Aeronautical Information Exchange Model (AIXM)

Exchange Model goals, requirements and design

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1 Executive Summary

The mission of the Aeronautical Information Exchange Model (AIXM) is to provide a globally applicable model of aeronautical data and an exchange format that can be used to improve internal Aeronautical Information Services (AIS) systems as well as external AIS system to system information exchange. The standard is needed because of the increasing dependence of aviation on timely, consistent, high quality aeronautical information.

An information exchange standard is central to aeronautical information system modernization. The standard provides:
- A common language for expressing aeronautical information for human and computer interpretation;
- Cost savings through software reuse and data model reuse;
- Increased safety through improved data integrity and timeliness;
- Cost reduction through improvements in data quality checking and integration.

In addition, a common standard for aeronautical information enables new products that will lead to improvements in aviation efficiency, capacity and safety. Examples of such products include:
- Real time situational awareness displays, including latest information updates, for ground and air navigation;
- Automated data-driven charting;
- Electronic flight bags and pilot information briefings;
- Collaborative flight planning and automated air traffic management systems

By necessity AIS offices are moving from product-centric operations to data-centric operations. In a product-centric operation, each aeronautical product is maintained separately, which means that a change in aeronautical information must be manually propagated through every product. In a data-centric environment aeronautical products are created from a single logical data source, so that aeronautical data changes automatically propagate through all products. To enable this future, AIXM supports aeronautical information collection, dissemination and transformation throughout the data chain.

In 1999 EUROCONTROL began development of AIXM as a data exchange specification for establishing a centralized reference database of quality-assured aeronautical information for AIS: the European AIS Database (EAD). The success of the EAD has spurred other aviation community members to consider AIXM for adoption as an international standard for aeronautical information exchange.

AIXM is an exchange standard describing the aeronautical data necessary for international air navigation. The model accommodates:
- ICAO standards and recommended practices (especially Annex 4 and 15)
- Industry requirements such as ARINC 424 and EUROCAE ED-99/RTCA DO-272
- Civilian and military aeronautical data

The AIXM standard has two main components. One component describes the concepts of the aeronautical information domain as a collection of features, properties and relationships. This component is referred to as the Aeronautical Information Conceptual Model (AICM). The AICM can be used as the basis for the design of an AIS database. The second component derives from AICM and describes how to encode aeronautical data in a format that can be transmitted electronically between computer systems. The second component uses XML (Extensible Markup Language) as a language for system-to-system exchange. This component is also referred to as the XML Schema of AIXM.

With the support of the international community, the United States Federal Aviation Administration and EUROCONTROL are preparing AIXM for global adoption. An analysis of version 3 and 4 showed that AIXM sufficiently covers the scope of the aeronautical domain, but the exchange standard is too narrowly focused on a single application: data collection and dissemination from a centralized database. In addition, new international geospatial data standards and models (published after AIXM was created) are not included in AIXM version 4. It would benefit the aviation community if AIXM adopted these international standards for geospatial data.

As a result of this evaluation, AIXM needs to be refactored to support a wider range of applications and aviation requirements. AIXM version 5 is designed to meet these expanded requirements for aeronautical information exchange:

*   Alignment with ISO 19100 series standards for geospatial information, including the use of the Geography Mark-up Language (GML);
*   Inclusion of a temporality model, including support for distribution of information of temporary nature and of short duration contained in NOTAM;
*   Support for the latest industry and ICAO requirements for aeronautical data, including obstacles, terminal procedures and airport mapping databases;
*   Modularity and extensibility to support current and future aeronautical information messaging requirements

AIXM version 5 provides an international standards-based approach to modeling and exchanging aeronautical data.   With version 5, AIXM is positioned to support current and future data model and data exchange needs. For more information on AIXM version 5 visit www.aixm.aero.

2 Introduction to AIXM 5

2.1 Mission

The goal for AIXM 5 is to provide an extensible, modular aeronautical information exchange standard that can be used to satisfy information exchange requirements for current and future aeronautical information applications. These applications include:
- Automated production of Aeronautical Information Publications (AIPs)
- Automated aeronautical chart creation and publication systems
- Integrated, geo-spatial NOTAMs (e.g., xNOTAM)
- Aerodrome Mapping Databases (AMDBs) and related applications
- Electronic Flight Bag data requirements
- Cockpit situational displays and Flight Management System (FMS) data requirements

2.2 Scope

AIXM covers the information dissemination needs for the aeronautical domain. We follow the spirit of the ICAO definition of aeronautical data from Annex 15, which refers to the data necessary to support international air navigation [1]. From a high level point of view, it covers:
- Aerodrome/Heliport data
- Navigation Aids
- Terminal procedures
- En Route structures
- Airspace boundaries
- Air Traffic Control and NOTAM services
- Traffic restrictions
- Other data related with the above major concepts

The data publication requirements stated in the ICAO Annexes are fully supported. In addition, we intend to support a number of emerging requirements, expressed in "user requirements" documents issued by industry. The "airport mapping requirements" published by RTCA/EUROCAE are the most prominent example.

AIXM should also cover military aeronautical information, to the extent by which military data is published in Military AIPs. As long as the military specific features, attributes, list of values remain represent a small proportion (less than 5% in version 4) in the model content, it has not been considered necessary to segregate it from the rest of the model

2.3 AIXM – One of many Aviation Standards

There exist a number of related domains, which are part of the AIXM context and which are not part of the AIXM scope:
- Flights (FLT Objects)
- Weather and meteorology
- Air traffic management
- Terrain
- Airport operations
- Environmental Information
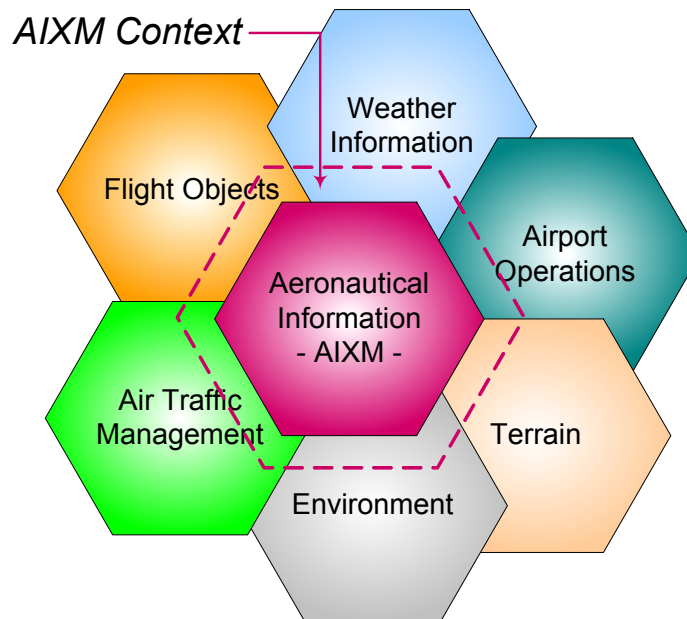
We think that the modelling approach and the set of international standards (such as the ISO 19100, the temporality model, GML) used for AIXM 5, are also applicable to the related domains, with potential positive impact on interoperability.

2.4   Background

AIXM stand for the Aeronautical Information Exchange Model. AIXM was initially developed by EUROCONTROL in 1999.

The AIXM standard has two main components. One component describes the concepts of the aeronautical information domain as a collection of features, properties and relationships. This component is referred to as the Aeronautical Information Conceptual Model (AICM). The AICM can be used as the basis for the design of an AIS database. The second component derives from AICM and describes how to encode aeronautical data in a format that can be transmitted electronically between computer systems. The second component uses XML (Extensible Markup Language) as a language for system-to-system exchange.   This component is also referred to as the XML Schema of AIXM. For a more detailed introduction to AICM and AIXM see [13].

AIXM has six high-level conceptual areas:
- Airspace
- Organizations and Services
- Navigation Aids and Designated Points
- Routes including usage restrictions
- Terminal Procedures, SIDs and STARs
- Aerodromes and Heliports

AIXM release 3.3 has been used for several years within EUROCONTROL for collection and distribution of aeronautical data within the European AIS Database (EAD). The AIXM release 4.5 is currently being implemented in the EAD and operations based on this release will start by the end of 2006. These initial versions of AIXM focused on encoding and exchanging data identified in ICAO Annex 15, to support creating the AIP (Aeronautical Information Publication) and aeronautical charts.

Since 2002, the United States, Japan and other countries, in partnership with EUROCONTROL, have been working to enhance AIXM as a global standard for aeronautical information exchange.

2.5   AIXM 5 Model objectives

Our objective is to develop a globally applicable aeronautical information exchange standard that takes advantages of existing information engineering standards and can support current and future aeronautical information system requirements.

With the planned version 5, AIXM 4.5 will be refactored to support the latest international aeronautical data exchange requirements in the following areas:
- Expanded terminal procedures model that accommodates the latest PANS-OPS and TERPS requirements for data publication.
- Expanded obstacle model in compliance with the latest ICAO and industry requirements
- Support for static and dynamic aeronautical data (e.g., xNOTAM)
- Support for aerodrome mapping as expressed by industry data requirements

This release of AIXM is also intended to be the framework for developing standardized system to system interfaces for all aeronautical information services. Not only traditional AIS operations like aeronautical data collection and aeronautical information distribution, but also:
- Support for avionic systems updates like "electronic flight bag"
- Notice to Airmen (NOTAM)
- Aeronautical chart production
- Procedure design
- Airspace system analysis and design improvements

Finally the AIXM 5 model will incorporate the latest information engineering standards and modelling techniques including:
- Alignment with the ISO 19100 series geo-spatial standards including the ISO 19107 spatial schema and 19108 temporal schema.
- Use of UML (Unified Modelling Language) for the AICM 5 conceptual schema

Incorporating the latest standards into AIXM will enable adopters to make use of the latest COTS technology and tools to obtain a fast return on investment from AIXM. Some technologies that will be enabled by AIXM 5 include:
- UML modelling tools for creating software classes, relational databases and XML documents
- COTS GIS
- Web Feature Services (WFS)

2.6   Supporting legacy AIXM adopters

AIXM 5 is based on the foundation of AIXM 3.x and 4.x. In fact, approximately 80% of the conceptual schema used to build AICM 5 is based on the latest AICM 4.5 data model. An important component of the AIXM 5 design is protecting legacy investments in AIXM and providing a path for migrating systems.

2.7   Development Team

The AIXM 5 development is a joint effort by an international drafting group led by FAA and EUROCONTROL, with the support of a number of States and organizations. On the European side, France, Norway, Spain, Switzerland and Ukraine are actively supporting the EUROCONTROL Agency in this activity, through their involvement in the "AIXM 5 Focus

Group". On the United States side, FAA is working in close cooperation with the United States National Geospatial Intelligence Agency (NGA).

The group is open for contribution by any State or organisation that supports our goals and objectives. All deliverables, when considered sufficiently mature to be discussed in a wider group of stakeholders, are being made available for public review through the www.aixm.aero portal site.

3 Document organization and references

3.1 Document description

This document is organized into subsections as described below:

- **Section 4. Current and Future AIM information flows**
  This section provides an overview of aeronautical information management data flows as a motivation for developing an international standard for aeronautical information interchange.
- **Section 5. Version 5 Requirements and Approach**
  In this section we identify the main requirements for the aeronautical information exchange model and discuss our modeling assumptions and approach.
- **Section 6. Architecture**
  Section 6 summarizes the major architectural decisions.
- **Section 7. Requirements Analysis & Design Recommendations**
  This section analyzes information exchange requirements. We review how the requirements were implemented in earlier releases of AIXM, present a conceptual model and design satisfying each requirement.
- **Section 8. AICM and AIXM 5 Implementation**
  Describes AICM and AIXM implementation.
- **Section 9: Profiling AIXM 5**
  (To be completed). This section will cover the concept of modularity from the point of view of selecting kernels of features, relationships and attributes to be included in a specific application schema.
- **Section 10. AIXM Namespace Convention**
  (To be completed) The purpose of this section is to present a scenario that uses AIXM for data exchange between systems to illustrate how AIXM 5 framework supports a range of aeronautical system to system exchange requirements.
- **Section 11. AIXM Namespace Convention**
  This section summarizes AIXM Namespace conventions that support feature identification and feature relationships.
- **Section 12. GML Introduction**
  This section is an introduction to GML and GML benefits.

3.2 Definitions and Acronyms

The following definitions and acronyms are used through the AIXM 5 Design document.

AICM — Aeronautical Information Conceptual Model. A component of the AIXM data standard that provides a conceptual data model of aeronautical data. The AICM data model is the basis for the XML Schema of AIXM.

AIM — Aeronautical Information Management. The strategy of managing aeronautical information from origination to use in the aviation system. It is data (collection, storage, transfer) centric as opposed to the traditional product (AIP, chart) centric AIS.

AIP — Aeronautical Information Publication. An ICAO publication containing aeronautical information for a state. The content of the AIP is described in ICAO Annex 15.

AIRAC — An acronym (Aeronautical Information Regulation And Control) signifying a system aimed at advance notification based on common set of effective dates. The effective dates are used to promulgate significant changes in operating practices at set times.

AIS — Aeronautical Information System. The system that provides

	aeronautical data services in support of aviation.
AIXM	Aeronautical Information Exchange Model. A standard for aeronautical data based on ICAO, State and industry requirements. AIXM consists of an Aeronautical Application Schema in UML called AICM and an XML Schema that can be used to encode and exchange aeronautical data.
AMXM	Aerodrome Mapping Exchange Model
AMXS	Aerodrome Mapping Exchange Schema
ARINC	Aviation communications company. Author of common avionics transmission specifications, such as the ARINC 424 format for transferring aeronautical data to Flight Management Systems (FMS) data providers. http://www.arinc.com/aviation.html
EAD	European AIS (Aeronautical Information System) Database. For centralized collection, storage and distribution of European Civil Aviation Conference (ECAC) member State AIS data.
EUROCAE	European Organization for Civil Aviation Equipment. A forum for government, industry and airlines to discuss technical problems and issue specifications. http://www.eurocae.org
EUROCONTROL	The European Organisation for the Safety of Air Navigation. http://www.eurocontrol.int
FAA	United States Federal Aviation Administration
ICAO	International Civil Aviation Organization
NAVAID	Navigation Aid.
NOTAM	Notice to Airmen. A notification of a temporary event that has caused a change in the operating conditions of the aviation system.
PANS-OPS	ICAO DOC 8168 - Procedures for Air Navigation Services – Aircraft Operations.
RTCA	United States organization that acts as a Federal Advisory Committee providing recommendations regarding national airspace system issues such as communications, navigation, and air traffic management. http://www.rtca.org
SARPS	ICAO Standards and Recommended Practices.
SID	Standard Instrument Departure. A prescribed flight procedure used to navigation an aircraft from takeoff to the boundary of the terminal environment.
STAR	Standard Instrument Arrival. A prescribed flight procedure used to navigate an aircraft from the en route environment to a terminal procedure used to land at an airport.
TERPS	Terminal Procedure rules followed by the FAA and other countries when evaluating the feasibility of terminal procedures. Considers obstacles, terrain, aircraft characteristics and procedure design to determine the safety of the procedure.
UML	Unified Modeling Language

3.3 References

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Requests for copies of FAA Contract Deliverables and AIM meeting references should be made to Brett.Brunk@faa.gov. EUROCONTROL documents can be found on EUROCONTROL One-Sky online (https://extranet.eurocontrol.int).

4 Current and Future AIM information flows

The key driver for aeronautical data exchange requirements is the current and future AIM (Aeronautical Information Management) data flow. This section summarizes aeronautical information flow today and how it might evolve in the future (See illustration in Figure 1).
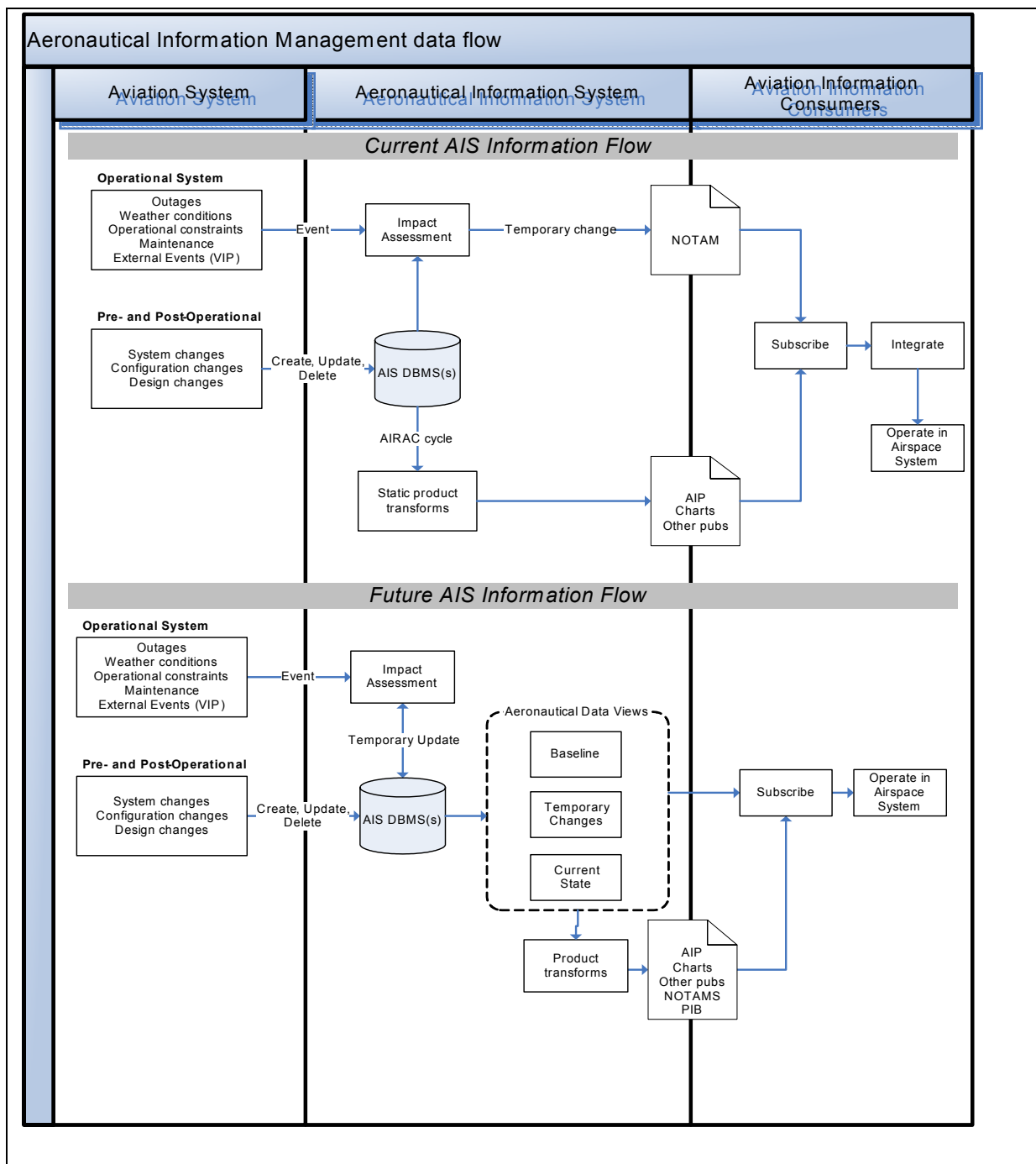
4.1 Current AIS data flow

Today, the AI (Aeronautical Information) data flow is product-oriented and characterized by disconnects between static data updated on the AIRAC cycle and temporary changes promulgated through NOTAM. Often NOTAMs and static publications (e.g., AIPs) are produced by different units resulting in more possibility for disconnects between products.

End users (AI Consumers) must subscribe to multiple aeronautical data products in order to obtain a complete view of the airspace system. AI Consumers are responsible for collecting and integrating static and temporary aeronautical data into a complete (and unfortunately sometimes contradictory) view of the operational airspace system.

4.1.1 Static aeronautical data flow

Generally today's AIS track static aeronautical data that is updated and published on regular AIRAC cycles. Changes to aeronautical data usually originate from pre- or post-operational system changes that result in new, deleted or updated features. For example, procedures designers may develop new terminal procedures for an Aerodrome that need to be incorporated into the static AIS data set. At the next AIRAC update cycle, the new procedures are distributed and activated

It should be stressed that for many AIS data providers, the static aeronautical data workflow has been totally document oriented with varying degrees of automation assistance. Static AIS systems employ automated and manual transformation engines to create and distribute familiar aeronautical products such as the Aeronautical Information Publication (AIP), charts and AIP Supplements. These publications are made available to AIS consumers for use when operating in the aviation system.

4.1.2 Dynamic AIS data flow

Today, dynamic AIS changes are communicated via NOTAM, AIRAC amendments and permanent NOTAM. As a result of an aviation system event, such as a facility outage, weather issues or other perturbation, one or more change notices may be issued to describe the effect of the event on the aviation system. Generally these changes are temporary changes (e.g., NOTAM) with defined start and end dates, although the start and end dates may not always be known.

NOTAM creation often involves an impact assessment in which static aeronautical data is analyzed to determine which aviation system resources are affected by the event. For example, a NAVAID outage may also affect procedures into an airport. These effects are communicated in the NOTAM, but generally no attempt is made to integrate the NOTAM changes into the aeronautical data set that is stored in the AIS database.

NOTAMs are highly abbreviated messages that follow a specific format designed to support limited bandwidth distribution systems. The NOTAM format includes a limited set of data fields such as the NOTAM Selection Criteria (NSC) code designed to encode the purpose of the NOTAM. In general, however, NOTAM content is unstructured and in their present format, NOTAMs are unsuitable for computer interpretation.

Aeronautical Information Consumers subscribe to NOTAM publications and must integrate the NOTAM information with the static AIS publications in order to safely and effectively operate within the airspace system. In some cases, NOTAM data flow and static data flow are provided by separate units with quite poor connections in between.

4.1.3 Current automation

Today AIS data flow automation is limited and disconnected. The AIXM data exchange standard is used successfully in regional systems such as the EAD (European AIS Database) to electronically transmit aeronautical information from States to a centralized reference database and further downstream to data integrators and end users. In addition, several static and dynamic AIS products are available digitally, for example:
- NOTAM are available on the Internet (http://tfr.faa.gov for example) or through custom distribution channels
- Many charts and publications can be obtained in HTML or PDF

However these digital products are not integrated and they generally express content in human readable formats making it difficult to incorporate into downstream computer processing.

4.2 Future AIS dataflow

In the future, AIM systems are expected to integrate static and temporary change in a more data oriented approach.

