STATUS UPDATE

Enabling Civilian Low-Altitude Airspace and Unmanned Aerial System (UAS) Operations

By

Unmanned Aerial System Traffic Management (UTM)

Parimal Kopardekar, Ph.D.
Manager, NextGen Concepts and Technology Development Project

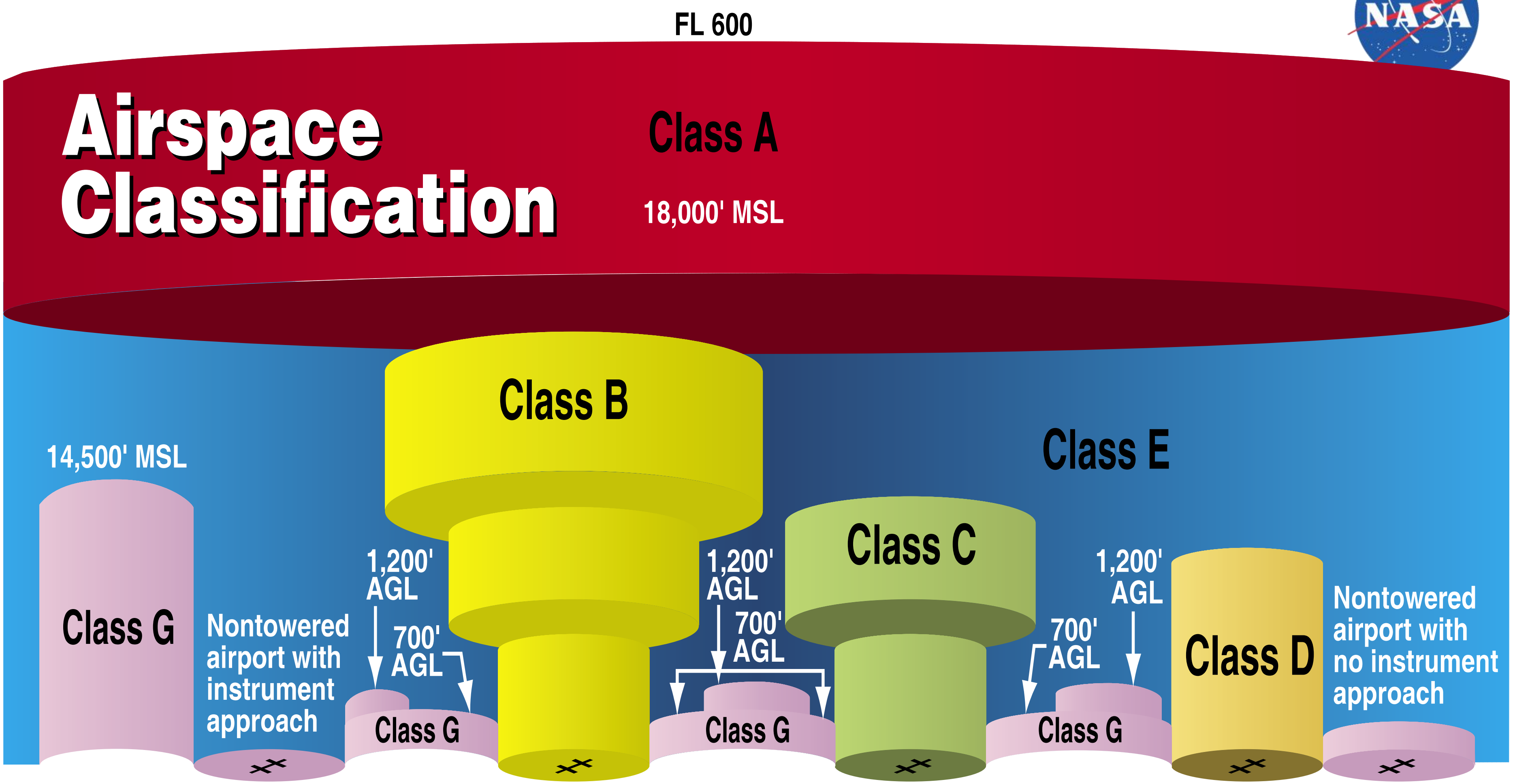
Joseph Rios, Ph.D.
UTM Sub-Project Lead

Current Team

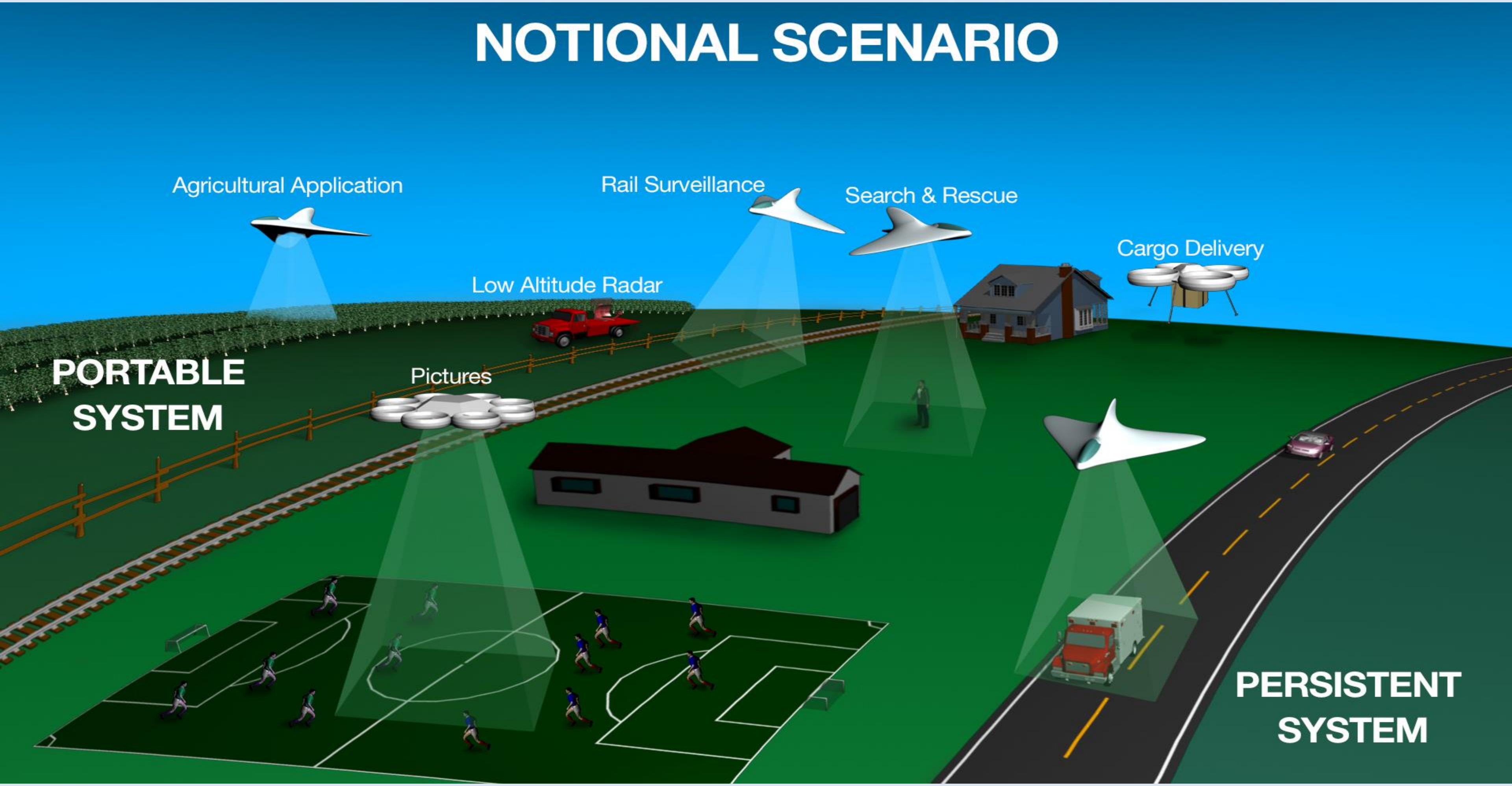
- Parimal Kopardekar (Concept originator and partnership)
- Joseph Rios (Sub-Project Manager)
- John Robinson (Chief Engineer)
- Tom Prevot (Simulations lead)
- Marcus Johnson (Concept and requirements)
- Jaewoo Jung (Communications)
- Daniel Mulfinger (Software development)
- Corey Ippolito (Test lead)
- Christine Belcastro (Safety analysis)

Outline

- UTM Overview
- Request for Information and Partnerships
- FAA and Technology Transfer
- Concept of Operations
- Requirements
- Demonstration Plan
- Architecture and Software Development
- Next Steps
- Summary



Source: Pilot’s Handbook of Aeronautical Knowledge, FAA



- Analogy: Regardless of whether a car is self-driving or not, an infrastructure and system governing operations that includes roads, traffic lights, and rules are needed
- Missing: Infrastructure to support operations at lower altitudes

UTM Technical Challenge Description

Safely enable UAS operations at lower altitudes

- **Current state of the art**: Commercial low altitude UAS operations are not allowed and demand is likely to grow considerably
- **Solution**: Develop a new system called UAS Traffic Management that will support- airspace design, geo-fencing, wind/weather integration, separation management, and contingency operations
- **Main activities**: UTM builds' design and development, FAA and stakeholder coordination, collaborative testing,
- **Benefit**: Being able to safely allow UAS at low altitudes
- **Stakeholders**: National and international interest – service providers, UAS operators, system integrators, UAS manufacturers, FAA, FAA test sites, etc.
- **Product**: UTM requirements and prototype cloud-based system

UTM: UAS Operator Needs

- Access to Airspace
  - Is airspace open or closed now and in the near-future?
  - In which airspace they can operate; which airspace should they avoid?
- Traffic Awareness
  - Will there be anyone else in the vicinity?
  - UAS, gliders, helicopters, and general aviation
- Changes to Trajectory to optimize business
  - What should I do if I need to change my trajectory?
- Contingencies Management
  - How to manage a contingency?
- Airspace Manager
  - Who should operate the airspace and how?

