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UTM TCL 2 Software Requirements

Irene S. Smith
Ames Research Center, Moffett Field, California

Joseph L. Rios
Ames Research Center, Moffett Field, California

Patrick O. McGuirk
Millennium Engineering & Integration Co.

Daniel G. Mulfinger
Ames Research Center, Moffett Field, California

Priya Venkatesan
ASRC Federal, Moffett Field, California

David R. Smith
SGT Inc., Moffett Field, California

Vijayakumar Baskaran
SGT Inc., Moffett Field, California

Leo Wang
SGT Inc., Moffett Field, California

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National Aeronautics and
Space Administration
Ames Research Center
Moffett Field, CA 94035-1000

Acknowledgments

1 Overview

The Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Technical Capability Level (TCL) 2 software implements the requirements described herein. These software requirements are linked to the higher level UTM TCL 2 System Requirements. Each successive TCL implements additional UTM functionality, enabling additional use cases. TCL 2 demonstrated how to enable expanded multiple operations by implementing automation for beyond visual line-of-sight, tracking operations, and operations flying over sparsely populated areas. The UTM

TCL 2 software implementation is a cloud-ready, monolithic architecture. The software is a research platform and not an operational system; rather it is a proof-of-concept and allows for identifying gaps in the UTM TCL 2 System Requirements.

The purpose of this document is to ensure that UTM's research results will be fully utilized, and sufficient to meet interim goals of the UTM FAA & NASA Research Transition Team (RTT). The UTM RTT is a NASA-FAA coordinating committee collaborating on UTM concepts to ultimately be adopted by the FAA and other federal agencies and transfer them for commercialization by industry for integrating UAS operations in the National Airspace (NAS). This software specification is expected to be an artifact in the RTT technology transfer package. A secondary purpose of this document is to solicit feedback to improve the content and format of its successor, the UTM TCL 3 Software Specification.

The audience for this document is UTM software stakeholders. It is meant to serve as a roadmap into the User Stories listed in Table 2.

This document first defines the main services of TCL 2, as well as their relationship to the overall architecture. Each service is then described separately. Finally, the requirements list is presented, where each service is mapped to its requirement(s) and each requirement is mapped its actual software implementation.

2 Related Documents

Table 1: Related Documents

Document	Description
UTM TCL 2 System Requirements	System level requirements that reference the software requirements in this document.
UAS Operator ICD	Guide to NASA's UAS Service Supplier (USS). UAS Operators and their software developers use this to understand NASA's USS. USS developers may use this as a USS reference implementation.
UAS Operator OpenAPI-Spec	Open API specification ("swagger spec") of Operator to USS interface. UAS Operator software developers use this to interface with NASA's USS. USS developers may use this as a USS reference implementation.
USS Software Requirements Specification	Requirements for USS.
Supplemental (External) Data Providers OpenAPI Spec	Externally defined Supplemental Data Service Providers (SDSPs).

3 Services

The network architecture sketch shown in Figure 1 depicts the TCL 2 services and their system services. In some cases, a service corresponds to a software module and in other cases, the service is integrated within other modules. The web application layer consists of the NASA UAS Service Supplier (USS), also named the "UTM Core." The USS is either cloud-hosted or hosted on premises. It is behind a web layer and protected in a secure subnet. The USS interacts with a set of Supplemental Data Service Providers (SDSPs) and UAS Operators. Also shown for concept completeness is the Air Navigation Service Provider (ANSP). All network traffic is routed through a single, encrypted port. Inbound and outbound traffic is managed at the HTTPS level by a web server (TCL 2 uses NGINX) which routes traffic to the USS web applications. The web layer also guards against overuse, such as (intentional or unintentional) denial-of-service events. The USS is at the business application layer.