4.2.1 AIS inputs

In the future concept, aeronautical data inputs would come from static changes as well as dynamic airspace system events. Design activities[*] (pre- and post-operational) will lead to new, deleted and changed aeronautical features. Operational system events such as weather, facility maintenance and other operational constraints will be captured as events. Events may affect one or more aeronautical features. These aviation system events will be integrated with the static aeronautical data.

4.2.2 AIS data representation

Future AIM systems are expected to operate using three aeronautical temporal views:
- Baseline Data – representing the state of a feature and all its properties between two permanent changes, as communicated during regular AIRAC update cycles.
- Temporary Data – representing changes to aeronautical data that result from system events.
- Current Data – representing the current state of a feature at a point in time. The current state is the reconciliation of the Baseline Data with any active Temporary Data.

Automated product transforms can be used to create traditional AIS products such as AIPs and NOTAM. Through electronic data exchange it is expected that these traditional aeronautical products will be enhanced to include "just in time" publication and product customization.

4.2.3 Future AIS data products

The future of AIM is creating integrated data repositories that enable efficient, timely and on-demand access to database driven product generation or information usage. Systems will be able to seamlessly merge static and dynamic aeronautical data updates to provide a view of the airspace system at a single point in time or over a time interval.

AIS Consumers are expected to have access to traditional AIS products as well as direct electronic data feeds. When static and dynamic aeronautical data are merged, AIM products such as AIPs, charts and other publications can be tailored to include:
- Permanent information as reflected in AIRAC updates (Baseline)
- Permanent information overlaid with temporary information
- Actual system state at a moment in time (Snapshot)

Permanent information overlaid with temporary information might include a view of the static aeronautical data with the temporary changes highlighted. Figure 2 illustrates this approach in an example taken from the Final Demonstration xNOTAM/AMDB EUROCONTROL study completed by the Technical University of Darmstadt [20]. This drawing shows a cockpit

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[*] Design activities include tasks like procedure design, airspace redesign or traffic flow rerouting activities that attempt to improve the operating environment. Often these design activities occur pre-operationally meaning they are instigated through strategic initiatives to improve the aviation system. Alternatively the design activities may be instigated post-operationally as a result of observing the current behaviour of the aviation system.

display of an airport. A runway is closed for landing and take off. The closed runway is graphically displayed using the red x's.

Figure 2: Notional cockpit display showing static data and dynamic data indicating a taxiway closure.

In addition to traditional products, a fully integrated AIM system will be able to support new AIS products such as Obstacle Databases and new user requirements, such as Aerodrome Mapping Databases (AMDBs).

4.3   Implications for data standardization

Mechanisms for international data exchange are crucial to realizing the future AIM system. An integrated view of the global aviation system will require advanced automated systems that can capture and integrate aeronautical data from multiple sources. These future systems can only evolve if common standards are used to represent aeronautical data. AIXM fulfills this goal by providing:

- A common international language for aeronautical data and concepts
- A computer interpretable standard for encoding, transmitting and receiving aeronautical information
- A standard mechanism to represent dynamic data.
- A framework for developing system to system interchange messages.
- A design that incorporates best practices and global standards

5 Version 5 Requirements and Approach

The purpose of this section is to introduce the key modeling goals and describe our modeling and analysis approach.

5.1 Version 5 Requirements

Since its inception AIXM has been based on a desire to develop a standard for aeronautical information dissemination. The core requirements of AIXM 3 were [3]:
- Globally applicability data exchange standard
- Compliant with ICAO SARPS (Standards and Recommended Practices)
- Support international aeronautical information exchange requirements of the EUROCONTROL states

Several states, agencies and companies outside the EUROCONTROL showed interest in adopting AIXM and enhancing AIXM to support use cases beyond AIXM's original intent. As a result, the requirements for AIXM 4.x were expanded to include [2]:
- International aeronautical information dissemination of the stakeholder States
- Support a wide spectrum of aeronautical information services applications
- Protect legacy investments by providing a full backwards compatibility model

Further analysis showed that developing an aeronautical data model that fully supports global needs for international aeronautical information dissemination as well as incorporating contemporary international data modeling standards will require refactoring the AIXM model. To that end, AIXM 5 was envisioned as a major release incorporating the following requirements [2]:
- Full coverage of aeronautical domain data content
- Feature identification and relationships
- Geometry
- Temporality
- Extensible data model
- Extensible exchange message framework
- Modularity
- Alignment with ISO geo-spatial standards

5.2 AICM and AIXM

There is often confusion about the relationship between AICM and AIXM. Most often, new AIXM adopters focus on the exchange language, AIXM. At other times both terms are used interchangeably.

We use the term AIXM to represent the international aeronautical information exchange standard. AICM is a part of AIXM. AICM is an implementation-independent conceptual model for the aeronautical domain that tries to capture aeronautical information supporting international air navigation. The role of AICM is to enable systems to manage aeronautical information and to enable humans to communicate and understand the information that is managed. For version 5, AICM is represented as an object model using UML.

The XML Schema for AIXM 5 is the XML exchange format based on AICM.

5.3   Approach

5.3.1 Modeling guidelines

Earlier in this document the AIXM modeling domain was broadly defined based on ICAO Annex 15 as all aeronautical information required to support international air navigation [1].

We interpret this requirement to mean that the aeronautical domain covers the following features:

- All physical entities that aid in aircraft movements from departure point to arrival point.
  - Aerodrome layout supporting aircraft movement, takeoff and landing
  - Navigation aids
  - Lighting, landing systems and other physical infrastructure that aids in navigation.
- All physical entities that have to be taken into consideration in order to protect the movement of aircraft in the air
  - Obstacle, both natural and man-made
- All conceptual entities that enable aircraft to operate in the air traffic system
  - Fixes, waypoints and other designated points
  - Routes and procedures
  - Airspace
  - Flow restriction rules
- All organizations, units and services that provide for the provisioning of air navigation
  - Air traffic control facilities
  - Pilot briefing services, NOTAM offices and flight information services

These features have properties that characterize the features and there are relationships that link many of these features with each other. Often the properties and relations of a feature are tied to a specific implementation or system. For example, a charting system may be interested in properties such as feature styling (color, line thickness, etc) that are irrelevant for flight planning systems. Besides charting, other applications include:

- Design activities
- Avionic system updates
- Flight planning and simulation
- Data collection and validation
- Facility maintenance and management
- Air navigation / Air traffic control

Each of these application areas can have its own view on the properties and relationships of a feature. Many of the properties and relationships used in these specific systems may not be good candidates for the exchange model because the applications are country or system specific.

In AIXM our focus is on feature properties and relationships that directly support aircraft navigation in the air and on the ground and thus have relevance to pilots, aircraft and air traffic control. Air navigation is the fundamental purpose of aeronautical data and by focusing the AICM and AIXM model on air navigation it is our intent to provide a generally applicable model that can be readily adapted to support more specialized applications and systems.

Relationships are used to connect features to each other. For instance a Runway is on an Aerodrome and a Route Segment startsAt a Significant Point and endsAt a Significant point. Like properties, it is important to set boundaries on the types of relationships that will be supported in the model.

We use the term *derived relationship* to indicate a relationship that can be calculate or obtained by using more fundamental relationships. For example, a route segment may cross and airspace border. The relationship between the route segment and airspace border is geometric and it could be represented explicitly in the data model. In this example, most would probably say that this relationship does not belong in the model – instead it is derived through a spatial operation. In other situations, characterizing a relationship as fundamental or derived is more difficult to determine. A VOR can be collated with a DME. Is that a derived relationship or a fundamental relationship? In AICM 4.x the relationship is modeled and considered fundamental to AICM, because collocation implies more than a simple geographical vicinity. Collocated NAVAIDs also have frequency pairing and the same ID.

In version 5 we have tried to avoid modeling derived relationships especially when these relationships cross conceptual areas.

Finally we note that version 5 is based on AIXM 4.5. As a result, version 5 inherits much of its modeling style from previous releases. In some cases the guidelines defined above may have not been followed in the past. In these situations we have decided to keep the legacy model unless the area is undergoing significant refactoring. It is our intent to review these modeling issues in future incremental releases of AICM/AIXM 5.

5.3.2 Alignment with ISO Geo-spatial standards

The ISO Technical Committee 211 (TC211) is responsible for developing the ISO 19100 geographic series of standards. The purpose of these standards is to provide a common framework for developing domain specific standards based on geography. The ISO TC211 standards include temporal, metadata, and spatial schemas. In addition, the major GIS (Geographical Information System) XML standard, GML (Geography Markup Language) is scheduled to be integrated into the TC211 standards by 2007.

To the extent feasible, AIXM should use established standards for data modeling, geographic representation, temporality and metadata. By aligning with the ISO 19100 series, AIXM gains the following benefits:
- Increased global interoperability with other data standards
- Improved data modeling by leveraging analysis and design decisions developed by the ISO TC211 committee
- Standardized data models by supporting standard representations for common constructs such as temporality and geometry.
- Increased credibility by demonstrating that AIXM is incorporating international standards.
- Cost and efficiency improvements by leveraging COTS tools and products that are also based on the ISO standards.

5.3.3 Methodology

In our analysis and design work we applied the following methodology:
1. Evaluate how well the current AIXM 4.x data exchange specification meets requirements and identify any short coming that need to be addressed in the AIXM 5 specifications.
2. Review industry and international standards to determine if there is a standard that satisfies the requirements.
   - If a standard can be found that meets most of the requirement then adopt the standard and adapt requirements to be compliant with the standard
   - If a standard exists but is inadequate then adapt or extend the standard and work to influence the standards organization.
3. Develop or adapt a model that satisfies the AIXM exchange specification requirements.
4. Implement the requirements at the conceptual level and at the XML exchange specification level.

5.3.4 Modeling conventions

A separate document called "Data Modeling Conventions for AIXM 5" describes terminology and standards used to develop the AIXM 5 UML model.

6 Architecture

The purpose of the model architecture is to present a framework for AIXM 5 so we can ensure that AIXM 5 is robust enough to support aeronautical information exchange for the long term.

In this section we summarize major design decisions as a series of architectural views:

- **ISO 19100 Series view** – AIXM within the ISO19100's framework
- **AIXM Framework view** – The AIXM framework and how it enables system to system information interchange.
- **Implementation view** - Relationship between AIXM and how legacy investments in AIXM 4.x will be protected and migrated to version 5.
- **Aeronautical Domain view** – Model organization based on loosely coupled subject areas within the aeronautical domain
- **Data modeling compartment view** – separation of data modeling components to simplify versioning and extensibility

6.1 ISO 19100 Series view

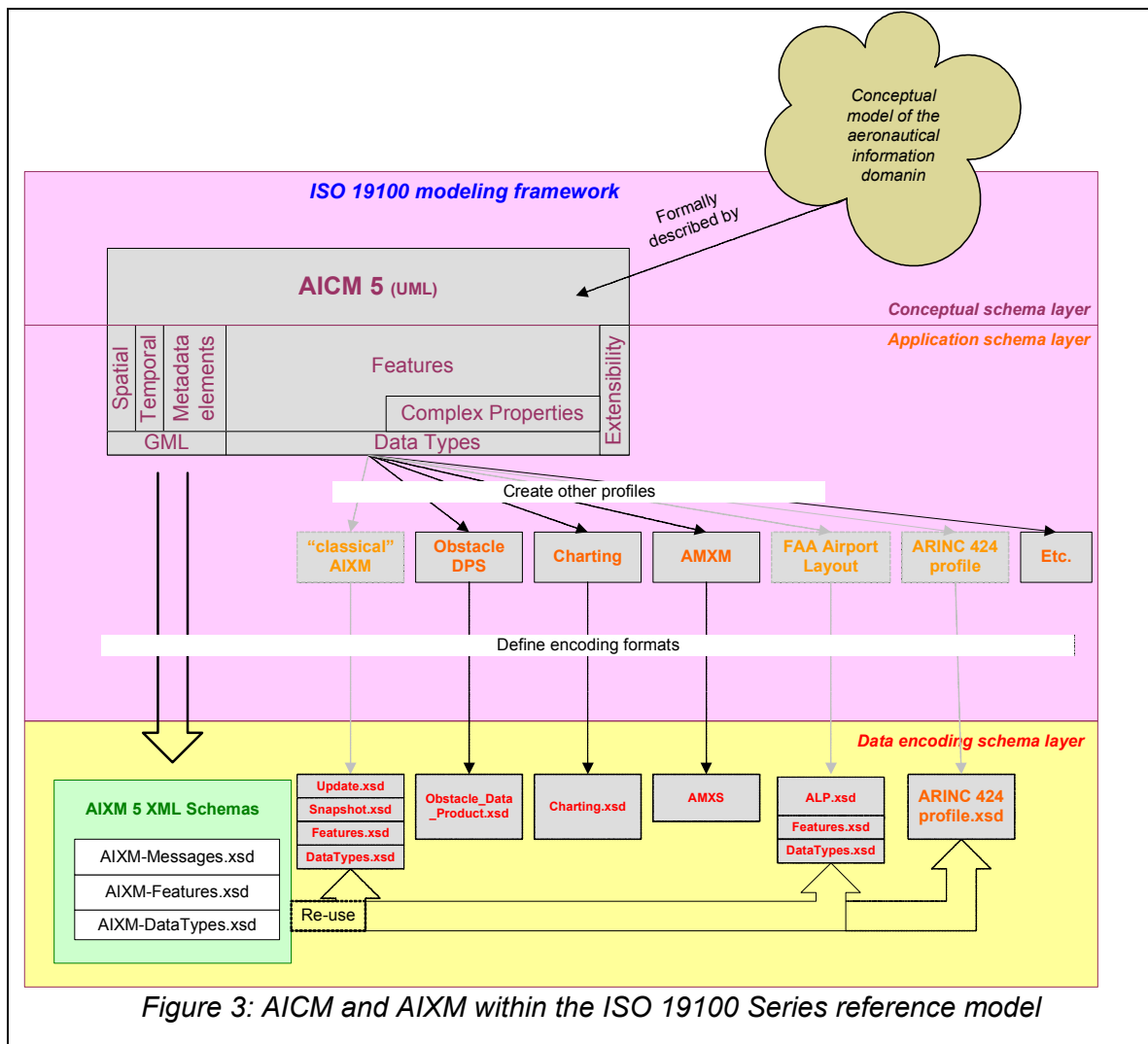*Figure 3: AICM and AIXM within the ISO 19100 Series reference model*

Figure 4 shows how AICM and AIXM fit within the ISO 19100 series reference model.

The Application Schema Layer is where the domain model is constructed. ISO 19100 series includes a set of model frameworks to help build application schemas. These include spatial, temporal, and metadata application schemas as well as a general feature model. These modeling frameworks are used to build the AIXM 5 conceptual schema in UML and the AIXM 5 XML Schema. The AIXM exchange schema implements AICM using GML. GML 3.2 is an XML realization of the ISO19100 series standards that is expected to be published in 2007.

One component of the ISO 19100 modeling framework consists of Data Product Specifications. Data Products define data sets that are used in systems. Examples of data products might include:

- **AMDB** – Aerodrome Mapping Databases
- **Airport Layouts** – Full CAD details of an airport.
- **AIXM 4.5 Snapshot/Update** – Data product specifications, as currently used in collection and dissemination of aeronautical data through the EAD.
- **ARINC 424** – a data product specification for transferring aeronautical data to flight management systems data providers.
- **xNOTAM** – a data product specification for communicating notices of temporary changes to the aviation system.

It should be noted that from the above examples, currently, only the AMDB is supported by a Data Product Specification (AMXM) that complies with the ISO 19100 modeling framework.

6.2   AICM / AIXM Framework view
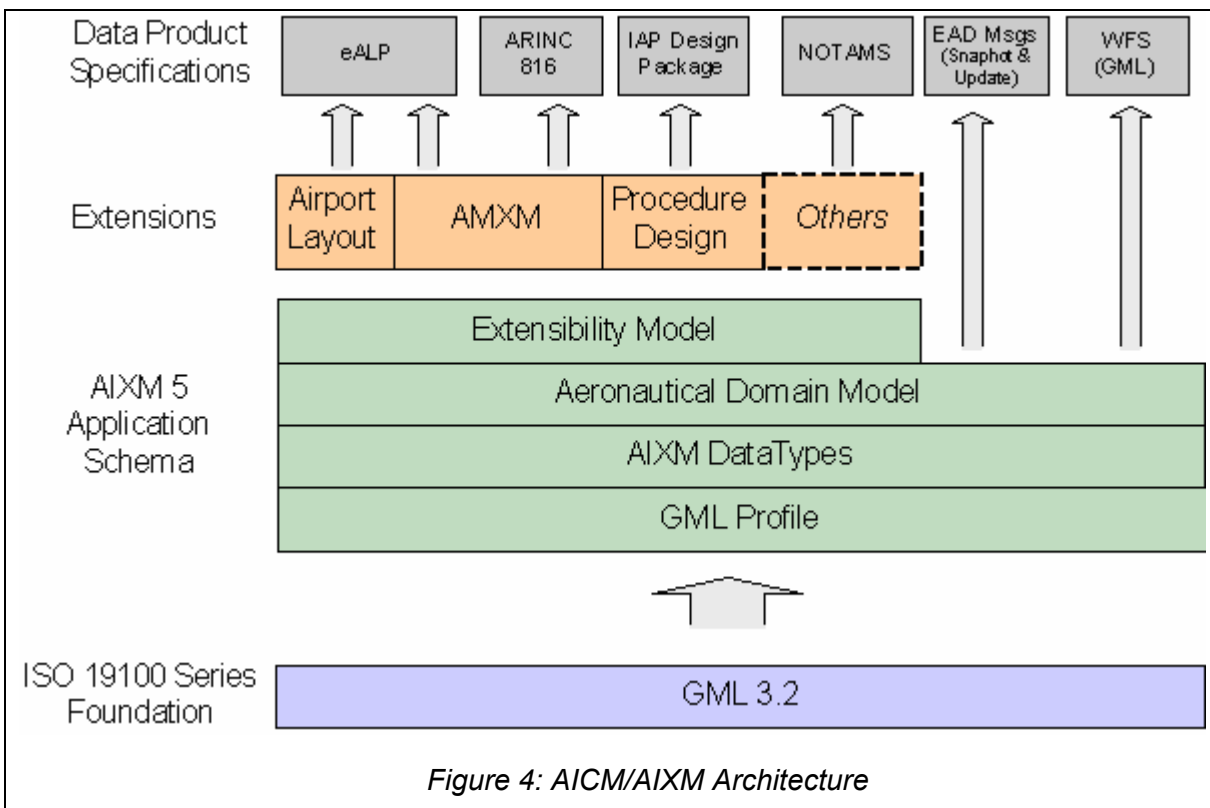
Figure 4: AICM/AIXM Architecture

Building upon the underlying ISO 19100 series foundation, AIXM has been developed as a framework for supporting aeronautical information exchange. The framework includes:

- A profile of GML that specifies the features of GML that are incorporated into AIXM.
- Common set of data types and values domains used for aeronautical data.
- Core aeronautical data model supporting international air navigation
- Provisions for extending the AIXM data model to support additional applications by allowing for new properties, relationships and messages.

Using the framework, communities of interest can develop extensions to support specialized requirements. Example extensions might include:
- Airport Layout
- Procedures Design

At the application level, systems take the core AIXM 5 features along with extensions to develop a series of data products or messages that will be used for information exchange.

6.3   Implementation view

Figure 5: Implementation view (Supporting Legacy Systems)
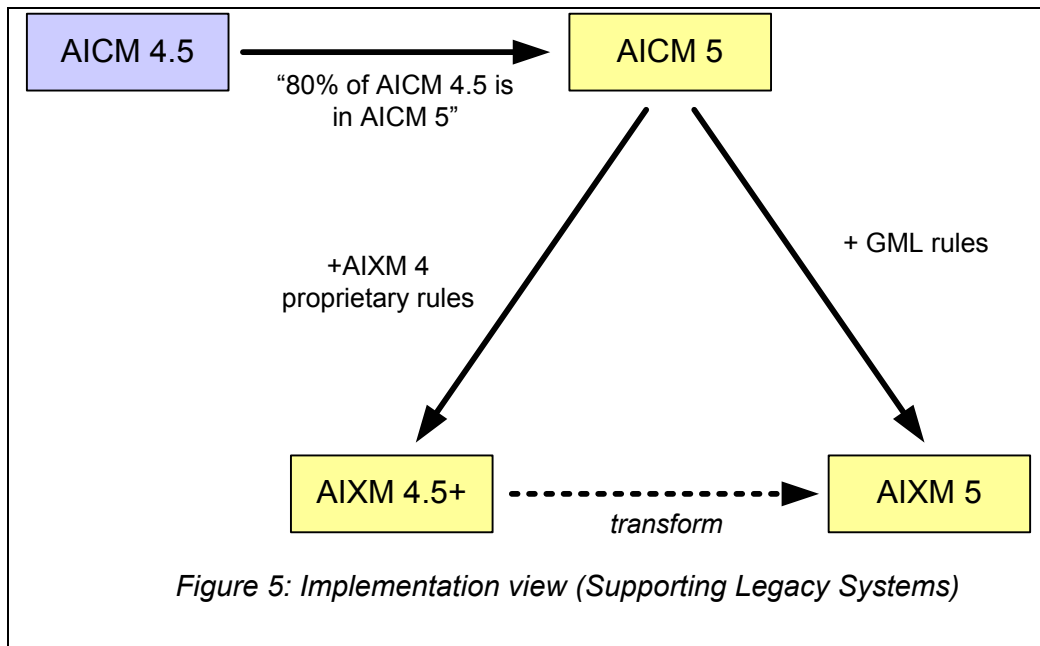
As much as possible AIXM 5 should preserve legacy investments and provide a path for systems migrating from AIXM 3.x and AIXM 4.x.

The cost of transiting from legacy AIXM to AIXM 5 will be reduced by basing AIXM 5 on the AIXM 4.5 data model. It is expected that roughly 80% of the current AIXM 4.5 model will be carried over and implemented as part of AIXM 5. Most of the major design changes such as alignment with the ISO standards, incorporating temporality and modelling AICM in UML should have little effect on the content of the conceptual model.

AIXM 5 will then become the basis for the AIXM 5 exchange model by applying GML application schema rules to generate AIXM 5. At the same time it is possible to transform AIXM 5 using the proprietary AIXM 4.x encoding rules to create an AIXM 4.5+ that has the same XML style of AIXM 4.5 but also incorporates changes to the aeronautical conceptual areas.

