Designation: F3548 − 21

Standard Specification for UAS Traffic Management (UTM) UAS Service Supplier (USS) Interoperability[1]

This standard is issued under the fixed designation F3548; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification is intended to be a global specification providing components that may be used to satisfy requirements expected to be common to many UTM-related regulations. This specification is not intended to comprehensively address all aspects of any particular UTM-related regulation or concept of operations. Similarly, because varying terminology for the same concept is frequently used across different regulations, readers should not expect an exact terminology consistency with any particular UTM-related regulation.

1.2 This version of the specification is focused on strategic aspects of UAS operations, including strategic conflict detection, aggregate conformance of operations to their operational intents, constraint awareness, and situational awareness in the event of nonconforming or contingent operations. The intention is that this specification will evolve to address increasingly complex strategic aspects of UAS operations and potentially certain tactical aspects of UAS operations.

1.3 This specification addresses the performance and interoperability requirements, including associated application programming interfaces (APIs), for a set of UTM roles performed by UAS Service Suppliers (USSs) in support of UAS operations.[2] Roles are groupings of one or more related UTM services. A competent authority may choose to use the roles defined in this specification in establishing the granularity of authorizations granted to a USS. The roles defined in this specification are:

(1) Strategic Coordination, comprising the Strategic Conflict Detection and Aggregate Operational Intent Conformance Monitoring services;

(2) Conformance Monitoring for Situational Awareness (CMSA);

(3) Constraint Management, comprising the Constraint Management service; and

(4) Constraint Processing, comprising the Constraint Processing service.

1.4 Section 4, Conceptual Overview, provides a description of each of the services and roles and includes further discussion on their scope.

1.5 A regulator may choose to require that a USS support a minimum or prescribed set of roles and services and may adopt terminology other than USS for a software system that provides something other than that minimum or prescribed set of roles and services. However, for purposes of this specification, a USS is a system that provides one or more of the UTM services defined in this specification.

1.6 A USS is not required by this specification to perform all roles or implement all defined services, providing business case flexibility for implementers. A typical USS that supports operators in the planning and execution of UAS operations may implement the Strategic Coordination, Constraint Processing, and CMSA roles. (Note that a USS providing CMSA for a UAS operation is required to also provide Strategic Coordination for the operation.) However, other implementations more limited in scope are possible. For example, a USS may implement only the Constraint Management role and be intended for use only by authorized constraint providers; or, a USS may implement only the Constraint Processing role to provide general airspace awareness to users independent of planning UAS flights. USSs may also provide additional, value-added capabilities and still be compliant with this specification as long as the value-added capabilities do not conflict with the services defined in this specification, and the implementation of services defined in this specification conforms to the applicable requirements.

1.7 A USS may also support other UTM roles such as Remote ID and airspace access (for example, the FAA's LAANC), specified in other documents.

1.8 This specification addresses aspects common to all roles and services, such as Discovery and Synchronization Services (DSS), security, auditing, and handling of off-nominal cases (for example, USS or DSS failures).

[1] This specification is under the jurisdiction of ASTM Committee F38 on Unmanned Aircraft Systems and is the direct responsibility of Subcommittee F38.02 on Flight Operations.

Current edition approved Dec. 1, 2021. Published March 2022. DOI: 10.1520/F3548-21.

[2] Many terms describe UTM and UAS Service Suppliers. For example, UTM is referred to as U-Space, and USSs are referred to as U-Space Service Providers (USSPs) in Europe. In the United Kingdom, UTM Service Providers (UTMSP) is used. In Japan, USSs are referred to as UAS Service Providers (UASSPs). Unless otherwise stated, the terms are interchangeable in this specification.

1.9 Additional services or enhancements to the current services will be added to subsequent versions of this specification. Appendix X2, Future Work Items, identifies a set of these items.

1.10 The safety case for this version of the specification, summarized in Appendix X4, is limited to strategic deconfliction, which is accomplished using the services provided by the Strategic Coordination role. This analysis does not constitute a full safety case for any particular operator or set of operations, which will have their own unique factors and variables. It does help operators understand, however, the contribution of using strategic deconfliction to their safety case and what the key variables are in increasing or decreasing the contribution. Using assumptions similar to those documented in Appendix X4, strategic deconfliction reduces the probability of midair collisions by approximately two to three orders of magnitude, with the rate of off-nominal events and participation being the key variables.

1.11 Of particular note, this version of this specification does not establish requirements for fairness or equitable airspace access among UAS operations, but instead includes requirements for the logging of information that will inform future requirements in this area.

1.12 *Usage:*

1.12.1 In a region where participating UAS operators voluntarily agree to or are required by the competent authority to comply with this specification, it enables strategically deconflicted UAS operations as well as situational awareness for operations that may not be required to be strategically deconflicted. This specification is not dependent upon the use of segregated or nonsegregated airspace.

1.12.2 For regions where this specification is required by a competent authority, this specification assumes regulations established by the competent authority (or its delegate) identify any prioritization of operations and whether or not strategic conflicts are allowed between operations of the same priority. For example, it may be legal in some jurisdictions for recreational operations to share airspace and have overlapping operational intents, relying on UAS personnel to coordinate and maintain visual separation; whereas in other jurisdictions, this may not be allowed. The specification takes no position on allowed or disallowed strategic conflicts. Instead it addresses requirements for when conflicts are allowed by regulations (for example, notifications to involved USSs and UAS personnel) and for when conflicts are not allowed (for example, replanning, inability to activate an operation with nonallowed conflicts).

1.12.3 This specification is not intended to address the complete safety case for air collision risk. It provides a mechanism to address one portion of a safety case, specifically the strategic separation of participating UAS from other participating UAS. Other technologies or procedures, outside the scope of this specification, may be required to mitigate air risk with nonparticipating aircraft and to address other aspects of a complete safety case for air collision risk.

1.12.4 Through the use of constraints, this specification also provides awareness of geographically and time-limited airspace information to USS, UAS personnel, or the operator's automation, or combinations thereof. In circumstances where a constraint is used to represent the volume within which a manned operation is planned, it provides a mechanism to address the strategic separation of participating UAS from the manned flight. However, USS responsibility is limited to providing awareness of constraints, and it is the responsibility of the UAS personnel to comply with any regulatory aspect of constraints.

1.13 *Applicability:*

1.13.1 This specification applies to operations conducted in a connected environment, meaning the UAS personnel have access to the USS (typically by means of the internet) and connectivity to the Unmanned Aircraft (UA). This specification anticipates and accommodates limited gaps in connectivity, but does not purport to address operations in locations where persistent connectivity is unavailable.

1.13.2 This specification does not purport to address tactical conflicts between UAS. Notifications and data sharing requirements in this specification associated with Strategic Conflict Detection and Conformance Monitoring for Situational Awareness may be useful in aiding some tactical conflict detection and dynamic rerouting capabilities. However, those capabilities are beyond the scope of this specification, and an implementation cannot assert compliance for tactical conflict detection or dynamic rerouting using this specification.

1.13.3 This specification does not purport to address conflicts between UAS and manned aircraft outside of instances where a manned operation is encapsulated in a constraint.

1.13.4 This specification does not purport to address authorization for UAS to operate in controlled or uncontrolled airspace.

1.13.5 This specification does not purport to address UAS that are not participating in UTM.

1.14 *Relationship to Other International UTM Standards and Specifications:*

1.14.1 It is an objective of this specification to be compatible with certain UTM specifications that address common subject matter and are developed under other standards development organizations (SDOs).

1.14.2 The existence of multiple specifications on the same subject matter can occur when the regulatory environment in a region requires that a necessary specification be developed by a particular SDO. In these cases, ASTM International seeks to establish a cooperation arrangement with the applicable SDO to ensure consistency between the related specifications.

