Aeronautical Information Exchange Model (AIXM) GIS interoperability through GML

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Abstract

The Aeronautical Information Exchange Model (AIXM) is an ICAO-based (International Civil Aviation Organization) XML exchange format originating from Eurocontrol that is now readable using ArcGIS, PLTS aeronautical extension. Currently, AIXM contains a custom model for representing geographical features. To standardize the GIS elements of AIXM and to improve our ability to read AIXM using ESRI tools, we have shown one approach for integrating Geography Markup Language (GML) into the AIXM specification (GML is an Open Geospatial Consortium (OGC) standard that is now undergoing the ISO standards process.). The resulting "AIXM profile of GML" defines a subset of GML geometry features and GML application schema constructs. We are planning to evaluate this new capability by serving AIXM data through Web Feature Services (WFS) producible with IMS. Incorporating GML into AIXM should reduce the costs of using AIXM by allowing adopters to benefit from existing ArcGIS GML support.

Introduction to AICM and AIXM

The Aeronautical Information Exchange Model (AIXM) and the related Aeronautical Information Conceptual Model (AICM) contain hundreds of entities, attributes, data types, and relationships used to represent aeronautical data. AICM and AIXM are based on ICAO (International Civil Aviation Organization) standards. The aeronautical information models were originally developed by EUROCONTROL to aid in standardizing data exchange and aeronautical products within the European States [3,4,7]. Today, there is increasing momentum to evolve AICM and AIXM into a global standard for the exchange of aeronautical data.

AICM and AIXM are being increasingly adopted by military and civil government organizations and aeronautical and GIS vendors:

- Eurocontrol is successfully using AICM and AIXM to store and transmit aeronautical information from member states to a consolidated electronic AIS database [5]. Several Eurocontrol states are already using the exchange standard and related technology to create electronic Aeronautical Information Publications (eAIPs) [6].
- The United States Federal Aviation Administration's (FAA) temporary flight restriction (TFR) NOTAM prototype project demonstrated that AIXM Features could be used to encode and transmit NOTAM information in a GIS format. The output from the TFR NOTAM prototype project leverages ESRI ArcGis technology to produce text and map representations of NOTAMS on the FAA's official TFR web site [8].

- ESRI has added extensions to PLTS enabling ESRI to interpret AIXM data and use the data to drive automated charting applications.

As part of the 2004 ESRI International Users conference we motivated the use of AICM and AIXM by illustrating how AICM and AIXM could improve aeronautical data integrity, submission and exchange issues and provide cost savings [2]. In addition, a separate paper provided an overview of AICM and AIXM [1].

Since 2004 AICM and AIXM have continued evolving to ensure that the exchange standard meets the data requirements imposed by ICAO and to ensure that the model is based upon the latest geospatial standards. Currently AIXM uses an aeronautical-specific model for representing geographical information. While this model provides good aeronautical domain-specific descriptions of the aeronautical feature geometry, custom programs must be written to geo-enable this data in COTS (Commercial Off-the-Shelf) GIS tools like ESRI ArcGIS.

GML (Geography Markup Language) is an alternative, standards-based approach to representing geometries in XML. In an effort to improve the consistency of geometric representations in AIXM, to reduce the costs of implementing AIXM and to improve AIXM's credibility as an emerging international standard for aeronautical data exchange, we conducted initial studies to evaluate the feasibility of incorporating GML into AIXM. In the rest of this paper, we introduce the GML geographical data model, discuss the advantages of incorporating GML into AIXM and summarize one approach to adding GML into AIXM[*].

Introduction to GML

Geography Mark-up Language (GML) is an internationally accepted standard for exchanging geographical features using XML [10]. GML was developed by the Open Geospatial Consortium (OGC), an international consortium of companies, government agencies, and universities participating in a consensus process to develop publicly available geo-processing specifications [11]. In addition, GML is compliant with the ISO Technical Committee 211 19100s series geo-spatial standards [10].

GML includes an extensive set of XML schemas for expressing simple geometries like:

- Points
- Lines
- Polygons

GML also supports complex geometries, topologies and temporal data like:

- Surfaces
- Curves and splines

[*] This document illustrates one approach to incorporating GML into AIXM and the paper analyzes the costs and benefits of this approach. GML and AIXM are both comprehensive data standards. The integration of these standards into a single aeronautical data model can be accomplished in multiple ways. The authors wish to emphasize that an official AIXM/GML solution may be significantly different from the approach described in this paper.

- Directed graphs and networks
- Observations
- Coverages

In addition, the GML specification includes rules for incorporating these geometries into GML Feature Types that represent real world objects. Figure 1 shows a simplified view of an Aerodrome and how the aerodrome's attributes might be mapped to GML.
As illustrated in the figure, GML includes a model for representing:

- Features: abstraction of a real world phenomena [ISO 19107]
- Properties: describe some aspect of the Feature
- Geometry Properties (e.g., Point Properties): represent a geometric aspect of the feature. [10]

