OGC Testbed-13

Geospatial Taxonomies ER

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Chapter 1. Summary

This Engineering Report (ER) documents the Geospatial Taxonomy research activities conducted by the Aviation (AVI) subthread of the Cross Community Interoperability (CCI) thread in OGC Testbed 13. One of the critical factors in the overall usability of services - and System Wide Information Management (SWIM) enabled services in particular - is the ability of a service to be discovered. The ability of a service to be discovered is assured by providing a uniformly interpretable set of service metadata that can be accessed by a service consumer through a retrieval mechanism (e.g., a service registry). Such a set of metadata (commonly referred to as a service description) has been defined by Federal Aviation Administration (FAA) and European Organization for the Safety of Air Navigation (EUROCONTROL) and formalized in a Service Description Conceptual Model (SDCM) [2].

The SDCM is currently used in standard service description documents and service registries by both FAA and EUROCONTROL. As part of the effort of enhancing service discovery, both organizations also use a number of categories that can be associated with all services and are generally referred to as taxonomies. The current set of taxonomies used by both EUROCONTROL and FAA categorizes (i.e., meta tags) services based on their availability status, interface model, data product, etc. However, despite the increasing role of OGC services in the SWIM environment, no taxonomies for categorizing services based on geographical coverage or other geospatial characteristics have been defined. This ER documents the work conducted as part of Testbed 13 CCI thread and AVI subthread to identify and classify SWIM-enabled Service Oriented Architecture (SOA) services with geographical taxonomies and the integration thereof into SDCM [2].

1.1. Requirements

The following requirements are to be addressed in this ER:

1. Develop a concept of geospatial taxonomies that will efficiently support classification of services based on their geospatial characteristics (e.g., geographical coverage). The concept should take into account all relevant geospatial characteristics, such as nation states, flight information regions, and airspace classifications.
2. Provide considerations for modifications of the SDCM to support the use of geospatial taxonomies.
3. Produce one or more taxonomies in formats suitable for use by software clients (e.g., Extensible Markup Language (XML) and Resource Description Framework (RDF)).

1.2. Key Findings and Prior-After Comparison

The topic of geosemantics and taxonomies for aviation has been explored previously in OGC Testbed 12 (OGC 16-039) and in other domains in depth. In past demonstrations, analyses recommended the use of run-time registries and complex use cases for service discovery and data taxonomy/ontology, but this assumes that the information contained within those services incorporate OWS Context Specification and/or Geography Markup Language (GML) such as the Aeronautical Information Exchange Model (AIXM). However, much of the information exchanged within the FAA National Airspace System (NAS) System-Wide Information Management (SWIM) network is made up of various data models which do not conform with OGC OWS Context specifications. For example, the FAA Traffic Flow Management System (TFMS) and SWIM Terminal Data Distribution System (STDDS) data models contain an XML format which contain geography data (e.g., Lat/Lon coordinates) but do not contain OGC OWS Context data elements or GML.

Another observation is that the current FAA SWIM registry is a design-time registry and does not use the OGC Catalog Service for Web (CSW) [OGC 12-168r6]. While this could potentially change with the anticipated release of FAA Common Support Services (CSS) such as CSS-Aeronautical Information Management (AIM), CSs-Weather (Wx), and CSS-Flight Data (FD), the current direction for the FAA NAS Service Registry Repository (NSRR) is to enhance the current registry search capabilities by creating semantic taxonomies which can be used to categorize services for improved service discovery. These services must have a standard taxonomy in order to incorporate geospatial metadata to enable the discovery of geospatial services. One approach is to define and apply commonly accepted terminology through the use of international definitions at the International Civil Aviation Organization (ICAO) level and national definitions at the FAA level, and so on. Through hierarchical categorization, other nation states may also develop their own national or regional level taxonomies which can be mapped to the international taxonomy for commonality across multi-national domains.

The goal of this ER is to formulate a taxonomy that can incorporate geospatial characteristics identified within a data set into the service metadata and integrate it with SDCM to enable geospatial service discovery in the current registry. Future work areas include a proposed concept for a geospatial identification service using WPS to analyze a dataset and identify geographic characteristics according to a set of taxonomy inputs resulting in a metadata document which can be included in SDCM.

1.3. What does this ER mean for the Working Group and OGC in general

This engineering report documents the concepts of geospatial taxonomies that will efficiently support classification of services based on their geospatial characteristics such as geographical coverage for nation states, flight information regions, and airspace classifications. Thus, the considerations include the use of SDCM and required modifications to support taxonomies developed as part of this activity. The chosen working group for review of this ER is the Geosemantics Domain Working Group (DWG). This work may also be applicable to the Aviation DWG which is co-sponsored by the FAA and EUROCONTROL.

The scope of the Geosemantics DWG is any aspect of conceptual modeling and formal representation of geospatial knowledge which advances the geospatial interoperability mission of OGC. A particular focus will be the adoption or development of tools and methods in support of these activities. It is the mission of the Geosemantics DWG to establish an interoperable and actionable semantic framework for representing the geospatial knowledge domains of information communities as well as mediating between them. This ER will address the need for geospatial taxonomies using aviation-specific geographical conventions (i.e., named boundaries). The use of geospatial semantics will enable better descriptions of services, including OGC web services in the FAA’s SWIM registry as well as in OGC catalogue services.

1.4. Document contributor contact points

All questions regarding this document should be directed to the editor or the contributors:

Table 1. Contacts

Name	Organization
Charles Chen	Skymantics

1.5. Future Work

The solutions described in this engineering report may provide further insights if implemented as a greater solution for service registries such as the OGC Catalogue Service. Furthermore, implementation of the recommendations for SDCM will provide a path forward for prototyping and implementation of SWIM registries and discovery of services containing geographical characteristics as described by the taxonomies contained herein.

1.6. Foreword

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

Chapter 2. References

The following normative documents are referenced in this document.

NOTE: Only normative standards are referenced here, e.g. OGC, ISO or other SDO standards. All other references are listed in the bibliography.

- FAA, Service Description Conceptual Model (SDCM), Version 2.0 [http://swim.aero/sdcm/2.0.0/sdcm-2.0.0.html]
- FAA Semantics.aero [http://www.semantics.aero/]
- Registry Integration Module [http://www.swim.aero/rim/]
- OGC 06-121r9, OGC Web Services Common Standard, Version 2.0 [http://portal.opengeospatial.org/files/?artifact_id=38867]
- FAA, NAS Service Registry and Repository [https://nsrr.faa.gov/]
- FAA Web Service Description Ontological Model (WSDOM) - an Introduction [https://www.faa.gov/nextgen/programs/swim/governance/servicesemantics/media/FAA%20WSDOM%20Introduction.pdf]
- OGC 16-039, OGC Testbed-12 Aviation Semantics Engineering Report [http://docs.opengeospatial.org/per/16-039.html]
- OGC 12-168r6 OGC Catalogue Services 3.0 [http://docs.opengeospatial.org/is/12-168r6/12-168r6.html]

Chapter 3. Terms and definitions

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard OGC 06-121r9 [https://portal.opengeospatial.org/files/?artifact_id=38867&version=2] shall apply. In addition, the following terms and definitions apply.

3.1. Semantics

```
A conceptualization of the implied meaning of information that requires words and/or
symbols within a usage context.
```

3.2. Service Description

```
The information needed in order to use, or consider using, a service.
```

3.3. Service-Oriented Architecture (SOA)

```
A paradigm for organizing and utilizing distributed capabilities that may be under the
control of different ownership domains. A SOA provides a uniform means to offer,
discover, interact with, and use capabilities to produce desired effects consistent
with measurable preconditions and expectations.
```

3.4. Registry

```
An enabling infrastructure that uses a formal registration process to store, catalog,
and manage metadata relevant to a service. A registry supports the search,
identification, and understanding of resources, as well as query capabilities.
```

3.5. System Wide Information Management (SWIM)

```
A concept using Service Oriented Architecture to facility the exchange Air Traffic
Management information amongst stakeholders in the aviation domain such as Air
Navigation Service Providers, airports, and airspace users.
```

3.6. Taxonomy

```
A system or controlled list of values by which to categorize or classify objects.
```

3.7. Web Service

```
A platform-independent, loosely-coupled software component designed to support
interoperable machine-to-machine interaction over a network. It has an interface
described in a machine-processable format. Other systems interact with the Web service
in a manner prescribed by its description by means of XML-based messages conveyed
using Internet transport protocols in conjunction with other Web-related standards.
```

Chapter 4. Abbreviated Terms

- ATM Air Traffic Management
- ICAO International Civil Aviation Organization
- FAA Federal Aviation Administration (United States)
- NAS National Airspace System (United States)
- NSRR NAS Service Registry and Repository
- OWL Web Ontology Language (W3C)
- OWL-S Web Ontology Language for Services (W3C)
- OWS OGC Web Service
- RDF Resource Description Framework (W3C)
- RDFS Resource Description Framework Schema (W3C)
- SDCM Service Description Conceptual Model
- SOA Service Oriented Architecture
- SWIM System Wide Information Management
- WSDOM Web Service Description Ontological Model

Chapter 5. Overview

The approach in this ER activity for developing the geospatial taxonomies begins with classification of known geospatial concepts. The International Civil Aviation Organization (ICAO) manages the administration and governance of 191 member states to reach consensus on international civil aviation standards and practices. It is important to assess the status quo for ICAO taxonomies by considering the geography of nation state boundaries, flight information regions, and airspace allocations to determine how data services can be identified and discovered by its users. Once the status quo is determined, additional taxonomies may be generated to fill the gaps where certain geospatial characteristics associated to services may be defined and used for service discovery.