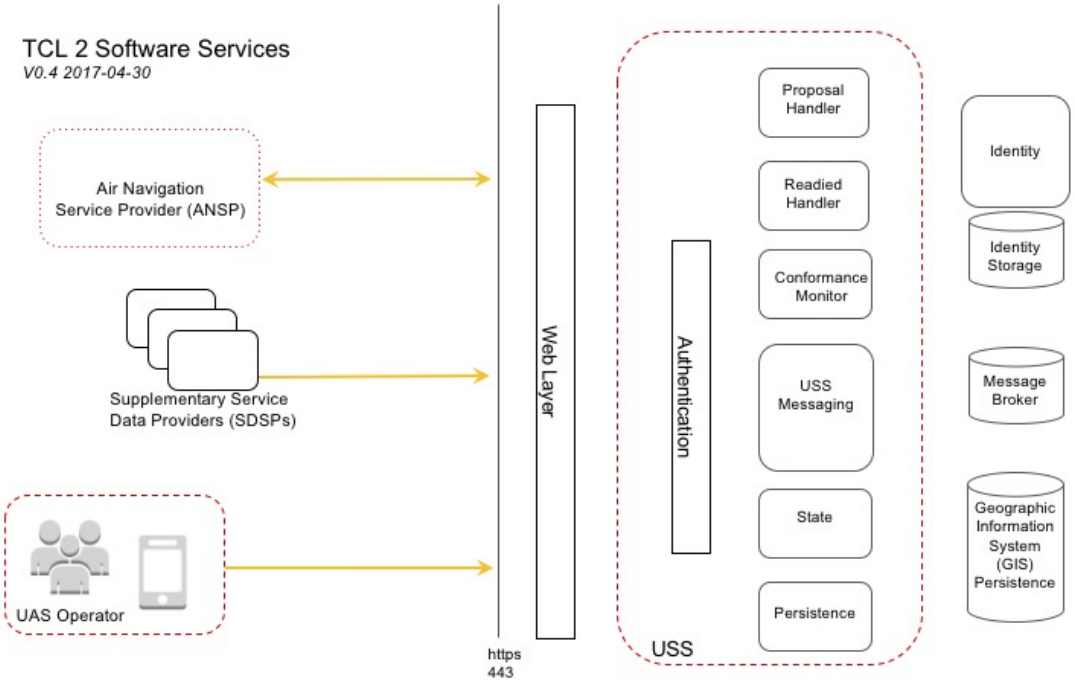

Figure 1: TCL 2 Software Services

3.1 Core Services

TCL 2 has two main services. These are the USS (also known as UTM Core), and the UAS Operator platform, which consists of the vehicle, the UAS Operator and the ground control station (GCS) software used by the UAS Operator.

The USS Identity service, implemented by local directory access protocol (LDAP) for TCL 2, stores the identities and credentials of its UAS Operators. Registration for TCL 2 is a manual out-of-band process. The USS Authentication component authenticates UAS Operators and authorizes them to services. It implements security roles which define privileges attached to

principals; one such role is the PRIORITY OP role that enables creation of priority operations such as UAS flown in support of emergency operations (e.g., firefighting or disaster response operations).

The USS Proposal Handler assists with planning of UAS operations such that they are strategically separated. The Proposal Handler decides if a proposed operation should be accepted or rejected. It checks that UAS operations do not intersect known constraints in the airspace such as controlled airspace and national parks. The Proposal Handler checks against Dynamic Constraints, that is constraints injected during runtime. A Dynamic Constraint can correspond to another operation, an override to an existing constraint, or the injection of a new airspace constraint. (In UTM, Dynamic Constraints are also called manager constraints.) The Proposal Handler also re-plans operations that are already flying. For TCL 2, when an Operator wishes to modify its volumes during flight, Proposal Handler evaluated whether those modifications will be accepted.

The USS Readied Handler rechecks accepted operations against possibly new, recently injected Dynamic Constraints.