1.14.3 This specification also seeks to support an international audience where differing regulatory requirements can exist. Where practical, this specification accommodates the differing requirements through a superset approach using a variety of techniques such as optional features and features that are configured to support a particular regulatory ruleset.

1.14.4 A summary of related specifications and the techniques used to achieve compatibility is provided in Appendix X3.

1.15 The values stated in SI units are to be regarded as standard.

1.15.1 Units of measurement included in this specification:

cm	centimeters
km	kilometers
m	meters
deg, °	degrees of latitude and longitude, compass direction
s	seconds
Hz	Hertz (frequency)
time	unless otherwise specified, formatted in accordance with IETF RFC 3339

1.16 *Table of Contents:*

1.17 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.18 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

F3060 Terminology for Aircraft

F3341 Terminology for Unmanned Aircraft Systems

F3411 Specification for Remote ID and Tracking

2.2 *EUROCAE Standard:*[4]

EUROCAE ED-269 Minimum Operational Performance Standard for UAS Geo-Fencing

2.3 *European Union (EU) Regulation:*[5]

GDPR General Data Protection Regulation

2.4 *IETC Standards:*[6]

IETF RFC 3339 Date and Time on the Internet: Timestamps[7]

IETF RFC 5905 Network Time Protocol Version 4: Protocol and Algorithms Specification[8]

IETF RFC 7519 JSON Web Token (JWT)[9]

2.5 *ISO/IEC Standards:*[10]

ISO/IEC 9001 Quality management systems — Requirements

ISO/IEC 27001 Information technology — Security techniques — Information security management systems — Requirements

2.6 *OAIC Document:*[11]

APPs The Australian Privacy Principles

3. Terminology

3.1 *Unique and Common Terminology:*

3.1.1 Terminology used in multiple ASTM UAS and aircraft-related standards is defined in F3341, UAS Terminology Standard, and F3060, Aircraft Terminology Standard. Terminology unique to this specification is defined in 3.2.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *3D volume, n*—a volume of airspace defined in terms of latitude, longitude, and altitude.

3.2.2 *4D volume, n*—a 3D volume plus a start and end time for the volume.

3.2.3 *Accepted, n*—one of the operational intent states. See 4.4 for more details.

3.2.4 *Activated, n*—one of the operational intent states. See 4.4 for more details.

3.2.5 *authorized constraint provider, n*—an organization or individual that has been granted the authority to create and manage constraints in a region by a competent authority.

3.2.6 *Aggregate Operational Intent Conformance Monitoring, n*—a USS service that monitors an operator's aggregate conformance with operational intents over time to ensure the target level of safety for strategic coordination is being met. Operators could also implement their own Aggregate Operational Intent Conformance Monitoring capability.

3.2.7 *coordinated operational intent, n*—an operational intent that has been coordinated with other relevant USSs to prevent disallowed conflicts. Operational intents are required to be coordinated prior to transitioning to the Accepted state

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from European Organisation for Civil Aviation Equipment (EUROCAE), 9-23 rue Paul Lafargue, "Le Triangle" building, 93200 Saint-Denis, France, https://www.eurocae.net/.

[5] Available from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0679.

[6] Available from IETF Administration LLC, 1000 N West Street, Suite 1200, Wilmington, DE 19801.

[7] Visit https://datatracker.ietf.org/doc/html/rfc3339.

[8] Visit https://tools.ietf.org/html/rfc5905.

[9] Visit https://tools.ietf.org/html/rfc7519.

[10] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[11] Available from Office of the Australian Information Commissioner, 175 Pitt Street, Sydney NSW 2000, Australia, https://www.oaic.gov.au/__data/assets/pdf_file/0006/2004/the-australian-privacy-principles.pdf.

and to the Activated state (including transitioning from the Nonconforming state back to the Activated state).

3.2.8 *conflict, n*—a situation where two operational intents intersect both in space and time. For operational intents to intersect both in space and time, at least one 4D volume from each operational intent must intersect. For two 4D volumes to intersect, the spatial dimensions of the 4D volumes must share at least one point and the start/end time range for the two 4D volumes must overlap.

3.2.9 *conformance, n*—a situation where a UA is flying according to its Activated operational intent. A UA flying inside of its Activated operational intent is in conformance. A UA flying outside of its Activated operational intent is nonconforming or contingent.

3.2.10 *Conformance Monitoring for Situational Awareness, n*—a USS role and service that determines whether a UA is in conformance with its operational intent on behalf of the operator or accepts self-reported conformance data from the UAS or operator. The service also initiates the sharing of situational awareness data with relevant USSs when nonconforming or contingent situations occur.

3.2.11 *Contingent, n*—one of the operational intent states. See 4.4 for more details.

3.2.12 *constraint, n*—one or more 4D volumes that inform USSs, UAS personnel, operator's automation systems, or other stakeholders, or combinations thereof, about specific geographically and time-limited airspace information. A constraint may restrict access to airspace for some or all operations, or it may be informational.

3.2.13 *constraint intersection, n*—a situation where an operational intent and a constraint overlap in both space and time. This is similar to operational intent conflicts, but *conflicts* is deliberately not used because a constraint may not restrict access to airspace.

3.2.14 *Constraint Management, n*—a USS service and role that supports the creation, modification, and deletion of constraints, as well as the dissemination of constraint information to other USSs.

3.2.15 *Constraint Processing, n*—a USS service and role that enables the USS to ingest constraint information and relay it to the UAS personnel, operator's automation systems, or other stakeholders, or combinations thereof, for applicable operations.

3.2.16 *discovery, n*—the process of determining the set of USSs with which data exchange is required for some UTM function; discovery is accomplished by means of the discovery and synchronization service (DSS).

3.2.17 *Discovery and Synchronization Service (DSS), n*—a service defined in this specification that enables USSs to discover other USSs with which data exchange is required and to ensure that USSs use current and consistent entity data.

3.2.18 *DSS instance, n*—for availability purposes, multiple synchronized copies of the DSS supporting a DSS region. Each copy is referred to as a DSS instance. USSs can interact with any DSS instance within a pool and switch over to any other instance in the event of a failure.

3.2.19 *DSS pool, n*—a synchronized set of DSS instances where operations may be performed on any instance with the same result, and information may be queried from any instance with the same result. A DSS region will often have a production DSS pool along with one or more test or staging DSS pools.

3.2.20 *DSS region, n*—the geographic area supported by a DSS pool.

3.2.21 *Ended, n*—one of the operational intent states. See 4.4 for more details.

3.2.22 *entity, n*—a generic term referring to types of data that need to be shared between USSs. This specification defines operational intent and constraint entities.

3.2.23 *entity reference, n*—limited information about an entity (including the approximate location and contact details for the managing USS) that is stored in the DSS and supports the discovery process.

3.2.24 *fail-safe, n*—denotes a situation where the failure of a system software or hardware component or interface does not result in an unsafe condition. Note that in a fail-safe situation, a loss of service may occur. (For example, operational intents cannot be activated if the associated USS is down.)

3.2.25 *lowest bound priority status, n*—a priority status value that is lower than the lowest priority bound defined by the regulator for the strategic conflict detection prioritization schema. For example, if the regulator assigns "0" as the lowest priority value for an operation that is subjected to strategic conflict detection prioritization, then a negative integer would be an acceptable value to assign as the *lowest bound priority status*.

3.2.26 *managing USS, n*—the USS responsible for an operational intent from creation (that is, successfully transitioned to the Accepted state) or a constraint, including activities such as making it discoverable through the DSS, providing associated details when requested by other relevant USSs, and making modifications. In the context of Conformance Monitoring for Situational Awareness, the managing USS monitors position reports and operator reports of nonconformance by means of approved methods.

3.2.27 *non-coordinated operational intent, n*—an operational intent that has not been coordinated with other relevant USSs and may contain disallowed conflicts. This situation occurs for operational intents with off-nominal 4D volumes.