This report identifies existing taxonomies defined at the international, national, and regional levels. Once these taxonomies have been defined, integration of the taxonomies in the Service Description Conceptual Model with existing taxonomies can be associated for better registry discovery. Metadata within a service description is the responsibility of the service provider. However, this ER provides recommendations on geospatial service methodologies which can assist in the metadata descriptions for web service descriptions and better service discovery with the FAA SWIM registry.

5.1. Requirements

The following requirements are associated with this engineering report

1. Develop a concept of geospatial taxonomies that will efficiently support classification of services based on their geospatial characteristics (e.g., geographical coverage). The concept should take into account all relevant geospatial characteristics, such as nation states, flight information regions, and airspace classifications.
2. Provide considerations for modifications of the SDCM to support the use of geospatial taxonomies.
3. Produce one or more taxonomies in formats suitable for use by software clients (e.g., XML, RDF).

5.2. Solutions

The following sections have been identified as part of the research conducted for this report:

- **Section 6.1 Taxonomy Methodology** identifies the status quo which identifies three common taxonomies developed for SWIM services.
- **Section 6.2 ICAO Airspace Classifications** describes the current ICAO requirements for Air Traffic Control Services based on airspace classifications.
- **Section 6.3 FAA Airspace Classifications** describes the FAA airspace classification methodology. These classifications are categorized into a taxonomy in Appendix A.1 Airspace Classification Taxonomy.
- **Section 6.4 ICAO Regions** describes the list of current ICAO regions. These regions are categorized into a taxonomy in Appendix A.2 ICAO Regions Taxonomy.
- **Section 6.5 ICAO Flight Information Regions** describes the list of current ICAO Flight

Information Regions (FIR). These FIRs are better categorized into a taxonomy based on the FIRs for a particular nation.

- **Section 6.6 Area Control Centers** describes the list of FAA Air Route Traffic Control Centers (ARTCC). These ARTCCs are categorized into a taxonomy in Appendix A.3 US Flight Information Regions Taxonomy.
- **Section 6.7 Airways** describes the classification methodology of U.S. Airways, which are categorized into a taxonomy in Appendix A.4 Airways Taxonomy.

The taxonomies developed for this engineering report activity are recorded in Taxonomies.

Chapter 6. Taxonomy Methodology

The methodology for geospatial taxonomies begins by analyzing the various geospatial characteristics of aviation data used for identifying airspace geographies. Most airspace users identify airspaces based on naming conventions defined by ICAO such as ICAO regions, flight information regions, and air traffic control centers. By determining the naming conventions for these airspaces and their associated areas of governance, services that contain these data types can be tagged with associated metadata to assist in discovery of relevant data.

Information discovery using this method is not intended to replace advanced search and discovery of data using a run-time registry or web service based search using OGC web service interfaces such as CSW or Web Feature Services (WFS). Rather, this method complements the advanced capabilities of CSW and WFS. Much of the information accessible via SWIM does not conform to the international data model standards of AIXM, Weather Information Exchange Model (WXXM), and Flight Information Exchange Model (FIXM), and therefore is not geospatially discoverable using OGC registry methods. Overhauling all data on SWIM is not feasible considering the number of operational users. Therefore, for those data types which are not discoverable based on geospatial information, this engineering report analyzes the semantics for geospatial taxonomies such that metadata can be annotated on the service descriptions contained within the SWIM registry.

6.1. Status Quo

The FAA and SESAR have jointly developed several (SCR) semantic artifacts including common taxonomies (http://www.semantics.aero/). These taxonomies include:

- Service Product (http://www.semantics.aero/service-product)
- Service Availability Status (http://www.semantics.aero/availability-status)
- Service Interface Type (http://www.semantics.aero/interface-type)

As an example, these taxonomies above can be visualized in Figure 1 below.

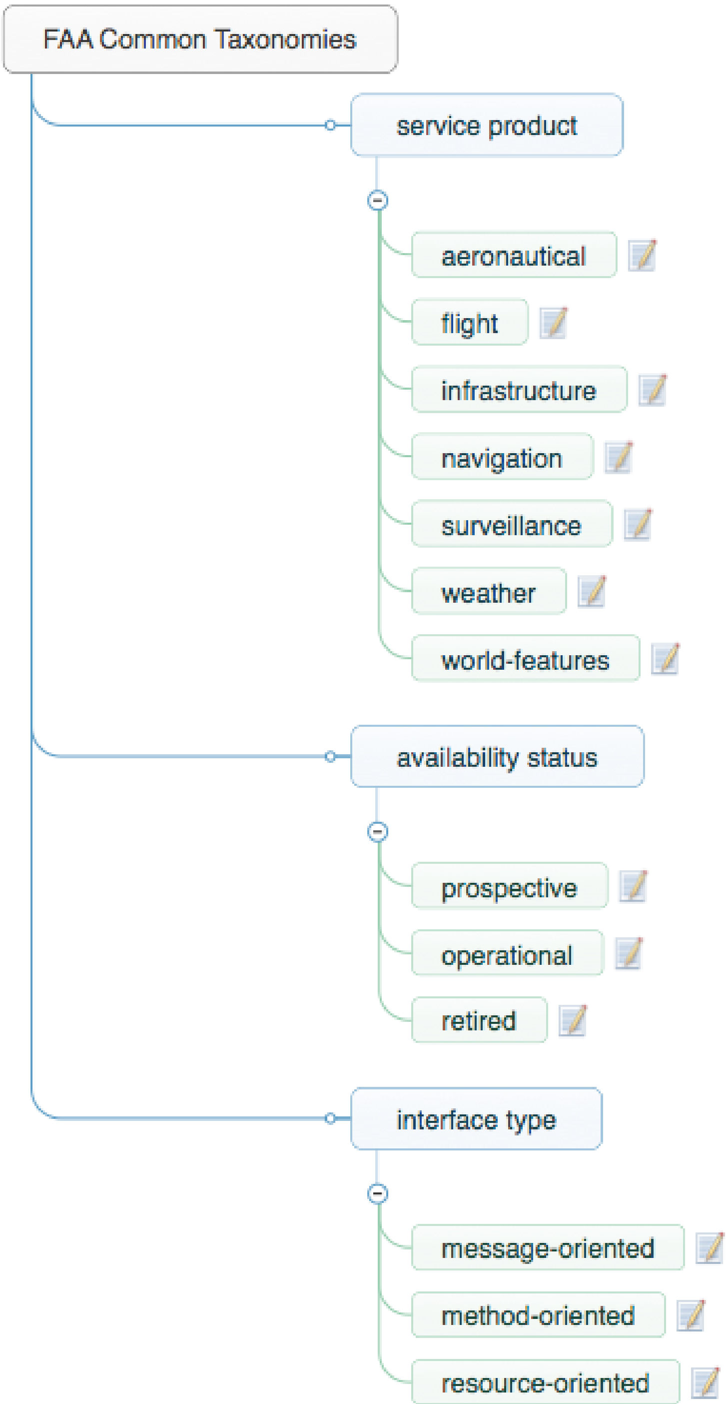

Figure 1. SWIM Common Taxonomies

These taxonomies, written in Web Ontology Language (OWL) and RDF, provide the basis for taxonomy representation for geospatial taxonomies defined in this engineering report.

6.2. ICAO Airspace Classifications

ICAO classifies airspace in an alphabetical format (e.g., Class A, B, C, D, E, F, & G). These classes are defined based on separation, altitude, ATC services, aircraft speeds, and communication methods. Generally, airspace classifications depend on concepts of aircraft separation, air traffic control clearance, traffic information (aircraft intent and hazards), and flight rules. Figure 2 is an excerpt from the ICAO Annex 11, Appendix 4 which provides a list of defined airspace classifications. It should be noted that not all nations follow the ICAO methodology for airspace classifications.

APPENDIX 4. ATS AIRSPACE CLASSES — SERVICES PROVIDED AND FLIGHT REQUIREMENTS

(Chapter 2, 2.6 refers)

Class	*Type of flight*	*Separation provided*	*Service provided*	*Speed limitation**	*Radio communication requirement*	*Subject to an ATC clearance*
A	IFR only	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
B	IFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
C	IFR	IFR from IFR IFR from VFR	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	VFR from IFR	1) Air traffic control service for separation from IFR; 2) VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
D	IFR	IFR from IFR	Air traffic control service, traffic information about VFR flights (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
E	IFR	IFR from IFR	Air traffic control service and, as far as practical, traffic information about VFR flights	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
	VFR	Nil	Traffic information as far as practical	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No
G	IFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No

* When the height of the transition altitude is lower than 3 050 m (10 000 ft) AMSL, FL 100 should be used in lieu of 10 000 ft.