UTM: Role of Airspace Manager

- Airspace Design and Dynamic Adjustments
  - Corridors design, altitude/direction allocation, geo-fencing definition, community concerns, airspace blockage due to severe weather/wind prediction or contingencies
  - Delegated airspace as the first possibility
- Support fleet operations as well as singular operators (analogy - airline operations center and flight service stations)
- Overall schedule driven system to ensure strategic de-conflictions (initially, overtime much more dynamic and agile)
- Management by exception
  - Operations stay within geo-fenced areas and do not interrupt other classes of airspace operations in the beginning stages
  - Supports contingency management

UAS User Access to UTM

- Cloud-based: user accesses through internet
- Generates and files a nominal trajectory
- Adjusts trajectory in case of other congestion or pre-occupied airspace
- Verifies for fixed, human-made, or terrain avoidance
- Verifies for usable airspace and any airspace restrictions
- Verifies for wind/weather forecast and associated airspace constraints
- Monitors trajectory progress and adjust trajectory, if needed (contingency could be someone else's)
- Supports contingency – rescue
- Allocated airspace changes dynamically as needs change

UTM Design Functionality

- For safe UAS operations, UTM should support:
  - Airspace management and geo-fencing (reduce risk of accidents, impact to other operations, and community concerns)
  - Weather and severe wind integration (avoid severe weather areas based on prediction)
  - Allow only authenticated operations (avoid unauthorized airspace use)
  - Predict and manage congestion (mission safety)
  - Terrain and man-made objects database and avoidance
  - Maintain safe separation (mission safety and assurance of other assets)

Request for Information

Federal Business Opportunities

- Request of information was solicited through Federal Business Operations focused on partnerships and collaborative tests
- Over 95 respondents in the UAS community indicated interest to collaborate with NASA on the development of UTM
- Currently sorting through responses and identifying what various partners can provide
- Universities, private industry, other government agencies all provided responses to the RFI
- No exchange of funds, collaboration to accelerate development, testing, and in-field operations
- Novel partnerships: Vehicle manufacturers, test sites, DOI, insurance companies, academia, communication, surveillance, system integrators, etc.