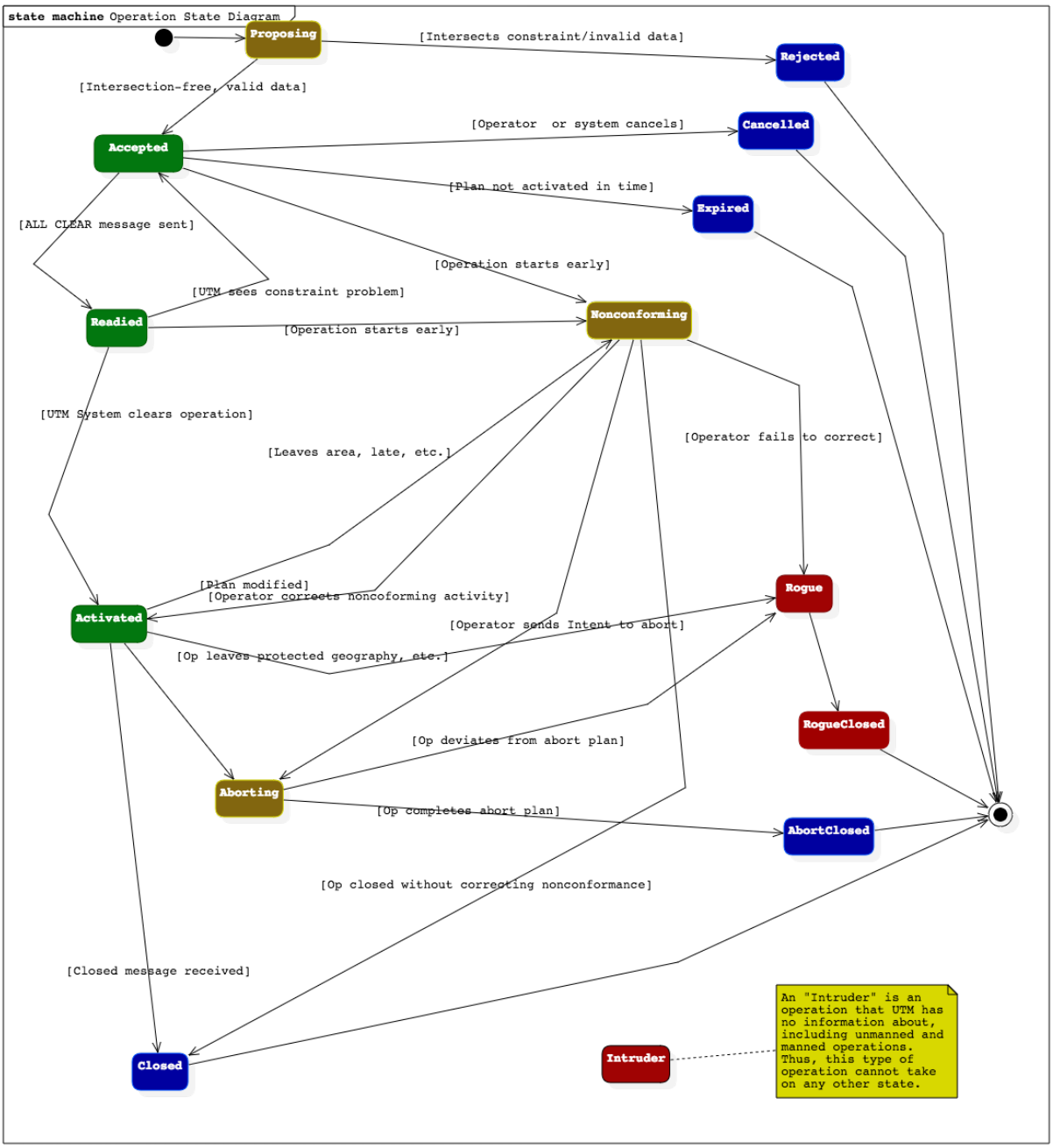

Figure 2: USS Operational State Diagram

Figure 2 graphs the USS data model of operational states. These states are tracked by the USS and are not directly modifiable by the UAS Operator. These states are updated based on information received from the UAS Operator, the state of other data in the system, rules and regulations, and other factors. Upon submittal, an operation is in the Proposing state and will subsequently move into either the Accepted or Rejected states. An Activated operation that leaves its volume is moved to the Nonconforming state, and if that off-nominal condition is not

rectified, USS moves it the Rogue state. As indicated, Rogue is a terminal state which cannot be rectified.

Figure 3 shows (abstracted in two dimensions) the data model for 4-dimensional (4-D) Operation Volumes. When a UAS Operator submits a flight geography, USS adds a conformance buffer and computes a conformance geography. The operation is expected to stay within the conformance geography at all times; a violation results in automated actions such as alerts. USS also computes its protected geography. Proposal Handler uses this geography for de-conflicting operation plans and constraints. Protected geographies from separate operations should never overlap in space and time.

The USS Conformance Monitor compares vehicle position reports against the 4-D volumes contained in the UAS Operator's operation plan. The Conformance Monitor issues alert messages when a vehicle leaves its conformance geography, and determines the operational state between conformance (within conformance geography), nonconformance (outside of conformance geography), rectification of nonconformance, and rogue (outside of protected geography). It also monitors aborting operations and propagates abort messages to nearby UAS operations. Conformance Manager is a key player in managing beyond visual line-of-sight (BVLOS) UAS operations.