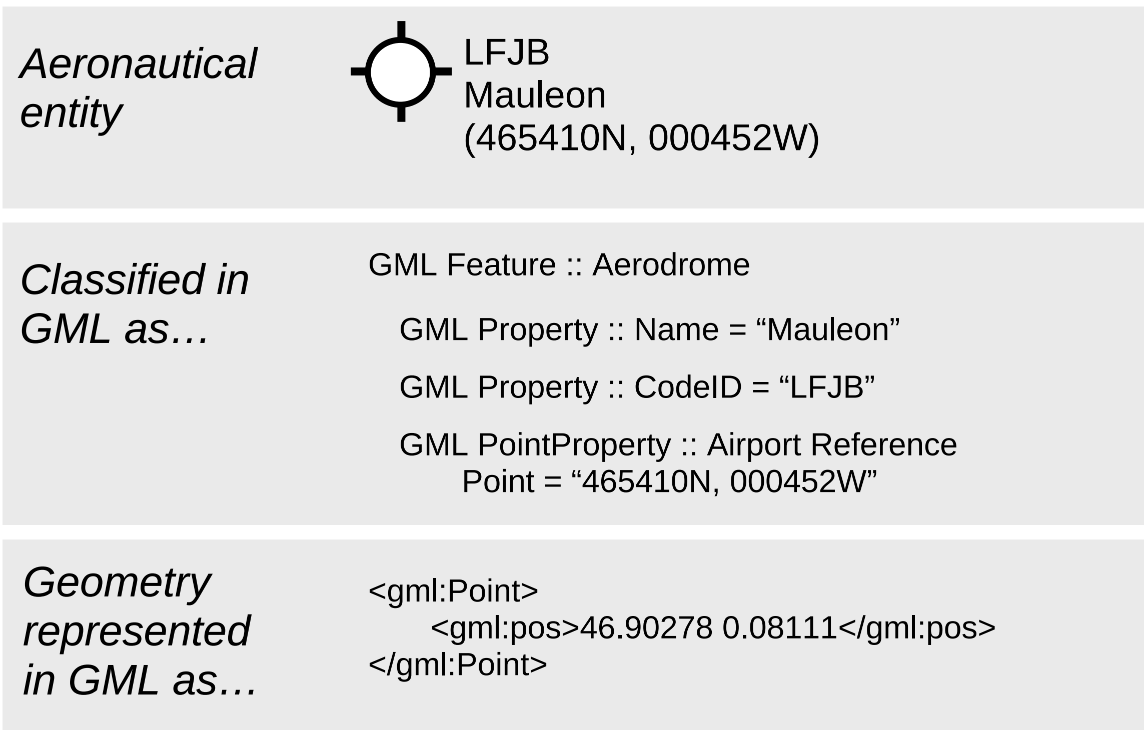

Figure 1: An AIXM Aerodrome and how it might be mapped into GML

GML provides the building blocks for representing features, properties and geometries. Furthermore, GML includes an extensive set of predefined geometry types like points, lines and polygons. However, GML does not contain specific real-world geographic entities. That is, you will not find a road or runway defined in GML. Instead GML provides a standard framework that can be used to define a road or runway in a consistent way. By using the GML framework, specific geographic entities like the road and runway can be generically interpreted by any tool that can understand GML.

Benefits of Including GML into AIXM

Including GML into AIXM has benefits for AIXM adopters:

- Compliance with established international geo-spatial standards
- Cost savings in information system development

Compliance with established international standards
Including GML into AIXM ensures that AIXM is compliant with international geo-spatial standards. The ISO geo-spatial standards technical committee (TC211) is adopting GML as part of the ISO geo-spatial standards series. By leveraging GML, AIXM becomes compliant with many of the specifications published by TC211.

In addition, GML is consistent with recent ICAO amendments. Amendment 33 to ICAO Annex 15 states that: "To allow and support the interchange and use of sets of electronic terrain and obstacle data among different data providers and data users, the ISO 19100 series of standards for geographic information shall be used as a general data modelling framework. [9]" As obstacles are part of the AIXM Scope, it is desirable that the relevant ISO standards referenced by ICAO are considered in the AIXM development. This will guarantee that States using AIXM are *de facto* compliant with the ICAO requirements.

Cost savings in information system development
Up to now, AIXM has relied on a custom model for representing geographical data. For example, an airspace border is described as a series of vertices; these vertices are characterized by position (lat/long), datum, elevation, accuracy, etc. In order for a system to be able to process this information, the system must include a custom geometry interpreter. GML offers a standardized and internationally accepted model for describing geographical data.

By incorporating GML, AIXM will be able to leverage existing COTS tools and systems that can process, visualize and exchange GML data:

- It would be possible to build an AIXM XML document that can be ingested into generic GML viewers such as those produced by COTS vendors such as ESRI ArcGis products.
- It would be possible to leverage other OGC standards such as the Web Feature Service (WFS) to develop system to system interfaces for aeronautical data exchange.

As a consequence, incorporating GML into AIXM will reduce system costs and development time by enabling system developers to leverage GML-compatible COTS products

Towards an AIXM Profile of GML

GML was designed to meet the needs of virtually all geographic systems. Because of this, GML is a complex standard suitable for representing any type of geography feature. The GML standard recognizes that specific domains may only need a subset of GML features; therefore the GML standard includes provisions for adopting subsets of GML for specific applications [10]. The subset of GML appropriate for a specific application is called a GML profile.

A GML profile makes it easier to apply GML for a specific application because the profile:

- Restricts the application to use a subset of geography features
- Reduces the complexity by simplifying the GML data model

For example, AIXM may not need to include support for GML coverages and splines, so the AIXM profile of GML can specify that GML coverages and splines are not valid when using GML in AIXM.

Analysis of AIXM Geometry Requirements

As a first step, we analyzed the current release of AIXM to identify AIXM geometries and classify them as GML geometries. AIXM is made of about 80 primary entities such as Runway Directions, Taxiways, Airspace and Organizations. These entities contain hundreds of attributes. Some of these attributes are spatial and some of the attributes are non-spatial.

Figure 2 shows the distribution of geometry properties within the primary AIXM features. Of the 80 primary AIXM features, only about 50% had explicit geographic properties. As shown in Figure 2 the majority of the AIXM geographic properties represent points. This includes Airport Reference Points, the location of a Navigation Aid and the location of a Unit providing Air Traffic Control services. Other geometric descriptions used in AIXM include curves, multiple points, polygons and multiple polygons.