Collaboration with FAA, NOAA, and DOI

- Formed a research transition team between FAA and NASA that is focused on UTM (as part of overall autonomy thrust)
- Held kick-off meeting to discuss UTM vision
- Conducted FAA, NASA, local UAS industry meeting to understand the needs of the UAS industry and FAA
  - Operational tempo (frequency, density, locations, etc)
- NASA will be UTM technology developer and conduct collaborative tests
- NOAA: Weather service (wind, severe weather) at low altitudes
- DOI: UTM capability to manage national parks (largest landowner)

Student and Faculty Projects

- University of Massachusetts
- Duke University
- Stanford University
- University of California, Berkeley
- Others in planning
  - University of Maryland
  - Rutgers University
  - Boise State University
  - Cal Poly

International Interests

- Korea
- France (Exploring collaboration on similar activity called Mach7)
- Poland
- Japan

Concept of Operations

- Developing ConOps document
- Formalizes the concepts discussed in this presentation
- Seek comments from industry and government partners in the coming months
- ConOps being developed in parallel with requirements documentation and demonstration planning. All are converging

Requirements

- Developing the functional requirements for the system as a whole broken down on a “per build” basis.

- Build 1:
  - UTM securely communicates with external clients.
  - UTM manages UTM airspaces/geo-fences/restricted areas
  - UTM provides non-towered-like services to UAS
  - UTM provides some level of separation services
  - UTM supports replay of a UTM scenario
  - All UAS adhere to their accepted plans (no off-nominal scenarios)

- Build 2, 3, 4 each add further services and capabilities.

Schedule

- UTM research and development driven by various “Builds”
- Each Build adds more services and capabilities

Build 1

- Demo: **Aug 2015**
- Geo-fencing and airspace design
- Open/close airspace for wx
- Basic procedural separation
- Simple scheduling
- Initial constraint database

Build 2

- Demo: **Oct 2016**
- Dynamic airspace adjustments
- Demand/Capacity imbalance
- Initial contingency management

Build 3

- Demo: **Jan 2017**
- Trajectory conformance monitoring
- Web portal for UTM access
  Heterogeneous operations

Build 4

- Demo: **Mar 2018**
- Large scale contingency management

Near-term UTM Builds Evolution

UTM Build	Capability Goal
UTM1	Mostly show information that will affect the UAS trajectories • Geo-fencing and airspace design • Open and close airspace decision based on the weather/wind forecast • Altitude Rules of the road for procedural separation • Basic scheduling of vehicle trajectories • Terrain/man-made objects database to verify obstruction-free initial trajectory
UTM2	Make dynamic adjustments and contingency management • All functionality from build 1 • Dynamically adjust availability of airspace • Demand/capacity imbalance prediction and adjustments to scheduling of UAS where the expected demand very high • Management of contingencies – lost link, inconsistent link, vehicle failure

Near-term UTM Builds Evolution

UTM Build	Capability Goal
UTM3	Manage separation/collision by vehicle and/or ground-based capabilities • All functionality from build 2 • Active monitoring of the trajectory conformance inside geo-fenced area and any dynamic adjustments • UTM web interface, which could be accessible by all other operators (e.g., helicopter, general aviation, etc.) • Management of separation of heterogeneous mix (e.g., prediction and management of conflicts based on predetermined separation standard)
UTM4	Manage large-scale contingencies • All functionality of build 3 • Management of large-scale contingencies such as “all-land” scenario