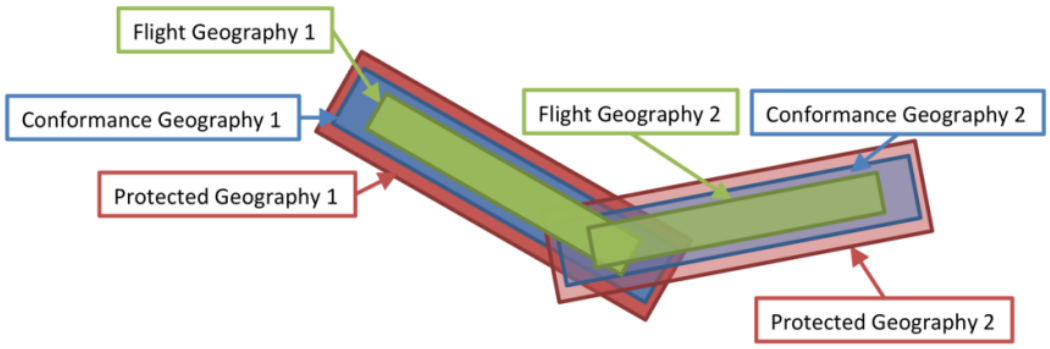

Figure 3: USS Operation Volume Model

The USS Messaging, USS Operational State and USS Persistence services support most other USS services. Messaging can alert or message UAS Operators of dynamic information relevant to UAS operations. The Simple (or Streaming) Text-Oriented Messaging Protocol (STOMP), implemented on top of WebSockets, allows for asynchronous messages to be pushed from USS to UAS Operators. These may be informational messages, safety-related messages, or any other type of text-based message. The Operational State and Persistence services together provide persistence. The State service defines Operation states and their transitions as shown in Figure 2 above. State also ensures consistency of operational state between persisted data and USS runtime. The Persistence service encapsulates access to the database.

3.2 Supplementary Data Provider Services (SDSPs)

UTM Software includes a set of SDSP implementations. SDSPs are accessed by the Proposal Handler, and other services, so that decisions are informed by dynamic environmental concerns such as weather. TCL 2 includes a set of external SDSPs for vehicle data, weather and conformance calculation. The interfaces to these services are described in the SwaggerHub dataProvider specification, as summarized in Table 1.

The Vehicle-Weather data provider takes as input the operation geography and vehicle data. It returns Weather Concerns derived by looking at vehicle capabilities with the current wind velocity. The Conformance Calculator data provider takes vehicle data and calculates a geographic buffer around the flight geography representing the conformance geography tuned by vehicle performance capability.

TCL 2 also includes a set of internally defined SDSPs for UAS Reports (UREPs) and Surveillance. In TCL 2, their definitions are integrated in the TCL 2 SwaggerHub specification; however, these are to be moved to an externally defined SDSP in the future.

3.3 System-Provided Services

As shown in the TCL 2 Software Service network diagram in Figure 1, some services are provided outside of the USS. The messaging system service is provided by the ActiveMQ Message Broker. A relational database is provided by PostgreSQL with a PostGIS library that supports Geographic Information Systems (GIS) functions. For TCL 2, LDAP provides secure storage of USS identities and their credentials.

4 Lost Hiker Example

The following example illustrates the operational context for multiple UTM operations in the same general airspace which the software must address. Five operations are flying in the same region near a public park; some operations are altitude-stratified (refer to Figure 4 and Figure 5 below). All UAS Operators are authenticated.

Traffic Monitor (GCS1) is a UAS with emergency supplies such as camera and basic medical first aid; today it is checking out road traffic. Because of its status as an emergency vehicle, GCS1 submits Traffic Monitor as a Priority Operation, while logged in to NASA USS (USS-nasa) with the Priority Op security role. Cell Tower Inspector (GCS2) is operating at an altitude of 200 feet above ground level (AGL). Forest Ranger (GCS3) is flying its daily awareness operation. Two news operations (GCS4 and GCS5) are recording a soccer match – they are sharing the airspace in an altitude-stratified configuration.

Then, Forest Ranger at GCS3 gets a call – a hiker is lost and needs medical supplies.