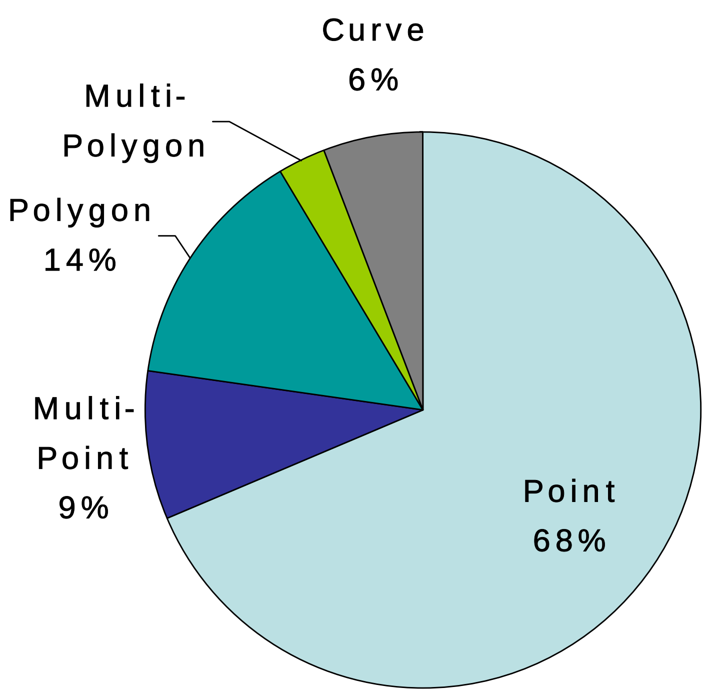

Figure 2: Mapping AIXM geometries into GML geometries

Perhaps the most complex geographic mapping from AIXM to GML is the AICM Airspace entity (see Figure 3 for an example Air Traffic Control sector in the United States). In AICM and AIXM, three-dimensional airspace is represented using a data model that describes the airspace geometry from an aeronautical perspective [3]. The entity-relationship model for airspace is reproduced in Figures 4 and 5 [7].

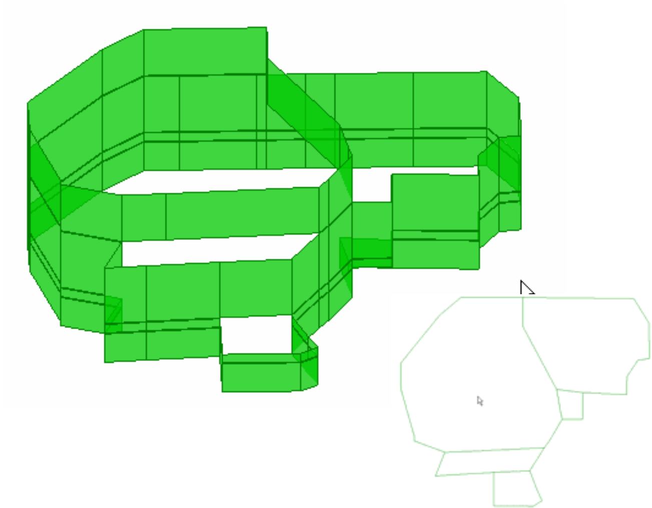

Figure 3: Example air traffic control sector in the United States

AICM and AIXM use what is sometimes termed a 2.5D model for Airspace: The Airspace Border and Airspace Corridor entities are used to describe the horizontal boundary of the airspace. These horizontal boundaries are then associated with an Airspace entity. The Airspace entity includes attributes for specifying the upper and lower altitude limits of the horizontal boundary. The net result is a 3-D volume created by vertically extruding a horizontal polygon.