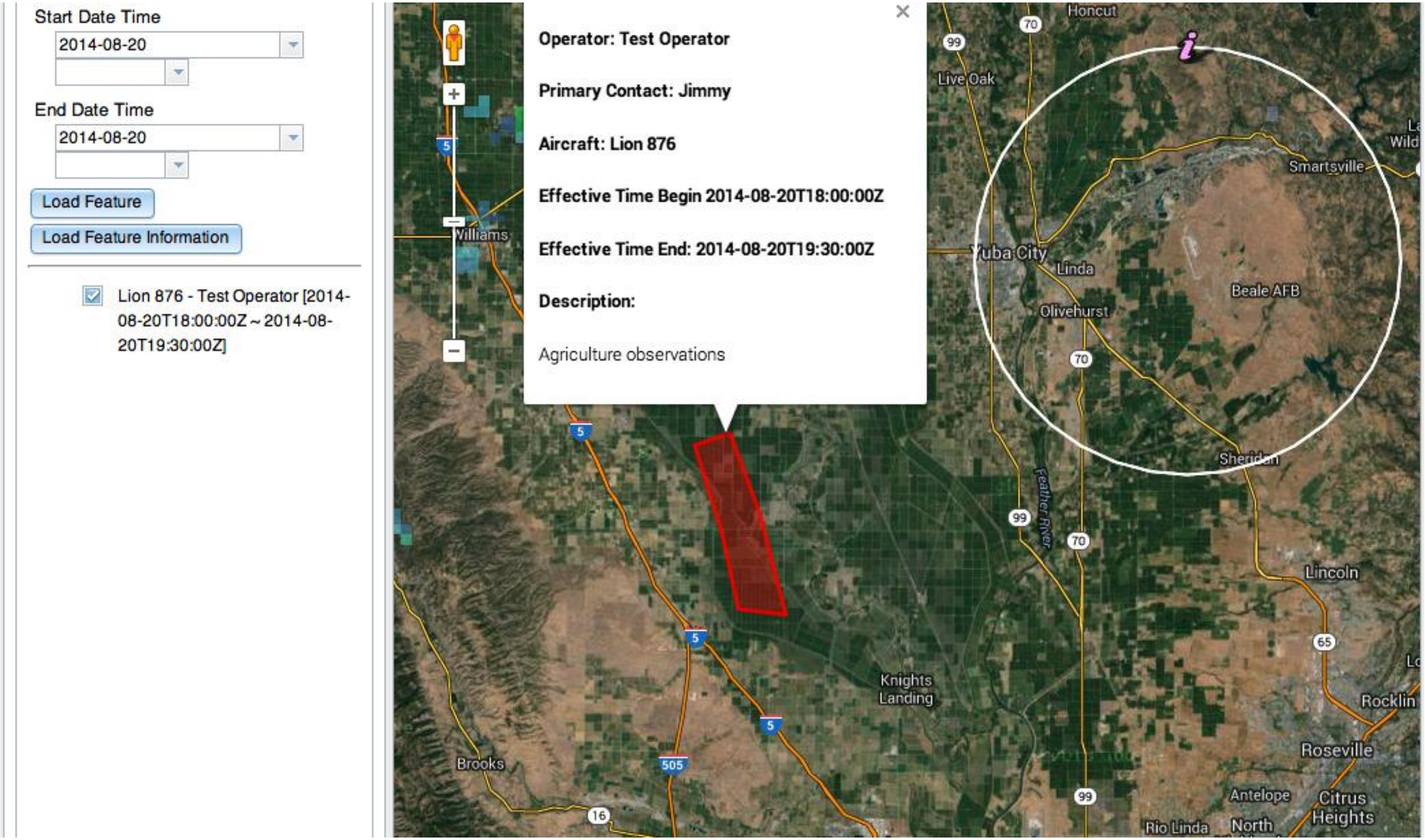
Build 1 Demonstration

- Identifying partners
  - Vehicles and auto pilot systems
  - Operators services
  - Logistics, insurance, and etc.
  - Academic institutions
  - Communication and Surveillance
- Plan to run the demo in simulation in early 2015
- Plan to run the initial tests with NASA and/or partner vehicles in Spring 2015
- Full demo at end of summer 2015 with participation of RFI partners
- Test site being determined
  - NASA's Crow Landing is likely, provides us greatest control
  - All UAS Test sites are interested
  - External partners also have sites identified that we may leverage

Build 1 Demo Description

- Two vehicles separated procedurally by staying in their own planned space
- Surveillance provided by operators: they report their own position
- UTM system accepts/rejects plans as they are submitted free of constraint intersection or not
- For testing/safety/post-operations analysis, maintain active surveillance of UAS
- Test various operation plan combinations of: planned, rejected, early ending, etc.

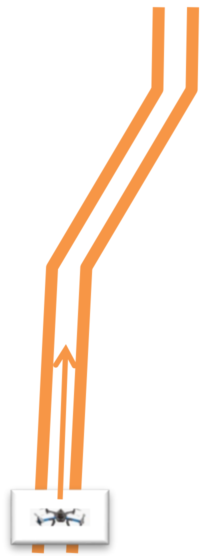
Example Interface



Geo-fenced Areas

UAS area of operations geo-fence

Operators may request an area of operation. If granted, a geo-fence is implemented wherein other requests that intersect spatially and temporally with the operation could be denied.



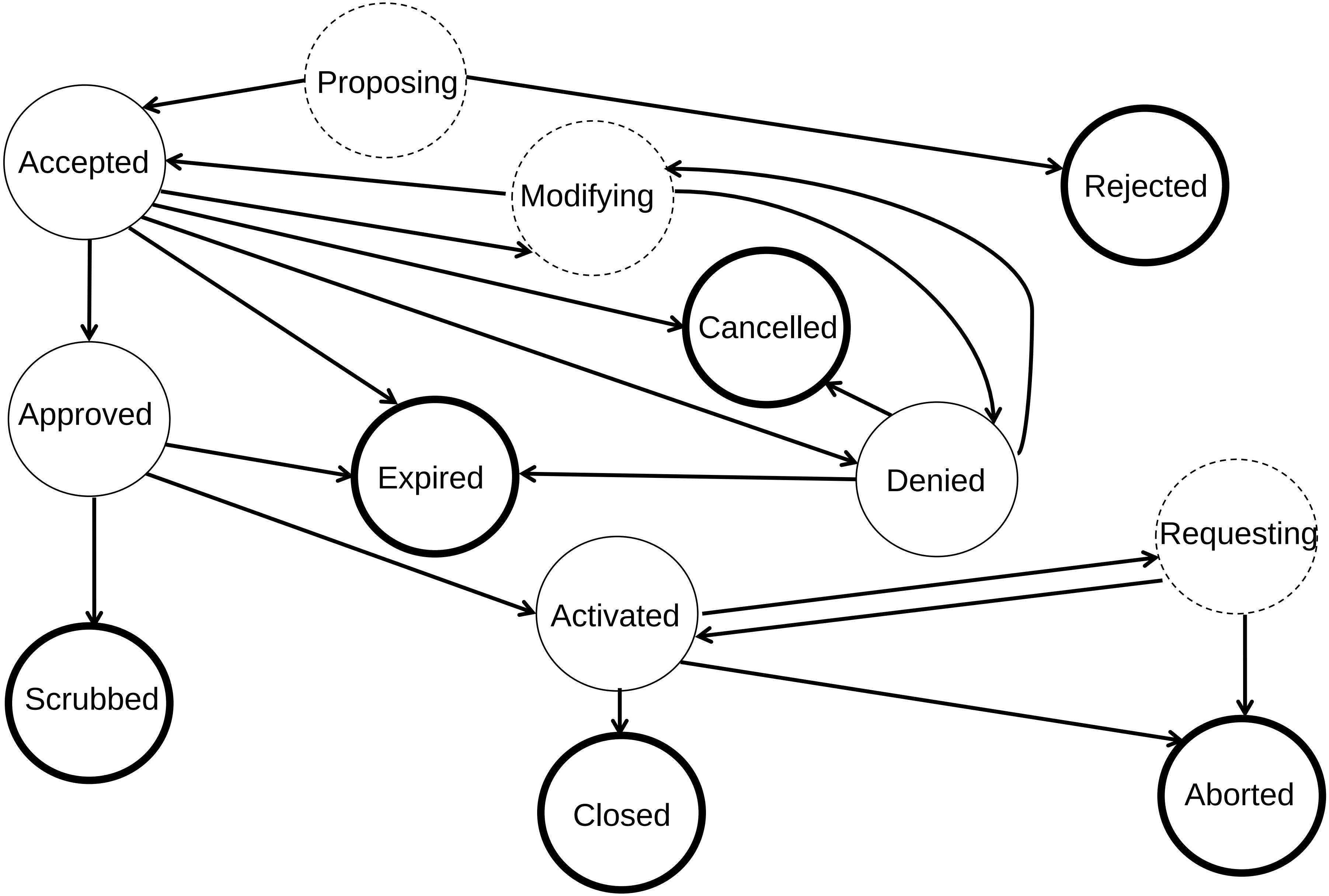
UAS trajectory geo-fence

Operators may request specific trajectory for an operation. If granted, a geo-fence based on the vehicles operating parameters will be created to keep other vehicles within the UTM system from intersecting.