3.2.28 *Nonconforming, n*—one of the operational intent states. See 4.4 for more details.

3.2.29 *off-nominal, adj*—in the context of this specification, refers to situations where an operational intent is in the Noncoforming or Contingent states.

3.2.30 *off-nominal 4D volumes, n*—4D volumes that characterize where and when a UA is expected to travel while it is off-nominal. Off-nominal 4D volumes may reflect a specific route of flight when known, or a broader area when a specific route of flight is not known.

3.2.31 *opaque version number (OVN), n*—unique value associated with a version of an entity, updated when the entity is modified. OVNs are used to ensure that USSs have the current version of entities.

3.2.32 *operational intent, n*—a volume-based representation of the intent for a UAS operation; comprises one or more overlapping or contiguous 4D volumes, where the start time for each volume is the earliest entry time, and the stop time for each volume is the latest exit time. Volumes are constructed based on the performance of the UAS and represent the airspace to which a UA must conform to a sufficient degree to achieve a target level of safety for strategic deconfliction. An operational intent's volumes normally indicate the intent for the operation in the Accepted and Activated states. However, an operational intent is supplemented with off-nominal 4D volumes when in the Nonconforming or Contingent states. Strictly speaking, off-nominal 4D volumes do not represent intent, but the underlying structure of operational intents (4D volumes) and the mechanisms for discovery and notification of relevant USSs and operations makes the operational intent a convenient vehicle for conveying the necessary information in off-nominal situations.

3.2.33 *operator, n*—the person or organization that applies for CAA approval to operate a UAS or who seeks operational approval for types of flight operations prohibited by a CAA for that UAS.

3.2.34 *operator's automation, n*—optional automation used by an operator to handle aspects of UAS operations during the preflight, in-flight, or postflight timeframe that otherwise would be performed by UAS personnel. The scope of functionality is operator-dependent. Operator's automation may interact with a USS instead of UAS personnel.

3.2.35 *position data, n*—information provided by a UAS that describes the location of an unmanned aircraft, including its latitude, longitude, altitude, and the time the unmanned aircraft was at the location.

3.2.36 *relevant operational intent, n*—an operational intent that overlaps or is in close proximity to another operational intent. Close proximity versus strict overlapping is included because the DSS defined in this specification does not determine intersection using the precise 3D extents of operational intents (or constraints), but instead using a coarser representation. The coarser representation results in actual intersections always being detected, but also in the occasional identification of operational intents that are merely close to each other. (This concept also applies to constraints.) The distance that qualifies as in close proximity is not fixed, but depends on the configuration of the DSS airspace representation. See Annex A2 for further detail.

3.2.37 *relevant USSs, n—(a)* USSs that manage operational intents or constraints, or both, that, due to their proximity, must be evaluated by the Strategic Conflict Detection or the Constraint Processing service, or both, of a USS attempting to create or modify an operational intent; *(b)* USSs that manage operational intents that, due to their proximity, are potentially affected by a Nonconforming or Contingent operational intent or a new or modified constraint; or, *(c)* a USS that has established a subscription for operational intents or constraints, or both, in an area where it may not yet manage operational intents.

3.2.38 *Strategic Conflict Detection, n*—a USS service that determines if an operational intent conflicts with other operational intents. The process of detecting conflicts by comparing operational intents. In contrast, tactical conflict detection generally relies on nonstrategic information such as current location, heading, and speed.

3.2.39 *Strategic Conflict Resolution, n*—the process of resolving conflicts through the modification of operational intents. Although there is no absolute time threshold, strategic conflict resolution requires sufficient time before the conflict to generate, coordinate, and implement the modification to the operational intent.

3.2.40 *Strategic Coordination, n*—a USS role comprising the Strategic Conflict Detection and Aggregate Operational Intent Conformance Monitoring services.

3.2.41 *Strategically Coordinated, adj*—refers to an operational intent that has been constructed with awareness of other relevant operational intents and has no disallowed conflicts.

3.2.42 *subscription, n*—a DSS mechanism that allows a USS to be notified and provided the details of any new, modified, or deleted entities in a specified area of interest defined by a 4D volume.

3.2.43 *UAS personnel, n*—refers to any personnel associated with a UAS operation, including the operator, the remote pilot in charge, and other personnel who may perform preflight, in-flight, or postflight activities. This generic reference to personnel is frequently used in order to avoid incorrect assumptions about the activities carried out by any particular role in an operator's organization.

3.2.44 *UAS Service Supplier (USS), n*—for purposes of this specification, a USS is an entity that provides one or more of the UTM services defined in this specification.

3.2.45 *UAS Traffic Management (UTM), n*—a federated set of services operated under regulatory oversight that support safe and compliant UAS operations.

3.2.46 *UAS Zone (alt. UAS Geographical Zone), n*—the terms used in EUROCAE ED-269, Minimum Operational Performance Standard for UAS Geo-Fencing, for what are defined as constraints in this specification. (From ED-269, *a UAS zone is an airspace of defined dimensions, above the land areas or territorial waters of a state, within which a particular restriction or condition for UAS flights applies.*)

3.2.47 *User notification, n*—information provided by a USS to UAS personnel or to an operator's automation system, or both. Because UAS-related concepts of operations can vary widely from operator to operator, this specification does not mandate a particular form for a user notification; possible implementations include messages or graphical indications through a user interface; text messages; email; and system to system messages.

3.2.48 *Unmanned Aircraft System (UAS), n*—composed of unmanned aircraft (UA) and all required on-board subsystems, payload, control station, other required off-board subsystems, any required launch and recovery equipment, all required crew members, and communication links.

3.2.49 *USS network, n*—the set of USSs operating collaboratively in a region.

3.2.50 *USS role, n*—a grouping of one or more USS Services. USS roles may be used by a competent authority to establish the granularity of authorizations that can be granted to a USS. Roles are also used within this specification to indicate services that should be provided together.

3.2.51 *USS service, n*—a UTM-related function performed by a USS.

3.3 *Acronyms and Abbreviations:*

3.3.1 *3D, adj*—three dimensional

3.3.2 *4D, adj*—four dimensional

3.3.3 *AFIT, n*—Air Force Institute of Technology

3.3.4 *AIRAC, n*—aeronautical information regulation and control

3.3.5 *ANSP, n*—air navigation service provider

3.3.6 *AOI, n*—area of interest

3.3.7 *API, n*—application programming interface

3.3.8 *BVLOS, adj*—beyond visual line of sight

3.3.9 *C2, n*—command and control

3.3.10 *CAA, n*—civil aviation authority

3.3.11 *CMSA, n*—conformance monitoring for situational awareness

3.3.12 *DAA, n*—detect and avoid

3.3.13 *DAR, n*—DSS airspace representation

3.3.14 *DSS, n*—discovery and synchronization service

3.3.15 *EMI, n*—electromagnetic interference

3.3.16 *FMEA, n*—failure modes and effects analysis

3.3.17 *FTE, n*—flight technical error

3.3.18 *ISMS, n*—information security management system

3.3.19 *LAANC, n*—low altitude authorization and notification capability

3.3.20 *MAC, n*—midair collision

3.3.21 *NSE, n*—navigation system error

3.3.22 *OIV, n*—operational intent volume

3.3.23 *OVN, n*—opaque version number

3.3.24 *PBN, n*—performance-based navigation

3.3.25 *PII, n*—personally identifiable information

3.3.26 *SDO, n*—standards development organization

3.3.27 *SMS, n*—safety management system

3.3.28 *TBO, n*—trajectory-based operations

3.3.29 *TLS, n*—target level of safety

3.3.30 *TSE, n*—total system error

3.3.31 *TTL, n*—time to live

3.3.32 *UA, n*—unmanned aircraft

3.3.33 *UAS, n*—unmanned aircraft system

3.3.34 *UASSP, n*—unmanned aircraft system service provider

3.3.35 *USS, n*—UAS service supplier

3.3.36 *USSP, n*—U-Space service provider

3.3.37 *UTM, n*—UAS traffic management

3.3.38 *UTMSP, n*—UTM service provider

3.3.39 *VLOS, adj*—visual line of sight

3.3.40 *YAML, n*—YAML ain't markup language

4. Conceptual Overview

4.1 This section provides a conceptual overview for the services defined in this specification. No requirements are provided in this section.