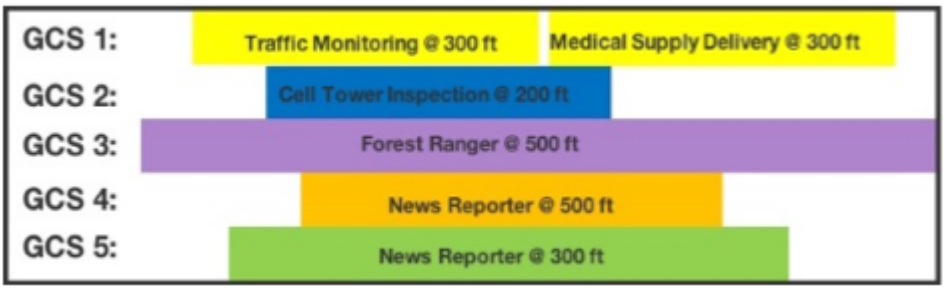

Figure 4: Lost Hiker Timeline

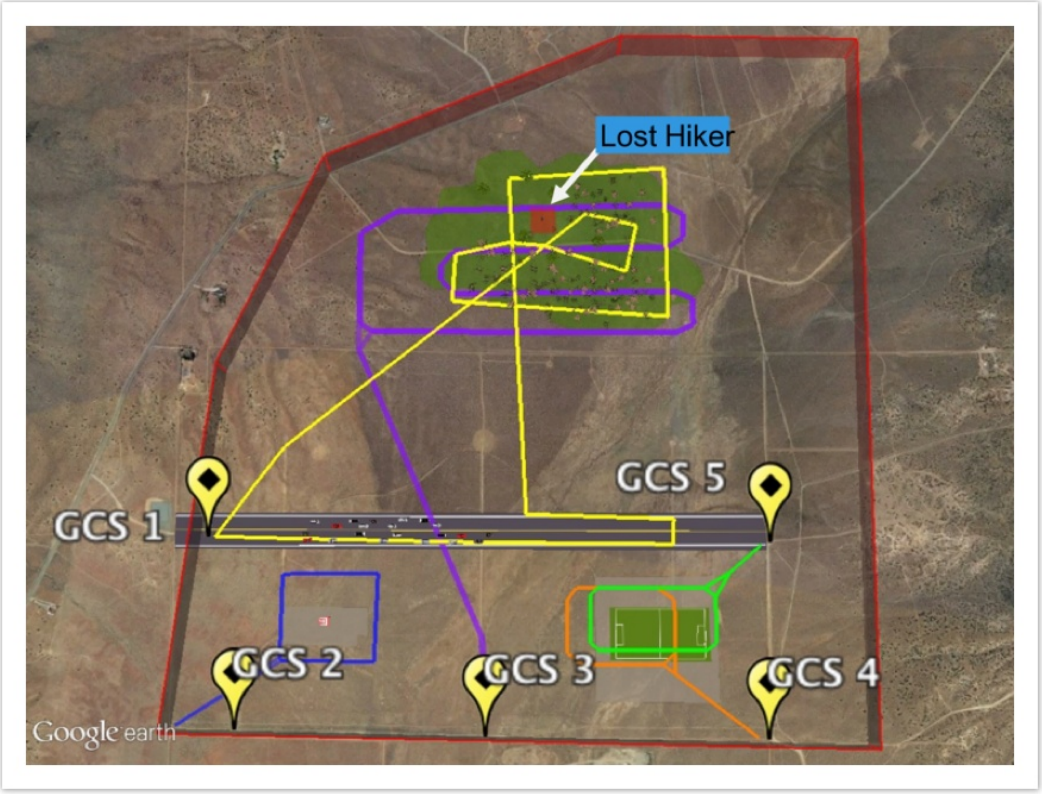

Figure 5: Lost Hiker Operations

Forest Ranger at GCS3 sends a message to Research Coordinator (RC): “Reporting a simulated lost hiker in park.” (In this context, the Research Coordinator is the "controller" for the TCL 2 simulation.) RC broadcasts this alert to all other UAS Operators, both flying and planned. Forest Ranger determines the approximate search area for the hiker and prepares an operation modification by creating a new volume set that is then is submitted to USS-nasa. The Traffic Monitoring UAS at GCS1 already has the needed medical supplies, and its operator submits an operation modification request to USS so it can assist with the lost hiker, and USS-nasa almost immediately approves the operation. Rerouting of UAS operations is in place, transforming Traffic Monitor to a Medical Supply operation. USS-nasa calculates that the Cell Tower Inspector (GCS2) is close to the Medical Supply operation (GCS1) and sends an “Emergency UA in proximity” message to GCS2, which then aborts its Cell Tower Inspector operation to avoid a conflict with the higher priority operation. Note that if another operation was flying nearby the Cell Tower Inspector operation, this "nearby neighbor" would have also received an alert message from USS-nasa. Meanwhile, the news reporter at GCS5 ("the nosy reporter") is

interested in viewing the lost hiker situation. GCS5 submits a new operation to USS-nasa; however, this operation request is rejected because it conflicts with the volumes of the higher priority GCS1 operation.

This example demonstrates authentication to USS (requirement UTM-318) and authorization as a Priority Operator (requirement UTM-1755), Operation Planning for simulated virtual aircraft (requirement UTM-328), altitude stratification (requirement UTM-1892), abort alerts for BVLOS (requirements UTM-2750 and UTM-1118), dynamic rerouting (requirement UTM-1894) and injection of additional constraints (requirement UTM-333)
In the example above, most of the operations were flying BVLOS. UTM software supports BVLOS by providing automatic alerts to nearby neighbors of an aborting operation (requirement UTM-1750, messaging). USS-nasa demonstrates planning capabilities by allowing Operators to submit, cancel and complete operations. In this example, operations can be flown in altitude-stratified configuration because the Operation Volume models allow partitioning of airspace by altitude as well as lateral distance.