Airspace constraint geo-fence

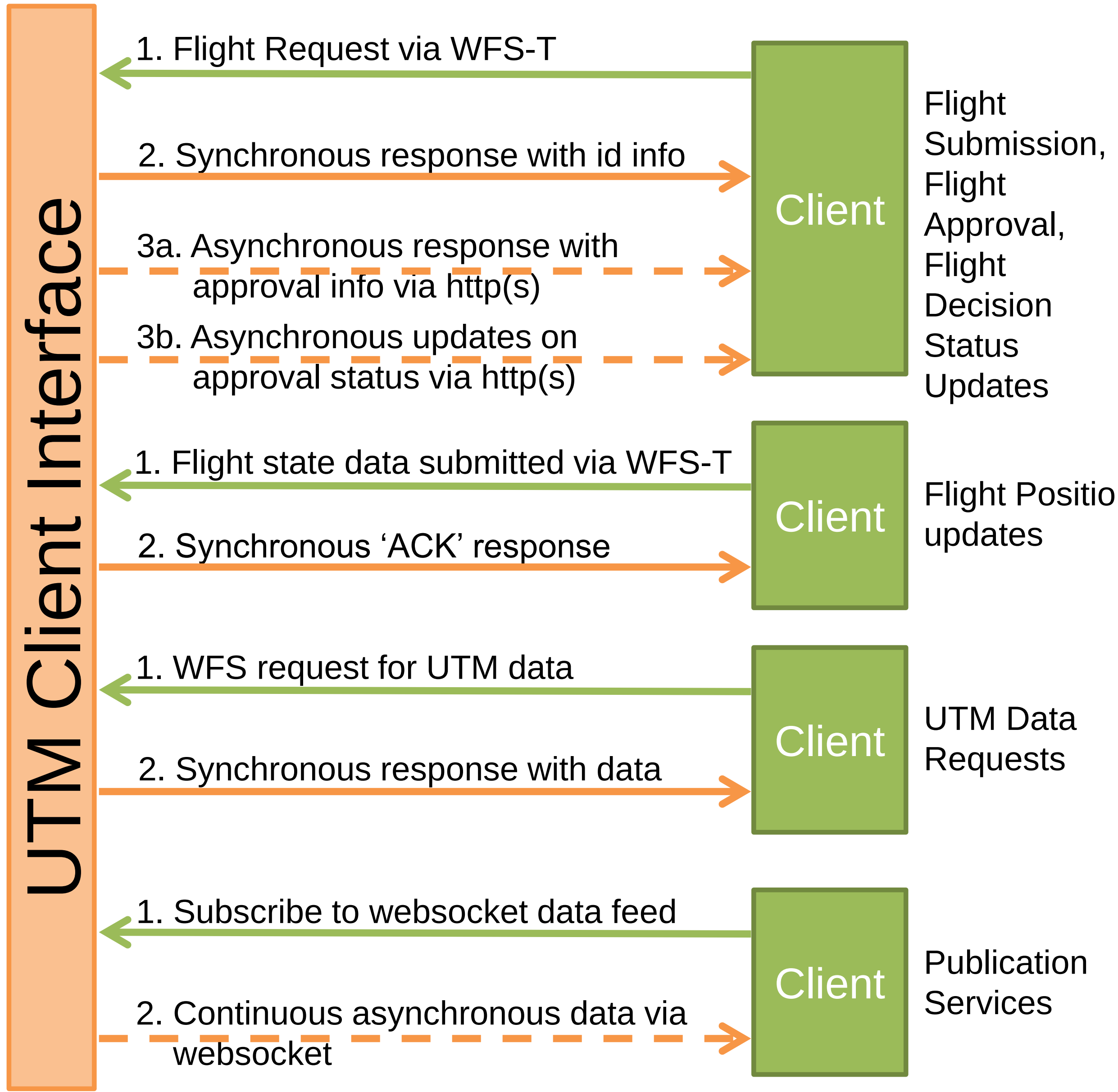
Airspace that is off limits to UAS operations (airports, TFRs, etc.) will have a geo-fence prohibiting acceptance of plans that intersect.