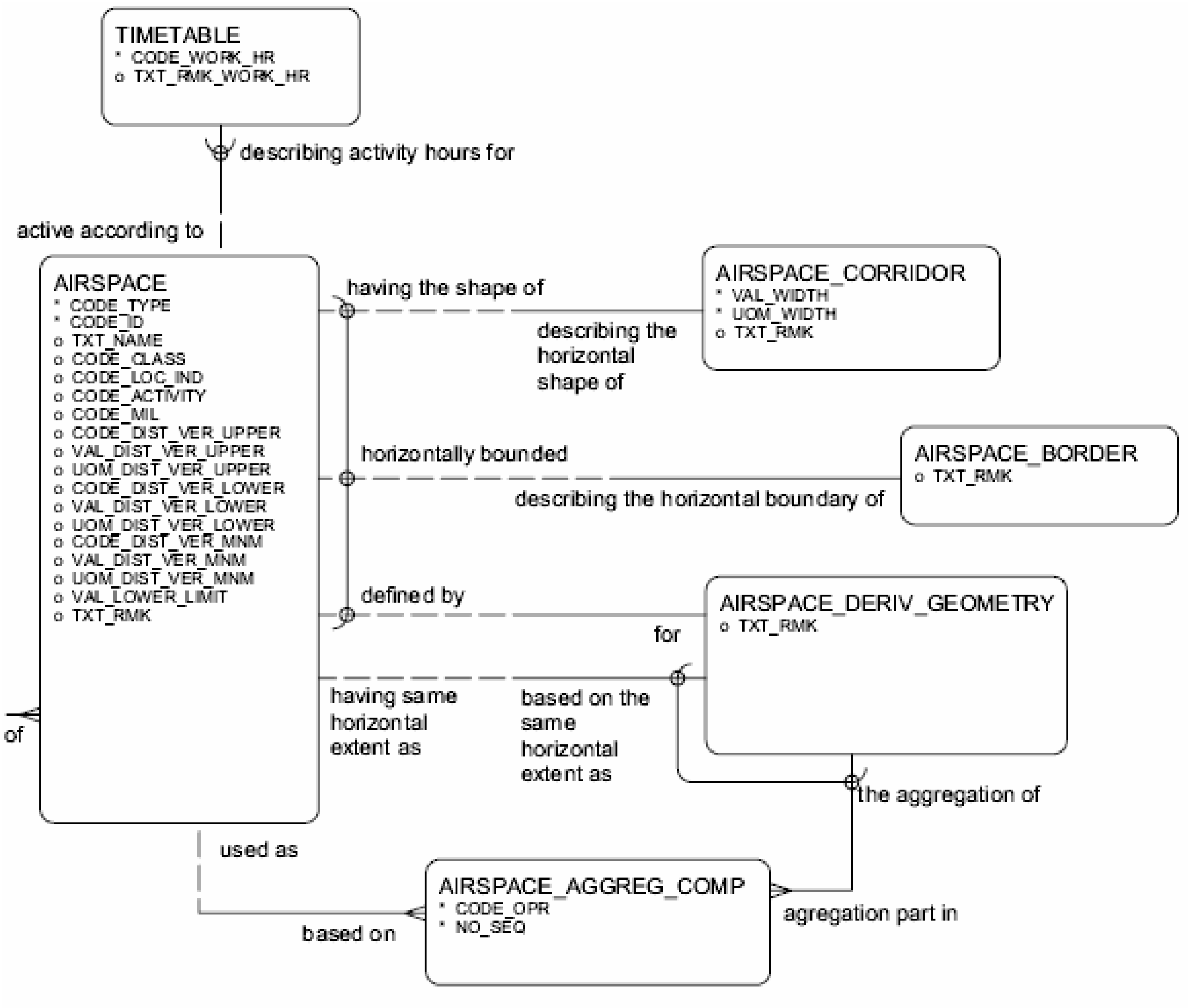

Figure 4: Airspace entity-relationship model in AICM

In addition, the Airspace model in AICM and AIXM includes a model for creating more complex airspace shapes through aggregation. AICM and AIXM include four aggregation approaches:

- The resulting airspace has the same horizontal boundary as the existing airspace (a unary operation)
- The resulting airspace is the union of two airspaces (a binary operation)
- The resulting airspace is formed by subtracting the second airspace from the first airspace (a binary operation)
- The resulting airspace is formed by the intersection of the two airspace (a binary operation)

The binary operations are illustrated in Figure 6. Note that Figure 6 displays aggregation in 2D, AIXM supports 3D airspace aggregation so the actual operations are more complex than depicted in Figure 6.

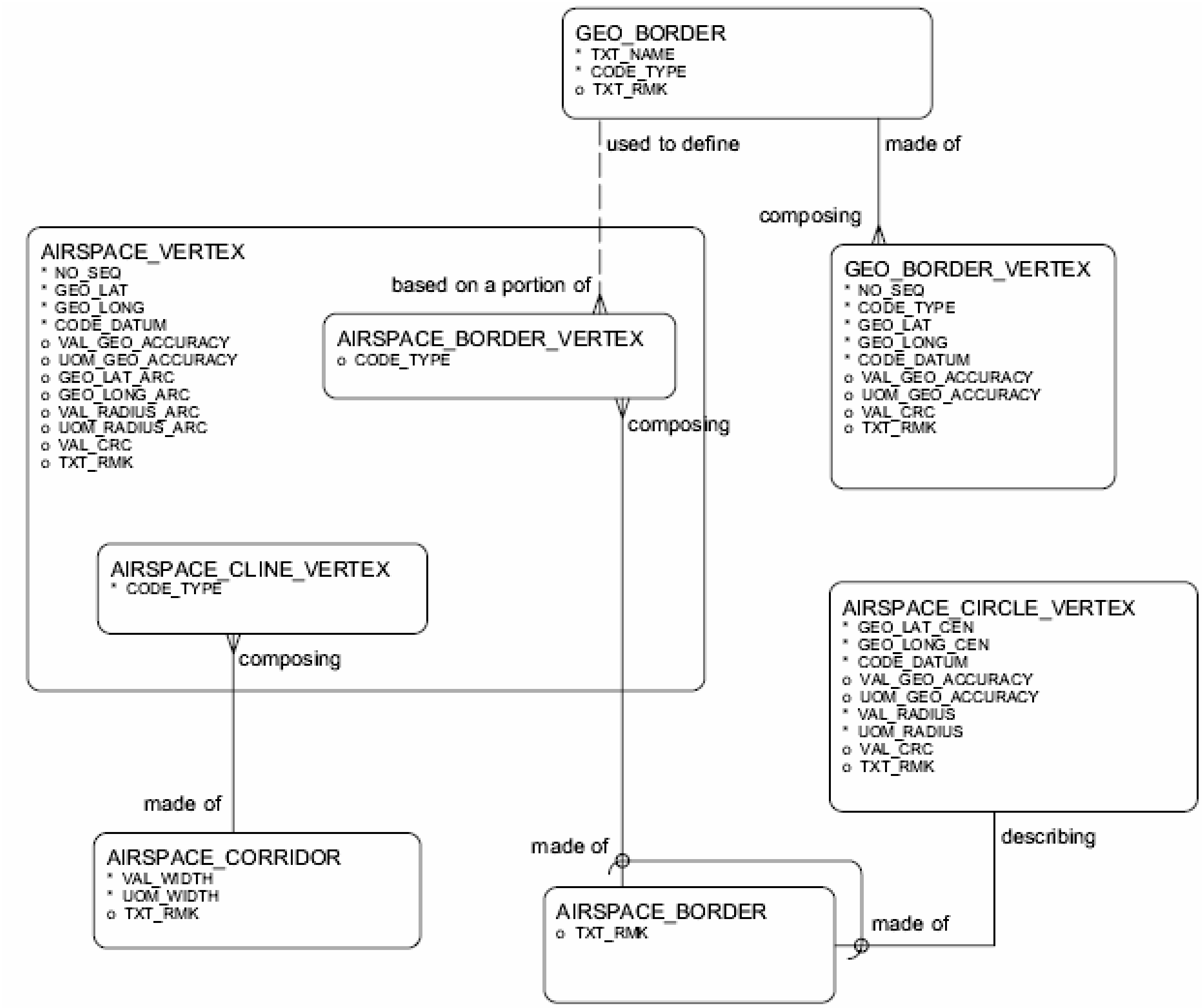

Figure 5: Entity-relationship model for airspace vertices and airspace borders

While GML does contain provisions for representing 3-D solids, we considered the GML representation for 3-D solids too complex to be implemented. Instead, each entity within the AICM airspace data model is represented by a 2D GML geometry. The resulting aggregated airspace can be assembled using the AICM/AIXM aggregation concepts and the upper and lower altitude parameters. The table below summarizes the mapping of AICM/AIXM Airspace entities to GML geometries.