5 List of TCL 2 Software Requirements

Table 1 contains TCL 2 software requirements in the form of a "user story". The format of a traditional requirement generally includes 1) ID, 2) title, 3) requirement statement and 4) rationale where the requirement statement usually includes one "shall" statement. However, in Agile processes, requirements are often stated as user stories. These stories don't use "shall" statements but instead combine the requirement statement and the rationale together in the form, "As a <role>, I want <goal or feature> so that I can get <some benefit>."

In the following table, top-level User Stories and are linked *from* the UTM System Requirements. In turn, top-level user stories are linked *to* their implementation in UTM's issue-tracking system. Furthermore, UTM's issue-tracking system maintains links to the UTM Software Configuration Management (SCM) code repository.

Table 2: TCL 2 Software Requirements in User Story Form

Key	Summary	Component/s	Linked Issues	Description
UTM-2000	UAS Operator wants to find USS matching Operational requirements	SDSP	UTM-1999, UTM-2003	As a UAS Operator (machine or human) I want to find USS services in the UTM ecosystem automatically and dynamically because my Operations have often-changing requirements that must match the USS capabilities. Solution: implementation planned for TCL 3
UTM-1904	Ensure access to resources is balanced and not overloaded	web-load-balancer		As a USS I want web layer load balancing and denial of service protection because I want my Operator community to be served USS resources fairly and promptly.

Key	Summary	Component/s	Linked Issues	Description
				Solution: nginx is used as a reverse proxy web server. It is not load balancing for TCL 2. Cloud deployment will include application and network load balancers managed by the cloud provider.
UTM-1897	UAS Operator software provides USS interaction	UAS Operator Software		As an Operator, I want to be able to interact with USS because I want to Cancel, Close, or otherwise change the state of my operation. Solution: A python client implemented for TCL2 allows commanding All clear, Cancel, Close, and Start tracking state changes. It also implements Save Plan and Load Plan.
UTM-1894	USS supports Operation Modification	USS		As a UAS Operator I want to modify operations so I can react to unplanned events. Solution: An active operation's volumes can be modified. This is done transactionally; if data is invalid or otherwise is disallowed, the volumes will not be changed.
UTM-1893	unique IDs for all UTM operations	USS		As a UTM stake holder I want unique IDs for all UTM operations to assure accuracy and consistency of all UTM data over its entire life-cycle, and across disparate vendors. Solution: Upon successful submission of an operation, USS generates it GUFI. This ID remains with the operation through all operational states, and terminal states. The GUFI is the key for all future data exchanges; it is also referenced (as a foreign key) by Positions, Messages and other data. UTM uses Version 4 of the UUID specification, thus 6 bits are reserved leaving 122 random

Key	Summary	Component/s	Linked Issues	Description
				bits. The large number of random bits allows high statistical confidence that duplicates will not be generated during the lifetime of most applications. Each operation has a unique identifier so that data exchanged throughout the National Airspace System related to a flight are unambiguously associated correctly. The data schema driving these changes in the FAA (and globally) is the Flight Information Exchange Model (FIXM).
UTM-1892	USS supports altitude stratified operations	USS		As a USS I want to support altitude stratified operations because I want to provide safe and efficient use of shared airspace. Solution: Multiple 4-d volumes are used to model an operation. Each volume has a minimum and maximum altitude. This model enables an operation to share vertical volume with other operations.
UTM-1755	USS supports Priority Operations	USS		As any UTM stakeholder, I want secure, authenticated Priority Operations because I want safety and security for my community. Solution: A security role associated with a user enables the user to create priority operations. During planning, this operation can 'bump' inactive operations. During active is-flying, a priority operation may cause other operations to be alerted to relinquish airspace.
UTM-1754	USS registers with FIMS to get identity.	USS		As a UTM stakeholder I want USS identities known and authenticated by FIMS because I want secure, safe and fair USSs.