4.2 *Scope of Standard:*

4.2.1 The scope of this specification is delineated by the dotted purple box in Fig. 1. The four USS roles defined in this specification are identified by bold text: Strategic Coordination, Conformance Monitoring for Situational Awareness, Constraint Management, and Constraint Processing. A USS may support all or a subset of the roles.

4.2.2 The USS indicated by the central, blue rectangle in Fig. 1 contains three roles: Strategic Coordination, Conformance Monitoring for Situational Awareness, and Constraint Processing.

4.2.3 Strategic Coordination is composed of two services: Strategic Conflict Detection and Aggregate Operational Intent Conformance Monitoring.

4.2.4 Strategic Conflict Detection is used to compare operational intents to detect conflicts. It is used in the context of a flight planning or authorization service in which a USS discovers or is informed of relevant operational intents and attempts to construct a conflict-free route for a new or modified operational intent. (A planning or authorization service including conflict resolution is beyond the scope of this specification. Further, it is deliberate that Strategic Conflict Detection detects conflicts rather than resolves conflicts. The manner in which a USS finds a conflict-free route during planning or resolves a conflict that arises does not need to be prescribed and should allow for innovation. There will be cases where a conflict-free route cannot be found. During the preflight period, this results in some operations not being able to be accepted. During flight, this results in situations where tactical avoidance methods or some other form of arbitration are required. These are beyond the scope of this specification.)

4.2.5 Strategic Conflict Detection assumes certain regulations are established by the competent authority (or its delegate) that guide the evaluation and processing of conflicts. These regulations include the identification of priorities of operations and whether or not conflicts are allowed to exist within a given priority level. A lower priority operation must be planned not to conflict with a higher priority operation. Where conflicts are allowed within the same priority level, notifications are provided to the USSs and UAS personnel and/or the operator's automation for both UAS. Where conflicts are not allowed within the same priority level, the first-planned operation is given priority over subsequent operations.

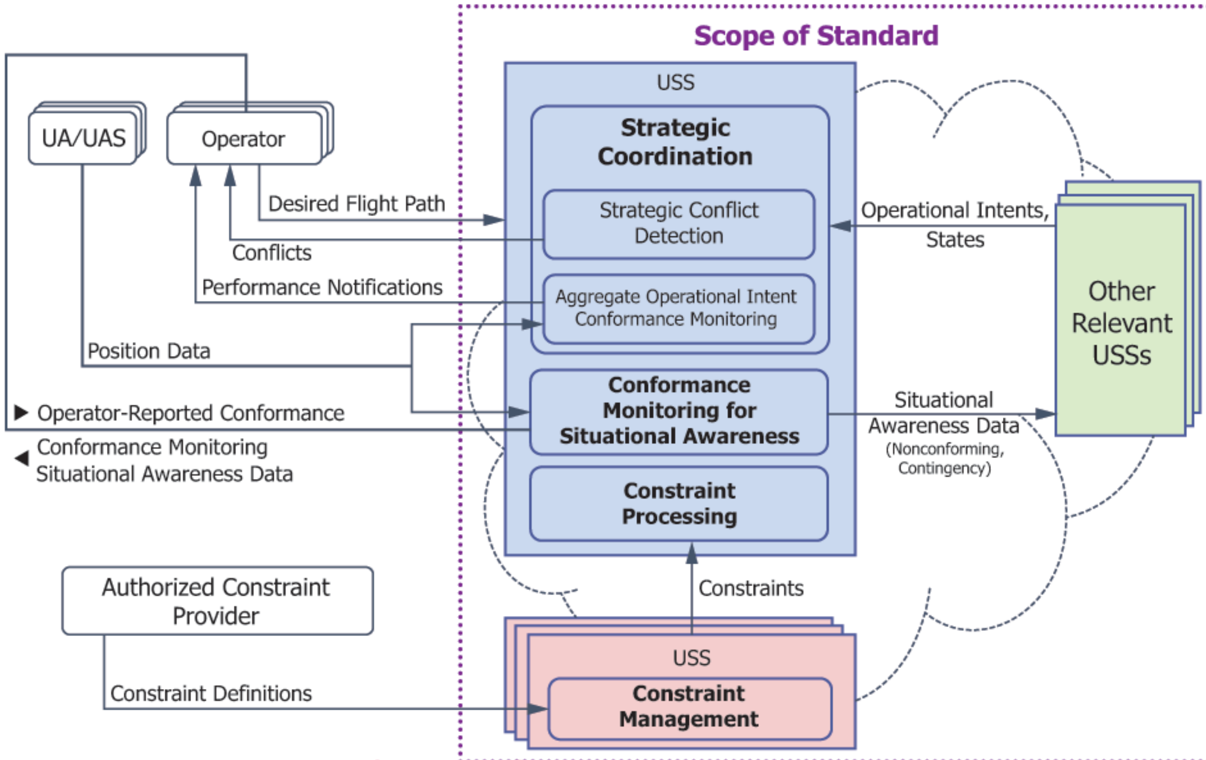

FIG. 1 Scope of Standard

4.2.6 When determining whether an operational intent is conflict free, Strategic Conflict Detection must consider other operational intents in the same vicinity. Some of the operational intents may be managed by other USSs referred to as *other relevant USSs* and denoted by the green box (upper right) in Fig. 1. The operational intents are discovered through a standardized service (the Discovery and Synchronization Service, or DSS), and relevant operational intents are shared through standardized APIs. Mechanisms are also provided in the standardized APIs and DSS to ensure that a USS has the current version of all relevant operational intents.

4.2.7 Aggregate Operational Intent Conformance Monitoring determines if operators are conforming with their operational intents over time. This verification is necessary to ensure that the target level of safety intended to be achieved through strategically deconflicting operational intents is being met. If an operator is chronically not in conformance, it could indicate a problem such as incorrect construction of the operational intents, incorrect characterization of UA performance characteristics, or an issue with some aspect of the operator's operating procedures. Performance notifications are provided to the operator when aggregate conformance is inadequate.

4.2.8 Conformance Monitoring for Situational Awareness is a role and service. Its primary function is to provide situational awareness to relevant USSs and UAS personnel or the operator's automation when a UA is not in conformance or has become contingent. This information can be used by a relevant USS for strategic planning purposes (for example, avoiding airspace where a contingent UA is located). In the future, CMSA may support ground-based tactical conflict avoidance capabilities, but in this version of this specification, any use of CMSA data for tactical purposes is beyond the scope of this specification, and the specification takes no position on the usefulness of the data for those purposes.

4.2.9 There are many possible methods to implement conformance monitoring to detect nonconformance that fall into one of two categories: USS-provided methods and operator-provided methods approved by the competent authority. This specification defines one USS-provided method based on monitoring of position reports from a UAS (position report-based detection of nonconformance). Additional USS-provided methods may be added to future versions of this specification. This specification also allows for the use of approved operator detection methods.

4.2.10 Detection of nonconformance based on position reports is accomplished by comparing ongoing position data for a UA in flight with the associated operational intent. Position data comes from the UAS. The absence of position data is also taken into consideration. If the position data indicate the UA is within the Activated operational intent, the operation is considered in conformance; if the position data indicates the UA is not within the Activated operational intent or is not received over a time threshold, the operation is considered nonconforming.

4.2.11 If an aircraft remains Nonconforming beyond a prescribed time threshold, the operational intent transitions to the Contingent state and cannot return to the Activated state. (States of operations are discussed in greater detail in 4.4.)