Flight Plan States



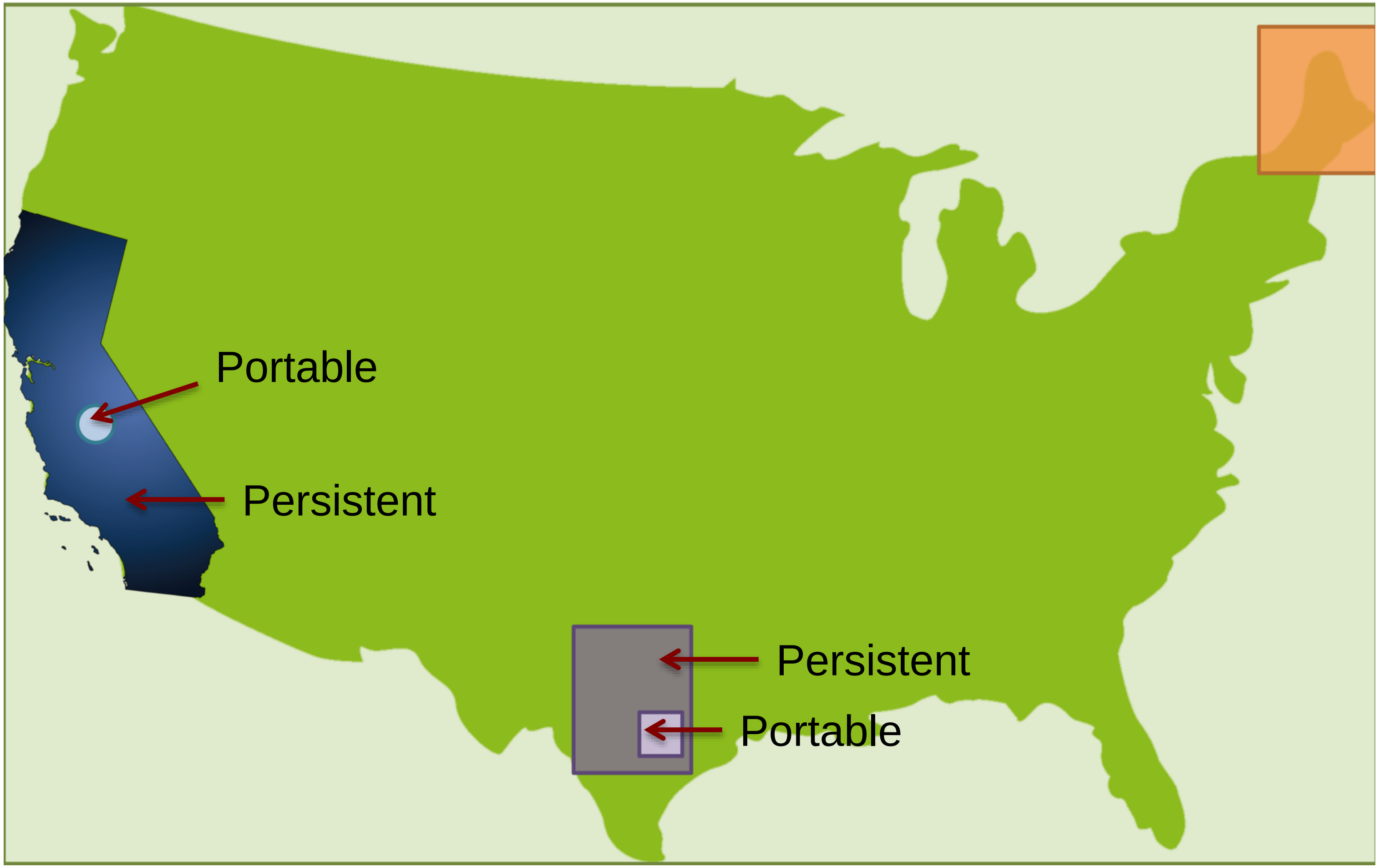
Client services: software perspective

- Developed initial prototype software to handle client requests.
- Clients can submit a flight plan and track updates via our API.
- Clients can also request data with the system related to flights and constraints



UTM Hierarchical Topology

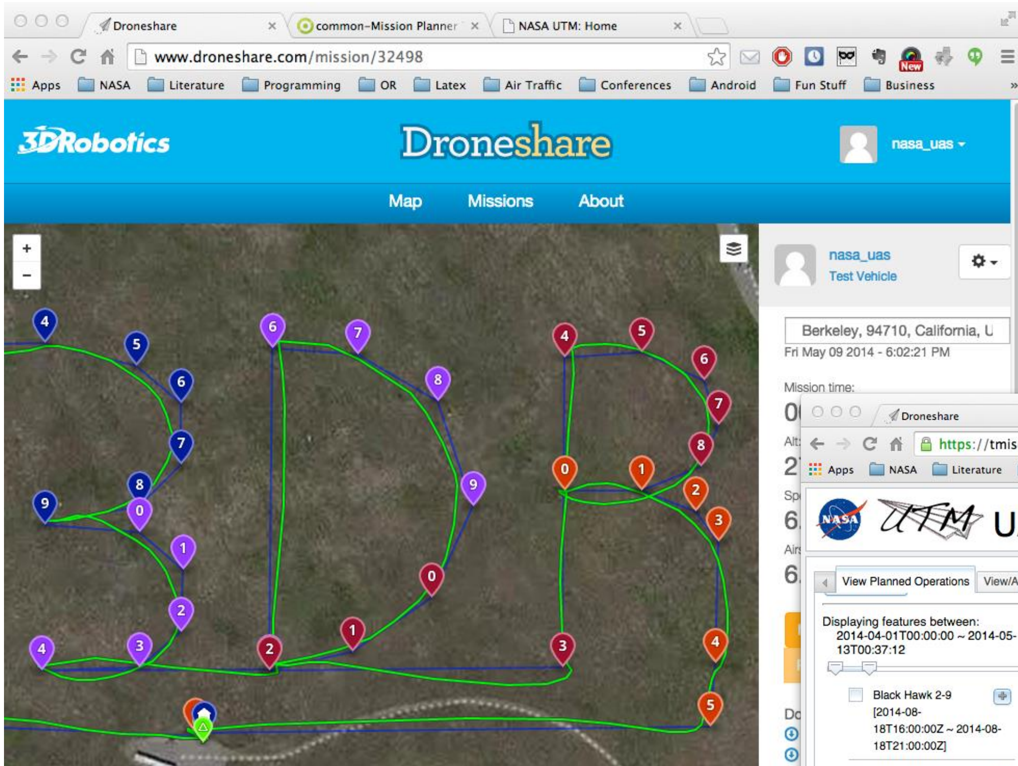
Portable and Persistent System Can Co-exist