Figure 2. Excerpt of ICAO Annex 11, Appendix 4

6.3. FAA Airspace Classifications

Airspace classifications in the U.S. use a modified version of the ICAO Airspace classification rules. These classifications often refer to Air Traffic Management flight rules based on an aircraft's navigational equipage and classified as Instrument Flight Rules (IFR) and Visual Flight Rules (VFR). For VFR flights, navigation must typically remain at a lower altitude and separation and landing maneuvers are made using human visual cues. In IFR operations, aircraft must be equipped with sufficient navigational equipment such as radar, altimeter, etc. such that the pilot can maneuver aircraft and maintain separation from other aircraft using minimal or sometimes no visual cues (e.g. through fog).

Figure 3 provides a visual representation of the types of airspace classifications used in the U.S. [1]:

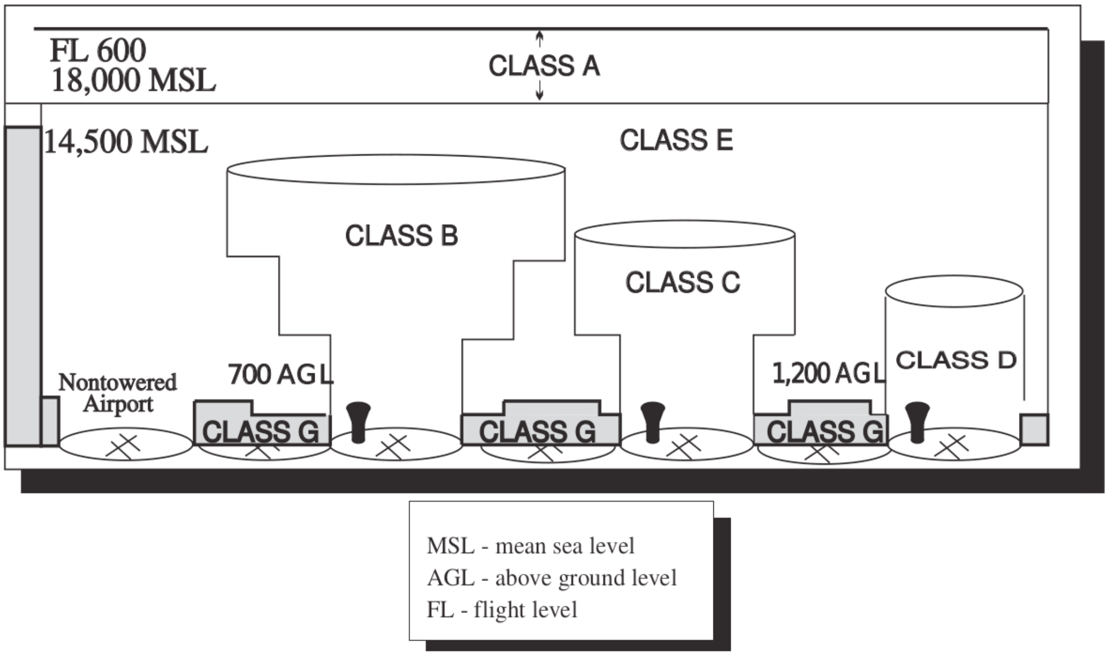

Figure 3. Airspace Classes in the United States

Figure 4 provides a description for each Airspace class in the U.S.

Airspace			Flight Visibility	Distance from Clouds
Class A			Not applicable	Not applicable
Class B			3 statute miles	Clear of clouds
Class C			3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
Class D			3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
Class E	At or above 10,000 feet MSL		5 statute miles	1,000 feet above 1,000 feet below 1 statute mile horizontal
	Less than 10,000 feet MSL		3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
Class G	1,200 feet or less above the surface (regardless of MSL altitude).	Day, except as provided in section 91.155(b)	1 statute mile	Clear of clouds
		Night, except as provided in section 91.155(b)	3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
	More than 1,200 feet above the surface but less than 10,000 feet MSL.	Day	1 statute mile	1,000 feet above 500 feet below 2,000 feet horizontal
		Night	3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
	More than 1,200 feet above the surface and at or above 10,000 feet MSL.		5 statute miles	1,000 feet above 1,000 feet below 1 statute mile horizontal

Figure 4. Airspace Classification

Source: https://www.faasafety.gov/gslac/ALC/course_content.aspx?cID=42&sID=505&preview=true

Class A Airspace is from 18,000 feet Mean Sea Level (MSL) up to and including Flight Level (FL) 600. This includes airspace up to 12 nautical miles off the coast of the contiguous United States and Alaska. Any space beyond the 12 nautical miles off the coast line is considered international airspace. Domestic radio navigational signal and ATC radar coverage is required to be considered Class A airspace. All aircraft must fly under IFR in Class A airspace.

Class B Airspace is bounded from the surface to 18,000 feet MSL surrounding major airports. The volume of airspace for Class B is designed based on the surface area of the airport and the volume of terminal airspace controlled by the airport or terminal air traffic control center. All aircraft require ATC clearance to operate within this airspace. ATC manages separation of aircraft. VFR operation may be flown if a cloud clearance is provided by ATC. Class B aeronautical charts contain geographical fixes which correlate to appropriate frequencies in which aircraft must obtain ATC clearance before entering the airspace. Currently, 12 airports have Class B airspace. A list of Class B airspaces for FAA based on airports are provided in Airports and Facilities.

Class C Airspace is bounded from the surface of the airport to 4,000 feet MSL. The first layer of the airspace is from the surface area to the ceiling boundary with 5 nautical miles radius. The second layer is from 1,200 feet MSL to the ceiling at a 10-mile radius. The outer layer extends to 20 nautical miles radius. Class C airspace surrounds airports containing regular commercial traffic of 100 passengers per flight or more. Class C airspaces contain an operational tower, radar-controlled approach system, and a minimum number of IFR approaches per year.

Class D Airspace is bounded from the surface of an airport to 2,500 feet MSL. The outer boundary radius varies but is typically 4 nautical miles. Class D airspace is classified as any airport with a functional control tower with minimal IFR approaches. The airspace reverts to Class E or G during hours when the tower is closed or under special conditions.

Class E Airspace is controlled airspace that is neither A, B, C, or D. this airspace extends from 1,200 feet Above Ground Level (AGL) up to 18,000 feet MSL. Some areas as low as 700 AGL are included and are notated in sectional charts. Most of the airspace in the United States is class E.

Class F Airspace is not used in the U.S. ICAO defines Class F airspace as a hybrid of Class E and G airspace in which ATC separation guidance is available but not required for IFR operation.

Class G Airspace includes all airspace below 14,500 feet MSL which is not otherwise classified or controlled. Class G airspace is considered uncontrolled airspace.

Special Activity Airspace (or Special Use Airspace) refers to airspace which can be designated for a given geospatial volume for reasons such as national security, public events, military exercises, etc. SAA can be contained within any given airspace classification above, and should be designated by both with a service taxonomy.

6.4. ICAO Regions

Historically, ICAO led a study to define regional air navigation (RAN) and continued to refine the air navigation regions in 1964 with the Air Navigation Commission. Further consolidation occurred in 1980, and the present regional structure is defined in the Appendix 1 of the ICAO Doc 8144-AN/874: Directives to Regional Air Navigation Meetings and Rules of Procedure for their Conduct. These regions are comprised of the following regions:

1. AFRICA-INDIAN OCEAN (AFI) REGION
2. ASIA (ASIA) REGION
3. CARIBBEAN (CAR) REGION
4. EUROPEAN (EUR) REGION
5. MIDDLE EAST (MID) REGION
6. NORTH AMERICAN (NAM) REGION
7. NORTH ATLANTIC (NAT) REGION
8. PACIFIC (PAC) REGION
9. SOUTH AMERICAN (SAM) REGION

A visual depiction of an ICAO Region taxonomy is shown in the Figure 5:

Figure 5. ICAO Regions

A taxonomy for ICAO Regions is provided in Taxonomies.

6.5. ICAO Flight Information Regions (FIR)

Each of the ICAO regions defined above also contain multiple Flight Information Regions defined based on major areas of air traffic control services such as flight information services and alerting services (ALRS). Each ICAO region contains a number of agreed upon FIRs [4]. Each FIR contains an FIR ID annotated using a four letter code. Primarily, the ICAO FIR ID will be used for identifying an ICAO designated FIR. However, when attempting to identify an Area Control Center, a different identification code may be used based on each nation.

6.6. Area Control Centers

In the U.S., Area Control Centers are called Air Route Traffic Control Centers (ARTCC), or simply Centers, which contain ARTCC codes which differ from ICAO FIR IDs. For example, ARTCC ZDC is for the Washington D.C. ARTCC, but the ICAO FIR ID is KZDC. An ARTCC taxonomy would provide value for identifying data which either refers to information contained within an ARTCC, but also for information such as flight plans which either depart or arrive in an ARTCC's airspace. Taxonomies could be defined based on ARTCC codes, but usage should take into consideration additional taxonomies for usage (e.g., Departures, Arrivals, En Route, etc.) to maximize the relevant discovery of services.

In the U.S., ARTCCs are also further broken down into En Route sectors or oceanic sectors. These are separated based on En Route navigation systems (i.e., En Route Automation Modernization - ERAM), Oceanic navigation systems (i.e., Advanced Technologies & Oceanic Procedures - ATOP), and

Terminal Approach. These sectors can also be identified according to the taxonomy structure shown in Figure 6.