4.2.12 Approved methods for operator detection of nonconformance is acceptable and necessary in certain operational environments. For example, some operations may take place in an environment where the C2 link over which position information would normally be received is unavailable due to EMI or signal blocking (for example, an operation inside an electrical transmission tower, in a tunnel or pipe, or under a bridge). In such cases, visual confirmation of conformance combined with an appropriate operator interface to the USS to communicate conformance or nonconformance could be used. Alternatively, a UA may have approved onboard conformance monitoring capabilities as well as methods to mitigate nonconformance such as autonomous course correction or geofencing, or both, in combination with DAA. In such cases, the operator may only need to communicate failures of the onboard capabilities to the USS. This specification does not specify requirements for all possible operator detection of nonconformance methods or nonconformance mitigation capabilities, but does permit their use provided the operator obtains approval for the method from the competent authority.

4.2.13 Regardless of the method used to detect nonconformance to provide situational awareness to relevant USSs and operators, for both Nonconforming and Contingent cases, the managing USS is required to add off-nominal 4D volumes to the operational intent. Relevant USSs that have operational intents that conflict with or are in close proximity to the updated Nonconforming or Contingent operational intent are notified and can use the off-nominal 4D volumes to inform actions they deem necessary.

4.2.14 In addition, if position report data are available for a nonconforming or contingent UA, relevant USSs may request the data. (This data can only be requested by a relevant USS while the UA is nonconforming or contingent. In some cases, such as a failed C2 link, the position data will not be available.)

4.2.15 The third role shown in the large blue rectangle is Constraint Processing. It is a counterpart to the Constraint Management role shown in the red box at the bottom.

4.2.16 A constraint informs UAS personnel or the operator's automation, or both, about specific geographically and time-limited airspace information. The Constraint Management service allows an authorized constraint provider to create, modify, and delete constraints. (The specification supports one or more USSs performing the Constraint Management role in a region.) Once a constraint is created or modified and made discoverable through the DSS, the associated USS performing the Constraint Management role must also support requests from other relevant USSs for information about the constraint, as well as proactively send a notification to other USSs that have operational intents or subscriptions that intersect the new or modified constraint.

4.2.17 The Constraint Processing service in the central, blue rectangle represents the consumer side of constraints. There are two use cases for Constraint Processing. First, USSs ingest the constraints from the Constraint Management service so that intersections with operational intents can be detected, and the associated 4D information can be communicated to UAS personnel or the operator's automation, or both, to inform operational intent creation, modification, or deletion. Mechanisms are also provided in the standardized APIs and DSS to ensure that a USS has the current version of all relevant constraints. Second, a USS may ingest constraints strictly for the purpose of providing geo-awareness to interested parties.

4.2.18 To achieve interoperability, all interfaces contained in the dotted purple box denoting the scope of the standard are standardized and specified in this document. See Annex A2 and Annex A3 for additional details, including an overview of the interoperability paradigm comprising the DSS and USS peer-to-peer interfaces.

4.2.19 Interfaces that traverse the dotted purple box for communication with systems or people external to the scope of the standard are predominantly left to the discretion of the implementer. For example, this specification does not mandate a particular interface for how position data is received from an aircraft. However, the specification does levy requirements on these interfaces pertaining to basic function, security, and response times.

4.3 *Operational Intents and Off-Nominal 4D Volumes:*

4.3.1 An operational intent is a volume-based representation of a UAS flight used to define the airspace and time bounds intended to contain the flight. An operational intent comprises a set of one or more contiguous or overlapping 4D volumes that define the horizontal and vertical bounds of airspace and the corresponding volume start and end times (which correspond to the earliest entry time and latest exit time, respectively) to which the flight is intended to conform. Operational intents can represent diverse operations including, but not limited to, starting/stopping on the surface and starting/stopping in the air. Operational intents are key inputs to the Strategic Conflict Detection, Aggregate Operational Intent Conformance Monitoring, and CMSA services.

4.3.2 The use of a volume-based representation of UAS flights draws on the ICAO definition of strategic deconfliction as "a service consisting of the arrangement, negotiation and prioritization of intended operational volumes, routes or trajectories of UAS operations to minimize the likelihood of airborne conflicts between operations."[12] A volume-based approach has been widely used in international UTM research, trials, and live operations for several years. Benefits of this approach are discussed further below.

4.3.3 Operational intent 4D volumes are constructed based on the performance of the UAS and represent the airspace to which a UA must conform to a sufficient degree to achieve a target level of safety for strategic deconfliction. The performance of a UA can vary throughout the flight depending on what the UA is doing, such as taking off, operating at cruise altitude, hovering, or landing. The operator may also enhance the performance of the UA in certain locations through augmentations to the operational environment, such as the use of supplemental navigational aids to improve navigation performance. Consequently, the performance-based horizontal and vertical buffering may vary across the 4D volumes comprising an operational intent.

[12] *Unmanned Aircraft Systems Traffic Management (UTM) – A Common Framework with Core Principles for Global Harmonization*, Edition 3, ICAO, September 2020, p. 11, https://www.icao.int/safety/UA/Pages/UTM-Guidance.aspx, *and* https://www.icao.int/safety/UA/Documents/UTM%20Framework%20Edition%203.pdf.

4.3.4 The intention of this specification is that the volumes are constructed (both spatially and temporally) in accordance with the minimum dimensions and time values appropriate for the target level of safety. Volumes that are larger or occupy more time than necessary could adversely impact airspace efficiency.

4.3.5 Operational intents generally fall into one of two categories: area-based or trajectory-based; however, it is possible that one operational intent has both area-based and trajectory-based 4D volumes. An area-based operational intent does not require a desired flight path for the operation, whereas a trajectory-based operational intent does require one. Typically, an area-based operational intent comprises a single volume for the flight duration; however, it is not limited to a single volume. A trajectory-based operational intent consists of a series of volumes that follow the desired flight path and overlap in space and time. An example of an operational intent with both area-based and trajectory-based 4D volumes is an operation that initially proceeds along a trajectory-based segment, enters an area-based 4D volume, and then completes with another trajectory-based segment to the destination.

4.3.6 In order to provide an upper computational bound for operational intents, this specification limits their overall size based on the total number of vertices across the constituent 4D volumes. However, the number of 4D volumes used for an operational intent is not limited or prescribed based on factors such as distance or time in the volume. Implementations must balance the potential for false conflicts that can result from insufficiently granular operational intents with unnecessary computation than can result from overly granular operational intents.

4.3.7 An underlying assumption of trajectory-based operational intents or portions of operational intents is that the desired flight path is generally along the centerline of the volumes, whereas there is no such assumption for an area-based operational intent.

4.3.8 Operational intent boundaries are constructed to buffer the intended operation, whether a path or a volume, such that the aircraft stays within the operational intent boundary for, at least, a specified percentage of the flight time and exits the volume sufficiently infrequently. An example of how to construct and size operational intent boundaries is based on the Total System Error (TSE) of the UAS. For a trajectory-based operational intent, the lateral dimensions are based on the TSE from the centerline of the intended flight trajectory. UAS TSE is a combination of the Path Definition Error (PDE), Flight Technical Error (FTE), and Navigation System Error (NSE), as is illustrated in Fig. 2. Note that this example is similar to the TSE found in Performance Based Navigation (PBN); however, a key difference is that TSE in this standard is a preflight measure, whereas TSE is an in-flight, dynamic measure in PBN.

4.3.9 For UAS operations, the operational intent creation can be composed of errors associated with the ability of the Flight Management System (FMS) to follow a lateral path, environmental factors such as wind, or the ability of a human remote pilot to fly a predefined path or stay within a predefined area. However, the specific build-up of the operational intent size could be different for each UAS or use case, and can also vary by phase of flight (for example, cruise versus vertical ascent or descent versus hover). For an area-based operational intent, the lateral dimensions can be based on the TSE from the outer boundary of the intended flight volume. See Fig. 3 for a depiction of operational intents.