Since both AIXM 4.5+ and AIXM 5 derive from the same conceptual model one could encode the same feature content in both exchange models (Of course, AIXM 4.5+ would remain limited to the <AIXM-Snapshot> and <AIXM-Update> messages only and would not be able to leverage GML capabilities, temporality and other AIXM 5 advanced features). In fact, it should be possible to create a one way transformation that converts AIXM 4.5+ XML into AIXM 5 XML.

6.4   Aeronautical domain view

Figure 6: Aeronautical domain view
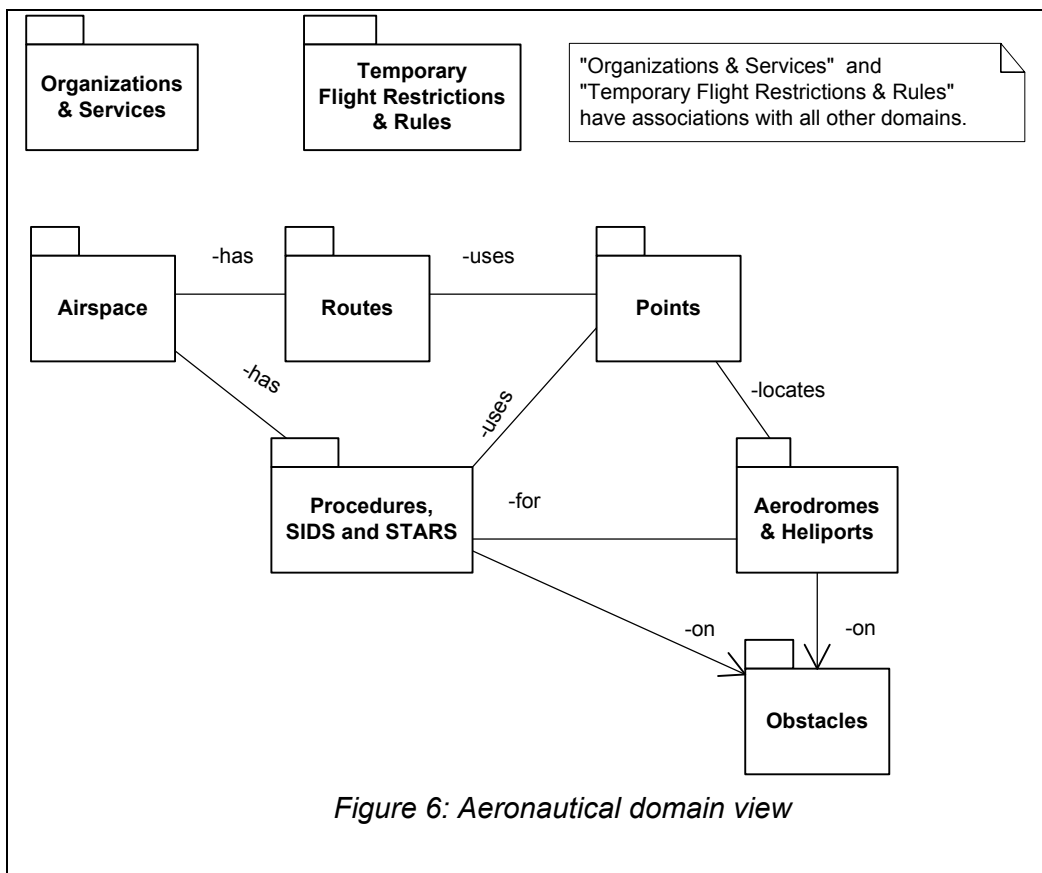
The Domain View shows how the AICM/AIXM 5 model is subdivided into loosely coupled concept areas. In the diagram the associations are meant to represent connections between the areas. In AIXM there are eight major conceptual areas:

- **Organization & Services.** Describes organization authorities and units responsible for other aeronautical facilities and systems. Describes services provided by aeronautical assets such as Air Traffic Control services provided in Air Traffic Control Sector airspace. Organization & Services has associations to all other concept areas.
- **Temporary Flight Restrictions & Rules.** Encodes flight plan restrictions that limit aircraft access to the airspace system in support of traffic flow management strategies. Temporary Flight Restrictions & Rules has associations to all other concept areas.
- **Airspace**. Defines volumes of airspace of different types. Airspace is also used to define protection areas for Routes, Procedures, SIDs and STARS.
- **Routes**. Defines the en-route route structure. Routes use significant points as the start and end of each route segment.
- **Significant point.** Includes navigation aids, fixes and waypoints used to define the trajectory of an aircraft in flight or as aid in navigation.
- **Procedures**, SIDs and STARs. Routes used for arrival, landing and departure at an aerodrome or heliport.
- **Aerodrome & Heliport.** Defines aerodrome and heliport layout and facilities, navigation services and access restrictions.
- **Obstacles**. Defines natural and man-made obstacles and includes associations as controlling obstacles on terminal procedures and as significant obstacles on an aerodrome/heliport.

6.5 Data modeling compartment view

Figure 7: Data modelling compartment view
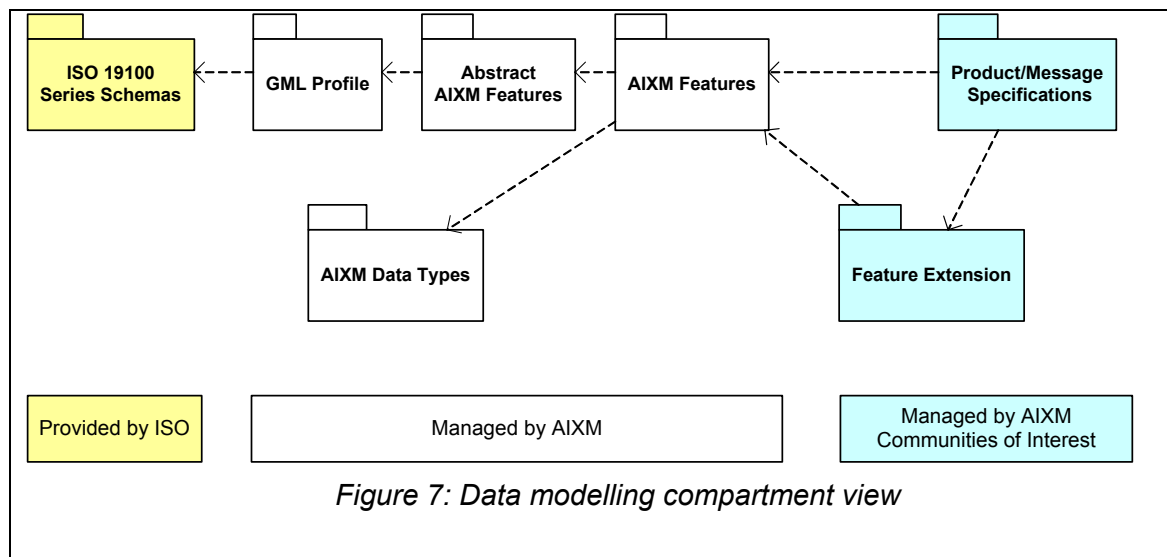
The data modeling compartment view shows the AIXM 5 specification broken into information units to make it easier to configuration manage and version. The yellow ISO 19100 Series Schemas are provided by ISO and is not configuration managed by AIXM. The white packages are under AIXM configuration management and these include:

- **GML Profile**. The subset of GML features implemented in AIXM 5.0
- **Abstract AIXM Features**. Establishes the basic AIXM 5.0 feature model including extensions to the GML Profile supporting AIXM 5.0 requirements and anticipated GML 3.2 changes.
- **AIXM Features**. Definition of all AIXM feature types.
- **AIXM Data Types**. Value domains and enumerations of AIXM Feature properties.

The blue packages are developed by communities implementing the AIXM 5.0 specification. These include:

- **Feature Extensions.** Optional additional feature properties and relationships that are added into AIXM
- **Product/Message Specification.** Defined aeronautical interchange messages based on the extensible messaging framework specified by AIXM 5.

7 Requirements Analysis & Design Recommendations

In this section we present our analysis and design decision for each of the AICM/AIXM 6 main model requirements:

- Full coverage of the aeronautical domain
- Feature identification and relationships
- Geometry
- Temporality
- Extensible data model
- Extensible exchange message framework

7.1 Full coverage of aeronautical domain

AIXM is intended to support AIS data requirements by covering the data needs of the aeronautical domain as described in ICAO Annex 15 [1]. According to Annex 15:

> *The object of the aeronautical information service is to ensure the flow of information/data necessary for the safety, regularity and efficiency of international air navigation. The role and importance of aeronautical information/data changed significantly with the implementation of area navigation (RNAV), required navigation performance (RNP) and airborne computer-based navigation systems. Corrupt or erroneous aeronautical information/data can potentially affect the safety of air navigation.*

> *To satisfy the uniformity and consistency in the provision of aeronautical information/data that is required for the operational use by computer-based navigation systems, States shall, as far as practicable, avoid standards and procedures other than those established for international use.*

EUROCONTROL originally developed AICM and AIXM to support aeronautical data collection and data product harmonization in the European states. EUROCONTROL based the AICM and AIXM 4 data model on:

- ICAO (International Civil Aviation Organization) standards and recommended practices (SARPS)
- Data concepts contained in Aeronautical Information Publications (AIPs) and which are not covered by ICAO SARPS
- Industry standards such as ARINC 424 (mainly for encoding instrument approach and departure procedures)

We interpret the ICAO recommendation to include the standard aeronautical domains identified and modeled in prior AIXM versions:

- Aerodromes and Heliports
- Navigation Aids
- Airspace
- Enroute Routes
- Terminal procedures, SIDs and STARs
- Aeronautical Organizations, Units and Services
- Traffic flow restrictions and rules

These domains contain features, properties and relationships described explicitly in the ICAO Annexes such as:

- Runway threshold locations
- Airway definitions
- Instrument landing system (ILS) descriptions

- Etc.

In addition, we recognize that new ICAO amendments, industry requirements and future AIM concept of operations are increasing the scope of aeronautical data necessary to support international air navigation. Therefore, the scope of AIXM 5 must be expanded to cover those features that might be used for future systems such as:
- Protection surfaces for terminal procedures and airways that might be used as part of an electronic "Flight Bag" to provide pilot alerts
- Temporary flight restriction rules meant to restrict access to aeronautical resources based on system capacity constraints, State regulations and/or strategic and tactical traffic flow management.
- Full situational awareness based on Aerodrome Mapping displays with own aircraft position.

7.1.1 Review of current AIXM data model enhancements

Since the release of AIXM 3.0 in 2002 there has been increased international interest in evolving AIXM to support international requirements for aeronautical information exchange. In recent years the United States FAA and NGA has been actively working with EUROCONTROL to validate the AIXM model and identify areas where the model requires improvement. The recent AIXM 4.x releases have incorporated:
- Value domain changes to accommodate lists of values collected and published by NGA from international sources.
- Improvements to the data models for lighting systems, airspace and, approach lighting systems.

7.1.2 Design recommendations

International review of the AIXM model that has occurred over the past few years have identified several conceptual areas and features that need to be validated and possibly refactored. Table 1 lists these issues and provides a recommended prioritization. Based on past experience, we anticipate that the investigations will validate most of the AICM model. The most critical analyses are in three areas:
- Terminal procedures. A more comprehensive terminal procedure model is needed to support world wide conventional and RNAV procedures.
- Aerodrome mapping. AICM needs to be able to support aerodrome mapping database requirements.
- Obstacles. New obstacle data collection and transmission requirements published by ICAO require that the AICM obstacle model be refined.

Table 1: Summary of aeronautical domain areas that need to be validated and possible modified as part of AICM 5

Area to Investigate	Priority	Comments
Airport Mapping	High	Integrate the Airport Mapping Database requirements. Primarily this involves decomposing existing AICM features, such as a Runway made from a composition of Runway Elements.
Obstacles	High	Incorporate Amendment 33 to ICAO Annex 15. This includes describing obstacles as points, lines or polygons.
Terminal procedures, SIDs and STARs	High	Incorporate both TERPS and PANS-OPS. Update data model with latest

Area to Investigate	Priority	Comments
		PANS-OPS criteria.
Metadata	Medium	Null value handling and integration of the ISO19100 series metadata recommendations.
Military aeronautical information	Medium	Support for aerial refuelling and arresting gear.
Navigation Aids	Medium	Modularize navigation aids and separate physical equipment from navigational services.
Services and Organizations	Low	The services model is not consistent with other model areas in AICM
VFR Procedures	Low	Support for curves and routes that reference geopolitical and topological features.

The data model enhancements stated for AIXM 5 are currently being implemented and the recommended model updates are being provided in separate reports.

The focus of the conceptual area refactoring and improvements is to ensure compatibility with the latest ICAO and aeronautical data requirements as well as more complete coverage of civilian and military data requirements. Costs of data acquisition and maintenance may limit whether the expanded feature model is populated by data providers. The extent to which data providers populate the AIXM data model and comply with the latest aeronautical data standards is an exchange model implementation issue that is beyond the scope of this proposal.

7.2   Feature identification and relationships

Unambiguous feature identification is needed to allow data providers, value-added data and product suppliers as well as end users to be sure that they are communicating about the same aeronautical features.

Within the aeronautical data chain, definitive feature identification is a safety critical issue. Changes to aeronautical data through publications or NOTAM must clearly identify affected features so that pilots and air traffic service providers can correctly respond to the changing aeronautical environment.

With electronic data standards and electronic transmission of aeronautical data, feature identification becomes more critical because new systems are relying on computers to interpret aeronautical information. Persistence of unique feature identification throughout the data exchange chain therefore becomes a requirement.

7.2.1 Feature identification through natural keys in AIXM 4.x

Traditionally, natural keys have been used to identify features in AIXM. According to the AIXM Primer [4]:

> *AIXM-XML employs natural keys in order to uniquely identify feature instances. For example, the unique identifier of a VOR is composed of the position of the station (latitude and longitude) plus the radio identification. The unique identifier of a feature is declared as a separate complex type in the AIXM-Features.xsd sub-schema. For example, the unique identifier of the VOR feature is declared as the VorUidType complex type. The declaration of the VorType contains a child element named VorUid, having as type the VorUidType.*

Natural keys for commonly defined aeronautical features are straightforward:

Table 2: Examples of natural keys for well known features

Aeronautical Feature	Natural Key	Short key definition
Aerodrome	Identifier	Nominally the ICAO or IATA aerodrome code.
NAVAID	Identifier	Nominally 3-character navigation aid code
	Location	Latitude and Longitude

The natural key for some aeronautical features is more complex and may involve references to other aeronautical features:

Table 3: Examples of natural keys involving relationships to other features

Aeronautical Feature	Natural Key	Short key definition
Route Segment	Route Natural Key	The route segment applies to a route
	Start Significant Point Natural Key	The starting point for the segment
	End Significant Point Natural Key	The ending point for the segment.
Apron	Aerodrome Natural Key	The aerodrome natural key is the identifier of the aerodrome.
	Name	Up to 60 character Apron name.

Aeronautical features such as Runway Direction, ILS and Terminal Procedures can involve references to multiple aeronautical features and also nesting of aeronautical feature keys. For example, Runway Direction natural key is a text designator plus the Runway natural key. But, the Runway natural key is a text designator plus the Aerodrome natural key. The nested natural key for the Runway Direction is illustrated in the XML schema shown in Figure 8.
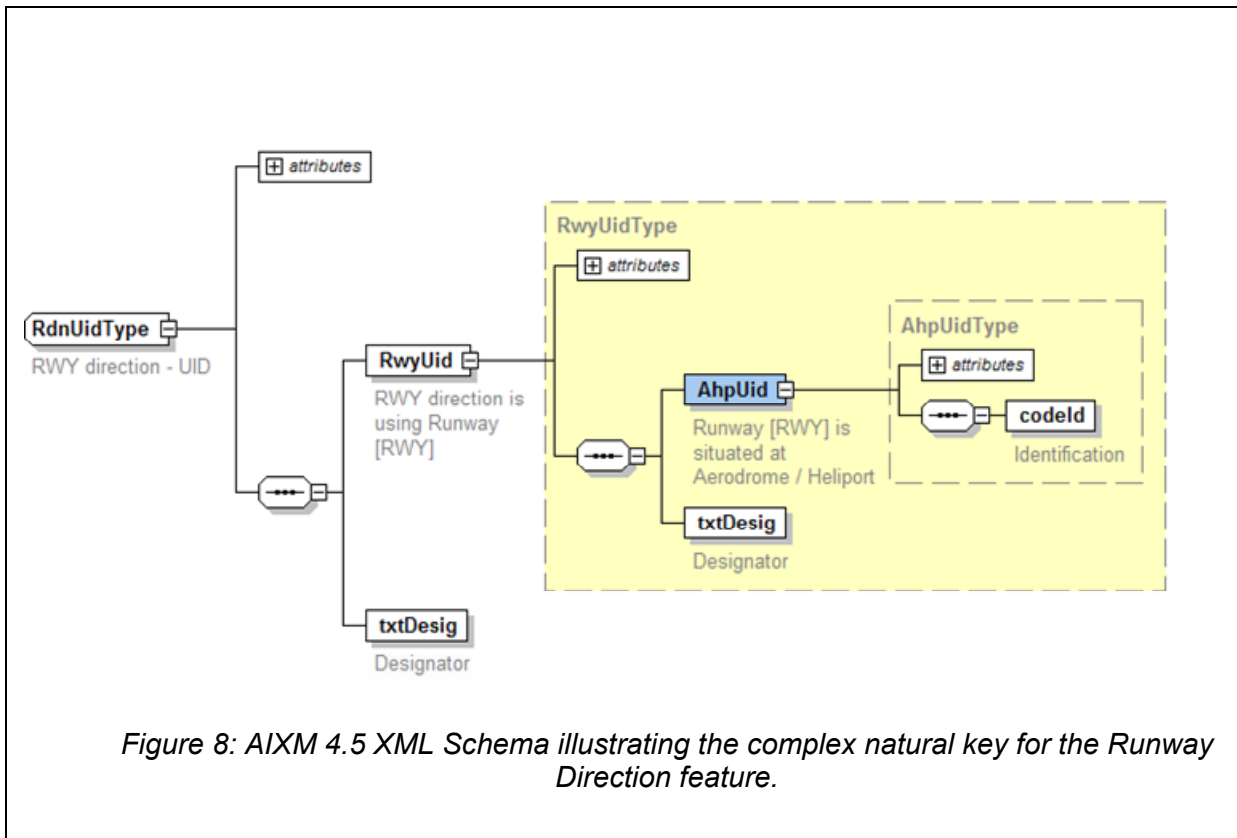
Figure 8: AIXM 4.5 XML Schema illustrating the complex natural key for the Runway Direction feature.

7.2.2 Problems with natural keys

In general, the natural key concept works for well known aeronautical features at large facilities. Major airports, runways and navigation aids are globally known and can be identified by their designators. Problems occur when dealing with traditionally unnamed aeronautical features, features lacking good natural keys, smaller facilities and potential geographic mismatches.

7.2.2.1 Natural keys may change in time

The properties that compose natural keys can change in time. AIXM 4.x includes a special mechanism in AIXM-Update message to notify a change of the natural key. This makes difficult to compare the content of a database over time (two Snapshot messages, for example) as the same feature could have two different natural keys.

7.2.2.2 Unnamed aeronautical features

Many aeronautical features modelled in AIXM do not adhere to standardized naming conventions or lend themselves to natural keys. In these situations AIXM employs three strategies:

- Construct arbitrary natural keys using text names/designators (e.g., Apron, Unit)
- Use sequence numbers or index numbers to track different objects of the same type (e.g,. Unit Address)
- Base the natural key on a composition relationship to another object (e.g., NavaidLimitation is based on the Navaid natural key plus a limitation type).

In these cases, the constructed natural key is "less than natural;" albeit, AIXM includes recommendations to make these constructed natural keys have some meaning.

In addition there is no guarantee that two systems will construct and interpret the keys in the same way: Two systems may name the aprons at an airport in different ways.

7.2.2.3   Feature lacking good natural keys

In some cases, it is not possible to identify a suitable natural key for an aeronautical feature. In these cases the aeronautical feature is converted to a complex type of a parent feature. For example, a procedure leg is defined as a complex element within a procedure, SID or STAR.

Some complex types, like the procedure leg, should probably be aeronautical features. However in AIXM 4.5 procedures legs are not features because a natural key could not be identified. A natural key should not be a prerequisite for classifying features.

7.2.2.4   Smaller facilities

Smaller domestic facilities may not have internationally assigned identifiers and this can make natural keys fail. For example, within the United States there are hundreds of airports without four-letter international airport codes. Similarly one can expect that there are airspace, routes, navigation equipment and other aeronautical systems that likewise do not have global identification.

7.2.2.5   Geographic mismatch

Some natural keys like the natural key specified for Navigation Aids depend on the aeronautical feature location expressed in latitude and longitude. This requires all systems exchanging the navigation aid to use the exact same location in order to positively identify a feature. Perfect location matching can be difficult to achieve due to:
- Different datums (for example, significant points situated on the border of two States using different datum)
- Different location representations: decimal degrees or degrees minutes seconds
- Differences in precision and rounding.

7.2.2.6   Synchronization issues

Even within the framework of an AIXM 4.x compliant system, natural keys can lead to problems when trying to synchronize data sets. There is no safe way to compare two <AIXM-Snapshot> messages. The same feature may be identified differently in the two <AIXM-Snapshot> messages because of a feature natural key update (<AIXM-Update>) that occurred in the time between the two <AIXM-Snapshot> messages.

The integrity of interconnected AIXM 4.x compliant systems relies on the assumption that all <AIXM-Update> messages are correctly processed by all interconnected systems.

7.2.2.7   Data modelling issues

In addition, to these technical problems with natural keys, the natural key implementation used in AIXM 4.x can lead to some data modelling issues [15]:
- The natural keys have a dual purpose: they are used as both the properties of the feature as well as a composite key for feature identification. This becomes problematic when one of the properties used as a natural key changes.
- Increased implementation effort because the natural keys of each feature are formed differently. This requires an implementing system to develop a feature specific rule set for interpreting each feature and its relationship.

7.2.3 Alternatives for feature identification

This subsection considers three alternatives for feature identification:
- Natural keys
- Global registry
- Artificial keys

7.2.3.1.1 Natural keys – Current approach

Systems like AIXM 4.x, ARINC 424 and NOTAM use natural keys to identify aeronautical features.

Natural keys work for AIXM 4.x because AIXM 4.x targets a regional EAD system. Specifically:

- The EAD members have accepted to adhere to the natural key identification established by AIXM 4.x and to strictly apply the ICAO SARPS on which some of the natural keys are based.
- The data stored in the EAD comes directly from clearly identified official sources. Each State is responsible for populating the properties that compose the natural key. There is no need to reconcile versions of the same data from different sources, thus no need to de-conflict keys.
- The EAD maintains a staff of analysts who provide manual quality control and harmonization of input AIXM data.