Figure 6. Area Control Centers and Sectors

6.7. FAA Terminal Radar Approach Control (TRACON) / Airport Traffic Control Tower (ATCT)

Terminal facilities include TRACONs and ATCTs which are located in various airport facilities across the FAA National Airspace System [3]. These terminal facilities can be designated as Class B or Class C airspaces and include Location ID (LocID) per each facility. Due to the long list of facilities, a taxonomy was not generated for this report, however a list of TRACON and ATCT facilities is provided in Airports and Facilities.

6.8. Airways

Airways in the U.S. were historically identified based on radio frequency. Later, they were based on frequency ground stations such as beacons. Low altitude airways below 18,000 feet are based on VOR stations and appear on published navigational charts. These airways are prefixed with the letter "V" and called "victor airways". High altitude airways from 18,000 feet which are based on VOR stations are called jet routes. They appear on high altitude charts and are prefixed with the letter "J". With the invention of RNAV routes, low altitude routs were prefixed with "T" and high altitude routes were prefixed with "Q". These routes can be identified according to the taxonomy structure shown in Figure 7.

Figure 7. Airways Identification

6.9. Conclusion

The airspace classifications can be identified based on geospatial boundaries of each airspace as determined by an ATM provider’s definition. These are defined differently per nation, which makes it near impossible to define a single taxonomy definition for every nation state. Therefore, an airspace classification taxonomy should be defined at the ICAO level, and another level of airspace classification needs to be defined at each national level. A reference mapping between the two taxonomies can provide a translation between airspace users trying discover the data services across multiple nation states by searching across airspace classifications.

If a data service provider wishes to annotate their data services with a taxonomy classification based on airspace, their specific nation’s taxonomy structure may be used, provided that a mapping from the national taxonomy to the ICAO taxonomy exists. In this way, a service user may search across a registry through SDCM profiles to discover the services based on a search parameter for the ICAO taxonomy term [2]. Specific geospatial features (e.g. Class B airports) will require identification of the airspaces around those features. For example, a user client may select "all Class B airspaces", in which all airports that fall within the geospatial classification of Class B airspace are associated and provided back to the user.

Based on the aforementioned geospatial classifications defined by ICAO and the U.S., the geospatial taxonomies can be represented as follows:

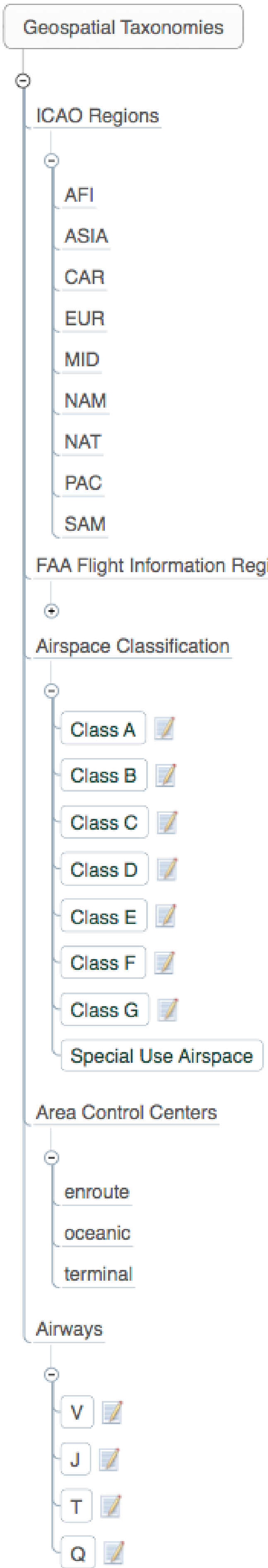

Figure 8. Geospatial Taxonomies

In Figure 8, each airspace can be categorized by airspace classification. The airspace classifications contain additional information which are documented in individual taxonomy documents attached in Taxonomies. Flight Information Regions are based on the area control centers for the U.S. The airspace volume regions can be identified using FIR ID, ARTCC code, and either enroute, oceanic, or terminal facility code. The airways are identified by instrument flight rule encodings. The combination of these taxonomies should be sufficient to identify data according to the following criteria:

1. Semantic geographical area of interest on a 2-dimensional X-Y axis containing an identified area down to the sector level without need to identify geospatial coordinates which may not be contained in an OGC Context to be filtered based on geospatial bounds (e.g. bounding box/circle/polygon)
2. Airspace classification identifies the volume of airspace including the 3rd dimensional Z axis for altitudinal margins based on airspace boundaries
3. Particular relevant airways based on VOR station routes or RNAV/RNP routes can be identified for flight planning purposes

The fourth dimensional component of time is not considered a geospatial taxonomy. However, temporal filters can be applied at the registry level to filter information contained within data based on data timestamps.

Using SDCM and the proposed taxonomies can provide sufficient discoverability for services containing geospatial information which do not conform to the OWS Context or GML. These data services can still be tagged with sufficient metadata to assist users in discovering relevant information for their operation. Additionally, services that do contain geospatially searchable data can still benefit from this method of metadata descriptions by tagging the services with taxonomy values which reflect the geospatial information for users who do not have OWS clients.

Chapter 7. Service Description

OWL-S defines a general class "Service", which serves as an organizational point to describe a service. The "Service" class contains three elements: "presents", "describedBy", and "supports" that are implemented by three classes of descriptions: "ServiceProfile", "ServiceModel", and "ServiceGrounding" respectively. Each of the three classes is a part of the aggregated class "Service". The "ServiceProfile" describes what the service does, including the function of the service, the application scope of the service, the rank of service quality, and the requirements to use the service. The "ServiceModel" describes how to use the service, including what input the service is required and what output or change the service will produce. The "ServiceGrounding" describes how an computer program to invoke the service, including a communication protocol to access the service, message formats to make the request, and the means for data exchange [2].

The FAA Service Description Conceptual Model (SDCM) provides a graphical and lexical representation of the properties, structure, and interrelationships of all service metadata elements, collectively known as a Service Description [3]. The SDCM follows the OWL-S paradigm in Figure 9.

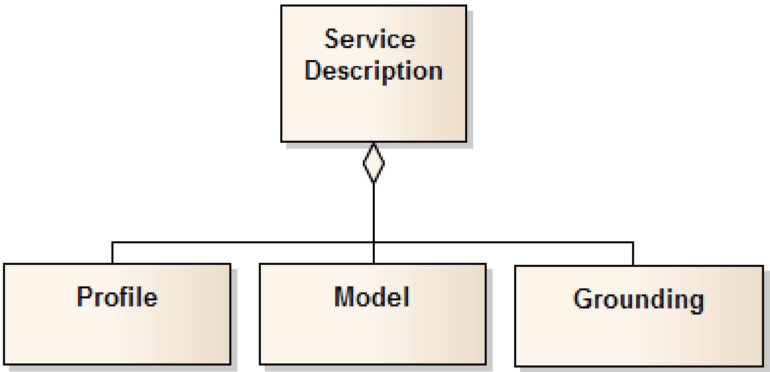

Figure 9. SDCM Service Description Diagram

Within the Profile of SDCM, a Taxonomy is classified as a Service Category which categorizes the profile with one to many (1..*) service categories.

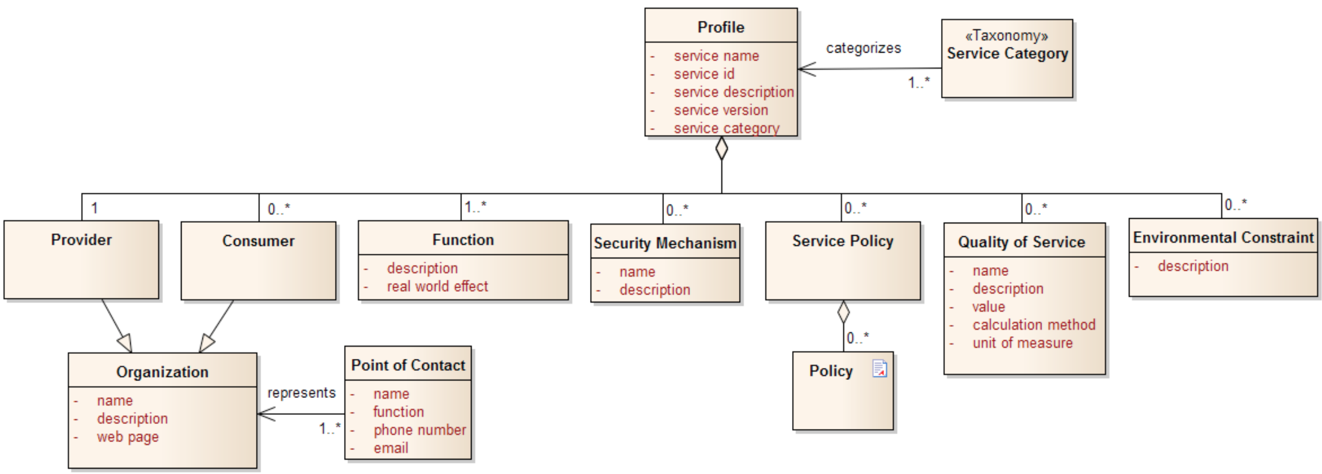

Figure 10. SDCM Profile Diagram

A service category within SDCM is defined as a taxonomy used to classify a service by the type of service provided or by some other technological or architectural solution. The extension of SDCM with the WSDOM ontology has been addressed previously in Testbed 12 Aviation Semantics ER. The proposal from the T12 ER is to extend the WSDOM ontology using GeoSPARQL geometries within the ServiceProfile. The divergence from previous testbeds which is proposed in this activity is to define service taxonomies under the Service Category of SDCM, and provide metadata values using name-value pairs. This is a very simple approach that allows indexing of services based on categories from one to many possibilities.