AICM and AIXM Entity	**GML Geometry**
Airspace	Multi-Polygon
Airspace Corridor	Polygon
Airspace Border	Polygon
Airspace Vertex	Curve

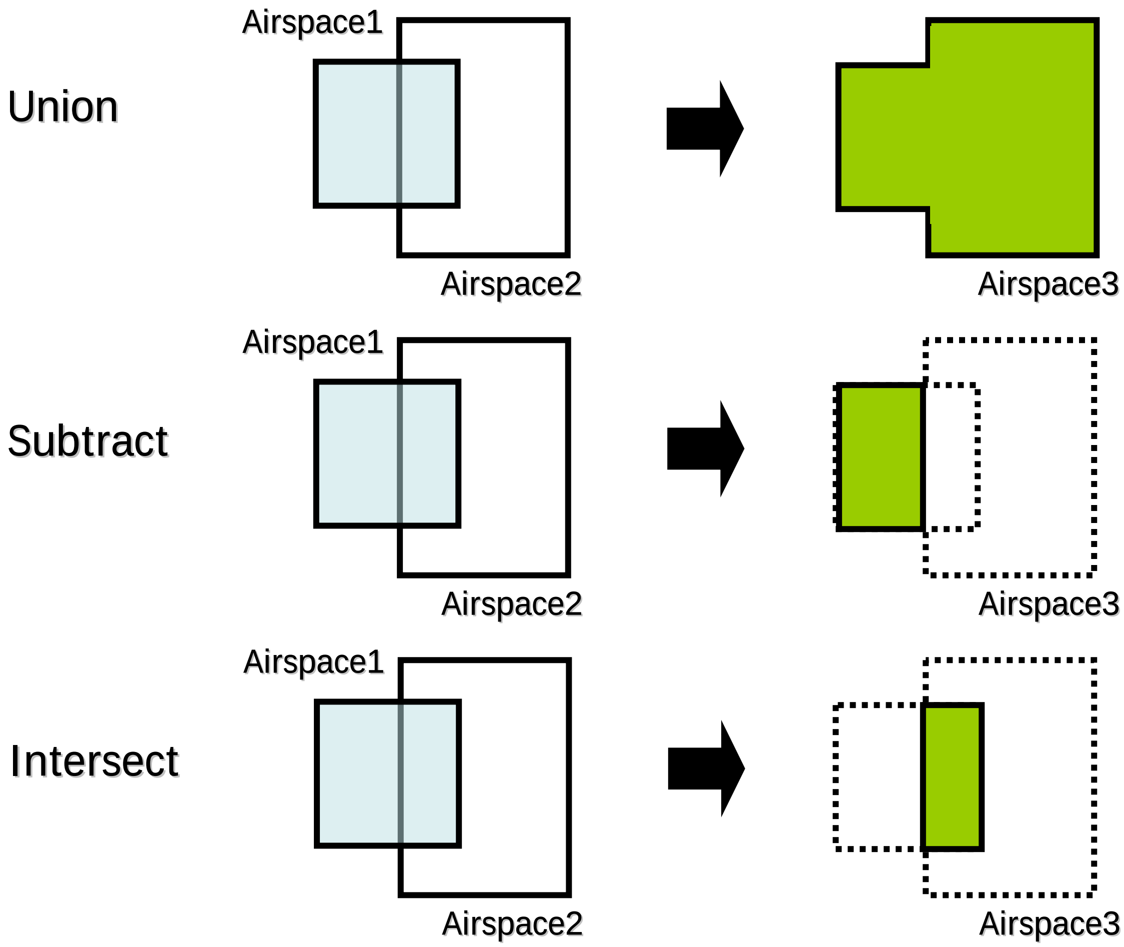

Figure 6: Illustration of AIXM airspace aggregation

Adding GML to AIXM

As discussed in the introduction, the AICM/AIXM data exchange specification has been in use since 2001. To protect the existing implementations, we cannot simply "switch to GML," instead GML should be incorporated into AIXM in such as a way that is possible to ensure technical backwards compatibility. This constraint to protect existing AICM and AIXM investments places some restrictions on how GML is integrated into AIXM. It may not be acceptable to switch to the GML style for representing aeronautical features and attributes. Instead it would be ideal if we could find a technique that preserves the basic structure of the AIXM features while also enabling AIXM to leverage the standard geometric representations contained in GML.

At the same time, applications programmed to interpret GML are expecting that a GML document conform to certain specifications outlined in the GML specification. Briefly these include:

- Use of the GML namespace
- Deriving all GML Features from the GML Abstract feature base class
- Ensuring that all feature properties follow the GML Association pattern

The full list GML compliance requirements are explained in Chapter 8 of the GML specification [10].

The approach taken in this paper is to cleanly separate the AIXM aeronautical exchange schema from the GML implementation of geometry. This separation is shown pictorially in Figure 7. As shown in Figure 7 the pure AIXM schemas, AIXM Data Types and AIXM Feature Types, contain the definitions of the features, relationships and attributes for aeronautical data. These schemas can be used to create AIXM messages such as the AIXM-Snapshot message. G-AIXM Feature Types is a GML compliant schema based on AIXM Feature Types and GML. The G-AIXM Feature Type schema can be used to create exchange documents based on GML.