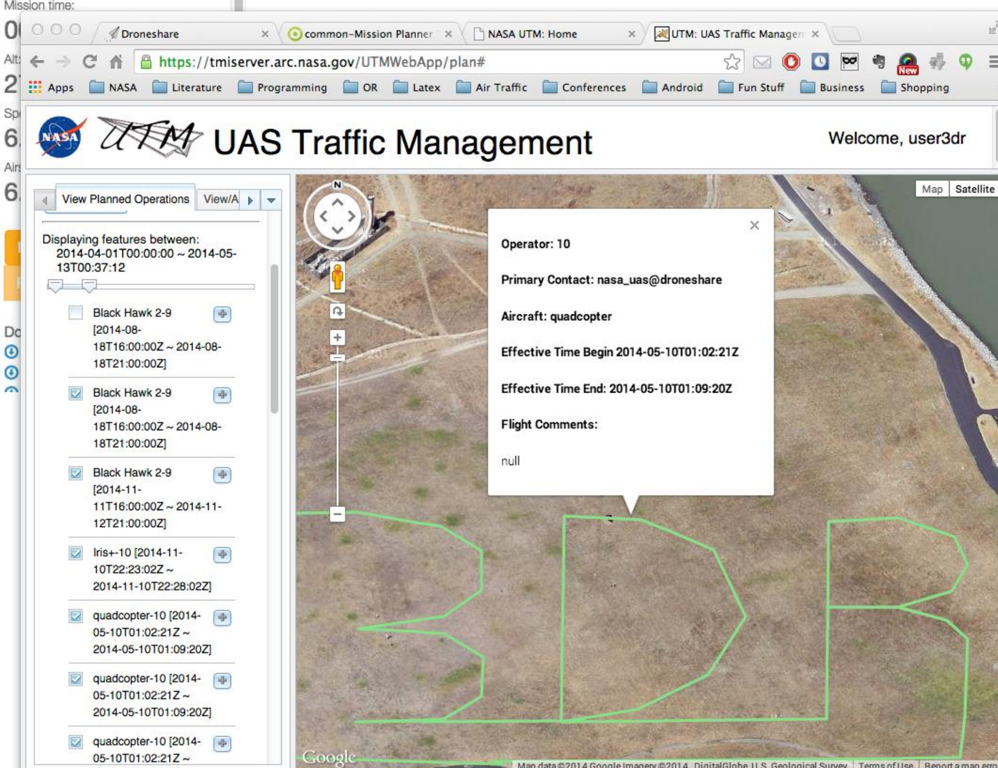
Client development

- Several initial testing partners for interface and integration
- Drone Deploy and 3D Robotics have each developed client software to interact with our prototype
- In discussions with other partners for various system-integration one-off tests
- Initial architecture has been well-received by industry partners

Example: 3D Robotics Integration



Software integration with existing UAS consumer tools already in development



3D Robotics demonstrated sharing data from their web-based platform to our prototype UTM system

FY15 Resources (Minimum)

Category	Total
Budget	$5M
Procurement (testing, logistics, etc.)	$2M
FTE and WYEs	13

Note: Budget based on continuing resolution and may adjust

Next steps

- Internal system integration tests in preparation of Build 1 Demo, Spring 2015
- Build 1 Demonstration, summer 2015
- Complete plan and schedule for future builds
- Strengthen external partnerships to leverage others' capabilities and receive buy-in of concept from non-government stakeholders
- Communicate with FAA to ensure solid transfer of technology

Summary

- Near-term goal is to safely enable initial low-altitude operations within 1-5 years
- Longer-term goal is to accommodate increased demand in a cost efficient, sustainable manner
- Strong support for UTM system research and development
- Collaboration and partnerships for development, testing, and transfer of UTM to enable low altitude operations
- **Major gathering around UTM late Spring**
- Step towards higher levels of autonomy

Parimal.H.Kopardekar@nasa.gov

BACKUP SLIDES

UTM – One Design Option

Multiple customers
With diverse mission
needs/profiles

UAS 1

UAS 2

UAS 3

UAS n

Range of UAVs from disposable to autonomous

Low altitude CNS options such as:

- Low altitude radar
- Surveillance coverage (satellite/ADS-B, cell)
- Navigation
- Communication

Autonomicity:

- Self Configuration
- Self Optimization
- Self Protection
- Self Healing
- Operational data recording

- Authentication
- Airspace design and geo fence definition
- Weather integration
- Constraint management
- Sequencing and spacing
- Trajectory changes
- Separation management
- Transit points/coordination with NAS
- Geofencing design and adjustments
- Contingency management

Real-time Wx and wind

Wx and wind Prediction

Airspace Constraints

Other low-altitude operations

Transition between UTM and ATM airspace

Constraints based on community needs about noise, sensitive areas, privacy issues, etc.

3-D Maps: Terrain, human-made structures

Example Research and Development Needs

- Minimum UTM system design and requirements
- Minimum vertical and horizontal separation minima among UAS and other operations (gliders, general aviation, helicopters)
  - Static or dynamic
  - Analytical, Monte Carlo or other types of modeling
- Tracking accuracy and separation minima trade-off
  - Oceanic separation vs en route aircraft separation
- Trajectory models for better prediction of different UAS
- Vehicles and wind/weather related considerations – modeling and prediction of winds, eddies, and weather at low altitudes
  - May need to enhance weather prediction capabilities
- Classification of UAS – bird strike example

Example Research and Development Needs

- Contingency procedures: large-scale and individual vehicle
- Sense and avoid – many products, research activities, and NASA UAS challenge
- Human computer interface design options for UTM manager
- Human computer interaction options for UAS ground control station
  - How many UAS can a ground control station operator manage
- Type of UAS and minimum autonomy capabilities
  - Humans can’t operate two rotor failure mode for a multi-rotor vehicle
- Last/first 50 feet operations landing and safety
  - Various sensor pack and networked options for all weight classes
- Vehicle risk category
- Minimum equipage requirements

Consideration of Business Models

- Single service provider for the entire nation such as a government entity
- Single service provider for the entire nation provided by a non-government entity (for-profit, or not-for-profit entity)
- Multiple service providers by regional areas where UTM service could be provided by state/local government entities
  - Need to be connected and compatible
- Multiple service providers by regional areas where UTM service could be provided by non-government entities
  - Need to be connected and compatible
- Regulator has a key role in certifying UTM system and operations

Example Student Projects

- Overall UTM design
- UTM interface
- Ground control station interface for multiple vehicle control
- Separation minima analysis (beyond well clear)
- Trajectory definition of UAS
- Wind/weather as related to geo-fencing
- Noise impact modeling
- Highways in the sky design (rules of the road)
- UAS trainer – who is qualified to operate? How quickly you can train?
- Wireless infrastructure (e.g., CDMA, LTE, etc.)
- Affordable and light weight sensors for sense and avoid
- Requirements on UAS – communication, latency, lost communication, energy depletion, etc. - Minimum
- Last/first 50 feet technology options (sensors, architecture, human-autonomy role, manual input, auto abort, etc.)
- Business case for private industry

Types of UTM

- Portable UTM System: Set up, operate, and move
  - Support humanitarian, agricultural and other applications and be able to move from one location to another

- Persistent UTM System: Sustained, real-time, and continuous operations
  - Denali National Park
  - Between mega-cities
  - Urban areas