4.3.10 The vertical dimensions of an operational intent can also be based on TSE; however, the vertical TSE is an abstraction of the lateral TSE construction from PBN. The vertical TSE is a function of the ability of the FMS to fly a vertical profile, the accuracy of the altitude sensing equipment, any errors associated with the definition of the vertical profile, and ground elevation uncertainty if the desired altitude references the surface.

4.3.11 The time component of an operational intent is a buffer applied to the entry and exit times of each volume to ensure that the aircraft is contained in at least one volume with the specified performance. The buffer should reflect errors that would result in timing inaccuracies, such as those caused by wind uncertainty and departure time uncertainty, among other factors.

4.3.12 The operational intent creation can include uncertainty associated with path definition, georeferencing error, FMSs, altitude and positioning systems, remote pilot proficiency, departure timing, and weather conditions, if applicable to the specific operation.

4.3.13 Buffering 4D volume-based on the performance of the UA provides significant benefits to operators and the UTM ecosystem. Operators can take advantage of investments in high performance UAs or supplementary navigation aids, or both, in the operational environment, safely allowing more closely spaced operations or varying the required spacing by

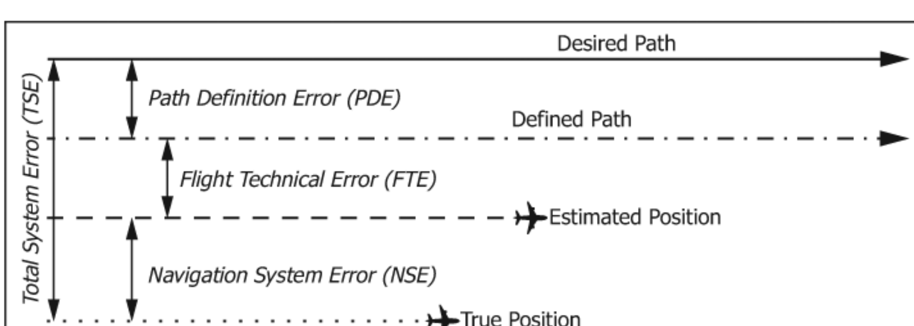

FIG. 2 Derivation of Total System Error

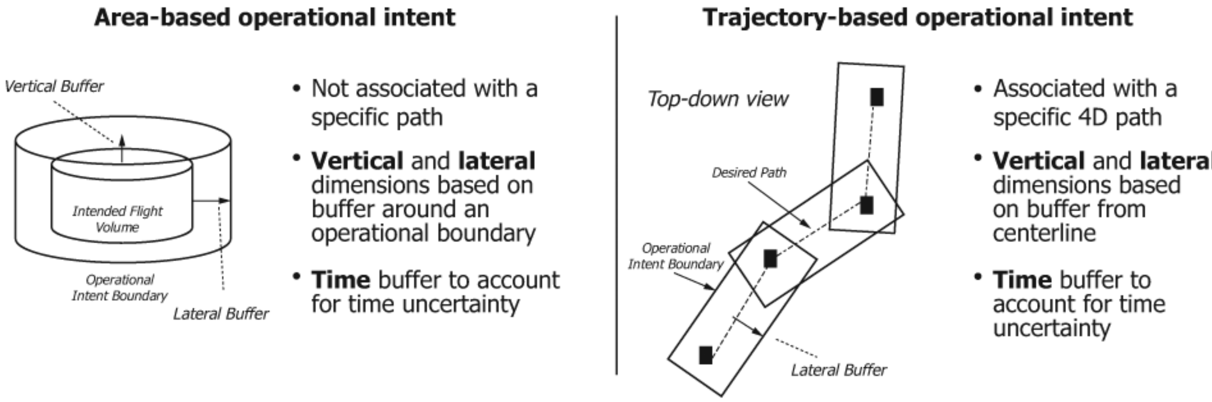

FIG. 3 Operational Intents

phase of flight. This can be critical in certain high-density areas and benefits all operators by making more efficient use of the available airspace.

4.3.14 Another benefit of sharing volume-based operational intents is that only the USS that creates the operational intent is required to have a detailed understanding of the UA performance characteristics and an operator's operational environment. That understanding is reflected in the shared operational intent, allowing every participating USS to have a consistent understanding of an operation and properly consider it in services such as Strategic Conflict Detection. Alternative approaches, such as sharing information analogous to a traditional flight plan and having each USS produce the operational intent, requires every USS to have a detailed and consistent understanding of the performance of every UAS and every operator's operational environment. If all USSs cannot keep pace with this diversity, it can result in some degree of least common denominator logic that prevents an operator from exploiting the performance of a UA or their operational environment, or both, and reduces the overall efficiency of the UTM ecosystem.

4.3.15 Sharing volume-based operational intents also means only the USS that creates it must bear the associated computational load. In addition, operational intents enable straightforward and computationally efficient conflict detection.

4.3.16 Operational intents are supplemented with one or more off-nominal 4D volumes if the operational intent enters the Nonconforming or Contingent states. The intention is that these 4D volumes confidently encompass where a UAS is expected to or may travel during off-nominal situations with minimal consumption of airspace. They can and should be updated to reflect an evolving off-nominal situation.

4.3.17 Off-nominal 4D volumes do not represent actual intent as operators, generally speaking, would never intend for their operations to be Nonconforming or Contingent. Rather, these 4D volumes are used to convey what is actually happening, to the extent possible, in off-nominal situations. They provide the basis for situational awareness for relevant USS and UAS personnel and/or the operator's automation. Associating this information with the operational intent conveniently provides the discovery, notification, and data-sharing mechanisms that are necessary when off-nominal situations arise.

4.3.18 The composition of off-nominal 4D volumes is not precisely prescribed in this specification, and the nature of an off-nominal situation affects the precision with which they can be composed. For example, in a nonconforming situation from which recovery is expected, a single, relatively small 4D volume may be sufficient to bound where the UA is expected to travel until it reestablishes conformance with the operational intent. In some contingency situations, the UA may fly a well-understood route or simply execute a quick landing as part of a contingency procedure, and that route can be characterized relatively precisely with a set of one or more 4D volumes. In other contingency situations, control of the UA may have been lost and the best that can be done is to characterize the remaining range of the UA.

4.3.19 As the density of UAS operations increase over time, it will become increasingly important that off-nominal 4D volumes accurately reflect impacted airspace as much as possible both to minimize disruptions to other operations and to contain the scope of any necessary replanning. For this version of this specification, precision is encouraged; however, the key requirement is that off-nominal 4D volumes encompass where the UAS may travel.

4.4 *Operational Intent States:*

4.4.1 To specify data exchange requirements for USSs to enable the Strategic Conflict Detection and Conformance Monitoring services, this specification uses certain operational intent states. Each operational intent managed by a USS will have a single state at any given time. Data exchange requirements differ depending on the current state of the operational intent.

4.4.2 Operational intent states correspond to nominal or off-nominal circumstances. A key principle is that operational intents in nominal states must be coordinated, meaning they are constructed with awareness of other operations and constraints in the vicinity and have no disallowed conflicts. Operational intents in off-nominal states (Nonconforming or Contingent) are not required to be coordinated and are referred to as non-coordinated operational intents. Coordination is not required in off-nominal states because the need is to communicate to other USSs what is actually happening with the UA. If a UA is able to recover from nonconformance, it must reestablish conformance to a coordinated operational intent to reenter a nominal state. (This can be the operational intent in effect prior to nonconformance, or an updated but coordinated operational intent.)

4.4.3 Fig. 4 depicts the operational intent states and allowed transitions between states.

4.4.4 The operational intent states are described as follows:

4.4.4.1 *Accepted (nominal)*—This state is set by the USS when the operational intent is created, strategically coordinated, and made available to be shared with relevant USSs. The USS must have received and evaluated the latest airspace information prior to accepting an operational intent.