An example query in the registry using pseudo language:

```
Select all Services which contains a service category of "airspace-classification"
with member "class-a"
```

This query would return all services that contain a service category of "airspace-classification" taxonomy containing a "class-a" designation.

```
Select all Services which contains a service category of "icao-regions" with member
"NAM"
```

This query would return all services that contain a service category of "icao-regions" taxonomy containing a "NAM" designation for North American ICAO Region.

A combination of multiple taxonomies as defined in Taxonomies could look as follows:

```
Select all Services which contains a service category of "airspace-classification"
with member "class-a"
AND
contains service category of "icao-regions" with member "NAM"
AND
contains service category of "US-FIR" with member "KZDC"
AND
contains service category of "airways" with member "Q"
```

The above query would return all services containing Class A airspace data within the North American Region within the Washington DC FIR with high altitude RNAV routes. It is important that a service includes as many applicable taxonomy values as possible in order to maximize the discoverability. For example, while a query for "KZDC" will discover services containing "US-FIR" data, it does not automatically register a correlation between "US-FIR" and "NAM". This would require a semantic linkage between the US-FIR taxonomy and the icao-region taxonomy.

Chapter 8. Future Work

The content of this engineering report identifies a classification method based on geographical boundaries and airspace regions. The following future work ideas were developed as during this activity.

8.1. Service-based Metadata Using WPS

An OGC WPS can be used to analyze geospatial data sets which contain geographical identifiers which match taxonomy metadata which can be included in the service description based on a geospatial feature criterion. The criterion can be identified using the taxonomy sets and associated geospatial definitions from authoritative sources. This service could also be executed periodically to determine if a data set changes for automatic updating of registry metadata. Furthermore, such a service could also provide a validation for standard data sets to ensure they are properly described in the registry. For example, in Figure 11, a taxonomy such as US-FIR can be used as an input to the OGC WPS. This taxonomy identifies value pairs such as "KZDC" for an area control center which is semantically linked to an ARTCC facility value in a data set such as in the FAA’s Traffic Flow Management System (TFMS). The TFMS schema contains an element variable which acts as the geographical identifier which, in this case, is the ARTCC facility code. Using the schema and the taxonomy convention, the data of a corresponding data service can be analyzed for any matches between the schema data element and the taxonomy to determine matches. Any matches can be used to generate the service metadata documentation.

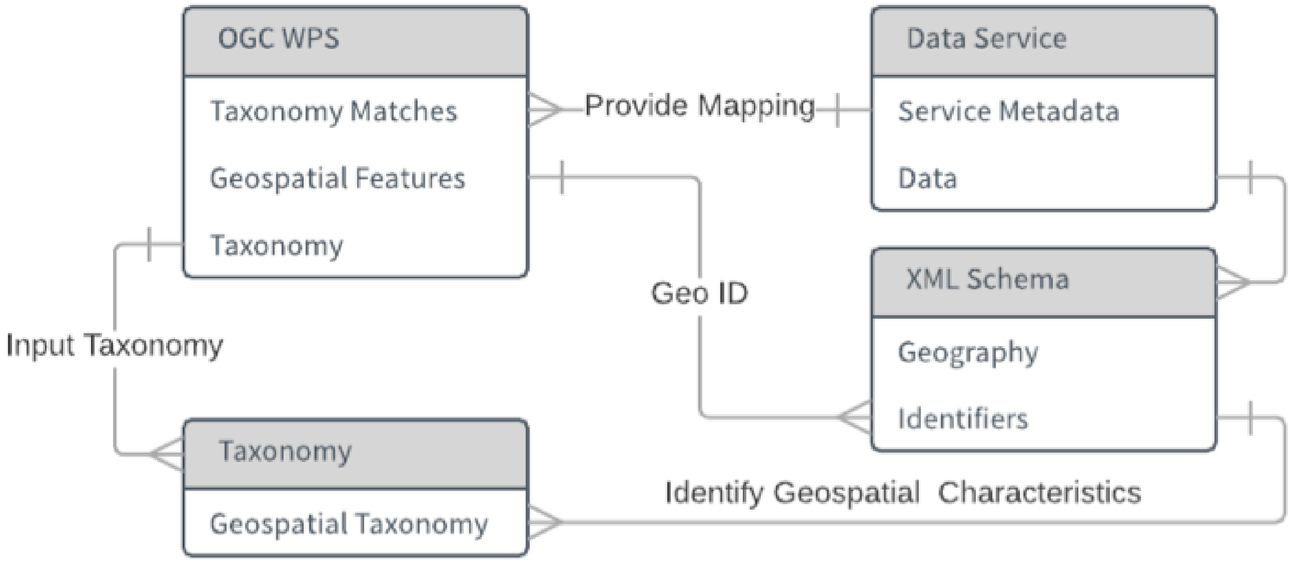

Figure 11. Taxonomy Matching with Geographical ID

Additional schema-specific logic would be required in order to map the Geospatial taxonomy to data to a geographical baseline. For example in the taxonomies provided in Taxonomies, an airspace class taxonomy for airspace class A, B, C, etc. is provided. A baseline geospatial mapping of these airspace volumes could provide a baseline to compare with other geographical data. If geographic information fields (i.e., lat/lon coordinates) in a data service field match geographical markers within the baseline data, the metadata can be assigned based on the taxonomy match and applied to the service metadata. In Figure 12, the addition of geography markers which identify geospatial boundaries can be used to identify geometrical values within data. For example, if the baseline data contains annotated geometry volumes for Class B Airspaces, then in the case of the SWIM Terminal Data Distribution Service (STTDS) which contains airport position reports within terminal airspace, the schema value for the lat/lon coordinates can be compared to the set of geometries to determine if that the data contains matching information. The WPS can then match the geography markers of the baseline data to generate the service metadata documentation.

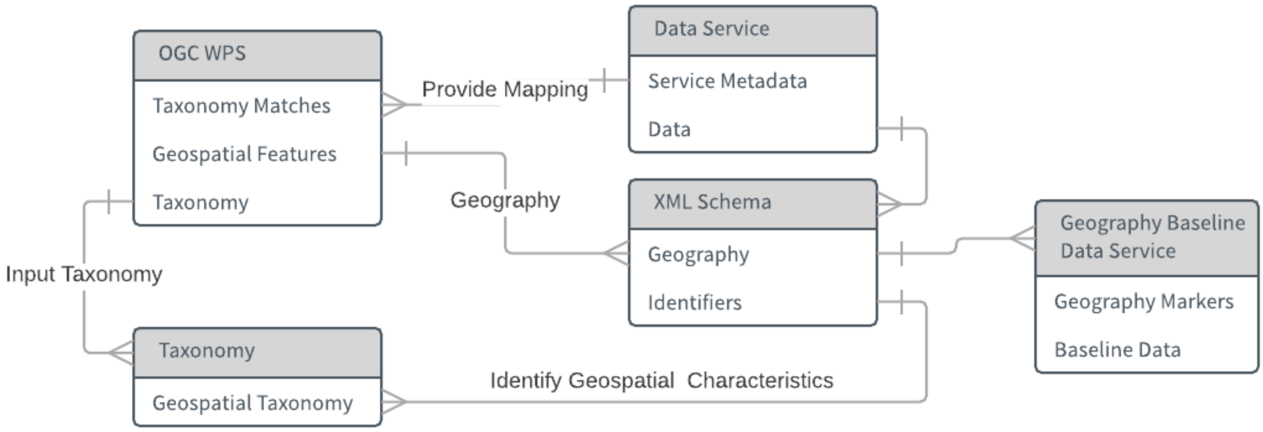

Figure 12. Taxonomy Matching with Baseline Data

8.2. ICAO ATM Information Reference Model (AIRM)

It can be considered that if an aviation geospatial taxonomy is to be designated for a service registry, and is maintained universally, the authority for determining the taxonomy and related sub-elements within the taxonomy lies on the governing authority. In this case, ICAO already develops and maintains a set of taxonomies for various operations. The ICAO ATM Information Reference Model (AIRM) is a structured, traceable, unified, harmonized, common, digital representation of civil and military information constructs relevant to ATM in support of information exchange via SWIM [1: https://www.eurocontrol.int/sites/default/files/events/presentation/1.8-atiec-2017-state-icao-airm.pdf]. The ICAO AIRM is based on similar work done by EUROCONTROL [2: http://airm.aero]. In the future, a standard methodology could be developed based on the conceptual model of the AIRM would provide an authoritative source for standardization of service metadata in the Aviation domain.

