pair must be equal; this closes the polygon according to the Geojson specification. If the 'type' is specified as 'Polygon' and the first and last points are not equal, the data will not be accepted

0.3 Lane-Based Approach

For Airspace Regulators and Transporation Planners: The airspace organization facilitated by the lane-based approach enables airspace regulators and transportation planners to plan ahead for required infrastructure to support an expected demand. Existing transportation planning techniques, such as traffic assignment, can be reused for the airways. Emergency lanes can be added dynamically, or reserved for common routes. Emergency landing areas for contingency planning can be pre-built to support the expected layout of airways. Also, we have developed the concept of utilization to help planners understand the capacity of the network, in real time if required.

For Operators and USSs: The lane based approach that we have developed ensures privacy because USSs don't need to know the flight plans of other operators in their LUN. Planning is also much easier because the configuration space is only two dimension inside an airway and they are protected from collision by the airspace structure. The lane-based approach does not preclude NASA's approach, they may be used simultaneously at different altitudes and operators may define their own lanes at the cost of computability.