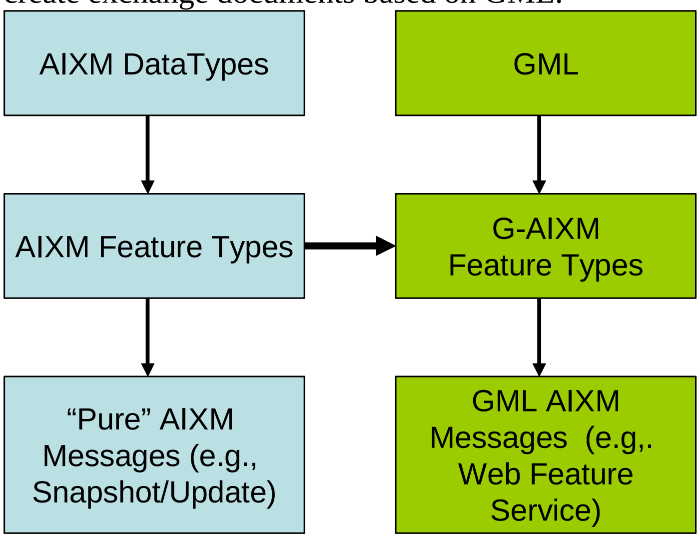

Figure 7: Illustration of separation between pure AIXM features and GML

We consider this approach useful because it allows us to preserve the existing AIXM Features while also incorporating GML. Advantages include:

- Full technical backwards compatibility with AIXM
- Continued support for the aeronautical-based description of geometries; this is useful, for example, in the automatic generation of textual descriptions of the geometry for Aeronautical Information publications, NOTAM and other types of aeronautical documents and messages.
- Support the GML description of geometries

Some of the disadvantages of this approach are:

- We are not replacing the aeronautical geometry descriptions; instead, we are augmenting AIXM with an optional GML geometry. It is therefore possible to have discrepancies between the aeronautical-based description and the GML geometry. It is the responsibility of the application generating the data to ensure consistency between the GML geometry(ies) and the aeronautical-based geometry.
- The GML feature includes a complex property containing all the AIXM Feature attributes. This is a more difficult to interpret and parse.
- The complex property containing the AIXM Feature attributes does not follow the GML Association pattern. The GML Association pattern is recommended but not mandatory so the resulting AIXM-GML is technical valid. Future releases of GML may make the GML Association pattern mandatory and thus invalidate this proposed approach.

The proposed integration of GML into AIXM is illustrated in Figure 8 for a generic AIXM feature. The AIXM-GMLFeature inherits from the GML Abstract feature class so that it is recognized as a valid GML feature. The AIXM-GMLFeature feature contains two complex properties: Property and Geometry.

An example property element for the Aerodrome Heliport G-AIXM feature is shown in Figure 9. As shown the Property element uses the Association pattern to reference all of the AIXM properties of the Aerodrome AIXM Feature. Even the AIXM representation of the aerodrome location (e.g., geoLat and geoLong) is included in the Property.

The Geometry element is a GML Geometry PropertyType. Figure 10 shows the Aerodrome example where Geometry is of type gml:PointPropertyType.

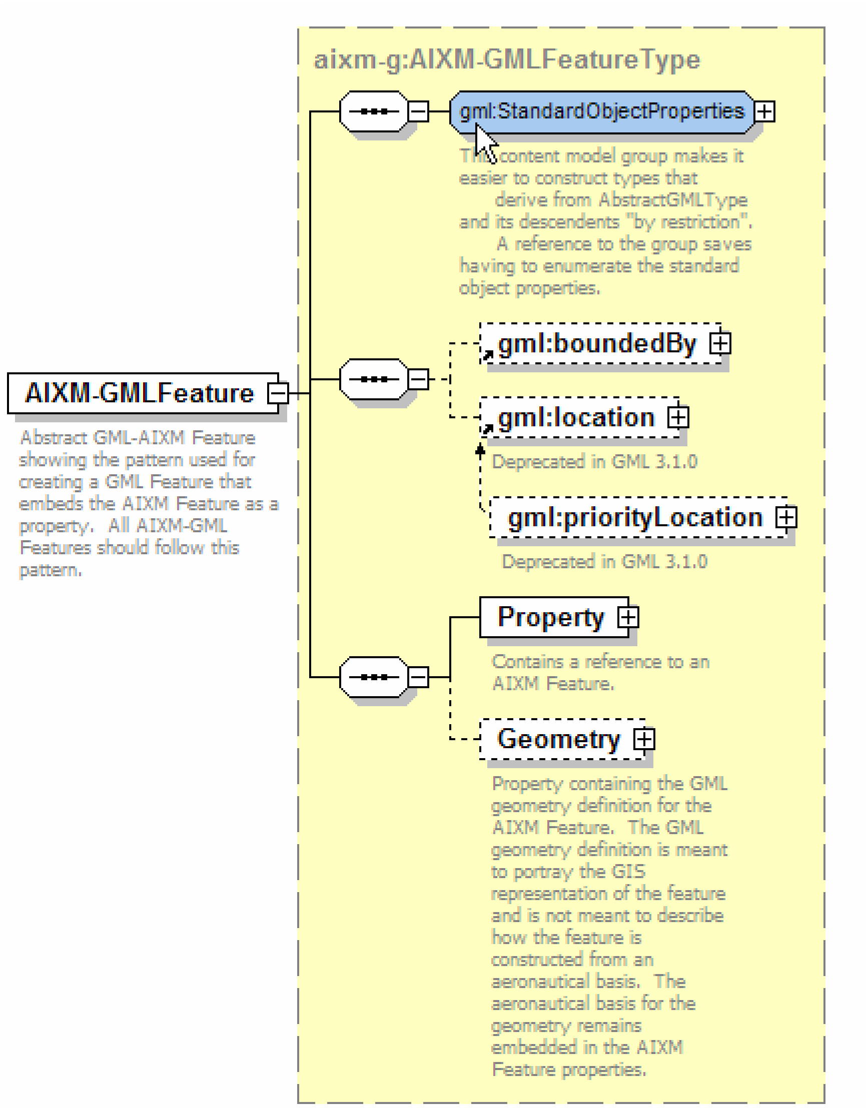

Figure 8: Proposed integration of GML into AIXM for a generic AIXM feature.

The net result is that an AIXM GMLFeature is created for each AIXM feature using the pattern shown in Figure 7. This AIXM GMLFeature has a Property element containing all of the AIXM attributes and a Geometry element defining the GML geometry representation. As another example, the XSD description for AIXM-GML representation of Organizational Authority is listed in figure 11.

Comparison with existing GML profiles

To our knowledge no commercial vendors supports the full suite of geometries, feature construction and, collection capabilities described in the GML specification. Instead it is common for GML users to specify a profile describing the subset of GML that is supported in their system.