Natural keys in ARINC 424 work because:

- typically, ARINC 424 files contain information about main facilities, with well established identifiers
- the country code is added in almost all records, thus ensuring the geographical separation of potentially mismatching data
- the exhaustive use of sequence numbers (for example, in route segments, vertex and procedure legs)
- the ARINC 424 format is rarely used as an update format, most frequently a file contains a full data set for a wide area.

Similarly, natural keys for NOTAM generally work because NOTAM are created by an originator, who tries to provide sufficient information so that the feature concerned by the temporary situation can be unambiguously identified. Within the context of the originator the natural key descriptions are unique. However, it is very likely that there have existed cases where ambiguous NOTAM have led to pilot misinterpretation, with the potential for accidents.

7.2.3.1.2 Global Aeronautical Registry

A future approach for feature identification might be the establishment of a global aeronautical feature registry. The registry would be operated by an international aviation authority and by working with data providers the registry could be used to assign unique identification to all aeronautical features. Data suppliers and consumers could then look up features in the registry to obtain a positive feature match. A global registry may be the ultimate solution for feature identification; however the mandate and resources for building a global aeronautical registry do not exist.

7.2.3.1.3 Provider specific keys

A third alternative is to rely on artificial keys and internal system processing to handle feature identification. In this alternative, data providers supply an artificial key that is unique within the data provider's context. Aeronautical data consumers would need to store the artificial keys provided by the data providers or develop internal feature reconciliation processes to identify features.

To see how this works today, consider one of the missions of the United States National Geospatial Intelligence Agency (NGA): collect and integrate the world's aeronautical data. To that end, NGA collects aeronautical data from a variety of data sources including host country providers and aeronautical companies. Consequently, NGA may receive information about the same aeronautical feature from more than one data provider. To resolve this duplication, NGA has developed internal reconciliation algorithms and processes to match transmitted data with the NGA internal database of aeronautical features.

Another example is obstacle data within the United States. Today it is not possible to identify obstacles using natural keys because a consistent set of key properties does not exist. Every publication cycle the United States National Aeronautical Charting Organization (NACO) publishes the Digital Obstacle File (DOF) containing a list of known obstacles throughout the United States. This file has become a *de facto* standard for obstacles in the United States and the NACO generated artificial DOF number has become *de facto* the unique key for obstacles.

7.2.3.2 Design recommendations

Our analysis suggests that none of the feature identification approaches satisfy our design requirements completely:

- Natural keys work well for well known features but fail for local aeronautical features and features without natural keys, such as runway markings
- A global aeronautical registry is probably decades from realization
- Provider specific keys may be acceptable in some circumstances but place a burden on the data receiver to reconcile data sources and potentially store the artificial keys of all data providers.

Instead we propose a hybrid approach where:

- All features will include an artificial global feature identification property that may be used in place of natural identification, and
- Relationships are specified with queries, which may refer to the feature artificial identifier or any set of a feature's properties.

7.2.3.2.1 Identifier property

In the recommended approach all AIXM features have an identifier property that is meant to be a globally unique identifier for the object. In the future this might contain the feature key from a globally managed aeronautical data registry. Alternatively the identifier can contain an artificial key provided by the data supplier.

To ensure that the artificial key is globally unique, we recommend that the identifier include the namespace of the data supplier. A recommended namespace convention is included in Section 11.

7.2.3.2.2 Query Relationships

Features are identified in relationships by specifying a subset of feature properties that can be used to uniquely identify the target feature. The subset of properties used for feature identification is encoded by the data supplier. Figure 9 shows the generic situation for two related features: Feature1 and Feature2. The relationship between the features is stereotyped with <<query>> and we show two possible queries used to define the association.

Figure 9: Relationship between two features using the <<query>> stereotype
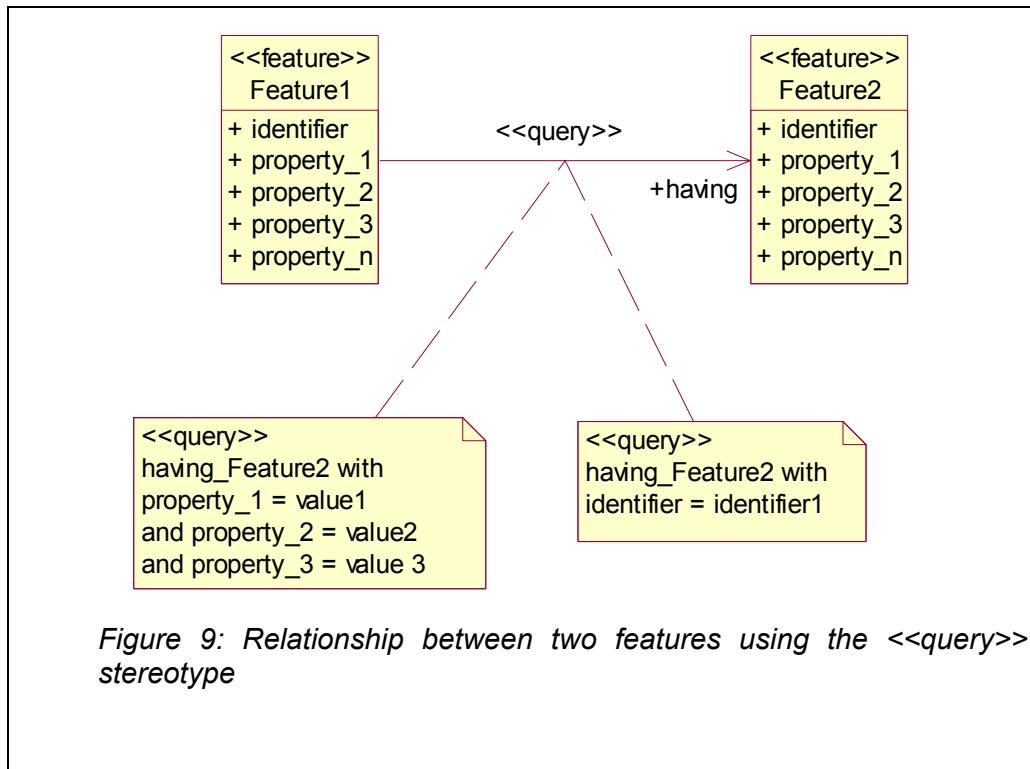
As an example consider the object diagram showing Runway Direction 20L on Runway 02R/20L at Aerodrome MABC (Figure 10).

Figure 10: Example of feature relationships for Runway Direction 20L at Aerodrome MABC.
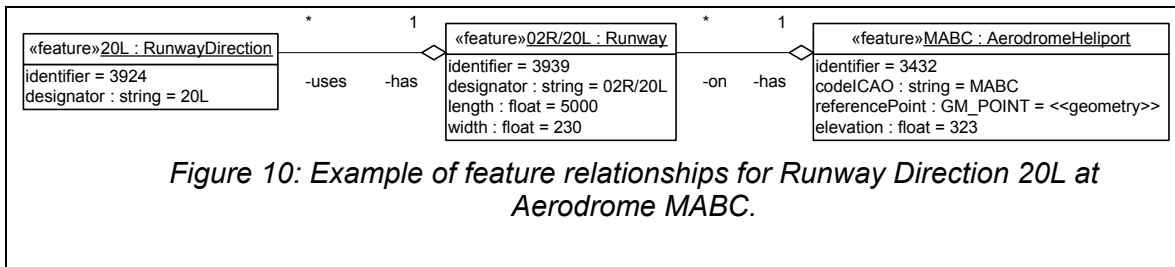
Following this design recommendation, the relationship between the Runway Direction and the Runway can be expressed in alternative ways by providing a query. Some examples in natural language are:

```
Alternative 1: Using an artificial identifier
Runway Direction   uses   Runway where identifier = 3939


Alternative 2: Using a natural identifier
Runway Direction   uses   Runway where designator = 20L/02R
                   and    on Aerodrome where codeID = MABC

Alternative 3: Using a combination natural identifier and
artificial identifier
Runway Direction   uses   Runway where identifier = 3939
             or
                   uses   Runway where designator = 02R/20L
                   and    on Aerodrome where codeID = MABC
```

The result of the query can return 0, 1 or more records:

Table 4: Interpretation of <<Query>> result set

Result Set	Interpretation
0	Target feature not found. The query can be incorrect. Data receiver may need to consult with the data provider to identify the target feature.
1	Exact match found. The normal situation.
2+	More than one target feature meets the relationship criteria. For relationships with a multiplicity of 1 the query is ambiguous. May be appropriate for relationships with cardinality greater than 1.

7.2.3.2.3 Advantages

The query approach to feature identification and feature relationships has several advantages:
- It supports both natural identification and artificial identification
- The properties used for natural identification are not hard coded in the exchange standard. This allows data suppliers to use flexible rules when encoding natural identifiers. For internationally known features like an international airport simple natural identifiers can be used while for local features like a small domestic airport other properties can be used.
- The query is implementation independent. For a database implementation the query can be implemented using SQL while for a GML-compliant XML exchange schema the query can be implemented using xlink:href.

7.2.3.2.4 Disadvantages

Disadvantages of the query approach include:
- For a data receiver, the exact composition of such 'relationship queries' is unknown in advance and it could even vary from instance to instance of the same feature. If this is a problem, then the user community affected by the problem should come together and agree, feature per feature, on the identifying properties.

7.3   Geometry

Geometry is an integral part of aeronautical feature definitions. In the aeronautical domain, feature geometries may be 2 or 3 dimensions. Some examples include (see Figure 11):
- Navigation aid represented as a point with an elevation
- Runway element represented as a line segment
- FIR (Flight Information Region) airspace represented as a prism (vertically extruded horizontal polygon)
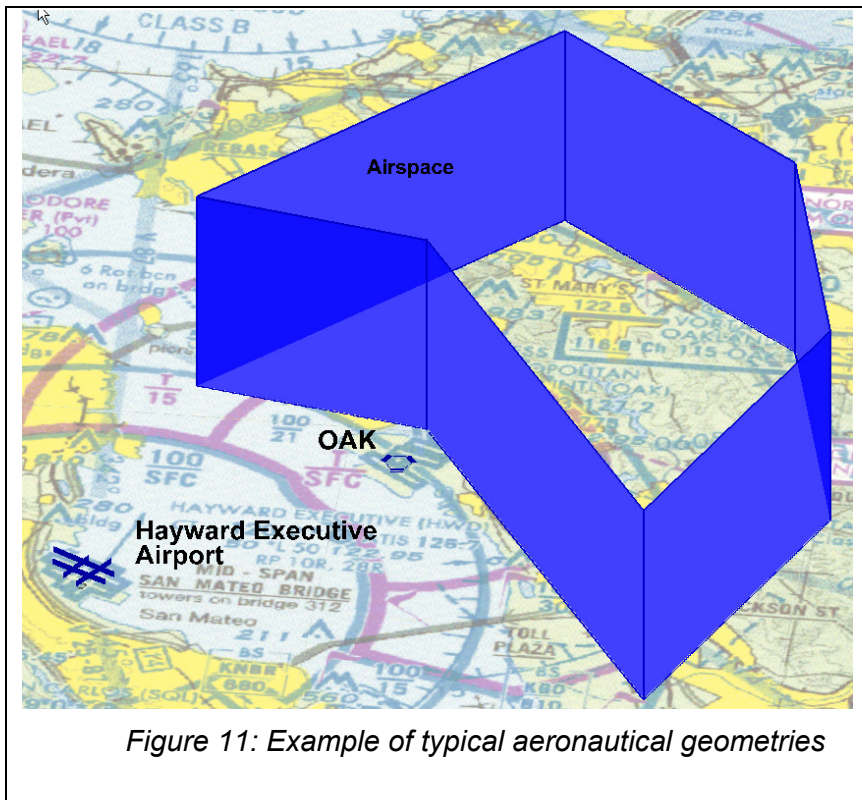
Figure 11: Example of typical aeronautical geometries

7.3.1 AIXM 4.x Approach

Currently AIXM uses an aeronautical-specific model for representing geographical information with definitions that are specific to the feature type [4]. For example:

- Airspace is defined using an airspace aggregation model where complex 3D airspace is constructed by union, subtraction and intersection of simple prisms.
- Airport surfaces like aprons and clearways are defined as closed curves using a custom point and path model
- Navigation aid limitations and Minimum Safe Altitude (MSA) areas are protected airspace defined as circle segments relative to a significant point.

The AIXM geometric specification includes the coordinate reference system (e.g., WGS-84) and the geometric definition. It is assumed that the data receiver properly interprets the geometric specification and can translate the geometric definition to the final output format (e.g., in chart projection, on an ellipsoid or on a spherical earth model).

The main advantage of the AIXM 4.x approach is that geometry definitions reflect how they are created in the aeronautical domain; however this means that COTS GIS software cannot readily interpret AIXM geometries without extensive customization.

7.3.2 Spatial properties in AIXM 4.x features

About 38 AIXM features contain geometric properties: most of the geometry properties describe points. The breakdown of geometry types is given in Table 5.

Table 5: Count of geometry types in AIXM 4.x

Geometry	Feature Count
Curve	6
Surface	3
Point	25
Solid	1
MultiSurface	2

The table below summarizes the AIXM features that have spatial properties. The geometries are mapped to point, surface and curve using the ISO 19107 terminology. In the last column, vertical properties are listed to identify features that have a vertical component.

Table 6: Summary of AIXM features that have geometry.

AIXM 4.x Feature	AIXM 4 Geometry	ISO 19107 Geometry Type	3D (Vertical)
Aerodrome Heliport	GeoLat, geoLong	GM_Point	Elevation
Aerodrome Heliport Surface Border	Polygon made from piecewise combination of Curve segments	GM_Surface	Elevation
Aerodrome Heliport Surface Vertex	geoLat, geoLong	GM_Curve	Elevation
Aerodrome Ground Light	GeoLat, geoLong	GM_Point	
Airspace	Solid made from combination of Airspaces or prism formed from Airspace Border	GM_Surface	Multiple (Upper, lower, minimum, maximum)
Airspace Border	Polygon made from piecewise combination of Curve segments	GM_Surface	
Airspace Border Vertex	geoLat, geoLong	GM_Curve	
Airspace Circle Vertex	geoLat, geoLong	GM_Curve	
Airspace Centerline Vertex	geoLat, geoLong	GM_Curve	
Airspace Corridor	Polygon made from a buffer of the Airspace CenterLine Vertex	GM_Surface	
Airspace Vertex	geoLat, geoLong	GM_Curve	
Designated Point	geoLat, geoLong	GM_Point	
DME	geoLat, geoLong	GM_Point	Elevation
FATO Centerline Point	geoLat, geoLong	GM_Point	Elevation
FATO Direction	geoLat, geoLong	GM_Point	Elevation
Gate Stand	geoLat, geoLong	GM_Point	
Geographic Border	Curve made from piecewise combination of Curve segments	GM_Curve	
Geographic Border Vertex	geoLat, geoLong	GM_Curve	
ILS Glide Slope	geoLat, geoLong	GM_Point	Elevation
ILS Localizer	geoLat, geoLong	GM_Point	Elevation

AIXM 4.x Feature	AIXM 4 Geometry	ISO 19107 Geometry Type	3D (Vertical)
Landing Protection Area	Curve made from piecewise combination of Curve segments	GM_Surface	
Marker	geoLat, geoLong	GM_Point	
MLS Azimuth	geoLat, geoLong	GM_Point	Elevation
MSL Elevation	geoLat, geoLong	GM_Point	Elevation
MSA	Polygon made from piecewise combination of curves	GM_Surface	Upper and Lower limits
MSA Group	Aggregation of MSA polygons	GM_Surface	
Navaid Limitation	Polygon made from piecewise combination of curves	GM_Surface	Upper and lower limits
Navaid Usage Limit	Aggregation of Navaid Limitations	GM_Surface	
NDB	geoLat, geoLong	GM_Point	Elevation
Obstacle	geoLat, geoLong	GM_Point	Elevation, Height
Runway Centerline Point	geoLat, geoLong	GM_Point	Elevation
Runway Direction	geoLat, geoLong	GM_Point	Elevation
Service	geoLat, geoLong	GM_Point	
Special Navigation System	geoLat, geoLong	GM_Point	
Surface Lighting Group	geoLat, geoLong	GM_Point	
TACAN	geoLat, geoLong	GM_Point	Elevation
TLOF	geoLat, geoLong	GM_Point	
Taxiway Centerline Point	geoLat, geoLong	GM_Point	Elevation
Unit	geoLat, geoLong	GM_Point	
VOR	geoLat, geoLong	GM_Point	Elevation

In this table only those features with explicit geometries (such as a geoLat and geoLong) and those features that aggregate other geometric features have been included. Other features such as stopways contain length and width properties that imply geometry; however, these features are not listed in the table.

Many of the feature geometric properties reference locations on the surface of the earth. Primary exceptions are airspace features like Airspace, Navigation Limitations and MSAs that contain upper and lower vertical limits.

7.3.3 Design recommendation

We recommend that AIXM 5:
- Use a 2 ½ D geometry model
- Use geometries based on the ISO 19107 schema
- Consolidate AIXM 4.x features used solely to construct geometry (e.g., Airspace Border Vertex)
- Continue to use feature properties to capture aeronautical information about geometry construction

These recommendations are discussed in the subsections below.

7.3.3.1   2 ½ D geometry model

We propose to use a 2 ½D geometry model in AIXM 5 with the following characteristics:
- The horizontal component of the AIXM feature geometry is modeled using 1D and 2D ISO 19107 geometries
- The vertical dimensions are modeled with additional feature properties.

For example an AerodromeHeliport feature would contain:
- A referencePoint property derived from GM_Point describing the latitude/longitude of the Aerodrome Reference Point
- A referenceElevation property describing the elevation of the Aerodrome Reference Point.

Similarly a Navaid Limitation Area would be described as:
- A GM_Surface describing the extent of the Limitation Area
- An verticalUpper and verticalLower property to describe the upper and lower limits of the Navaid Limitation area.

The 2 ½ D model has advantages for aeronautical data:
- We consider there to be good commercial support for 1D and 2D ISO 19107 geometries. 3D ISO 19107 geometries are complicated and poorly supported by vendors.
- Geometry vertical extents are normally implied and not specifically represented. For example an Airspace defined with a lower limit of 1000 FT AGL and upper limit of FL180 is actually a complicated 3D solid with a lower limit that undulates with the underlying terrain. Normally these complications are not modeled in 3D so the 2 ½ D approach is a natural representation.

For AIXM 5 we propose to extend the ISO 19107 2D geometries to include additional properties to represent the vertical dimensions. This is illustrated in Figure 12 below for the AerodromeHeliport feature where the aerodromeReferencePoint is described as an ElevatedPoint object containing vertical elevation and verticalExtent properties.   The ElevatedPoint object inherits from the ISO 19107 GM_Point class. Review the AIXM Profile of ISO 19107 document for AIXM extensions to ISO 19107 geometries.

Figure 12: Example of aerodromeReferencePoint based on ElevatedPoint object. ElevatedPoint contains vertical properties and inherits from the GM_Point class.
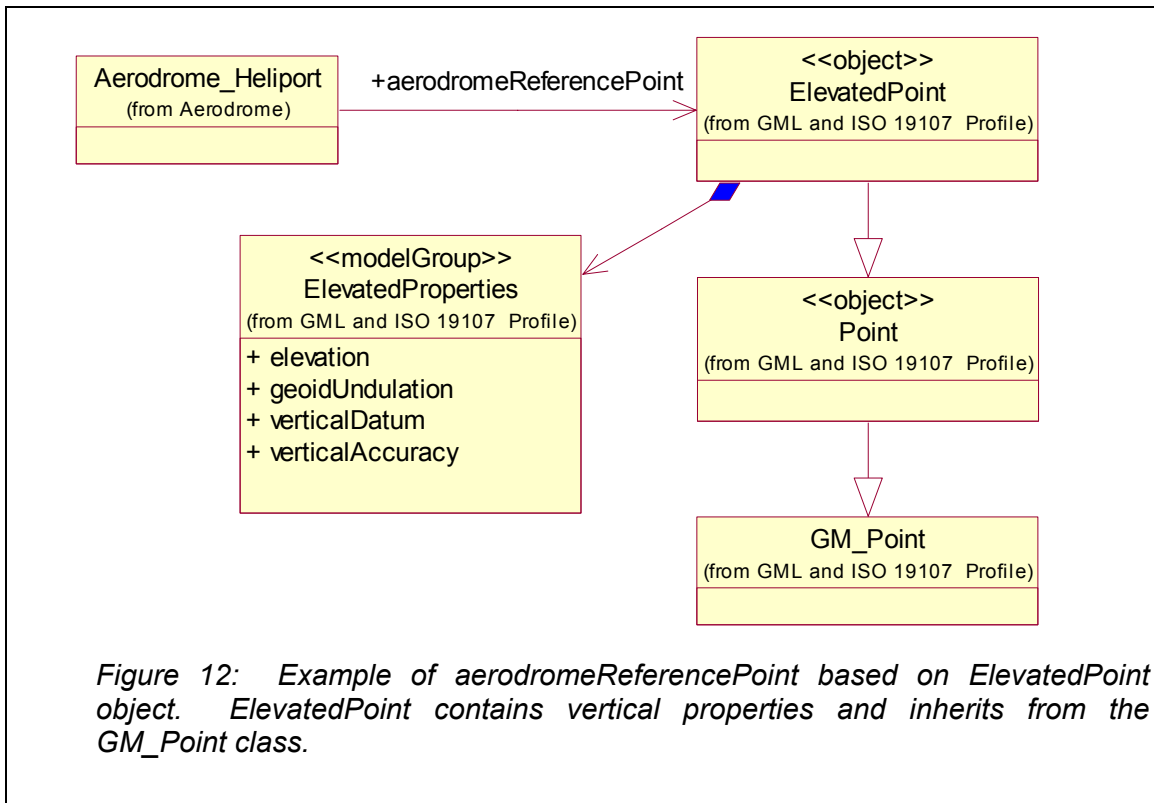
7.3.3.2 Geometries based on ISO19107

We propose to replace the custom AIXM 4.5 geometries with geometries based on ISO 19107.

ISO19107 spatial schema standard describes spatial objects with attributes and operations like size, shape and topology [16]. Using ISO19107 as the basis for geometric representation in AIXM has several advantages:
- Standardized geometric representation
- ISO19107 is the basis for Geometry Markup Language (GML), an XML grammar for spatial features.
- Increases the potential for AICM/AIXM implementers to leverage COTS GIS tools.