4.4.4.2 *Activated (nominal)*—To enter this state, UAS personnel or the operator's automation communicates to the managing USS their intent to commence flight operations within the coordinated operational intent. This state indicates that the UAS is within one or more of the operational intent 4D volumes, but may or may not be in flight. An action on the part of UAS personnel or the operator's automation, or UA movement, which may be detected automatically, must occur for the USS to transition the operational intent state from Accepted to Activated.

4.4.4.3 *Nonconforming (off-nominal)*—This state results from the UA being outside the coordinated operational intent while in the Activated state or upon an attempt to activate the operational intent early, late, or with the UA outside the operational intent. To provide situational awareness, off-nominal 4D volumes are added to the operational intent. Off-nominal 4D volumes are created irrespective of any resulting disallowed conflicts, and the resulting operational intent is non-coordinated. Relevant USSs that have operational intents that conflict with or are in close proximity to the non-coordinated operational intent are informed. While the UA is nonconforming, current position data can also be shared with other relevant USSs if available and requested. Other USSs are required to plan around both the nominal and off-nominal volumes of this operational intent. If the expanded operational intent overlaps an existing operation, it is the responsibility of UAS personnel or the operator's automation for the overlapped operation to take actions it deems necessary. This may include replanning to strategically deconflict or performing tactical deconfliction. The operational intent may return to the Activated state, but only after reestablishing a coordinated operational intent, meaning off-nominal 4D volumes have been removed and the UA is in conformance with the operational intent. Transitions between the Activated and Nonconforming states are automatically performed by the USS.

4.4.4.4 *Contingent (off-nominal)*—Entering the Contingent state occurs when a UA can no longer conform to an Activated operational intent. There are mutiple ways an operational intent can transition to the Contingent state, including manual initiation by UAS personnel (could occur from the Accepted, Activated, or Nonconforming states); automated initiation by the operator's automation; automated mechanisms such as the USS determining based on equipment status that control of the UA has been lost; or, as a last resort, automatically when a UA remains in the Nonconforming state beyond a defined time-out period. (A transition to the Contingent state may also be required if a tactical avoidance maneuver cannot be accommodated within the current operational intent and a conflict-free update to the operational intent cannot be devised.) To provide

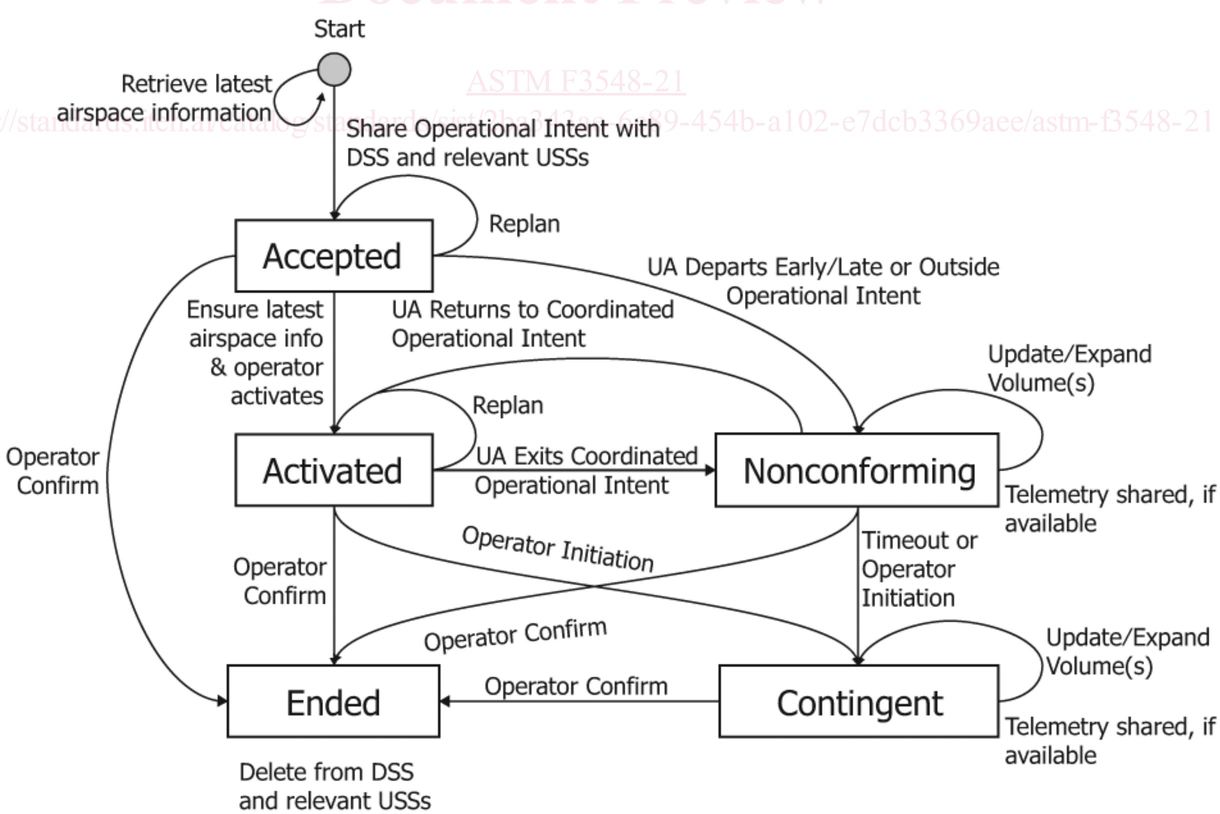

FIG. 4 Operational Intent States Transition Diagram

situational awareness, current operational intent volumes are replaced with one or more off-nominal 4D volumes. (Because an operational intent cannot return from the Contingent state to the Activated state, only off-nominal 4D volumes are appropriate in the Contingent state.). Relevant USSs are notified of the resulting non-coordinated operational intent. While the UA is in the Contingent state, current position data can also be shared with other relevant USSs if available and requested. The Contingent state is a terminal state from which the operation can only transition to the Ended state.

4.4.4.5 *Ended*—This state indicates the UAS is no longer using or will not use the operational intent. Action on the part of USS personnel or the operator's automation, or the USS, which may be automated, must occur to end the operation. When an operational intent is ended, the managing USS must delete the operational intent from the UTM system. Details about operational intents in the ended state are not communicated between USSs.

4.4.5 Figs. 5-7 illustrate representative nominal and off-nominal scenarios, including the resulting progressions through the operational intent states and the use of coordinated versus non-coordinated operational intents.

4.4.6 Fig. 5 illustrates two coordinated operational intents that do not conflict and remain nominal throughout both flights.

4.4.7 The solid line through the center of each operational intent is intended to convey that the UAs in both cases proceed along the intended route of flight, remaining in conformance throughout. Coordinated operational intents are used for the entirety of both flights. The state transition sequence for both operational intents is Accepted > Activated > Ended.

4.4.8 Fig. 6 illustrates the scenario where a UA temporarily goes out of conformance (off-nominal) but is able to correct the situation and return to a nominal state.

4.4.9 At point 1, the UA exits Operational Intent A and is transitioned to the Nonconforming state. The managing USS adds an off-nominal 4D volume to the operational intent (represented by the yellow rectangle) that encompasses the anticipated area of nonconformance. The expected route back to conformance is indicated by the dashed, yellow line. This update to Operational Intent A is non-coordinated and results in a conflict with Operational Intent B. At point 2, because Operational Intent B is in close proximity to Operational Intent A, its managing USS is notified of Operational Intent A's nonconformance. Detecting the conflict, the managing USS for Operational Intent B takes actions it deems necessary and can request position information for Operational Intent A to assist in the process. (Position data may or may not be available.) At point 3, the UA reestablishes conformance with the original operational intent. The managing USS for Operational Intent A can now remove the off-nominal 4D volume (the yellow rectangle) and reestablish a coordinated operational intent, allowing Operational Intent A to return to the nominal Activated state. The managing USS for Operational Intent B is notified of the state change for Operational Intent A and can determine through the 4D volumes that it no longer conflicts with Operational Intent B.