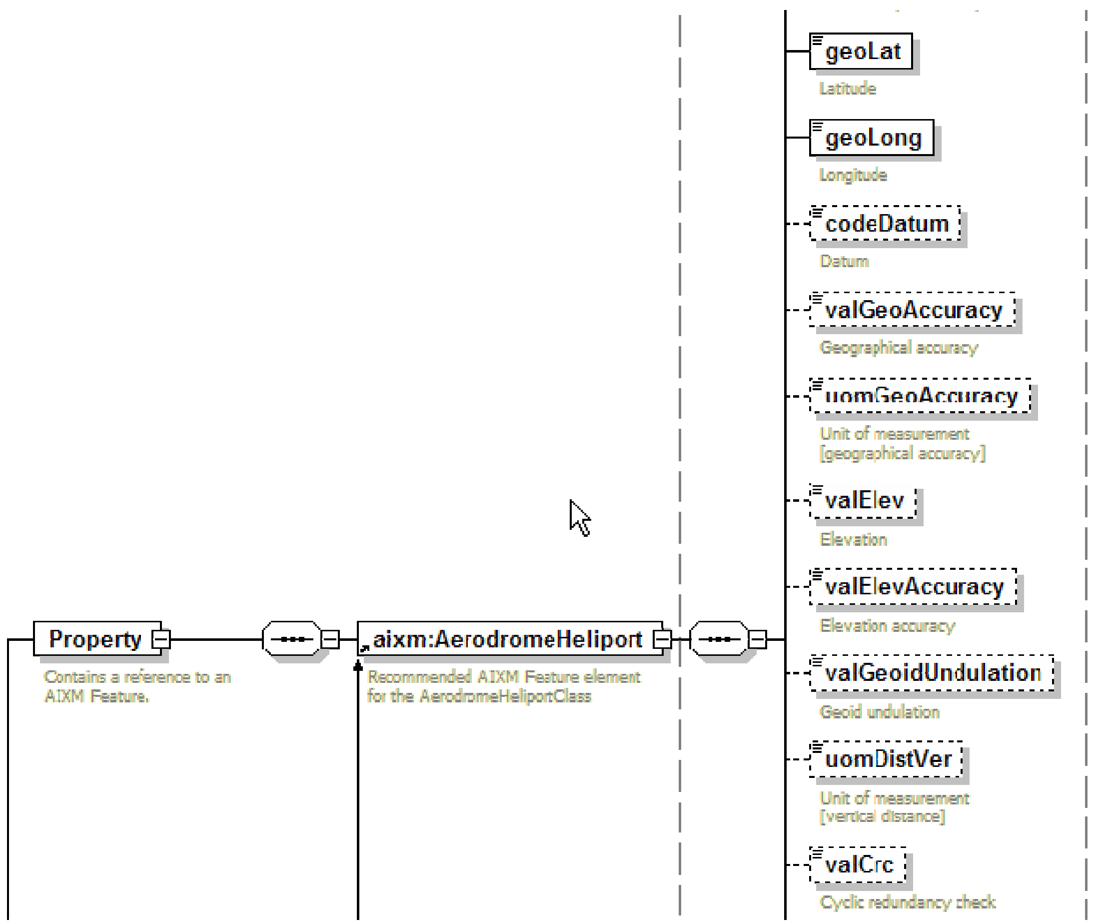

Figure 9: Excerpt of Property element for the Aerodrome AIXM-GMLFeature

ESRI and other GIS vendors are in the process of developing a simple profile of GML [12]. It is interesting to compare the GML profile for AIXM implied above with the draft proposal included in the *GML profile for simple feature exchange* [12] because gaps between the simple profile and AIXM's GML requirements can point to areas where AIXM's GIS requirements will be difficult to fulfill using standard COTS products.

In Section 7.2 of the March 2005 draft of the *GML profile for simple feature exchange* [12] there is a table describing supported geometry types. This table is partially reproduced below:

GML Geometric Property Type	Restrictions
gml:PointPropertyType	None
gml:CurvePropertyType	The interpolation between control points must be linear
Gml:SurfacePropertyType	Boundary interpolation must be linear and the surface interpolation must be planar
gml:MultiPointPropertyType	None
gml:MultiCurvePropertyType	Same as CurveProperty
gml:MultiSurfacePropertyType	Same as SurfaceProperty