Appendix A: Taxonomies

A.1. Airspace Classification Taxonomy

```
@base <http://semantics.aero/geospatial-taxonomy/airspace-classification>.

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix dc: <http://purl.org/dc/elements/1.1/>.
@prefix skos: <http://www.w3.org/2004/02/skos/core#>.
@prefix it: <http://semantics.aero/geospatial-taxonomy#>.

owl:Ontology rdf:about <http://semantics.aero/geospatial-taxonomy/airspace-
classification>;
    dc:title “Airspace Classification”;
    dc:version "1.0.0";
    dc:description “This taxonomy defines the FAA’s airspace classifications as part of
the OGC Testbed 13 Geospatial Taxonomies Engineering Report.”;
    dc:creator “Charles Chen“;
    dc:publisher “OGC Testbed 13”;
    dc:issued "2017-07-21";
    dc:format "RDF".

it:interface-type a skos:Collection;
    skos:prefLabel “airspace classification”;
    skos:altLabel “airspace classes”;
    skos:definition "A classification of airspaces based on the geospatial
characteristics as described in the FAA Pilot’s Handbook of Aeronautical Knowledge FAA-
H-8083-25B 2016.";
        skos:member it:class-a;
        skos:member it:class-b;
        skos:member it:class-c;
        skos:member it:class-d;
        skos:member it:class-e;
        skos:member it:class-f;
        skos:member it:class-g;
        skos:member it:sua.

it:class-a a skos:Concept;
    skos:prefLabel “class-a”;
    skos:definition "Class A Airspace is from 18,000 feet Mean Sea Level (MSL) up to
and including Flight Level (FL) 600.  This includes airspace up to 12 nautical miles
off the coast of the contiguous United States and Alaska.  Any space beyond the 12
nautical miles off the coast line is considered international airspace. Domestic radio
navigational signal and ATC radar coverage is required to be considered Class A
airspace.".

it:class-b a skos:Concept;
```

```
    skos:prefLabel “class-b”;
    skos:definition "Class B Airspace is bounded from the surface to 18,000 feet MSL
surrounding major airports.  The volume of airspace for Class B is designed based on
the surface area of the airport and the volume of terminal airspace controlled by the
airport or terminal air traffic control center.  All aircraft require ATC clearance to
operate within this airspace.  ATC manages separation of aircraft.  VFR operation may
be flown if a cloud clearance is provided by ATC.".

it:class-c a skos:Concept;
    skos:prefLabel “class-c”;
    skos:definition "Class C airspace is bounded from the surface of the airport to
4,000 feet MSL.  The first layer of the airspace is from the surface area to the
ceiling boundary with 5 nautical miles radius.  The second layer is from 1,200 feet
MSL to the ceiling at a 10 mile radius. The outer layer extends to 20 nautical miles
radius.  Class C airspace surrounds airports containing regular commercial traffic of
100 passengers per flight or more.  Class C airspaces contain an operational tower,
radar-controlled approach system, and a minimum number of IFR approaches per year.".

it:class-d a skos:Concept;
    skos:prefLabel “class-d”;
    skos:definition "Class D airspace is bounded from the surface of an airport to
2,500 feet MSL.  The outer boundary radius varies but is typically 4 nautical miles.
Class D airspace is classified as any airport with a functional control tower with
minimal IFR approaches.  The airspace reverts to Class E or G during hours when the
tower is closed or under special conditions.".

it:class-e a skos:Concept;
    skos:prefLabel “class-e”;
    skos:definition "Class E airspace is controlled airspace that is neither A, B, C,
or D.  this airspace extends from 1,200 feet Above Ground Level (AGL) up to 18,000
feet MSL.  Some areas as low as 700 AGL are included and are notated in sectional
charts.  Most of the airspace in the United States is class E.".

it:class-f a skos:Concept;
    skos:prefLabel “class-f”;
    skos:definition "Class F airspace is not used in the U.S.   In Canada, Class F
airspace is equivalent to the U.S. term, Special Use Airspace (SUA).  ICAO defines
Class F airspace as a hybrid of Class E and G airspace in which ATC separation
guidance is available but not required for IFR operation.".

it:class-g a skos:Concept;
    skos:prefLabel “class-g”;
    skos:definition "Class G airspace includes all airspace below 14,500 feet MSL
which is not otherwise classified or controlled.  Class G airspace is considered
uncontrolled airspace. This work is influenced by the OGC ISO/TC211 and GeoRSS
(georss.org). This document describes examples in which RDF syntax is used for Geo and
FOAF vocabularies, GML syntax for gml points, and geo-coding with RSS 1.0.".

it:sua a skos:Concept;
    skos:prefLabel “sua”;
    skos:definition "Special  use  airspace  or  special  area  of  operation  (SAO)
```

```
is the designation for airspace in which certain activities must be
confined, or where limitations may be imposed on aircraft operations that
are not part of those activities.".
```

A.2. ICAO Regions Taxonomy

```
@base <http://semantics.aero/geospatial-taxonomy/icao-regions>.

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix dc: <http://purl.org/dc/elements/1.1/>.
@prefix skos: <http://www.w3.org/2004/02/skos/core#>.
@prefix it: <http://semantics.aero/geospatial-taxonomy#>.

owl:Ontology rdf:about <http://semantics.aero/geospatial-taxonomy/icao-regions>;
    dc:title “ICAO Regions”;
    dc:version "1.0.0";
    dc:description “This taxonomy describes the ICAO Regions as defined ”;
    dc:creator “Charles Chen“;
    dc:publisher “OGC Testbed 13”;
    dc:issued "2017-09-21";
    dc:format "RDF".

it:interface-type a skos:Collection;
    skos:prefLabel “ICAO Regions”;
    skos:altLabel “ICAO Location Indicators”;
    skos:definition "The present regional structure, as defined in Appendix 1 to the
Directives to Regional Air Navigation Meetings and Rules of Procedure for their
Conduct (Doc 8144-AN/874)";
        skos:member it:AFI;
        skos:member it:ASIA;
        skos:member it:CAR;
        skos:member it:EUR;
        skos:member it:MID;
        skos:member it:NAM;
        skos:member it:NAT;
        skos:member it:PAC;
        skos:member it:SAM.

it:afi a skos:Concept;
    skos:prefLabel “AFI”;
    skos:definition “AFRICA-INDIAN OCEAN REGION”.

it:asia a skos:Concept;
    skos:prefLabel “ASIA”;
    skos:definition “ASIA REGION“.

it:car a skos:Concept;
```

```
    skos:prefLabel “CAR”;
    skos:definition “CARIBBEAN REGION”.

it:eur a skos:Concept;
    skos:prefLabel “EUR”;
    skos:definition “EUROPEAN REGION”.

it:mid a skos:Concept;
    skos:prefLabel “MID”;
    skos:definition “MIDDLE EAST REGION“.

it:nam a skos:Concept;
    skos:prefLabel “NAM”;
    skos:definition “NORTH AMERICAN REGION“.

it:nat a skos:Concept;
    skos:prefLabel “NAT”;
    skos:definition “NORTH ATLANTIC REGION“.

it:pac a skos:Concept;
    skos:prefLabel “PAC”;
    skos:definition “PACIFIC REGION”.

it:sam a skos:Concept;
    skos:prefLabel “SAM”;
    skos:definition “SOUTH AMERICAN REGION”.
```