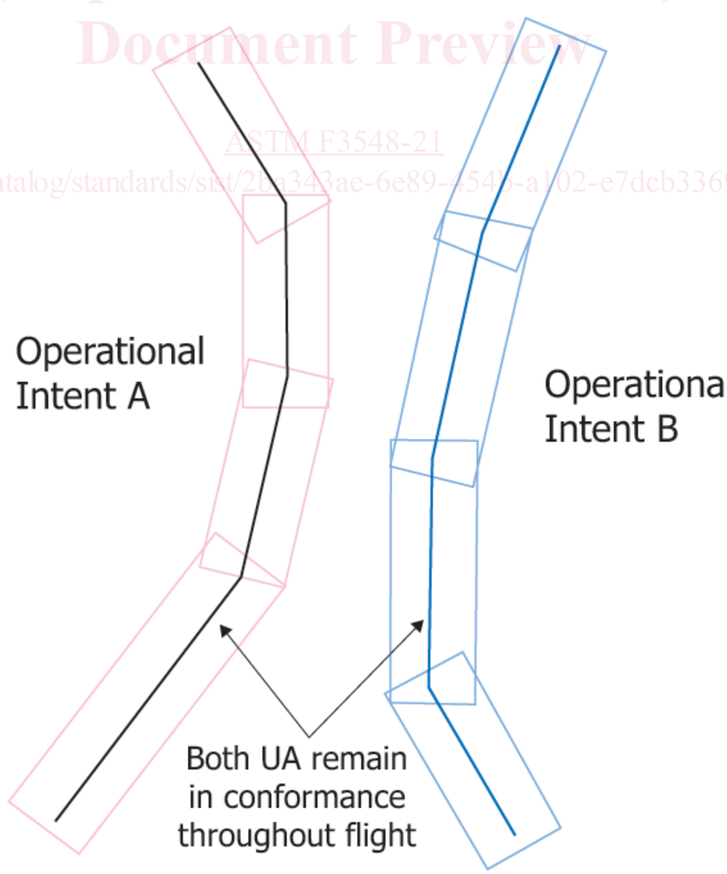

FIG. 5 Nominal, Coordinated Operational Intents

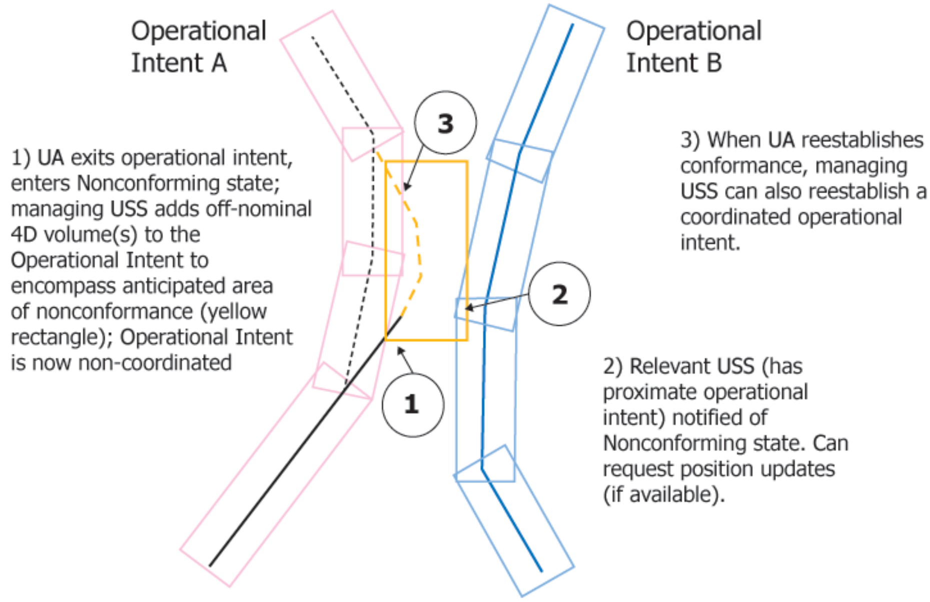

FIG. 6 Off-Nominal Operational Intent, Temporary Nonconformance

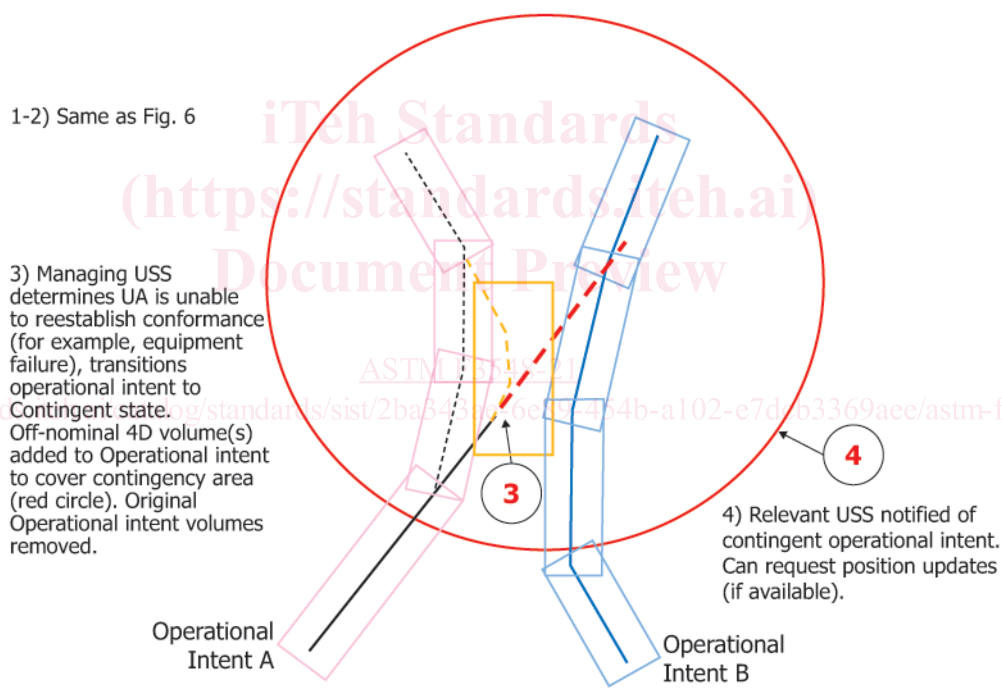

FIG. 7 Off-Nominal Operational Intent, Contingent State

4.4.10 In this scenario, the state transition sequence for Operational Intent A is Accepted > Activated > Nonconforming > Activated > Ended.

4.4.11 Fig. 7 illustrates the scenario where a UA goes out of conformance and is unable to reestablish conformance within the required period of time, resulting in a further transition to the Contingent state.

4.4.12 This scenario begins the same as in Fig. 6 with the managing USS detecting nonconformance for Operational Intent A. An off-nominal 4D volume is added to the operational intent to characterize the anticipated area of nonconformance (yellow rectangle), and the managing USS for Operational Intent B is notified. However, due to some failure, the UA is unable to fly the route that would reestablish conformance and continues along the red dashed line. This introduces an alternate point 3, where the USS recognizes the UA failure or is notified by UAS personnel or the operator's automation and transitions Operational Intent A to the Contingent state. The managing USS for operational intent A removes the original 4D volumes (since the operational intent cannot return to a nominal state) as well as the off-nominal 4D volume added for nonconformance (yellow rectangle), and replaces them with one or more off-nominal 4D volumes that cover where the UA is expected to travel (in this case, a single 4D volume, the red