The ISO 19107 spatial schema is very complex. It contains an extensive list of geometries, geometric properties and operations – many of which are not appropriate for AIXM. In addition, the ISO 19107 contains a complicated 3D geometry model that is not suitable for AIXM.

A separate document describes the AIXM 5 Profile of ISO 19107.

7.3.3.3 Consolidate AIXM 4.x features used to construct geometries

Some AIXM 4.x features exist to construct geometric properties for other features. For example, the horizontal extent of Airspace is created from the Airspace Border and Airspace Vertex features.

These specialized geometry features will be replaced by ISO 19107 geometries. Table 7 summarizes the consolidation.

Table 7: Consolidation of geometric features into ISO 19107 geometries

Feature	Consolidated Features	Child	ISO 19107 Geometry

| Aerodrome Heliport Surface Border	Aerodrome Heliport Surface Vertex	GM_Surface[†]
Airspace	Airspace Border, Airspace Border Vertex, Airspace Circle Vertex, Airspace Centerline Vertex, Airspace Vertex	GM_Surface
Geographic Border	Geographic Border Vertex	GM_Curve

7.3.3.4   Aeronautical Geometry Definitions

The disadvantage of ISO19107 is that geometries are represented without regard for the domain information on how they were created. For example in GML the Service Volume segments depicted for the OAK VOR in Figure 13 would be described as GM_Surface. However, in the aeronautical domain they are constructed as bearings and distances from the VOR.

By itself the ISO19107 geometry does not describe how the Service volume is constructed. Where custom aeronautical definitions must be maintained, additional feature properties must be included to supplement the standard geometry description with the aeronautical specific information. These will be represented as attributes and associations in UML that model normative information:

- as necessary for air navigation (bearings, distances, etc.)
- which compensate the incomplete 2D info (airspace aggregation, obstacle type)
- which documents 'how the airspace was built' (centreline with buffer; use of geo borders; significant point as centre of arc or as vertex, etc.)

This is illustrated for the Navaid Limitation feature in Figure 13 where the AIXM 5 feature definition includes fromAngle, toAngle, innerDistance and outerDistance in addition to the ISO19107 GM_POLYGON extent property.

Figure 13: Illustration of how aeronautical properties that define geometry are preserved in AICM/AIXM 5.
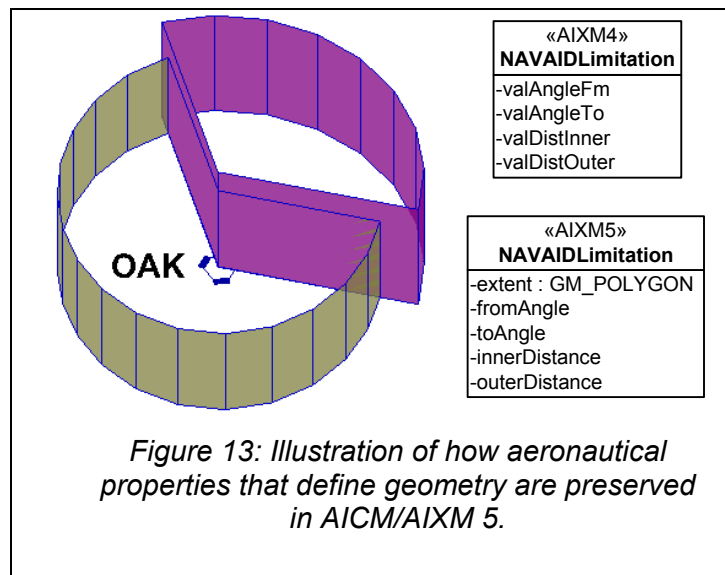
This duplication of geometry data leads to a situation where the two definitions may not be consistent. It is the responsibility of the data originator to ensure consistency between the GML geometries and the eventual normative information documented as feature properties. In case of discrepancy, the aeronautical properties will prevail over the GML geometries.

[†] The use of a GM_Surface is technically not correct since a Surface implies planar interpolation. What we really want to define is the geometry of the surface boundary. This is actually a closed curve.

7.4 Temporality

There are two levels at which aeronautical feature instances are affected by time [AICM Edition 1]:

- Every feature has a start of life and end of life
- The properties of a feature or the target of any feature relationship can change within the lifetime of the feature

AIXM is intended to support data exchange between systems; therefore, AIXM must support a temporality model that accurately represents the temporal state of the aeronautical features. Examples of temporal data that might be exchanged using AIXM include:

- Regular AIRAC cycle updates or data amendments
- Temporary changes to aeronautical data such as those changes currently recorded in NOTAM.
- Permanent changes to aeronautical data (e.g., PNOTAM) that notify the aviation community of a permanent change that will be included in the next set of publications.

From these principles and examples we derive a set of high level requirements:

- Any feature property may change at any time. The value of a feature property may have a start of effectivity and end of effectivity
- Feature property changes can be classified as temporary or permanent based on the need to support current AIM concepts of operation. For example permanent changes may be captured as AIRAC amendments and included on paper charts and publications. Temporary changes are typically NOTAM.

7.4.1 Assessment of AIXM 3.x and 4.x Temporal Model

In AIXM 3.x and 4.x, features and feature properties are implicitly static: AIXM 4.x and 3.x features do not contain properties for expressing feature-level or property-level temporality. Instead, aeronautical data temporality is handled in the two AIXM messages, <AIXM-Snapshot> and <AIXM-Update>, that comprise the AIXM 3.x and AIXM 4.x data exchange specification.

7.4.1.1 <AIXM-Snapshot>

The <AIXM-Snapshot> message has the following format:

```
<AIXM-Snapshot          xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance"        xsi:noNamespaceSchemaLocation="AIXM-Snapshot.xsd"
version="1"       origin=""       created="2005-05-23T10:00:00"
effective="2005-05-23T10:00:00">
   <Ahp>…</Ahp>
   <Ahp>…</Ahp>
   …
</AIXM-Snapshot>
```

The <AIXM-Snapshot> element contains an attribute *created* for recording the date that the AIXM exchange message was assembled and *effective* for recording the valid date for the snapshot message.

An <AIXM-Snapshot> provides the state of a set of aeronautical features at a point in time.

7.4.1.2 <AIXM-Update>

The <AIXM-Update> supports adding, removing and modifying aeronautical features. Like the <AIXM-Snapshot>, the <AIXM-Update> has attributes for specifying the created date and the effective date. A partial <AIXM-Update> looks like:

```
<AIXM-update  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="AIXM-Update.xsd"   effective="2005-
10-10T10:00:00"     created="2005-10-10T10:00:00"     version="2"
origin="FAA">
<Group>
   <New>
```

```
        <Aas>…</Aas>
        …
    </New>
    <Changed>
        <Aas>…</Aas>
        …
    </Changed>
    <Withdrawn>
        <Aas>…</Aas>

        …
    </Withdrawn>
</Group>
</AIXM-update>
```

The <AIXM-Update> supports permanent changes to features that occur at a point in time.

7.4.1.3   Conclusions

AIXM 3.x and 4.x provide limited temporality support. It is possible to exchange feature state at a point in time and communicate permanent changes. AIXM 3.x and 4.x do not support temporary changes to aeronautical data (such as xNOTAMS).

In addition, AIXM 3.x and 4.x embed temporality in the exchange message rather than in the aeronautical features. Consequently temporality becomes a property of the message rather than the aeronautical features. The message properties describe how receiving systems should interpret the message content.

7.4.2 Conceptual model

To refine our understanding of temporality and how it applies to the aeronautical domain, we have developed a conceptual model of temporality. In this model we have the concept of "version" and "delta" (see Figure 14):
*   **Version** – The state of a feature and the value of all its properties in the time period between two changes.
*   **Delta** – The difference between two consecutive versions. The delta contains only those properties that have changed from one version to the next.

Figure 14: Relationship between Versions and Deltas
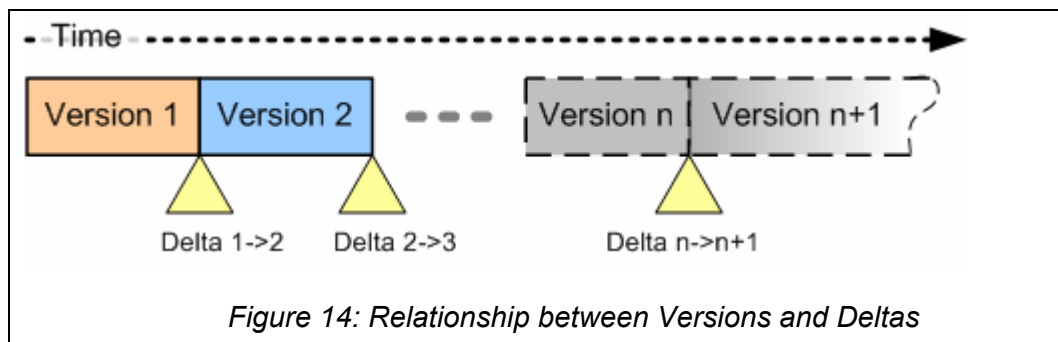
We also recognize that, in the aeronautical domain, feature state can be permanent or temporary. The distinction between temporary and permanent is rooted in current aeronautical system operational concepts:
*   **Permanent** - Permanent feature state is typically reported as an AIP, AIP amendment (AMDT) or a permanent NOTAM. The permanent state of a feature is normally incorporated into static publications and aeronautical charts.
*   **Temporary** – Temporary feature state is normally associated with NOTAM. Temporary states are normally transmitted to operational systems but they are not normally charted or printed.

The combination of "version" and "delta" along with the operational distinction between "permanent" and "temporary" leads to four temporal components that need to be supported in AICM and AIXM 5:

- **Baseline** – The state of a feature and all of the feature properties as a result of a permanent change. The Baseline state of a feature also exists when the feature is initially created. The baseline state lasts until the next permanent change.
- **Version** – The state of a feature and all the feature properties during the time period between two changes.
- **Permanent Delta** – A set of properties that have changed or will change permanently. The permanent delta will result in a new baseline.
- **Temporary Delta** – A set of values for one or more feature properties that are effective for a limited time. The result is a temporary change to an underlying feature version.

Figure 15 illustrates the temporal model by showing changes to a navigation aid between one AIRAC cycle to the next. In this example, NAVAID AML has a frequency change from 126.00 MHz to 132.5 MHz between two AIRAC update cycles. Changes in the operational status of the AML NAVAID during the frequency upgrade lead to two NOTAM. Based on this diagram we can identify the following temporal components:

- The diagram shows two Baselines. The first baseline has a NAVAID frequency of 126.00 MHz and the second baseline has the new frequency of 132.50 MHz.
- A Permanent Delta can be used to describe the different between the two baselines. In this example, the permanent delta would indicate that the AML NAVAID frequency was changed.
- Each NOTAM can be expressed as a temporary delta that changes the Operational Status of the NAVAID.
- Based on the changes shown in the diagram, four versions of the NAVAID feature can be identified. Each version begins and ends at the boundary of a Permanent or Temporary Delta.

Figure 15: Illustration of temporal component model for a Navigation Aid
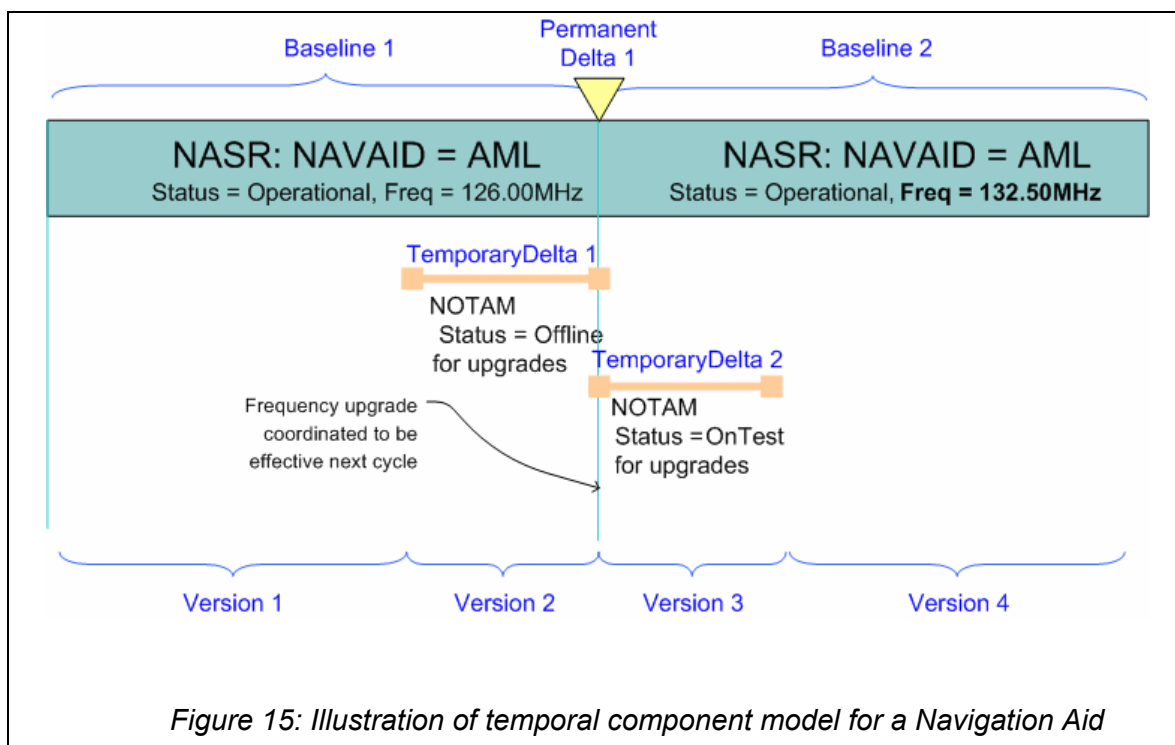
The temporality model is comprehensive and flexible enough to represent static and dynamic data in the aeronautical domain.

7.4.3 Implications for aeronautical information systems

The conceptual temporal model described in the previous section provides considerable flexibility for systems that implement temporality. A system that tried to fully implement the AIXM temporality model would be very complex. AIXM incorporates a complete temporal model to ensure that AIXM can support all current and future aeronautical applications; however there is no requirement for systems implementing AICM need to support all temporal components. Indeed:

- Systems may only store baselines and disregard any temporary or permanent changes. Examples include AIP publishers, paper chart publishers and ARINC 424 based systems.
- Systems may only transmit and store temporary changes. Examples include the conventional NOTAM office.
- Systems may only require periodic versions providing the current state of the system. An example is a passive monitoring system designed to report system status at selected time intervals.
- Systems may want a new version after every change without making a distinction between a temporary and a permanent change. Examples include traffic management and flight plan processing systems.
- Some systems may be developed that can process and interpret all of the temporal components and provide users with Baseline, Deltas and the actual Version at any given moment in time.

The AICM/AIXM contains a complete temporal model; however, as the examples illustrate it is the responsibility of interacting systems to negotiate specific temporal data exchange requirements as well as to integrate temporality into their internal subsystems.

More than one combination of temporal components can be used to express the same temporal information. As illustrated in Figure 16, a Version can be constructed by considering a Baseline and incorporating PermanentDeltas and any Temporal Deltas that are active during the effective start and end of the version.

Figure 16: Two ways to represent the same temporal state.
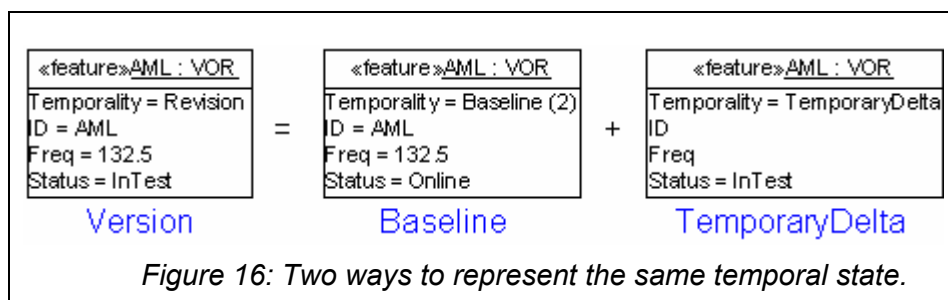
The conceptual temporal model explains how temporal information can be encoded in various forms for information exchange; however, an equally important implementation aspect is synchronization issues that could be experienced by systems realizing the AICM temporality model. For example, two systems might produce different snapshots at a time t if they are not fully synchronized. These synchronization problems are manifest today and it is not within the scope of AICM to impose a methodology for eliminating data integrity issues associated with database synchronization. However the AICM temporal model does provide the framework for supporting system synchronization.

7.4.4 Design recommendations

We assert that temporality affects all aeronautical features, so a single temporal model needs to be applied across the entire aeronautical domain. Key assumptions in this design approach include:

- Temporality is an essential characteristic of aeronautical information systems.

- A general temporal model should be uniformly applied to all aeronautical feature types.
- Since temporality applies to all aeronautical feature types, temporality should be abstracted from the task of modeling object properties.

AICM and AIXM will support all of the components described in the temporal concept model:
- Versions and Baselines
- Deltas (Temporary and Permanent)

To handle the complexities of overlapping temporal states and cases where feature providers need to re-transmit a corrected version of a feature's temporal state, AIXM will also support:
- Sequence numbers used to identifying subsequent transmissions about a feature's state
- Correction numbers used to issue corrects to a previously transmitted feature.

7.4.4.1 TimeSlice Model

To implement temporality in data exchange we will adopt the TimeSlice data content model that is defined as part of GML 3.1.1[‡] because the TimeSlice model closely matches AIXM's temporal requirements. According to the GML 3.1.1 specification [8], a TimeSlice encapsulates the time varying properties of a dynamic feature. A dynamic feature is any feature that varies in time.

The AIXM TimeSlice UML model is illustrated in Figure 17 [UML adapted from 8]. As shown in the model, the AIXM Feature has a static component which contains properties for the artificial identifier and feature validTime. The feature validTime contains the start of existence, end of existence for the feature. All other properties of the feature are assumed to be temporal. The temporal feature properties are encapsulated into a TimeSlice object.

[‡] Further analysis is needed to determine if the GML 3.1.1 TimeSlice model is compliant with the ISO19108 Temporal Schema. If it is then AICM should be based on 19108.

Figure 17: AIXM TimeSlice model
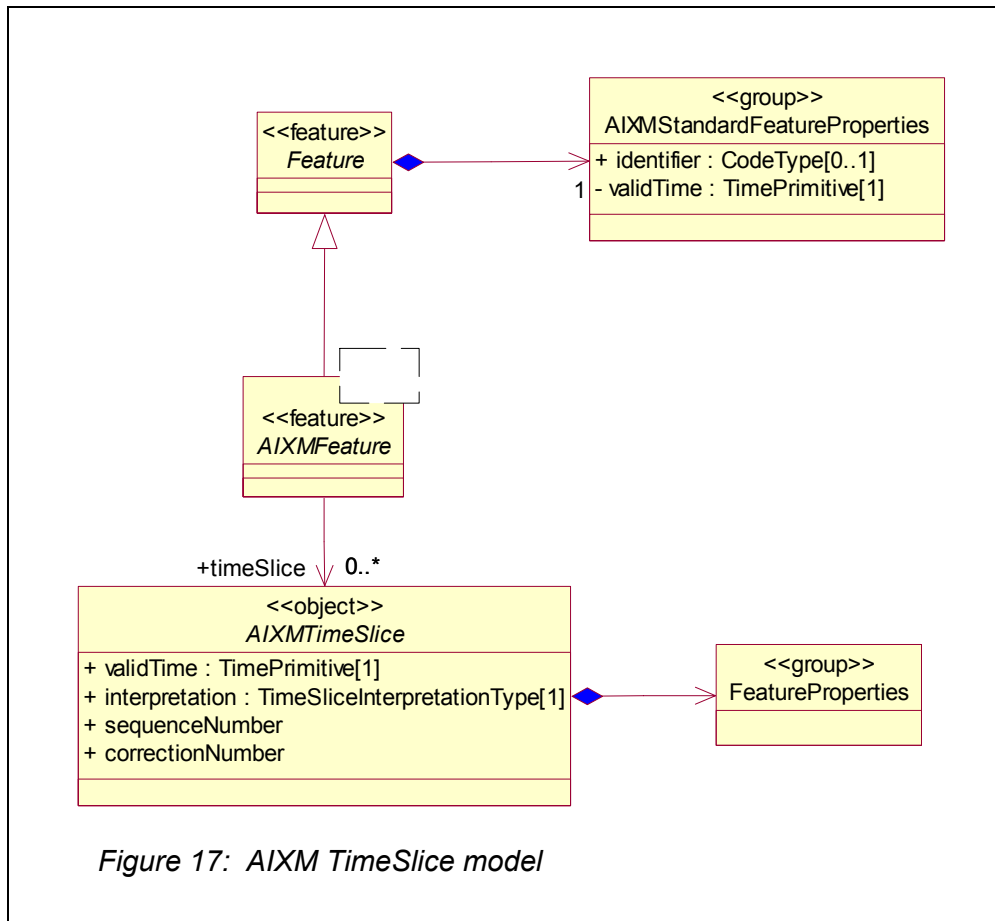
Each TimeSlice object contains a valid time interval and an interpretation property. The interpretation property indicates the temporal component that is being modeled. Valid values for the interpretation are:

- Baseline
- Version
- TempDelta
- PermDelta

The sequenceNumber is an increasing integer number used to track subsequent timeSlices for a feature from a single feature provider. Similarly the correction number is a feature provider specific number used to describe corrections to previously transmitted timeSlices.