A.3. US Flight Information Regions Taxonomy

```
@base <http://semantics.aero/geospatial-taxonomy/us-fir>.

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix dc: <http://purl.org/dc/elements/1.1/>.
@prefix skos: <http://www.w3.org/2004/02/skos/core#>.
@prefix it: <http://semantics.aero/geospatial-taxonomy#>.

owl:Ontology rdf:about <http://semantics.aero/geospatial-taxonomy/us-fir>;
    dc:title “US Flight Information Regions”;
    dc:version "1.0.0";
    dc:description “This taxonomy lists the US Flight Information Regions as defined
by ICAO.”;
    dc:creator “Charles Chen“;
    dc:publisher “OGC Testbed 13”;
    dc:issued "2017-09-21";
    dc:format "RDF".

it:interface-type a skos:Collection;
```

```
    skos:prefLabel “US FIR”;
    skos:altLabel “US Flight Information Regions”;
    skos:definition “The list of Flight Information Regions as defined by ICAO.“;
        skos:member it:KZAB;
        skos:member it:KZAK;
        skos:member it:KZAU;
        skos:member it:KZBW;
        skos:member it:KZDC;
        skos:member it:KZDV;
        skos:member it:KZFW;
        skos:member it:KZHU;
        skos:member it:KZID;
        skos:member it:KZJX;
        skos:member it:KZKC;
        skos:member it:KZLZ;
        skos:member it:KZLC;
        skos:member it:KZMA;
        skos:member it:KZME;
        skos:member it:KZNY;
        skos:member it:KZOA;
        skos:member it:KZOB;
        skos:member it:KZSE;
        skos:member it:KZTL;
        skos:member it:KZWY;
        skos:member it:PAZA;
        skos:member it:PGZU;
        skos:member it:PHZH;
        skos:member it:TJZS.

it:kzab a skos:Concept;
    skos:prefLabel “KZAB”;
    skos:definition “ALBUQUERQUE FIR”.

it:kzak a skos:Concept;
    skos:prefLabel “KZAK”;
    skos:definition “OAKLAND OCEANIC FIR“.

it:kzau a skos:Concept;
    skos:prefLabel “KZAU”;
    skos:definition “CHICAGO FIR”.

it:kzbw a skos:Concept;
    skos:prefLabel “KZBW”;
    skos:definition “BOSTON FIR”.

it:kzdc a skos:Concept;
    skos:prefLabel “KZDC”;
    skos:definition “WASHINGTON FIR“.

it:kzdv a skos:Concept;
    skos:prefLabel “KZDV”;
```

```
    skos:definition “DENVER FIR”.

it:kzfw a skos:Concept;
    skos:prefLabel “KZFW”;
    skos:definition “FT WORTH FIR”.

it:kzhu a skos:Concept;
    skos:prefLabel “HOUSTON FIR”;
    skos:definition “PACIFIC REGION”.

it:kzid a skos:Concept;
    skos:prefLabel “KZID”;
    skos:definition “INDIANAPOLIS FIR”.

it:kzjx a skos:Concept;
    skos:prefLabel “KZJX”;
    skos:definition “JACKSONVILLE FIR”.

it:kzkc a skos:Concept;
    skos:prefLabel “KZKC”;
    skos:definition “KANSAS CITY FIR”.

it:kzla a skos:Concept;
    skos:prefLabel “KZLA”;
    skos:definition “LOS ANGELES FIR”.

it:kzlc a skos:Concept;
    skos:prefLabel “KZLC”;
    skos:definition “SALT LAKE CITY FIR”.

it:kzma a skos:Concept;
    skos:prefLabel “KZMA”;
    skos:definition “MIAMI FIR”.

it:kzme a skos:Concept;
    skos:prefLabel “KZME”;
    skos:definition “MEMPHIS FIR”.

it:kzmp a skos:Concept;
    skos:prefLabel “KZMP”;
    skos:definition “MINNEAPOLIS FIR”.

it:kzny a skos:Concept;
    skos:prefLabel “KZNY”;
    skos:definition “NEW YORK FIR”.

it:kzoa a skos:Concept;
    skos:prefLabel “KZOA”;
    skos:definition “OAKLAND FIR”.

it:kzob a skos:Concept;
```

```
    skos:prefLabel “KZOB”;
    skos:definition “CLEVELAND FIR”.

it:kzse a skos:Concept;
    skos:prefLabel “KZSE”;
    skos:definition “SEATTLE FIR”.

it:kztl a skos:Concept;
    skos:prefLabel “KZTL”;
    skos:definition “ATLANTA FIR”.

it:kzwy a skos:Concept;
    skos:prefLabel “KZWY”;
    skos:definition “NEW YORK OCEANIC FIR”.

it:paza a skos:Concept;
    skos:prefLabel “PAZA”;
    skos:definition “ANCHORAGE FIR”.

it:pgzu a skos:Concept;
    skos:prefLabel “PGZU”;
    skos:definition “GUAM FIR”.

it:phzh a skos:Concept;
    skos:prefLabel “PHZH”;
    skos:definition “HONOLULU FIR”.

it:tjzs a skos:Concept;
    skos:prefLabel “TJZS”;
    skos:definition “SAN JUAN OCEANIC FIR”.
```

A.4. Airways Taxonomy

```
@base <http://semantics.aero/geospatial-taxonomy/airways>.

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix owl: <http://www.w3.org/2002/07/owl#>.
@prefix dc: <http://purl.org/dc/elements/1.1/>.
@prefix skos: <http://www.w3.org/2004/02/skos/core#>.
@prefix it: <http://semantics.aero/geospatial-taxonomy#>.

owl:Ontology rdf:about <http://semantics.aero/geospatial-taxonomy/airways>;
    dc:title “US Airways”;
    dc:version "1.0.0";
    dc:description “This taxonomy describes the US Airways prefixes”;
    dc:creator “Charles Chen“;
    dc:publisher “OGC Testbed 13”;
    dc:issued "2017-09-21";
    dc:format "RDF".

it:interface-type a skos:Collection;
    skos:prefLabel “US Airways”;
    skos:altLabel “US Airway Prefixes”;
    skos:definition “The US Airways prefix formats are determined based on High/Low
altitude VOR stations and High/Low Altitude RNAV Routes“;
        skos:member it:V;
        skos:member it:J;
        skos:member it:T;
        skos:member it:Q.

it:v a skos:Concept;
    skos:prefLabel “V”;
    skos:definition “Low altitude airways below 18,000 feet (5,500 m) MSL based on VOR
stations. Also known as VICTOR airways. Indexed with the letter V”.

it:j a skos:Concept;
    skos:prefLabel “J”;
    skos:definition “High altitude airways from 18,000 feet (5,500 m) MSL to FL450
based on VOR stations. Also called JET routes. Indexed with the letter J”.

it:t a skos:Concept;
    skos:prefLabel “T”;
    skos:definition “Low Altitude RNAV Routes, indexed with the letter T”.

it:q a skos:Concept;
    skos:prefLabel “Q”;
    skos:definition “High altitude RNAV route, indexed with the letter Q”.
```

Appendix B: Airports and Facilities

B.1. FAA Class B Airspace

The following Class B airports are defined for FAA:name: value

Arizona:

```
PHX / KPHX Phoenix Sky Harbor International
```

California:

```
LAX / KLAX Los Angeles International
NKX / KNKX Marine Corps Air Station Miramar
SAN / KSAN San Diego International/Lindbergh Field
SFO / KSFO San Francisco International
```

Colorado:

```
DEN / KDEN Denver International
```

Florida:

```
MCO / KMCO Orlando International
MIA / KMIA Miami International
TPA / KTPA Tampa International
```

Georgia:

```
ATL / KATL Hartsfield–Jackson Atlanta International
```

Hawaii:

```
HNL / PHNL Honolulu International
```

Illinois:

```
ORD / KORD Chicago–O'Hare International
```

Kentucky:

```
CVG / KCVG Cincinnati/Northern Kentucky International
```

Louisiana:

```
MSY / KMSY Louis Armstrong New Orleans International
```

Maryland:

```
ADW / KADW Andrews Air Force Base
BWI / KBWI Baltimore/Washington International
```

Massachusetts:

```
BOS / KBOS Boston–Logan International
```

Michigan:

```
DTW / KDTW Detroit Metropolitan Wayne County
```

Minnesota:

```
MSP / KMSP Minneapolis–Saint Paul International
```

Missouri:

```
MCI / KMCI Kansas City International
STL / KSTL Lambert–St. Louis International
```

Nevada:

```
LAS / KLAS Las Vegas–McCarran International
```

New Jersey:

```
EWR / KEWR Newark Liberty International
```

New York:

```
JFK / KJFK New York–John F. Kennedy International
LGA / KLGA New York–LaGuardia
```

North Carolina:

```
CLT / KCLT Charlotte Douglas International
```

Ohio:

```
CLE / KCLE Cleveland Hopkins International
```

Pennsylvania:

```
PHL / KPHL Philadelphia International
PIT / KPIT Pittsburgh International
```

Tennessee:

```
MEM / KMEM Memphis International
```

Texas:

```
DFW / KDFW Dallas/Fort Worth International
HOU / KHOU Houston–Hobby
IAH / KIAH Houston–George Bush Intercontinental
```

Utah:

```
SLC / KSLC Salt Lake City International
```

Virginia:

```
DCA / KDCA Ronald Reagan Washington National
IAD / KIAD Washington Dulles International
```

Washington:

```
SEA / KSEA Seattle–Tacoma International
```

B.2. Airport Traffic Control Towers (ATCT)/[TRACON]

Table 2. ATCT/TRACON

LocID	Facility Name	City	State
ABE	Allentown Tower	Allentown	PENNSYLVANIA
ABI	Abilene Tower	Abilene	TEXAS
ABQ	Albuquerque Tower	Albuquerque	NEW MEXICO
ACT	Waco Tower	Waco	TEXAS
ACY	Atlantic City Tower	Atlantic City	NEW JERSEY
AGS	Augusta Tower	Augusta	GEORGIA
ALB	Albany Tower	Latham	NEW YORK
ALO	Waterloo Tower	Waterloo	IOWA
AMA	Amarillo Tower	Amarillo	TEXAS
ASE	Aspen Tower	Aspen	COLORADO
AUS	Austin Tower	Austin	TEXAS
AVL	Asheville Tower	Fletcher	NORTH CAROLINA
AVP	Wilkes-Barre Tower	Avoca	PENNSYLVANIA
AZO	Kalamazoo Tower	Portage	MICHIGAN
BFL	Bakersfield Tower	Bakersfield	CALIFORNIA
BGM	Binghamton Tower	Johnson City	NEW YORK
BGR	Bangor Tower	Bangor	MAINE
BHM	Birmingham Tower	Birmingham	ALABAMA
BIL	Billings Tower	Billings	MONTANA
BIS	Bismarck Tower	Bismarck	NORTH DAKOTA
BNA	Nashville Tower	Nashville	TENNESSEE
BOI	BOISE Tower	Boise	IDAHO
BTR	Baton Rouge Tower	Baton Rouge	LOUISIANA
BTV	Burlington Tower	S. Burlington	VERMONT
BUF	Buffalo Tower	Cheektowaga	NEW YORK
CAE	Columbia Tower	West Columbia	SOUTH CAROLINA
CAK	Akron-Canton Tower	North Canton	OHIO
CHA	Chatanooga Tower	Chattanooga	TENNESSEE
CHS	Charleston Tower	Charleston	SOUTH CAROLINA
CID	Cedar Rapids Tower	Cedar Rapids	IOWA
CKB	Clarksburg Tower	Bridgeport	WEST VIRGINIA
CLE	Cleveland Tower	Cleveland	HIO
CLT	Charlotte Tower	Charlotte	NORTH CAROLINA