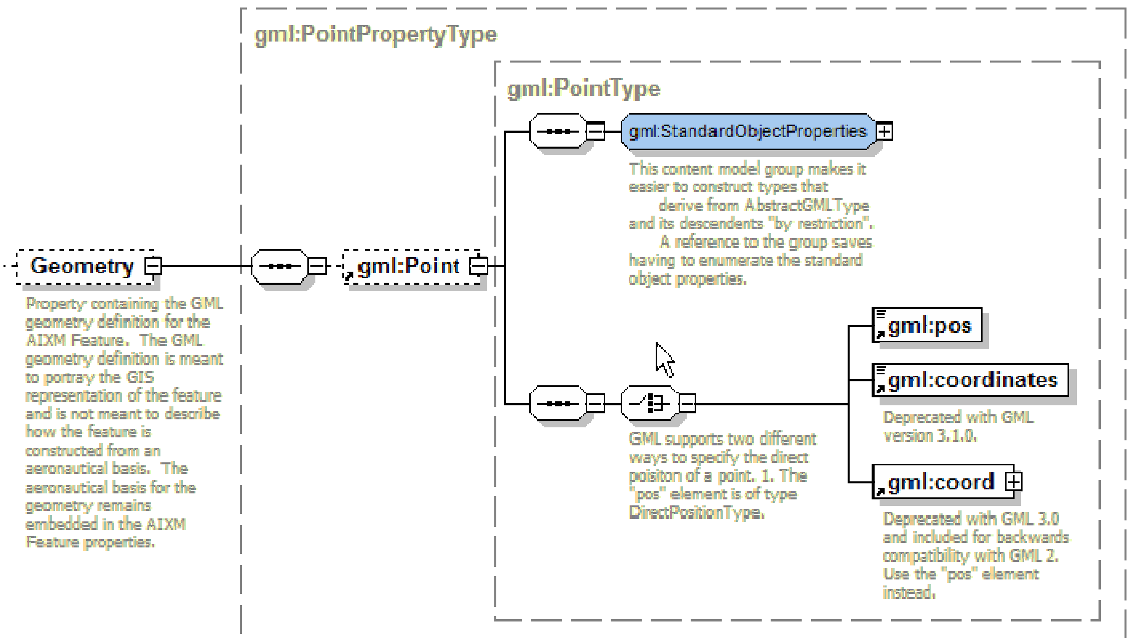

Figure 10: GML Geometry property for the Aerodrome AIXM-GMLFeature

The list of supported GML geometry types is consistent with the AIXM requirements summarized in Figure 2. The only difference is in the restrictions for the Curve and MultiCurve geometries. The draft simple GML profile only supports linear interpolation [12]. In addition to linear interpolation, the AIXM geometric requirements for Curves and Multi-Curves include:

- Arcs defined by a center point, radius and start and stop angles
- Arcs defined by a center point, radius and start and stop coordinates
- Arcs defined by three coordinates
- Circles defined by center point and radius
- Rhumb lines
- Great Circle Route lines

In addition, the simple profile specifies “This specification is concerned with the 'basic' schemas for use with relatively simple systems, such as those that use features that are represented (at least conceptually) by a single database table. That is, they have a flat list of feature properties and the properties may be of simple scalar types like Number, String, and Boolean and may include one or more spatial properties.” [section 7.1 of 12].

To ensure backwards compatibility, the approach taken in this paper is to decouple the AIXM Features, attributes and relationships from the GML representation as shown in Figure 7. This introduces a complex property called “Property” in the G-AIXM schema. As a result the proposed G-AIXM schema does not meet the “simple” feature property requirement outlined in the draft *GML profile for simple feature exchange* [12].

```
<xsd:element name="OrganisationFeature" type="aixm-g:OrganisationFeatureType" substitutionGroup="aixm-g:_AIXM_GML_AbstractFeature">
    <xsd:annotation>
        <xsd:documentation>AIXM-GML Organisation (GML geometry as a location)</xsd:documentation>
    </xsd:annotation>
</xsd:element>
<xsd:complexType name="OrganisationFeatureType">
    <xsd:complexContent>
        <xsd:restriction base="aixm-g:AIXM-GMLFeatureType">
            <xsd:sequence>
                <xsd:sequence>
                    <xsd:group ref="gml:StandardObjectProperties"/>
                </xsd:sequence>
                <xsd:sequence>
                    <xsd:element ref="gml:boundedBy" minOccurs="0"/>
                    <!-- additional properties must be specified in an application schema -->
                </xsd:sequence>
                <xsd:sequence>
                    <xsd:element name="Property">
                        <xsd:annotation>
                            <xsd:documentation>Contains a reference to an AIXM Feature.</xsd:documentation>
                        </xsd:annotation>
                        <xsd:complexType>
                            <xsd:sequence>
                                <xsd:element ref="aixm:Organisation"/>
                            </xsd:sequence>
                        </xsd:complexType>
                    </xsd:element>
                    <xsd:element name="Geometry" type="gml:PointPropertyType" minOccurs="0“/>
                </xsd:sequence>
            </xsd:sequence>
        </xsd:restriction>
    </xsd:complexContent>
</xsd:complexType>
```

Figure 11: Excert of XML Schema used to define an AIXM-GMLFeature for Organizational Authority.

Finally the *GML profile for simple feature exchange* requires systems to support WGS84 while support for other Coordinate Reference Systems (CRS) is optional [12]. This requirement is more restrictive than AIXM, where all common CRSs are allowed.

Of all the differences identified in this section, the simple feature profile’s limitation to simple property types [12] is probably the most important. The fundamental structure in the AIXM profile of GML described in this document is the use of two complex GML properties (i.e., the Property element and the Geometry element) to tie the AIXM Feature attributes and GML geometry together into a single AIXM GMLFeature.

Conclusions and Next Steps

AICM and AIXM are emerging international standards for describing and exchanging aeronautical data. AIXM is being increasingly used in government aviation agencies and COTS vendors are beginning to adopt AIXM for representing aeronautical data. Recently ESRI has developed parsers to ingest AIXM for use in automating aeronautical chart products.

Currently AICM and AIXM use a custom GIS model for representing the geography of aeronautical features. The AIXM GIS model is based on traditional representations of aeronautical data. In contrast, GML (Geography Markup Language) is an internationally recognized approach for representing GIS data in XML. Furthermore, there is broad support for GML within the commercial and government communities.

This paper considered one possible approach to incorporating GML into AIXM. The primary driver for the technique described in this paper is the desire to maintain backwards compatibility with the existing schema. The primary advantages for adopting GML are costs savings through use of COTS products for interpreting GIS data and conformance with international geo-spatial standards. The biggest constraint on adopting GML in AIXM is preserving the investments of early AIXM adopters. GML must be added to AIXM in such as way as to provide compatibility with existing systems. This paper advocates a clear separation of the pure aeronautical AIXM feature, attributes and relationships from the GML geometry.

Comparing the proposed AIXM implementation of GML with the draft *GML profile for simple feature exchange* [12] identified the following similarities and differences:

- Both GML profiles use the same geometry types although AIXM supports curvilinear interpolation between points.
- The draft simple profile does not support complex properties, but the AIXM approach includes complex property types.
- The draft simple profile requires that systems support WGS84 (other Coordinate Reference Systems are optionally support) and the AIXM approach allow any common reference system to be used.

This paper described one possible approach to embedding GML into AIXM. Alternative approaches may need to be evaluated. We are planning to use the results from this demonstration to serve AIXM data through Web Feature Services (WFS) producible with IMS. Incorporating GML into AIXM should reduce the costs of using AIXM by allowing adopters to benefit from existing ArcGIS GML support.

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