7.4.4.2   Communicating feature property changes

Depending on the temporal implementation employed by the exchanging systems, different methods can be used to communicate feature changes. A baseline is communicated as one TimeSlice, containing all properties that have a value for the specified time period

Feature

> **Timeslice**
> - *interpretation   =*
>   *baseline*
> - period of validity
> - sequenceNumber
> - property 1
> - property 2
> - property 3
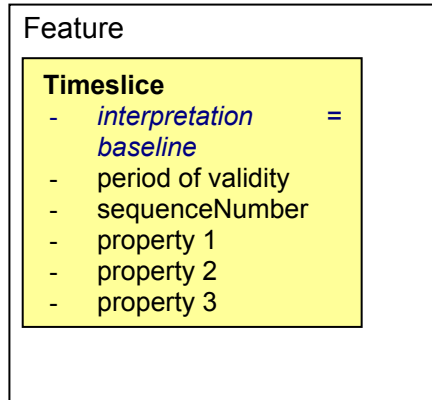
A permanent change may be communicated as a sequence of two TimeSlices; the following two possibilities exist:

one containing the previous baseline and one containing all properties that change (permanent delta)	one containing the previous baseline and one containing the new baseline

Feature
 	
Timeslice
- *interpretation   =*
  baseline
- period of validity
- sequenceNumber
- property 1
- property 2
- property 3
 	
Timeslice
- *interpretation   =*
  PermanentDelta
- start of validity
- sequenceNumber
- property 1'
	Feature
	
	Timeslice
	- *interpretation =*
	  baseline
	- period of validity
	- sequenceNumber
	- property 1
	- property 2
	- property 3
	
	Timeslice
	- *interpretation =*
	  baseline
	- start of validity
	- sequenceNumber
	- property 1'
	- property 2
	- property 3'

A temporary change may be communicated as a sequence of two TimeSlices: one containing the baseline and one containing all properties that change (permanent delta)

```
Feature
   ┌──────────────────────────────┐
   │ Timeslice                    │
   │   -  quality = baseline      │
   │   -  period of validity      │
   │   -  sequenceNumber          │
   │   -  property 1              │
   │   -  property 2              │
   │   -  property 3              │
   │   -  property 4              │
   └──────────────────────────────┘

   ┌──────────────────────────────┐
   │ Timeslice                    │
   │   -  quality = TempDelta      │
   │   -  start of validity        │
   │   -  sequenceNumber          │
   │   -  property 3'             │
   └──────────────────────────────┘
```
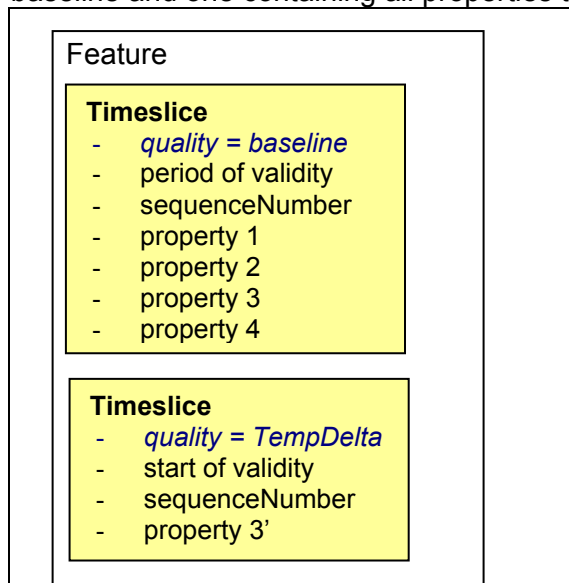
This section was intended to show examples of how to communicate temporal information. More than one approach can be used to transmit the same temporal information. It is our assumption that communities of interest will agree on the Timeslices that will be support by their applications.

7.4.4.3   Communicating feature histories

The Timeslice model can be used to transmit history of a feature by transmitting the sequence of changes that occur to the feature's property. The feature history can be the past history or future history.

Figure 18 shows an example history of a fictional VOR navigation aid. The navigation aid has the following events:
- Jan 7, 2006: Commissioned
- Jan 23 – Feb 18, 2006: Temporary frequency change
- Feb 11 – Mar 9, 2006: Temporary offline
- Feb 22, 2006: Change in magnetic variation
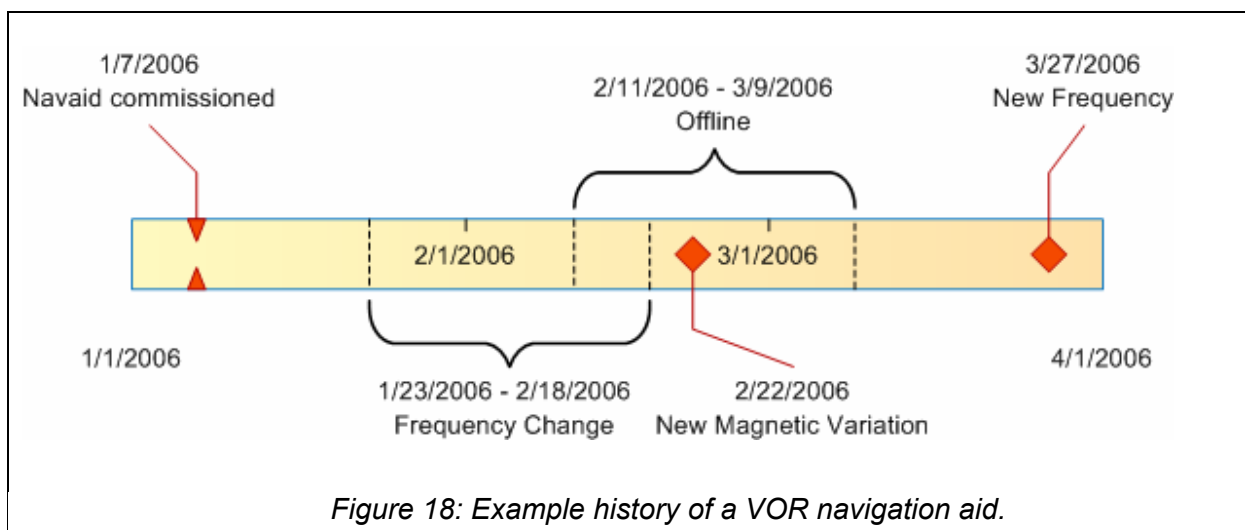- Mar 27, 2006: Change in frequency

Figure 18: Example history of a VOR navigation aid.

Using the Timeslice model we could represent the history of the VOR navigation aid as a series of five TimeSlices as shown in Figure 19. Five Timeslices are used to represent each event. Notice that overlapping events are encoded as separate Timeslices.

Figure 19: TimeSlices for the VOR navigation aid history
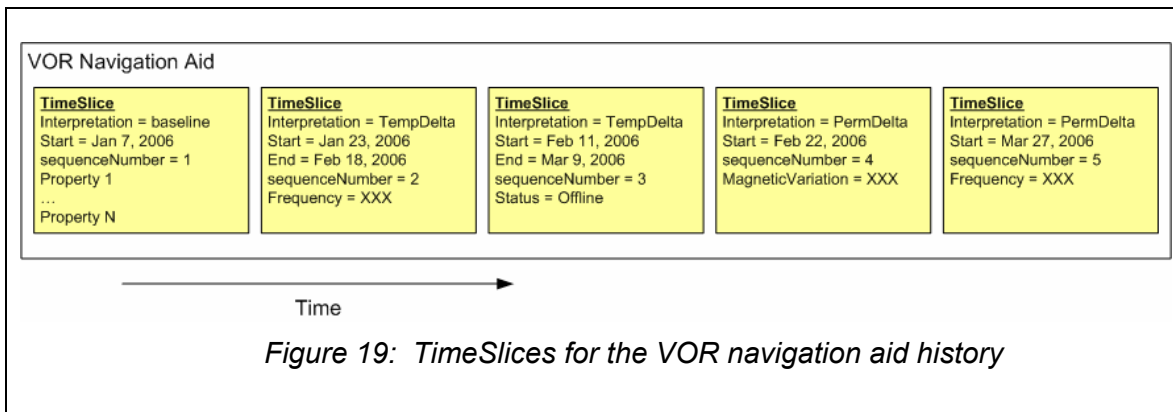
This approach to modeling history is equivalent to the recommended approach for GML 3.2 [7]. In actual implementations of the AIXM Timeslice mode, communicating histories can lead to very large messages. These large messages might be a problem for some resource constrained system. Although implementation issues are outside the scope of this design document we want to point out that the disadvantage of message size should be weighed against the value of standardization and compliance with GML. In many situations the value of standardization may outweigh the loss of message efficiency.

7.4.4.4   Multiple overlapping TimeSlices and corrections

The sequenceNumber and correctionNumber are used to resolve and interpret overlapping timeSlices. Consider the scenario shown in the figure below where a Feature's Status property is changed repeatedly over several overlapping time intervals. Each temporary change receives a sequenceNumber where the sequenceNumber is unique to the feature provider. In the example one of the TimeSlices is corrected leading to a duplicated sequenceNumber and different correctionNumber.

At the edges of each temporal event we can identify transitions to different feature versions. The combination of validTime and sequenceNumber can be used to unambiguously identify the value of the Feature's Status property at each version.

To determine the value of a property at a given time or over a given time interval the following rules should be used:
1. Identify all deltas that are active at the specified time interval
2. Sort the delta's by increasing sequenceNumber
3. Apply the delta's to the feature from low sequenceNumber to high sequenceNumber.
    a. When two or more deltas have the same sequenceNumber apply the delta with the highest correctionNumber.

The possibility to resolve overlapping TEMPDELTAs using the sequenceNumber and correctionNumber shows how cancellations and corrections can be communicated. In this example, sequenceNumber = 2 is initially used to communicate that the feature Status = test. Later a timeSlice correction is transmitted using the same sequenceNumber = 2 but with a correctionNumber = 1. The second sequenceNumber = 2 TimeSlice corrects the feature state to Status = MAINT.
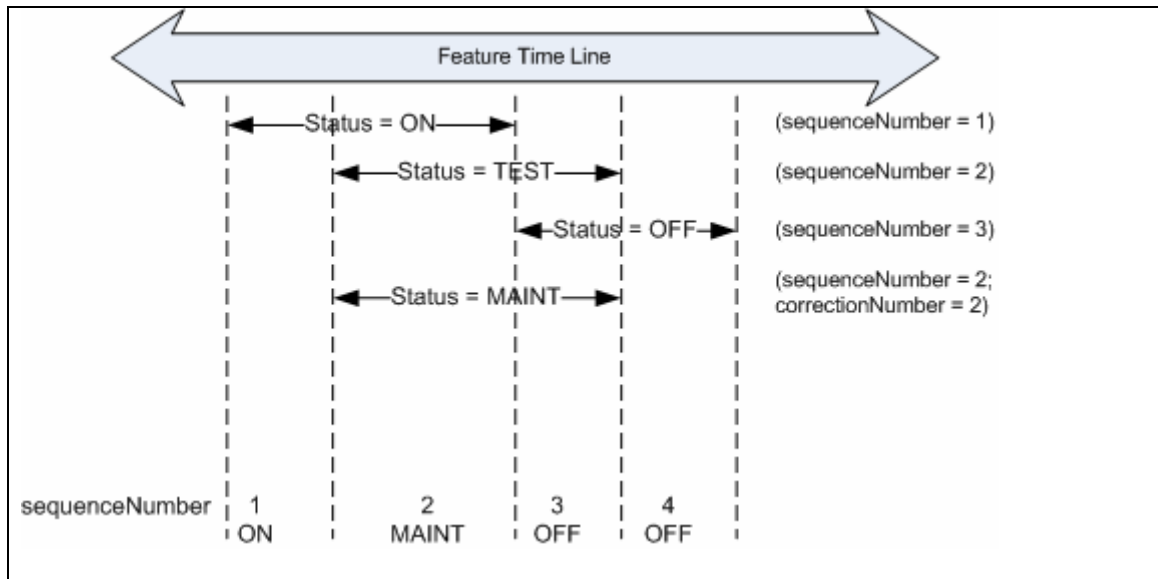
Figure 20: Example of TimeSlice corrections

7.4.4.5 Integration with the feature identification

In order to support the general recommendations for feature identification, some temporal components will need to be combined to fully define the aeronautical feature. If a system is using a natural property identification approach to feature identification then simply transmitting a Delta will not be sufficient to identify the feature because the Delta may not contain the properties referenced in the Feature Relationship query. In this case the Delta will need to be transmitted with a Version that was active at the time the Delta became effective.

7.4.4.6 Integration with feature relationship

The TimeSlice model for AIXM features makes feature relationships more complicated. Feature relationships, like other properties, can change with time so they need to be encoded within the feature TimeSlice.

Feature relationships are encoding using queries against sets of feature property data (see Section 7.2). The feature relationship query needs to incorporate the TimeSlice model into the queries. We have the following recommendations for integrating feature relationships with the TimeSlice model:
- The feature artificial identifier is time invariant, so expressing feature relationships with the feature artificial identifier is trivial.
- Delta TimeSlices cannot be used in feature relationships because the Delta TimeSlice does not contain all of the feature properties.
- Feature relationships that encode natural identification must reference a Baseline or Version TimeSlice.
    - The feature relationship must include the interpretation property to indicate if the relationship is based on a Baseline or Version.
    - We recommend that feature relationships be based on Baseline features.

Following these guidelines the feature relationships shown in Figure 10 would be re-written as:
- Example 1: Using an artificial identifier
    Runway Direction **uses** Runway where identifier = 3939

- Example 2: Using a natural identifier (alternative 1)
    Runway Direction **uses** Runway where interpretation = Baseline
                                    and startPosition >= Nov 21, 2005

and endPosition <= Dec 21, 2005
and designator = 20L/02R
and on Aerodrome where
     interpretation= Baseline
     and startPosition >= Nov 21, 2005
     and endPosition <= Dec 21, 2005
     and codeID = MABC

- Example 3: Using a combination natural identifier and artificial identifier (alternative 2)

Runway Direction **uses** Runway where identifier = 3939
          or **uses**   Runway where interpretation = Baseline
          and designator = 20L/02R
          and startPosition >= Nov 21, 2005
          and endPosition <= Dec 21, 2005
          and designator = 20L/02R
          and on Aerodrome where
               interpretation = Baseline
               and startPosition >= Nov 21, 2005
               and endPosition <= Dec 21, 2005
               and codeID = MABC

Example 1 has not changed because the artificial identifier is time invariant. Examples 2 and 3 indicate that the relationships reference the Runway Baseline TimeSlice that is active between November 21 and December 21, 2005. Also note that the secondary relationship from the Runway to the Aerodrome must also encode the Baseline, startPositon and endPosition.

7.5   Extending features

EUROCONTROL AISTEC/ACCB-04/WP1 discussed expanding the scope of AIXM to "develop AIXM as a globally applicable aeronautical data exchange specification, satisfying the needs for international aeronautical information dissemination of the stakeholder States, including temporary changes (NOTAM), with a standard extension mechanism [Emphasis added], which enables the use of AIXM for a wider spectrum of aeronautical services applications." [3].

As AIXM is augmented to meet other application requirements and the needs of other States, AIXM will need to be extended to support additional data types, attributes and messages. The requirements and scope of these extensions cannot be anticipated; therefore, AIXM requires a standard mechanism for adapting AIXM to specific application system requirements while simultaneously preserving the base AIXM standard.

The extension model allows AIXM XML documents to contain additional properties that might be specific to a country, a system interface specification or other use case. Examples of extensions include:
- A field to store country specific spelling of an airport name
- A code type classifying an airspace using country specific airspace types
- Styling codes used to mark-up an aeronautical feature so that it can be displayed on a chart or cockpit display

In other words, extensions may be needed whenever local or system specific information needs to be transmitted in an AIXM XML document.

Extensibility has two important advantages [17]:
- Increased adoption of AIXM by allowing AIXM to be used for applications for which it was not originally designed

- Decrease pressure on the AIXM configuration control board by allowing local extensions to AIXM

The high level requirements for extensibility include:
- Allow flexibility so that applications can add new AIXM Feature properties and relationships
- Establish a standard approach for implementing and documenting extensions
- Provide encoding rules so systems that can read the AIXM base standard will be able to read AIXM XML documents that contain extensions.

7.5.1 Guidelines for creating extensions

The extension model provides enormous flexibility for augmenting and expanding the core AICM and AIXM information exchange models. The intent of AIXM is to provide a common language for aeronautical information and a common format for data exchange. The use of extensions erodes AIXM's purpose by thwarting international aeronautical data harmonization efforts. For this reason, the use of extensions should be carefully managed by AIXM adopters.

In general the following guidelines should be used when considering feature extensions:
- New properties and relationships that have international application in support of modelling aeronautical data for use in international air navigation should be consider for direct addition to the AIXM model through the AIXM configuration management process
- Extensions supporting application specific implementations not directly covered by AIXM are candidates for extensions (see discussion in Section 5.3.1)
- Ideally extensions should be managed by communities of AIXM users so that common extensions can be shared
- Globally applicable extensions should be reviewed by the AIXM configuration control board as candidates for adoption into the base AIXM model.

7.5.2 Analysis of extension requirements

There are three ways that the AIXM data can be extended:

Extension	Description	Examples
Properties and Relationships	Add new properties or new AIXM Feature relationship to an AIXM Feature	• Add a LocalName field to the AerodromeHeliport AIXM Feature. • Add a relationship between Airspace and the AerodromeHeliport
Code Types	Add additional lists of values to existing AIXM code types.	• A country may have a specific airspace activity for "Unmanned Aerial Vehicles Testing". This new activity does not exist in the current list of values for the codeActivity in the Airspace AIXM feature.
AIXM Features	Create a new AIXM Feature describing an aeronautical object.	• Create a new feature called "Military Aerial Refueling Route"

7.5.3 Design recommendation

7.5.3.1 New Properties and Relationships

The need for feature property extensions applies to all AIXM features, so a system wide approach is recommended. The UML diagram in Figure 21 illustrates the extension model. Each AIXM Feature TimeSlice contains an extension property that is based on the abstract FeatureExtension class and are expected to be uniquely identified through a namespace. The AIXM namespace recommendations are discussed in Section 11.

Figure 21: UML model for feature property and relationship extensions
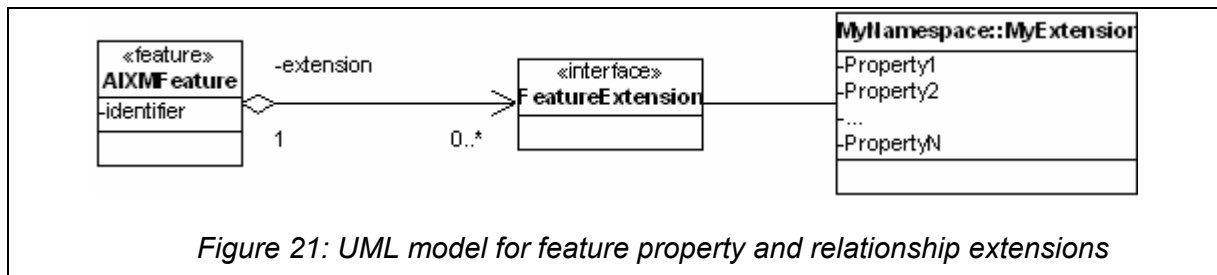
The extension model includes support for new Properties, Relationships and Code Types. Guidelines for adding property and relationship extensions are given below.

7.5.3.1.1 New properties

New properties are included as properties of an Extension class that derives from AbstractFeaturesExtension Class.

A new property must comply with the following conventions:
1. The property name must be meaningful
    a. The property description must be written in lowerCamelCase
    b. The property description must include only well known abbreviations.
    c. The property name must be written in UK English, in order to remain consistent with the overall AIXM model
2. The resulting property names must be different than the standard AIXM property names for the AIXM Feature that is being extended.
    a. For example, extending Aerodrome Heliport to include a new property named codeActivity is acceptable because this property name does not exist in the base Aerodrome Heliport Feature. However, adding a new property named codeActivity would not be acceptable for the Airspace Feature because Airspace already contains a property named codeActivity.
3. Identify the value domain type for each new property.
    a. Standard domains should be based on the existing AIXM data types.
    b. If a standard value domain type cannot be used then a new value domain type is required

An example is adding Acceleration property to an AIXM feature. Acceleration is a numerical quantity expressed in units like m/s^2. Assume that this new property is being added to the Procedure Leg to record the recommended aircraft acceleration. Applying the rules listed above we obtain the following:
1. Acceleration is a meaningful property description so the AIXM property name becomes "acceleration."
2. A review of the standard Procedure Leg properties shows that the name "acceleration" is unique.
3. A review of AIXM value domains shows that AIXM does not have a value domain for acceleration so new value domains will be required to document this extension.

7.5.3.1.2 New relationships

New relationships are included as properties of an Extension class that derives from the AbstractFeatureExtension Class.

A new relationship must comply with the following AIXM conventions:
1. The relationship name shall consist of three concatenated parts as defined below:
    a. A meaningful relationship role name that describes the association. The role name shall be written in UK English, in lowerCamelCase and include only well known abbreviations.
    b. An underscore separator
    c. The name of the target feature type in the relationship in UpperCamelCase.
2. The relationship name must be different than the standard AIXM Feature association names.

As an example consider a relationship to an emergency Aerodrome where the relationship describes the aerodrome that should be used in emergency situations. Applying the conventions listed above we obtain the following:
1. The relationship name should constructed as:
    a. The association role name is "forEmergency" and this is written in lowerCamelCase
    b. Followed by "_"
    c. Followed by the target AIXM feature, "AerodromeHeliport"
    The resulting association name is forEmergency_AerodromeHeliport.
2. A review of the Aerodrome Heliport feature shows that forEmergency_AerodromeHeliport is a unique name.
3. The forEmergency_AerodromeHeliport relationship should contain a query identifying the Aerodrome used for emergencies.

7.5.3.1.3 Updates to code values

An AIXM adopter may desire to expand one of the standard AIXM code lists. For example, an adopter may desire to add new Activity types to the list of Airspace code_Actvity.

Extending AIXM by adding additional domain values to a standard AIXM code type is not directly supported. The standard code lists provided in AIXM are meant to be internationally applicable, clearly defined lists. Allowing local extensions to these lists of code values can lead to problems when systems try to interpret the data. Instead this extension can be handled using either of the following solutions:
1. Create a new property to store the additional code values. For details on adding new properties to AIXM Features see 7.5.3.1.1.
2. Work through the AIXM configuration control board to submit the additional code values for adoption into AIXM.

For example, suppose the United States needs to add new Airspace Code_Activity such as "Bungee Jumping." This extension would require that the existing Airspace codeAcivity value domain be amended with an additional value. This extension is forbidden. Instead there are two options:
1. Create a new property to contain the addition code value, or
2. Submit the request to the AIXM configuration control board

The "Bungee Jumping" Airspace activity is a local extension, so submitting this to the AIXM configuration control board is not appropriate. Instead this extension is handled by:
1. Setting Airspace Code_Activity to "OTHER"
2. Extending Airspace by adding a new property called "activityUS" inside a USFeatureExtension class.

7.5.3.2   New features

The extensible modelling framework adopted for AIXM 5 will make it easy to add new features in the same style as the standard AIXM features. Conceptually a new feature is added by:

- Deriving the Feature Type from the abstract AIXM Feature.
- Deriving a new TimeSlice object from the abstract AIXM TimeSlice object
- Deriving a new Extension interface from the abstract FeatureExtension interface.

New features shall follow the AIXM naming convention for feature, properties and relationships names. The UK English language must be used.

As we will see when we discuss AIXM 5 implementation, AIXM Features will be implemented as GML features. So any GML-compliant feature could be included in an AIXM 5 exchange message.