Key	Summary	Component/s	Linked Issues	Description
				Solution: USS has capability to authenticate with FIMS using an identity managed by FIMS. The credential for this identity is securely stored by USS.
UTM-1753	USS receives alerts and notifications from FIMS.	USS		As a USS I want alerts and notifications from FIMS because I want situational awareness of possible safety, service quality and fairness issues. Solution: USS authenticates and connects with the FIMS async messaging mechanism. USS handles each message by inspecting its message type and, for alerts, its message severity.
UTM-1752	USS provides event specific data for analysis	USS		As a USS I want to provide event specific data for analysis because I want industry-government UTM collaboration that is evidence-based. Solution: USS persists all data exchanges between USS and its Operators. USS persists all data exchanges between USS and ANSP (FIMS).
UTM-1751	USS Service Quality	USS	UTM-428, UTM-461, UTM-588	As a USS I want high availability and data durability because I want my stakeholders to trust me to provide critical services and data. Solution: USS is deployed to a system that is synchronized with NIST time. USS data persistence is backed up and secure. Future deployments will increase data durability. USS uptime is monitored. Future deployments will provide one-nines uptime.
UTM-1750	USS shall be able to notify and alert UAS Operator	USS		As a USS, I want to be able to notify and alert Operators because I want to enable safety when Operators react to real-time events.

Key	Summary	Component/s	Linked Issues	Description
				Solution: USS to UAS Operator communication is implemented over a secure, async mechanism, WebSockets. Notifications and alerts messages are sent over this mechanism. UAS Operators are required to be always connected if at least one operation is active. USS offers 2 semantics for these channels: a user-specific queue which supports persistence, and a topic which only offers live data.
UTM-1749	USS Notifies FIMS	USS		As a USS I want to notify FIMS to ensure that FIMS and other USSs have situational awareness of my operations. Solution: USS implements the FIMS API, which includes POST Message. When USS is managing its Operations, and receives Operator-initiated alerts and notifications, it in turn messages FIMS if appropriate.
UTM-1465	Virtual Machine (VM) for TCL2 delivery	USS		As a USS I want to be deployable in a VM because I want to be scalable and portable. Solution: TCL 2 USS and system services are now built in a virtual machine. It may be imaged.
UTM-1157	USS re-evaluates operations upon new airspace constraints	USS State	UTM-1206, UTM-1200, UTM-1156, UTM-1203, UTM-1197, UTM-1196, UTM-1199, UTM-1198, UTM-1195	As a USS I want to e-evaluate operations when new airspace constraints are injected because I want to provide USS services that react to real time events. Solution: USS planner re-evaluates operational plans when new airspace constraints are injected. USS State moves operation to new state if needed, Messaging notifies of the change.

Key	Summary	Component/s	Linked Issues	Description
UTM-1118	USS supports ABORTING/ABORTED state	USS	UTM-1116, UTM-1119, UTM-1124, UTM-1076	As a USS I want to provide Abort services because I want to ensure safety under unplanned conditions. Solution: Conformance Monitor adds aborting ('T') and aborted ('B') states. Legal transitions have been added; intent to abort and intent to abort-close have been added; inform aborting and inform aborted have been added.
UTM-919	USS supports Rogue state for non-communication	USS	UTM-339, UTM-482, UTM-140, UTM-399	As a USS I want to provide Rogue state for non-communication because I want to ensure safety under unplanned conditions. Solution: For TCL2, if a non-conformant vehicle should be, but is not, sending position reports for a configurable prolonged time period (for example, 30 seconds) USS Conformance Manager changes operation state to Rogue and an alert is posted to the operation. Rogue is a terminal, non-recoverable state.
UTM-796	Monitoring USS health	SDSP	UTM-435	As a USS administrator, I want the ability to know the health of USSs over an endpoint because I typically do not have access to the server machine and endpoints are conveniently accessible from a browser. Solution: /utm-monitor/processes and /health endpoints return USS-nasa process status, which shows whether USS components are up or down, such as the database manager. The /sessions endpoint returns Async sessions that are active.
UTM-795	Operation Plan Definition	USS	UTM-329	As a UTM stakeholder, I want USS to accept operation plans

Key	Summary	Component/s	Linked Issues	Description
				containing properties such as requested airspace, desired start time, expected end time and UAS registration information because I want situational awareness and safety. Solution: Operation is modeled as an object identified by GUFI, with properties that associate it with an operator and a vehicle registration ID. An Operation contains a list of OperationVolumes that specify a list of 4-d volumes.
UTM-794	USS accepts surveillance data from external surveillance systems	USS	UTM-1029, UTM-1117, UTM-1039, UTM-788, UTM-1058, UTM-1038, UTM-1115, UTM-1037, UTM-1059, UTM-340, UTM-1054, UTM-1053, UTM-1111, UTM-1110, UTM-1074, UTM-1052, UTM-1040, UTM-1051	As a USS I want to accept surveillance data from external surveillance systems so I can react to events not tracked by USSs (such as intruder operations) and make informed decisions. Solution: The USS models surveillance regions and accepts Warning Regions submitted by surveillance providers.
UTM-787	USS supports Readied state transition	Readied Handler, USS	UTM-987	As a USS I want to have Readied state because I want to re-check an Accepted plan against constraints that may have been injected since the acceptance. Solution: Readied state added and ReadiedHandler is implemented. Moving directly from Accepted to Activated has been removed from valid transitions. All clear message now changes state from Accepted to Readied and begins