- Number of alternative options to design, architect, and operate UTM
  - All ideas are welcome

UAS User Access to UTM

- Cloud-based: user accesses through internet
- Generates and files a nominal trajectory
- Adjusts trajectory in case of other congestion or pre-occupied airspace
- Verifies for fixed, human-made, or terrain avoidance
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- Monitors trajectory progress and adjust trajectory, if needed (contingency could be someone else's)
- Supports contingency – rescue
- Allocated airspace changes dynamically as needs change

UTM System Requirements

- Authentication
  - Similar to vehicle identification number, approved applications only
- Airspace design, adjustments, and geo-fencing
  - Corridors, rules of the road, altitude for direction, areas to avoid
- Communication, Navigation, and Surveillance
  - Needed to manage congestion, separation, performance characteristics, and monitoring conformance inside geo-fenced areas
- Separation management and sense and avoid
  - Many efforts underway – ground-based and UAS based – need to leverage
- Weather integration
  - Wind and weather detection and prediction for safe operations

UTM System Requirements

- Contingency Management
  - Lost link scenario, rogue operations, crossing over geo-fenced areas
  - Potential “9-11” all-land-immediately scenario

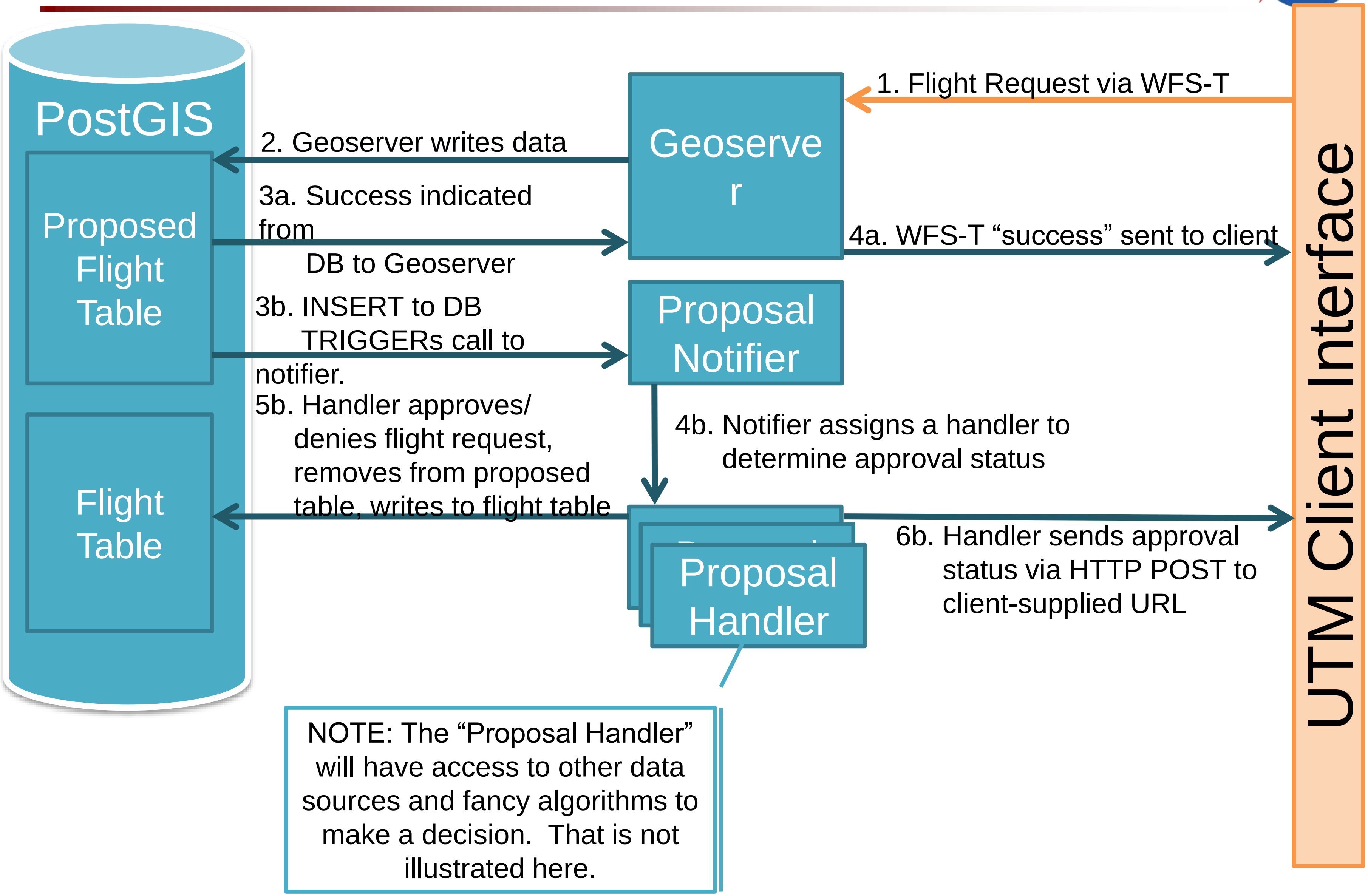
- UTM Overall Design
  - Enable safe operations initially and subsequently scalability and expected massive growth in demand and applications
  - As minimalistic as possible and maintain affordability

- Congestion Prediction
  - Anticipated events – by scheduling, reservations, etc.

- Data Collection
  - Performance monitoring, airspace monitoring, etc.

- Safety of Last 50 feet descent operation
  - In presence of moving or fixed objects, people, etc.

Data Flows


PostGIS
Proposed Flight Table
Flight Table
Geoserver
Proposal Notifier
Proposal Handler
UTM Client Interface
1. Flight Request via WFS-T
2. Geoserver writes data
3a. Success indicated from DB to Geoserver
3b. INSERT to DB TRIGGERs call to notifier.
4a. WFS-T "success" sent to client
4b. Notifier assigns a handler to determine approval status
5b. Handler approves/ denies flight request, removes from proposed table, writes to flight table
6b. Handler sends approval status via HTTP POST to client-supplied URL
NOTE: The "Proposal Handler" will have access to other data sources and fancy algorithms to make a decision. That is not illustrated here.