Despite the fact that the modelling framework supports new custom features there is no guarantee that AIXM data receivers will be able to interpret the custom features. Instead we recommend that requests for new features be submitted through the AIXM configuration control board.

7.5.3.3   Ensuring compatibility

Modelling extensions using the FeatureExtension class shown in Figure 21 is meant to ensure compatibility with systems that can only understand the base AIXM exchange messages or systems that understand a subset of feature extensions.

The extension interface encapsulates feature extensions in a defined location within the Feature TimeSlice. So systems that only read the base AIXM model can skip the contents of the extensions.

In addition, all extensions must have a namespace. Systems that can read selected extensions can identify valid extensions through their namespace and easily skip unknown extensions.

7.6   Extensible exchange message framework

Closely related to the requirement for providing a standard mechanism for extending the properties and relationships of a feature (Section 7.5) is the requirement to support a range of data exchange use cases through an extensible messaging framework.

Currently AIXM 4.x supports two messages: <AIXM-Update> and <AIXM-Snapshot>. These messages are an integral part of the AIXM 4.x specification. Both messages are customized to support aeronautical information collection and transmission by the EAD.

The close coupling between the AIXM 4.x data model and the AIXM 4.x messages makes it difficult to apply the AIXM model to other aeronautical information systems.

The high level requirements for an extensible message framework include:

- Separation of the AIXM data model from the messages
- Standard approach to encapsulating AIXM data into the messages
- Support for message content such as message properties, source/client metadata and operation parameters.

7.6.1 Message Structure

We can think of messages as having two components (see Figure 22):

- Actions
- Feature Payload

Figure 22: A message has an Actions component and a Feature Payload component.
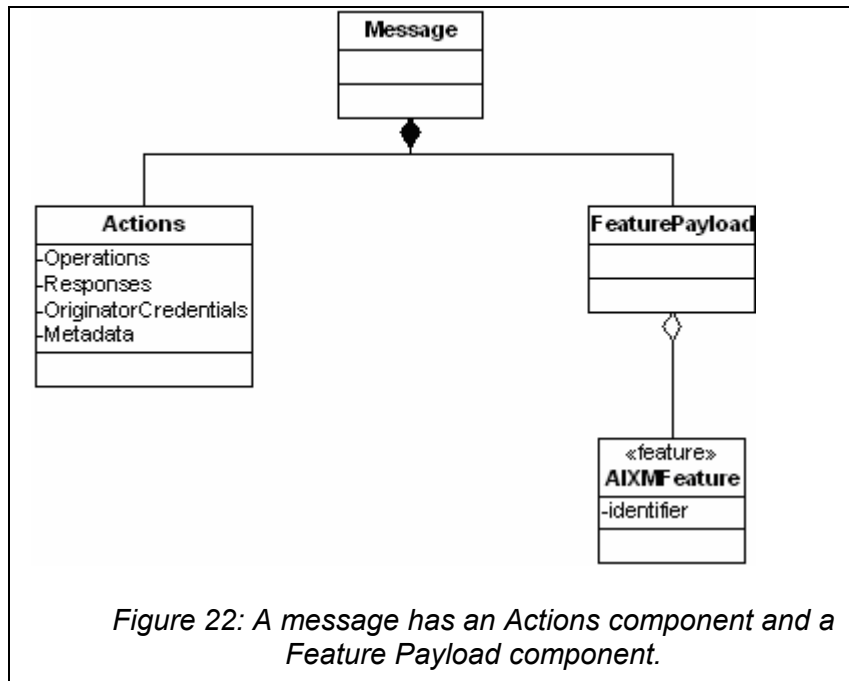
Messages contain the data content as "FeaturePayload" and tell receiving systems how to "Act" on or interpret the message content. The FeaturePayload contains a collection of AIXMFeatures. The Actions may contain:

- Operations to be performed
- Responses
- Message originator credentials
- Other message meta-data and properties.

Message formatting and interpretation can be as important as the data content. However, whereas the data content model can be explicitly defined, messages are often application specific. Sometimes, like in the case of a Web Feature Service, the messages are well known standards. In other cases, system to system interchange may occur through negotiate messages. For example, the AIXM 4.x <AIXM-Update> and <AIXM-Snapshot> are custom messages designed to support EAD activities.

For AIXM to be adopted for other systems, we can anticipate additional messages:

- xNOTAM (Notice of a temporary change)
- Obstacle data product (as specified in ICAO Amendment 33 to Annex 15)
- Aerodrome Mapping Databases (AMDBs)

7.6.2 Design recommendations

We adopted a generic message pattern from GML that can be used to construct custom AIXM messages.

Error! Reference source not found. is a UML diagram of the AIXM message format. Messages are derived from AIXM features and thus have the same generic properties and follow the same patterns for designating properties.[§] In addition, the AIXM messages can contain zero or more collections of AIXM data.

[§] This message pattern is exactly the gml:FeatureCollection and the message framework specifications will be covered in more details when GML is introduced.

Figure 23: AIXM message model
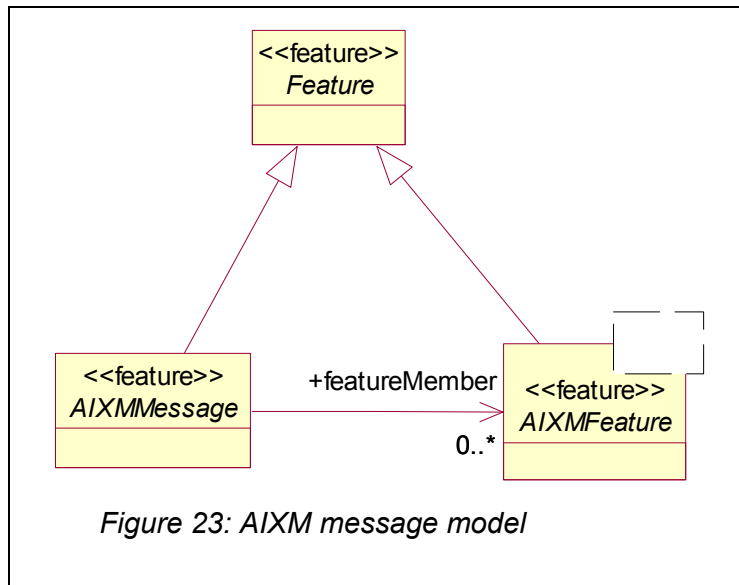
The messaging framework illustrated in Figure 23 has these advantages:

- Defined locations for AIXM feature data so that even systems that do not understand the specific message should be able to navigate to the feature data.
- Support for any message properties.

8 AICM and AIXM 5 Implementation

In this section we explain how the AICM and AIXM 5 specification is implemented to satisfy the desired requirements, design and architecture. AICM 5 is the natural evolution of the AICM 4.5 conceptual model with the addition of the new design requirements detailed in Section 7. Converting AIXM into a GML application schema is the most extensive and critical part of the AIXM specification so most of this section is devoted to discussing AIXM 5's implementation of the GML specification. For those readers unfamiliar with GML, a short introduction is provided in Section 12.

We begin this section by discussing specific GML and ISO 19100 series modeling styles that affect the structure of the AICM and AIXM data models.

8.1 AICM UML model

This section introduces the basic features of the AICM 5 model. The complete AICM model will be made available separately as UML and a companion document.

8.1.1 AICM Component Diagram

The UML package diagram in Figure 24 shows the organization of the AICM model. The model has four levels from bottom to top:

- **Data types level** – Description of AICM-specific data types and value domains
- **Conceptual model level** – Model of aeronautical features, properties and relationships. The diagram depicts a subset of conceptual areas; the full AICM 5 model incorporates all aeronautical conceptual areas.
- **AbstractAIXM level** – Description of base AIXM Feature classes interfaces and, relationships used to model temporality and extensibility.
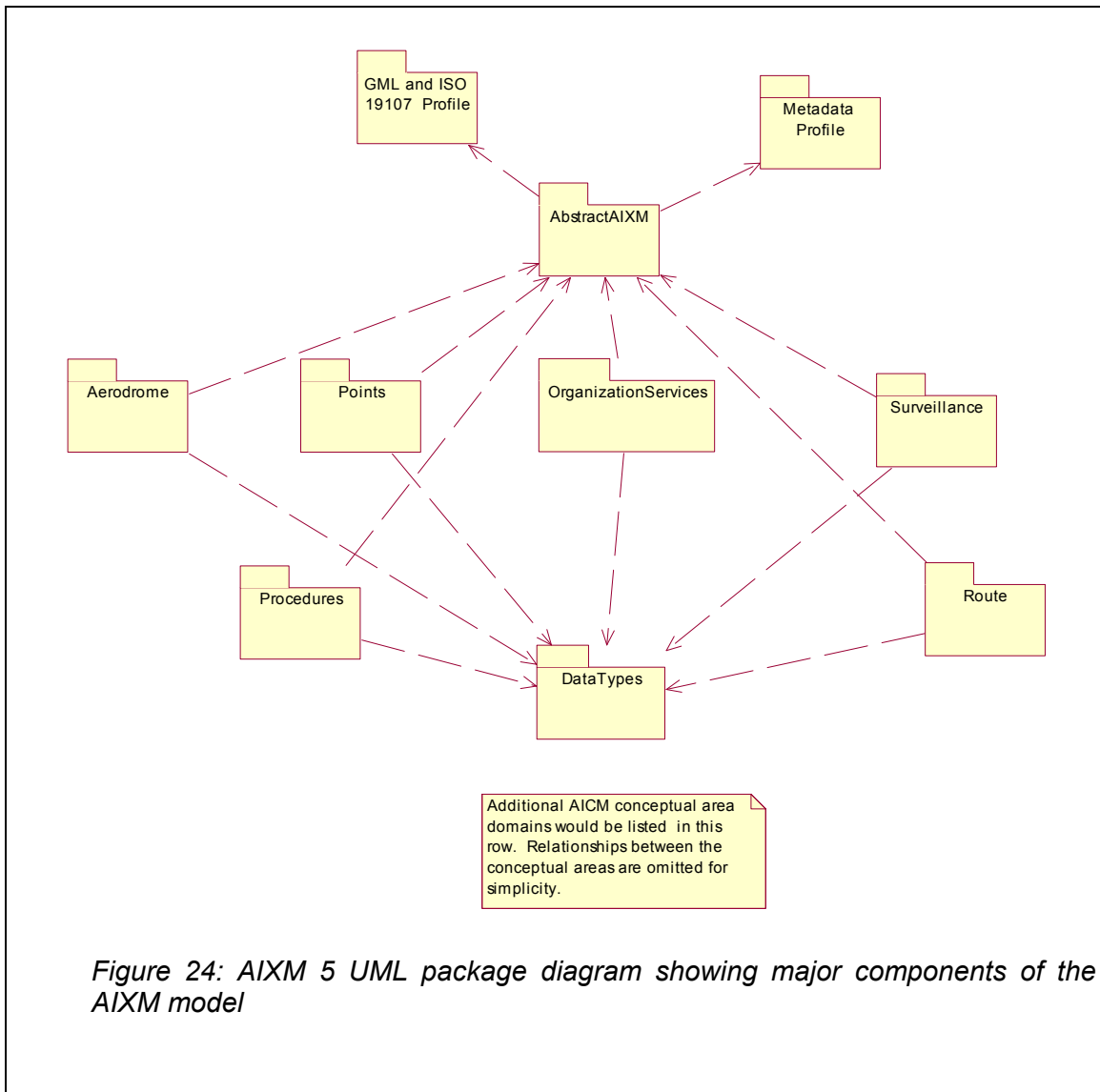- **GMLProfile level** – Description of the AIXM profile of GML

Figure 24: AIXM 5 UML package diagram showing major components of the AIXM model

8.1.2 AbstractAIXM package

The AbstractAIXM package (Figure 25) provides the building blocks for creating AIXM Features incorporating temporality, extensibility and feature relationships. In addition, the AbstractAIXM package serves as the linking point between the AICM model and GML so that AIXM 5 can be implemented in GML.

Figure 25: AIXM AbstractAIXM package
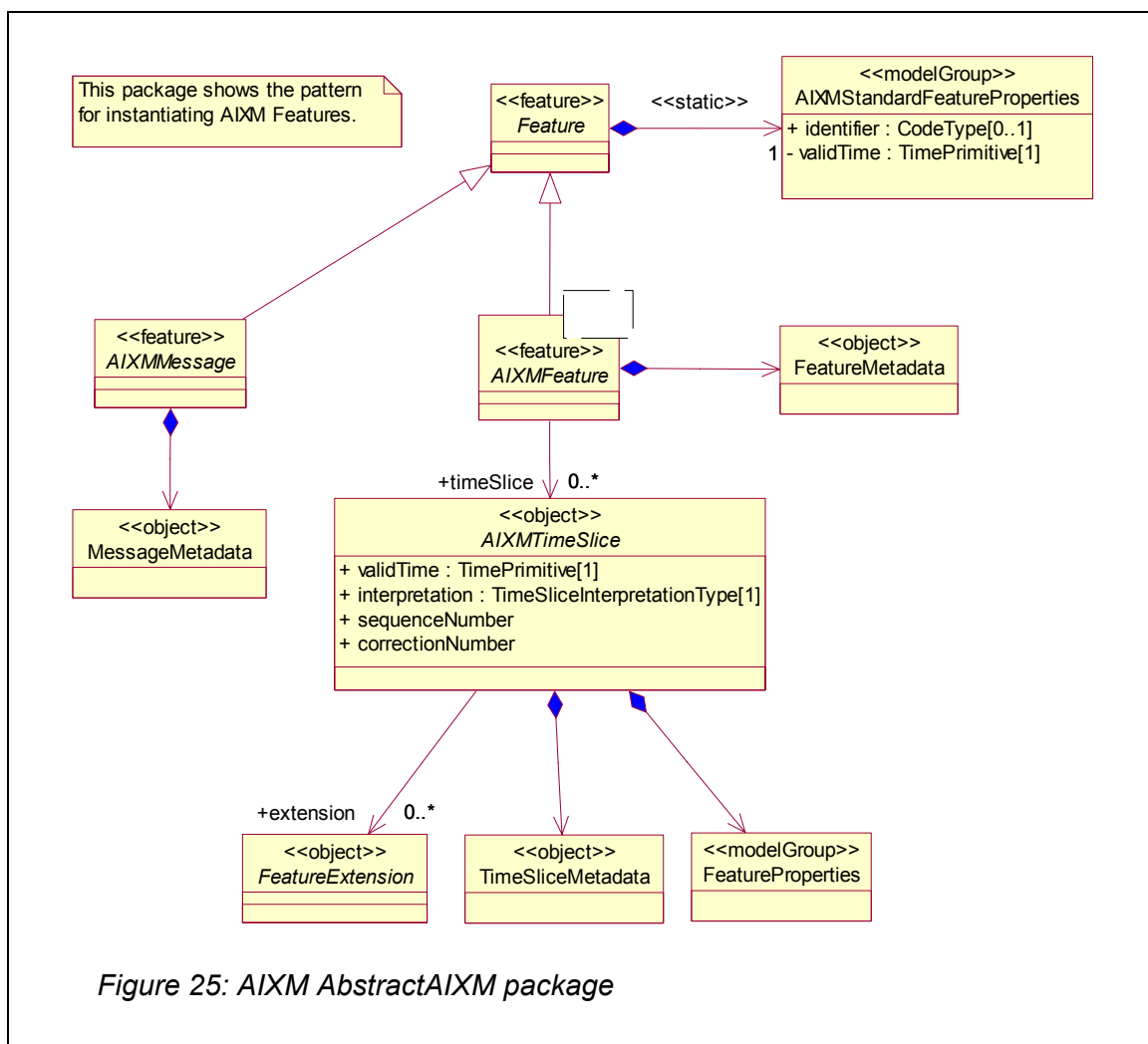
8.1.2.1   AIXMFeature

The key class on the diagram is the AIXMFeature. AIXMFeature is an abstract class that is the basis for all AIXM features. The AIXMFeature contains one or more AIXMTimeSlice.

The AIXMFeature includes a property groups: AIXMStandardFeatureProperties. Property groups are indicated with the <<modelGroup>> stereotype and they are always related to other classes through composition. The properties contained in <<modelGroup>> classes are assumed to be merged into the aggregating class. So in this example, AIXMFeature actually has two properties:

- Identifier
- validTime

The <<modelGroup>> classes are used in the AIXM model so that commonly used properties can be grouped and reused for different classes.

Note also that the composition relationship for AIXMStandardFeatureProperties is stereotyped with <<static>>. The <<static>> stereotype is used to indicate that these properties exist at the Feature level and are not dynamic.

The AIXMFeature class is a type of Feature.

8.1.2.2 AIXMTimeSlice

The AIXMTimeSlice class is an abstract class that is the basis for all AIXM Feature TimeSlice objects.
The AIXMTimeSlice abstract class has four properties:

- validTime
- interpretation
- sequenceNumber
- correctionNumber

The interpretation property is based on the AICM temporal model and is used to classify the TimeSlice as baseline, version, temporary delta or permanent delta. The sequenceNumber and correctionNumber properties are increasing integers used to track sequential Timeslices generated for a single object from a single data source.

8.1.2.3 AIXMMessage

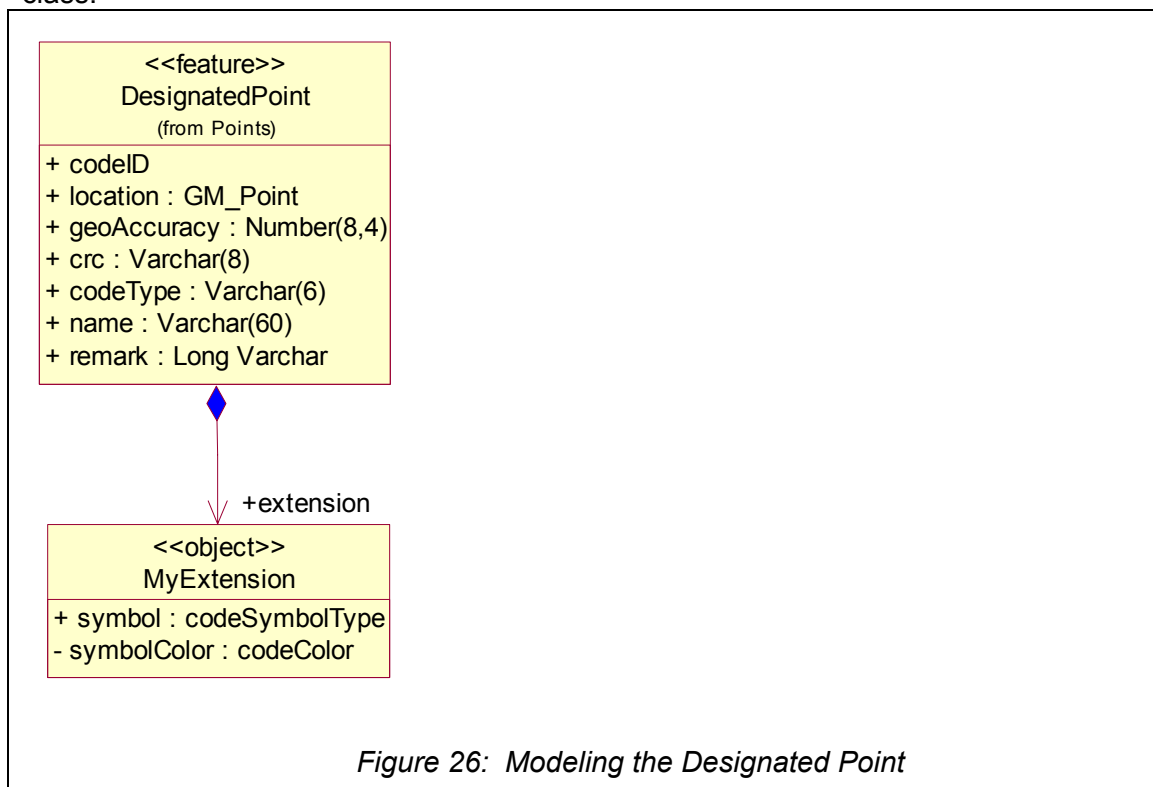AIXMMessage is also derived from Feature.

8.1.2.4 FeatureExtension

FeatureExtension is an abstract class that all feature extensions must realize.

8.1.3 Example Instantiation: Designated Point

We intend the AbstractAIXM package to act as a pattern for instantiating the AICM 5 UML model.

The figure below shows the Designated Point in the AIXM UML model. For modeling simplicity all of the Designated Point properties are included in the Designated Point feature. It is understood that the properties are actually included in the DesignatedPointTimeSlice class.

<<feature>>
DesignatedPoint
(from Points)

+ codeID
+ location : GM_Point
+ geoAccuracy : Number(8,4)
+ crc : Varchar(8)
+ codeType : Varchar(6)
+ name : Varchar(60)
+ remark : Long Varchar

+extension

<<object>>
MyExtension

+ symbol : codeSymbolType
- symbolColor : codeColor

Figure 26: Modeling the Designated Point

8.2   AIXM XML Schema

8.2.1   Developing a GML Profile for AIXM

Profiling simplifies AIXM's implementation of GML by restricting AIXM to the limited set of GML features required by AIXM. The goals of the GML Profile for AIXM are:
- Remove pre-GML 3.1.1 deprecated elements
- Restrict GML to a single choice where multiple options are provided.
- Limit GML to selected geometry and temporal properties
- Augment the GML 3.1.1. Profile with additional properties that are likely to be part of GML 3.2 (ISO 19136)

The GML Profile for AIXM was generated using the instructions and tools provided in the GML 3.1.1 specification, Annex G [8]. After analyzing AIXM geometry requirements we identified the following list of allowable geometry values:
- Arc
- ArcByCenterPoint
- CircleByCenterPoint
- CompositeSurface
- Curve
- Geodescic
- LineString
- MultiPoint
- Point
- Polygon
- Ring
- Surface

The following temporal features are included in the GML Profile:
- DynamicFeature
- TimeInstant
- TimePeriod

After the XML Stylesheet tools are used to extract the GML Profile, we further restricted the profile by following the methodology and rules contained in Section 22.1 of the GML 3.1.1 Specification [8]. As part of this customization we deleted global types, deprecated elements and local optional elements that were not needed for the AIXM application schema.   More details can be found in the separate AIXM profile for GML document.

9 Profiling AIXM 5

This section will cover the concept of modularity from the point of view of selecting kernels of features, relationships and attributes to be included in a specific product specification.

(To be completed) Profiling needs to be discussed in the context of ISO 19100 series (see Section 6.1) and we need to describe how to profile AIXM 5. Perhaps provide a profiling example based on one of the application schemas listed in Section 6.1 (such as AMDB).