LocID	Facility Name	City	State
CMH	Columbus Tower	Columbus	OHIO
CMI	Champaign Tower	Savoy	ILLINOIS
COS	Colorado Springs Tower	Peterson AFB	COLORADO
CPR	Casper Tower	Casper	WYOMING
CRP	Corpus Christi Tower	Corpus Christi	TEXAS
CRW	Charleston Tower	Charleston	WEST VIRGINIA
CVG	Cincinnati Tower	Erlanger	KENTUCKY
DAB	Daytona Beach Tower	Daytona Beach	FLORIDA
DAY	Dayton Tower	Vandalia	OHIO
DLH	Duluth Tower	Duluth	MINNESOTA
DSM	Des Moines Tower	Des Moines	IOWA
ELM	Elmira Tower	Elmira	NEW YORK
ELP	El Paso Tower	El Paso	TEXAS
ERI	Erie Tower	Erie	PENNSYLVANIA
EUG	Eugene Tower	Eugene	OREGON
EVV	Evansville Tower	Evansville	INDIANA
FAI	Fairbanks Tower	Fairbanks	ALASKA
FAR	Fargo Tower	Fargo	NORTH DAKOTA
FAT	Fresno Tower	Fresno	CALIFORNIA
FAY	Fayetteville Tower	Fayetteville	NORTH CAROLINA
FLO	Florence Tower	Florence	SOUTH CAROLINA
FNT	Flint Tower	Flint	MICHIGAN
FSD	Sioux Falls Tower	Sioux Falls	SOUTH DAKOTA
FSM	Fort Smith Tower	Fort Smith	ARKANSAS
FWA	Fort Wayne Tower	Fort Wayne	INDIANA
GEG	Spokane Tower	Spokane	WASHINGTON
GGG	Longview Tower	Longview	TEXAS
GPT	Gulfport Tower	Gulfport	MISSISSIPPI
GRB	Green Bay Tower	Green Bay	WISCONSIN
GRR	Grand Rapids Tower	Grand Rapids	MICHIGAN
GSO	Greensboro Tower	Greensboro	NORTH CAROLINA
GSP	Greer Tower	Greer	SOUTH CAROLINA
GTF	Great Falls Tower	Great Falls	MONTANA
HLN	Helena Tower	Helena	MONTANA
HSV	Huntsville Tower	Huntsville	ALABAMA

LocID	Facility Name	City	State
HTS	Huntington Tower	Huntington	WEST VIRGINIA
HUF	Terre Haute /Hulman ATCT/TRACON	Terra Haute	INDIANA
ICT	Wichita Tower	Wichita	KANSAS
ILM	Wilmington Tower	Wilmington	NORTH CAROLINA
IND	Indianapolis Tower	Indianapolis	INDIANA
ITO	Hilo Tower	Hilo	HAWAII
JAN	Jackson Tower	Jackson	MISSISSIPPI
JAX	Jacksonville Tower	Jacksonville	FLORIDA
LAN	Lansing Tower	Lansing	MICHIGAN
LBB	Lubbock Tower	Lubbock	TEXAS
LCH	Lake Charles Tower	Lake Charles	LOUISIANA
LEX	Lexington Tower	Lexington	KENTUCKY
LFT	Lafayette Tower	Lafayette	LOUISIANA
LIT	Little Rock Tower	Little Rock A	RKANSAS
MAF	Midland Tower	Midland	TEXAS
MBS	Saginaw Tower	Freeland	MICHIGAN
MCI	Kansas City Tower	Kansas City	MISSOURI
MDT	Harrisburg Intl Tower	Middletown	PENNSYLVANIA
MFD	Mansfield Tower	Mansfield	OHIO
MGM	Montgomery Tower	Hope Hull	ALABAMA
MIA	Miami Tower	Miami	FLORIDA
MKE	Milwaukee Tower	Milwaukee	WISCONSIN
MKG	Muskegon Tower	Muskegon	MICHIGAN
MLI	Quad City Tower	Milan	ILLINOIS
MLU	Monroe Tower	Monroe	LOUISIANA
MOB	Mobile Tower	Mobile	ALABAMA
MSN	Madison Tower	Madison	WISCONSIN
MSY	New Orleans Tower	New Orleans	LOUISIANA
MWH	Grant County Tower	Moses Lake	WASHINGTON
MYR	Myrtle Beach Tower	Myrtle Beach	SOUTH CAROLINA
OKC	Oklahoma City Tower	Oklahoma City	OKLAHOMA
ORF	Norfolk Tower	Virginia Beach	VIRGINIA
PBI	Palm Beach Tower	West Palm Beach	FLORIDA
PHL	Philadelphia Tower	Philadelphia	PENNSYLVANIA
PIA	Peoria Tower	Peoria	ILLINOIS

LocID	Facility Name	City	State
PIT	FAA Pittsburgh ATC Tower	Pittsburgh	PENNSYLVANIA
PSC	Pasco Tower	Pasco	WASHINGTON
PVD	Providence Tower	Warwick	RHODE ISLAND
PWM	Portland Tower	Portland	MAINE
RDG	Reading Tower	Reading	PENNSYLVANIA
RDU	Raleigh-Durham Tower	Morrisville	NORTH CAROLINA
RFD	Rockford Tower	Rockford	ILLINOIS
ROA	Roanoke Tower	Roanoke	VIRGINIA
ROC	Rochester Tower	Rochester	NEW YORK
ROW	Roswell Tower	Roswell	NEW MEXICO
RST	Rochester Tower	Rochester	MINNESOTA
RSW	Fort Myers Tower	Fort Myers	FLORIDA
SAT	San Antonio Tower	San Antonio	TEXAS
SAV	Savannah Tower	Savannah	GEORGIA
SBA	Santa Barbara Tower	Goleta	CALIFORNIA
SBN	South Bend Tower	South Bend	INDIANA
SDF	Standiford Tower	Louisville	KENTUCKY
SGF	Springfield Tower	Springfield	MISSOURI
SHV	Shreveport Tower	Barksdale AFB	LOUISIANA
SPI	Springfield Tower	Springfield	ILLINOIS
SUX	Sioux Gateway Tower	Sioux City	IOWA
SYR	Syracuse Tower	North Syracuse	NEW YORK
TLH	Tallahassee Tower	Tallahassee	FLORIDA
TOL	Toledo Tower	Swanton	OHIO
TPA	Tampa Tower	Tampa	FLORIDA
TRI	Tri-Cities Tower	Blountville	TENNESSEE
TUL	Tulsa Tower	Tulsa	OKLAHOMA
TWF	Twin Falls Tower	Twin Falls	IDAHO
TYS	Knoxville Tower	Louisville	TENNESSEE
YNG	Youngstown Tower	Vienna	OHIO

Table 3. TRACON

LocID	Facility Name	City	State
A11	Anchorage TRACON	Anchorage	ALASKA
A80	Atlanta TRACON	Peachtree City	GEORGIA
A90	Boston TRACON	Merrimack	NEW HAMPSHIRE

LocID	Facility Name	City	State
C90	Chicago TRACON	Elgin	ILLINOIS
D01	Denver TRACON	Denver	COLORADO
D10	Dallas - Ft Worth TRACON	Dallas-Fort Worth	TEXAS
D21	Detroit TRACON	Detroit	MICHIGAN
F11	Central Florida TRACON	Orlando	FLORIDA
I90	Houston TRACON	Houston	TEXAS
K90	Cape TRACON	Falmouth	MASSACHUSETTS
L30	Las Vegas TRACON	Las Vegas	NEVADA
M03	Memphis TRACON	Memphis	TENNESSEE
M98	Minneapolis TRACON	Minneapolis	MINNESOTA
N90	New York TRACON	Westbury	NEW YORK
NCT	Northern California TRACON	Mather	CALIFORNIA
NMM	Meridian TRACON	Meridian	MISSISSIPPI
P31	Pensacola TRACON	Pensacola	FLORIDA
P50	Phoenix TRACON	Phoenix	ARIZONA
P80	Portland TRACON	Portland	OREGON
PCT	Potomac TRACON	Warrenton	VIRGINIA
R90	Omaha TRACON	Bellevue	NEBRASKA
S46	Seattle TRACON	Burien	WASHINGTON
S56	Salt Lake City TRACON	Salt Lake City	UTAH
SCT	Southern California TRACON	San Diego	CALIFORNIA
T75	St Louis TRACON	St. Charles	MISSOURI
U90	Tucson TRACON	Tucson	ARIZONA
Y90	Yankee TRACON	Windsor Locks	CONNECTICUT

Appendix C: Revision History

Table 4. Revision History

Date	Release	Editor	Primary clauses modified	Descriptions
September 25, 2017	C. Chen	1.0	all	Initial Draft ER Release
October 25, 2017	C. Chen	1.0	all	Final Draft ER Release

Appendix D: Bibliography

[1] Web: FAA: Classes of Airspace, https://www.faasafety.gov/gslac/ALC/course_content.aspx?cID=42&sID=505&preview=true, Accessed May 2017.

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[3] FAA Terminal Radar Approach Control Facilities, https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/air_traffic_services/tracon/

[4] ICAO FIR List, https://gis.icao.int/gallery/ICAOFIR2015linkWEB2.htm