Key	Summary	Component/s	Linked Issues	Description
				ReadiedHandler. Works very similarly to ProposalHandler: calls Checkers and if no violations are found, moves state from Readied to Activated. If violations are found, a “Not Activated” message is sent with the violations and state is moved back to accepted. Not fully implemented for TCL 2.
UTM-566	USS supports UAS Reports (UREPs)	SDSP	UTM-1930, UTM-507, UTM-1918, UTM-567, UTM-1837	As a USS I want to consume UREPS because having immediate data from UAS Operators can inform my decisions. Solution: A UAS Report (UREP) is similar in function to a Pilot Weather Report (PIREP) or Position Report (AIREP) in the NAS. Presented and discussed an initial implementation of the UREP schema on Confluence (see link in ticket). Published UREP API and its data models on swagger hub. TCL2 implementation is an API in USS. Specified design for separating into SDSP for TCL3.
UTM-461	USS time sync with ANSP and Operators	USS	UTM-1751, UTM-588	As a USS I want time sync because I need to make accurate decisions when real time is compared to operational time when making planning and conformance decisions. Also, I need time sync to support some authentication schemes. Solution: NIST time service is provided by the operating system. Not fully automated for TCL 2.
UTM-338	USS recognizes operation as non-conforming	Conformance Monitor, USS	UTM-647, UTM-250, UTM-140, UTM-399	As a USS I want to recognize an operation as non-conforming when surveillance or report data indicates the operation does not conform its flight plan.

Key	Summary	Component/s	Linked Issues	Description
				Solution: Conformance Monitor (CM) consumes operations positions (the Point Geography) and compares it to 4-d volumes for time and geography. Conformance and Protected volumes are compared. If the maximum time period between position updates is greater than configurable threshold, or outside of Conformance geography, operation is moved to non-conformance state and alert is generated. This is a recoverable state. Non-recoverable state Rogue is also managed. CM detects and records operation non-conformances and sends alerts to the operation and, if in close proximity, to neighbors that are threatened. Categories are defined by AlertMessage type field as defined by the UAS Operator ICD.
UTM-333	USS transitions operation to activated state if no conflict or constraint conditions exist	Proposal Handler, USS	UTM-453	As a UAS Operator I want USS to transition readied operation to activated state if no conflict and constraint conditions exist because I need to responsibly use airspace. Solution: Proposal Handler plans operations. Input is Operation is proposed state. Decision determines accept or reject. In any case, UAS Operator is notified of decision. If rejected Operator decision reports detailed reasons for rejection. If accepted, Operation is moved to next state (Readied) and persisted.
UTM-328	USS allows Operator to submit, cancel and close operation	USS, USS State	UTM-396	As an Operator I want to submit, cancel and complete my operation because I need to responsibly use airspace.

Key	Summary	Component/s	Linked Issues	Description
				Solution: USS Operational States are implemented in application and database layer. Legal state transitions are enforced and support concurrency (are thread safe).
UTM-326	USS receives weather conditions	SDSP	UTM-5, UTM-274	As a USS I want to receive weather conditions because they inform my conformance planning decisions. Solution: Weather SDSP returns Weather Concerns derived by looking at vehicle capabilities with the current wind velocity.
UTM-318	USS authenticates and authorizes UAS Operation	USS		As any UTM stakeholder, I want USS to authenticate and authorize UAS Operators to guard against intentional or naive security attacks. Solution: The USS manages identities of its UAS Operators and assigns them credentials. (The registrar of these identities is a manual process.) USS manages roles that can be associated with Operators, which gives Operators privileges. The USS to Operator interface runs from a port that will not connect unless it can establish TLS encryption using server certificate. Most USS endpoints require authentication using the Operator credential. The USS API supports some anonymous endpoints which provides only public data. Nominally, an Operator is allowed to see only self-owned data.
UTM-125	USS automated system testing	USS	UTM-110	As a USS software stakeholder, I want automated USS system tests because they ensure deployed configuration and interactions with system-provided services (such as database and message brokers) are correct.

Key	Summary	Component/s	Linked Issues	Description
				Solution: UTM Testing Framework was implemented. It runs every 2 hours. It tests and validates tests through the API level, thus this framework is suitable for testing development, staged production and production, by changing the top-level URLs.

29 issues