10 Aeronautical information exchange use case

The purpose of this section is to present a scenario that uses AIXM for data exchange between systems to illustrate how AIXM 5 framework supports a range of aeronautical system to system exchange requirements.

(To be completed)

11 AIXM Namespace Convention

The AIXM namespace convention is based on the naming convention adopted by the Aerospace Operations division of the United States Department of Defense (DOD) [14].

The convention specifies:
- Use URL syntax with the http URI scheme
- Separate hierarchical components of the namespace with a slash "/"
- Separate subcomponents with periods "."
- Use lowerCamelCase and unreserved characters

The namespace should have the following syntax:
   http://organization//unit/system/resource

- Organization is the fully qualified name of the organization providing the data
   - Us.gov.dot.faa
   - com.jeppesen
- Unit is the subdivision within the organization that is providing the data
   - airTrafficOrganization.aeronauticalInformationManagement
- System is the database or application that generated the data
   - NASR
- Resource is a system component or operation used
   - eNASR

So a namespace for the electronic NASR interface to the FAA's NASR (National Airspace System Resources) database might be:
   http://us.gov.dot.faa/airTrafficOrganization/aeronauticalInformationManagement/NASR/eNASR
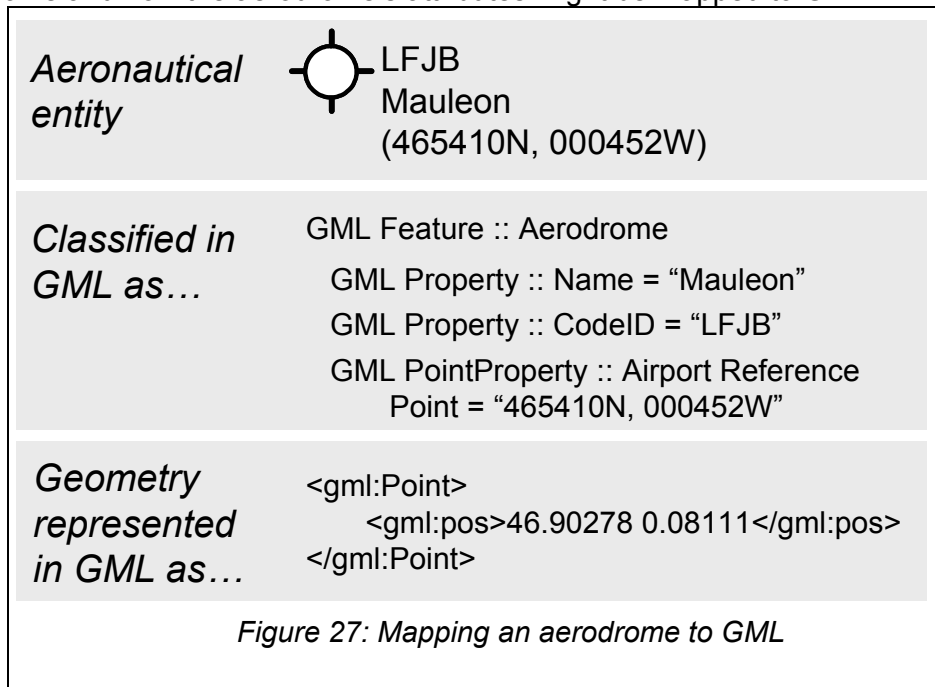
12 GML Introduction

This introduction is excerpted from "AIXM Profile of GML" presented at the EUROCONTROL AISTEC 10 meeting in April 2005 [18].

Geography Mark-up Language (GML) is an internationally adopted standard for exchanging geographical features using XML [7]. 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 [19]. In addition, GML is compliant with the ISO Technical Committee 211 19100s series standards [8]. Amendment 33 to ICAO Annex 15 asks for compliance with a number of standards from this ISO series for terrain and obstacle database products.

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
- 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. The figure below shows a simplified view of an Aerodrome and how the aerodrome's attributes might be mapped to GML.

|	
Aeronautical entity	⊕ LFJB Mauleon (465410N, 000452W)
Classified in GML as…	GML Feature :: Aerodrome GML Property :: Name = "Mauleon" GML Property :: CodeID = "LFJB" GML PointProperty :: Airport Reference Point = "465410N, 000452W"

Geometry represented in GML as…	`<gml:Point>`
	    `<gml:pos>46.90278 0.08111</gml:pos>`
	`</gml:Point>`

Figure 27: Mapping an aerodrome to GML

As illustrated in Figure 27, GML includes a model for representing:

- **Features** : abstraction of a real world phenomena [8]
- **Properties** : describe some aspect of the Feature
- **Geometry Properties** (e.g., Point Properties): represent a geometric aspect of the feature. [8]

Figure 28: Representing real world aeronautical features in GML.

GML provides the building blocks for representing features, properties and geometries. In addition, GML includes an extensive set of predefined geometry types like points, lines and polygons. However, GML does not contain specific 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.

When a domain uses the GML rules to create a specific vocabulary of geographic objects (e.g., aeronautical objects like runways and navigation aids) that vocabulary is described in a **GML application schema**.

Figure 29: Definition of a GML Application Schema
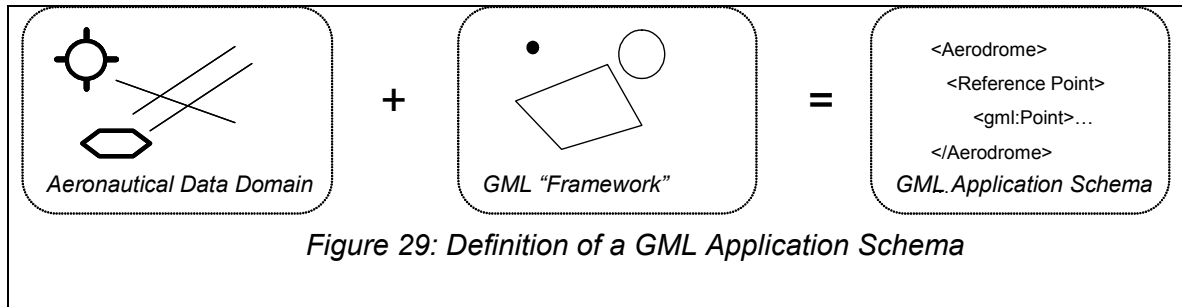
12.1 Definition of a GML Profile

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 [8]. 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 curves and splines, so the AIXM profile of GML can specify that GML curves and splines are not valid when using GML in AIXM.

12.2 Benefits of incorporating GML into AIXM

12.2.1 Compliance with established international standards

AIXM is emerging as an international standard for exchanging aeronautical data, as evidenced by its increased use in aeronautical information systems developed in Europe, United States, Japan and the rest of the world. Successful transition of AIXM into an international standard with broad government and vendor support requires that AIXM leverage existing/emerging data standards that provide a demonstrated value for aeronautical data providers and consumers.

Amendment 33 to ICAO Annex 15 states that:
> (10.5.1) "*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.*"

As obstacles are part of the AIXM Scope, it is desirable that the relevant ISO standards considered by ICAO are considered in the AIXM development. This will guarantee that States using AIXM are de-facto compliant with the ICAO requirements.

Up to now, AIXM has relied on a custom model for representing geographical data. For example, and airspace border is described as a sequence of points and paths, which are characterised by position (lat/long), datum, elevation, accuracy, etc. In order for a system to be able to process this information, custom code has to be developed. GML offers a standardized and internationally accepted model for describing geographical data.

12.2.2 Cost savings in information system development

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 as well as custom visualization tools such as EUROCONTROL's SkyView.
- It would be possible to leverage other OGC standards such as the Web Feature Service (WFS)[**] to develop system to system interfaces for 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

12.2.3 Enhanced capabilities for existing AIXM systems

In order to make use of the geometrical descriptions contained in AIXM, systems such as the EAD convert this information into a full geometrical model, such as Oracle Spatial. For example, if the geometry of an airspace is described as the union of two other airspace parts in AIXM, the EAD will build an internal geometrical representation for that airspace. A similar process takes place in any other systems that use AIXM airspace association data. This might be seen as an unnecessary multiplication of the effort. The incorporation of GML into AIXM would allow systems such as the EAD to export the already "digested" information about airspace associations, in the form of GML geometries. This could then be used directly by any interested system which supports the GML standard.

12.3 Temporality in GML

GML includes two content models that can be used to encode temporal changes to features [7,8]:
- Dynamic Features
- Observation model

The GML Dynamic Features content model is used to describe features that change in time. In addition GML includes an Observation content model that can be used to encode measurements made on a feature. More information can be found in [7,8].

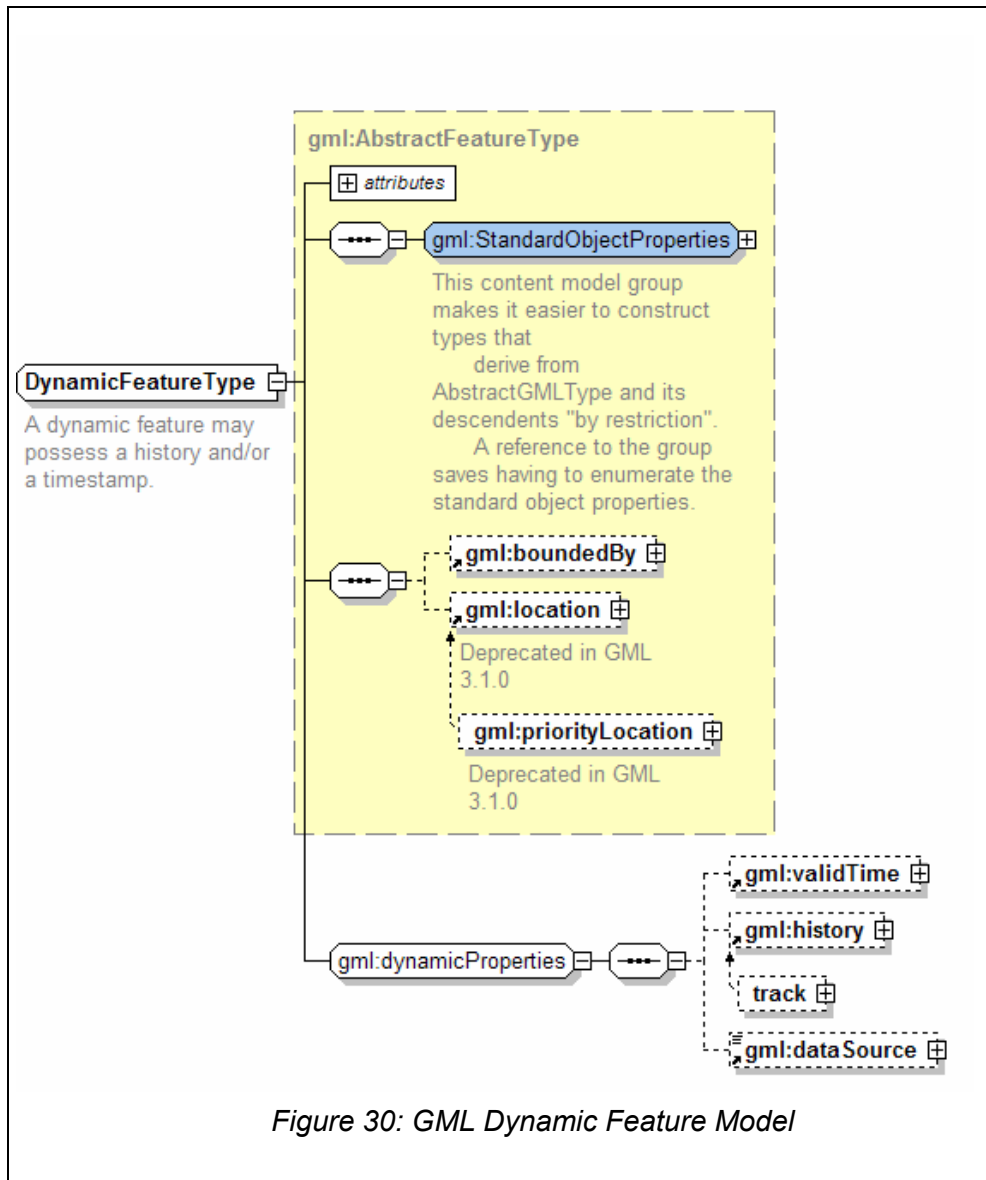[**] See also AISTEC-10/IP3, Agenda Item 13, "Geospatial Interoperability – WFS".

Figure 30: GML Dynamic Feature Model

12.3.1 Dynamic Features [6]

The GML Dynamic Features content model is used to describe features that change in time. In GML, dynamic features must derive from gml:DynamicFeatureType. The gml:DynamicFeature type adds temporal properties to the standard gml:AbstractFeatureType. The definition of the gml:DynamicFeature is depicted in Figure 30.

The gml:validTime element contains a time instance or time period for describing the state of a feature and its properties. The gml:history element contains a set of gml:TimeSlices and it is used to model dynamic properties in accordance with the TimeSlice model.

12.3.1.1.1 GML Snapshot model

The GML Snapshot model for dynamic features represents the state of a feature at a time instance or over a time interval. In the GML Snapshot model the time interval is encoded along with all of the feature properties. According to Galdos [6] GML Snapshot:

- Is typically used to update a feature that has already been defined.
- May contain redundant information since all properties – even time invariant properties – must be re-specified for every snapshot instance.

- Each snapshot instance of a feature must have a unique gml:id if the snapshots are included in the same instance document (gml:identifier could be used to assert that the feature instances actually correspond to the same feature.).

The excerpt from [6] shows how the SnapShot model could be used to encode the state of the Portugal FIR airspace feature at three time intervals:

```xml
<aixm:Airspace gml:id="id1">
 <gml:identifier     codeSpace="urn:UUID:">d6cd9be0-15d4-11da-8cd6-
0800200c9a66</gml:identifier>
 <gml:validTime>
  <gml:TimePeriod>
   <gml:beginPosition>2004-12-12T12:12:12</gml:beginPosition>
   <gml:endPosition>2005-08-31T23:59:59</gml:endPosition>
  </gml:TimePeriod>
 </gml:validTime>
 <aixm:txtName>PORTUGAL FIR</aixm:txtName>
 <aixm:lowerLimit>1000</aixm:lowerLimit>
 <aixm:upperLimit>4000</aixm:upperLimit>
 <gml:dataSource xlink:href="SomeSourceResourceIdentifier"/>
</aixm:Airspace>

<aixm:Airspace gml:id="id2">
 <gml:identifier     codeSpace="urn:UUID:">d6cd9be0-15d4-11da-8cd6-
0800200c9a66</gml:identifier>
 <gml:validTime>
  <gml:TimePeriod>
   <gml:beginPosition>2005-09-01T00:00:00</gml:beginPosition>
   <gml:endPosition>2005-09-31T23:59:59</gml:endPosition>
  </gml:TimePeriod>
 </gml:validTime>
 <aixm:txtName>PORTUGAL FIR</aixm:txtName>
 <aixm:lowerLimit>2000</aixm:lowerLimit>
 <aixm:upperLimit>4000</aixm:upperLimit>
 <gml:dataSource xlink:href="SomeSourceResourceIdentifier"/>
</aixm:Airspace>

<aixm:Airspace gml:id="id3">
 <gml:identifier     codeSpace="urn:UUID:">d6cd9be0-15d4-11da-8cd6-
0800200c9a66</gml:identifier>
 <gml:validTime>
  <gml:TimePeriod>
   <gml:beginPosition>2005-10-01T00:00:00</gml:beginPosition>
   <gml:endPosition indeterminatePosition="unknown"/>
  </gml:TimePeriod>
 </gml:validTime>
 <aixm:txtName>PORTUGAL FIR</aixm:txtName>
 <aixm:lowerLimit>1000</aixm:lowerLimit>
 <aixm:upperLimit>4000</aixm:upperLimit>
 <gml:dataSource xlink:href="SomeSourceResourceIdentifier"/>
</aixm:Airspace>
```

12.3.1.2 TimeSlice model

The GML TimeSlice model can be used to encode temporal properties of a feature over time. A canonical example of the TimeSlice model is modeling an aircraft in flight: Many of the aircraft properties would remain static and the GML TimeSlice model could be used to specify a Flight position property over time. According to [6] GMLTimeSlice:

- Allows time varying feature properties to be expressed as properties of a TimeSlice object. This approach may be more economical because only time varying properties must be repeated.
- A single feature instance can contain several TimeSlices thus avoiding the gml:id issue that affects the Snapshot model.
- TimeSlices can overlap allowing two TimeSlices to affect different feature properties.

An excerpt from [6] shows how the TimeSlice model could be used to model the time varying properties of the Portugal FIR airspace feature:

```
<aixm:Airspace gml:id="id1">
 <gml:identifier    codeSpace="urn:UUID:">d6cd9be0-15d4-11da-8cd6-
0800200c9a66</gml:identifier>
 <aixm:effectivity>
  <aixm:Status>
   <gml:validTime>
    <gml:TimePeriod>
     <gml:beginPosition>2005-09-01T00:00:00</gml:beginPosition>
     <gml:endPosition>2005-09-31T23:59:59</gml:endPosition>
    </gml:TimePeriod>
   </gml:validTime>
   <aixm:lowerLimit>2000</aixm:lowerLimit>
   <gml:dataSource xlink:href="SomeResourceIdentifier"/>
  </aixm:Status>
  <aixm:Status>
   <gml:validTime>
    <gml:TimePeriod>
     <gml:beginPosition>2004-12-12T12:12:12</gml:beginPosition>
     <gml:endPosition indeterminatePosition="unknown"/>
    </gml:TimePeriod>
   </gml:validTime>
   <aixm:txtName>PORTUGAL FIR</aixm:txtName>
   <aixm:lowerLimit>1000</aixm:lowerLimit>
   <aixm:upperLimit>4000</aixm:upperLimit>
   <gml:dataSource xlink:href="SomeResourceIdentifier"/>
  </aixm:Status>
 </aixm:effectivity>
</aixm:Airspace>
```

### 12.3.2 Combined Snapshot and TimeSlice Model

Both Snapshots and TimeSlices can exist within the same GML feature instance. This could enable a feature instance document to specify the static state of a feature using the gml:Snapshot model along with a set of dynamic property changes using the gml:TimeSlice model.

### 12.3.3 Observation model

The gml:Observation model is another approach for representing changes to features. In contrast to the direct temporal representation of the dynamic feature content model, the Observation Model provides a way to indirectly specify changes to features. The observation model was originally intended to model measurements taken by sensors. The observation model includes:

- Properties about the observation event
- Reference to the feature being observed
- Property values observed with the observation event.

The observation model is illustrated below:

*Figure 31: GML Schema model for Observations*
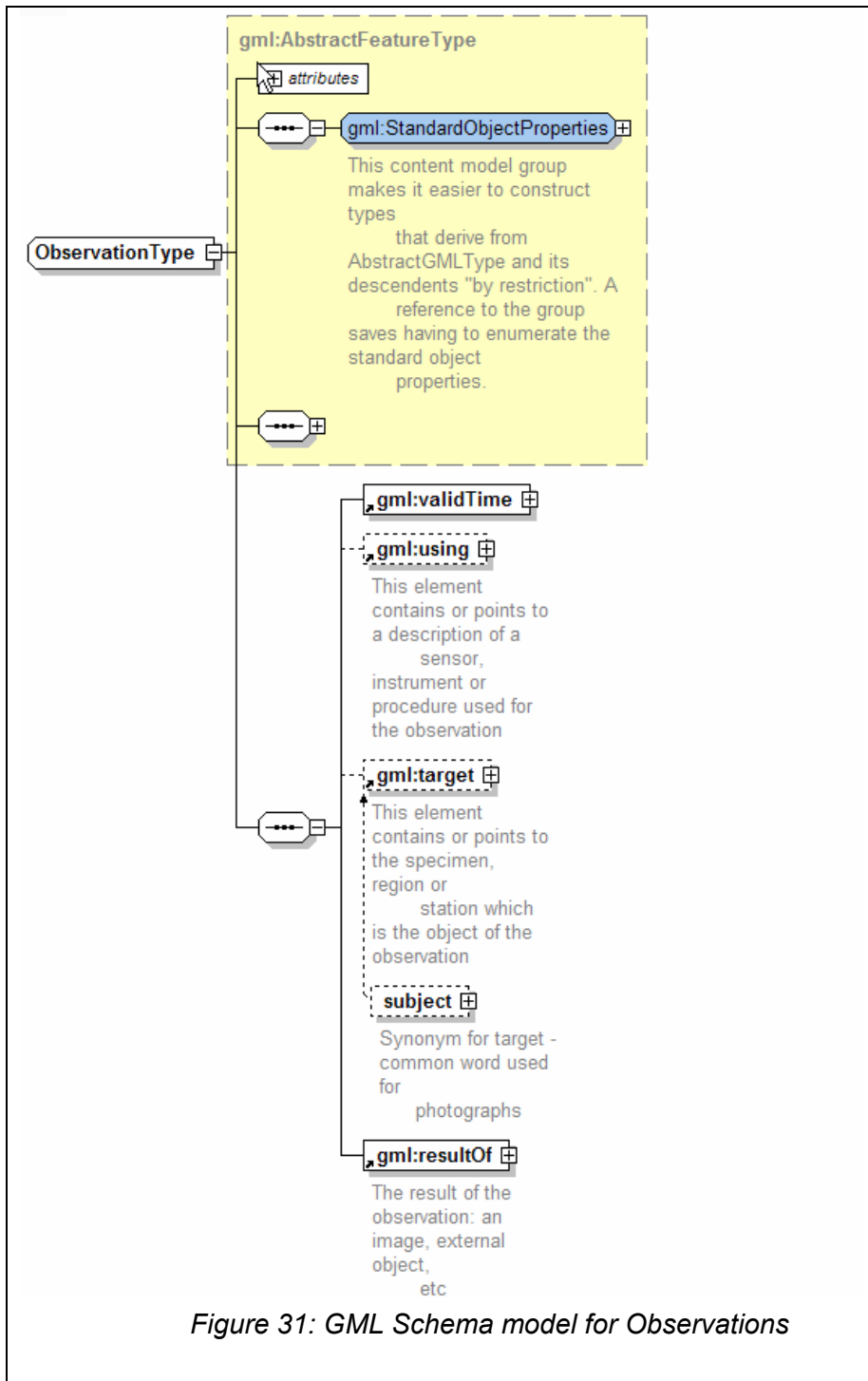
In a sense the observation provides a way to encode information *about* a temporal event on a feature rather than reporting state changes of a feature. The level of indirection associated with the Observation model might be useful for applications like NOTAM that describe temporal events that affect one or more features.