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OGC® Aircraft Access to SWIM (AAtS) Harmonization Architecture Report

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Preface

The FAA's Aircraft Access to System Wide Information Management (AAtS) initiative is in its evolutionary stages of requirements and standards development. Its goal is to provide aircraft connectivity to the FAA's SWIM infrastructure to communicate/share aviation data and services. This connectivity will establish a common operating picture between the flight deck and air traffic control for collaborative strategic decision-making. Distribution of the vast amount of operational information (such as AI, MET and ATM) needed to support the safe movement of aircraft during all phases of flight in the National Airspace System (NAS) will increase capacity, efficiency, and result in more timely departures and arrivals.

Similarly, there are a number of aviation standards in development by a variety of industry groups and committees (i.e., the RTCA Special Committee 206 (SC-206), ARINC 830 Aircraft/Ground Information Exchange (AGIE), and Open Geospatial Consortium (OGC) standards) that are also pursuing the development of requirements and standards that can extend ground-based aviation-related information and data networking technology to support the operation of aircraft as well.

With these efforts, the FAA and industry are moving towards consensus that electronic distribution of operational data and technical information will increase NAS/airline productivity and efficiency as well as deliver a more positive passenger experience both domestically and internationally. There is an additional need to encourage coordination and harmonization of these efforts worldwide since the aforementioned aviation committees also represent global interests.

The AAtS Harmonization project has developed and executed a plan whereby overlaps and conflicts in scope and functionality of SC-206, AGIE and OGC standards have been identified and harmonized for both domestic and international utilization. The goal has been to develop and document an updated AAtS architecture that harmoniously incorporates value and functionality from all three and supports aviation operations that are global in scope.

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Executive Summary

Background

The FAA's Systems Engineering, NAS Architecture organization has been sponsoring an effort to harmonize aviation-related industry standards with the Open Geospatial Consortium (OGC) as the lead. The effort has been organized with a small core team of experts responsible for developing strategy and products, and a larger industry-wide "Tiger" team providing inputs, cross-industry perspectives and expertise in industry standards efforts. The core team included members from: FAA AAtS, OGC, Boeing, Panasonic, and North Star. Other key members of the AAtS Harmonization Tiger team are listed in Annex A.

Approach and Methodology

This report focuses on the harmonization of AAtS as described in FAA IGD v.3.0 with RTCA SC-206 (architecture and requirements), ARINC 830 Air Ground Information Exchange (AGIE) and OGC standards. Harmonization tasks included:

1. Analyzing and shaping existing as well as emerging standards;
2. Developing a harmonized architecture that addresses the functional requirements; and
3. Formulating conclusions and recommendations to:
    a. address identified harmonization issues
    b. support decision processes of policy makers, government, and industry

Architecture

This report documents:

- a harmonized architecture based upon concepts and standards from FAA AAtS, RTCA SC-206, ARINC 830 (AGIE) and OGC
- a new, recommended, high-level system architecture that both updates and expands the scope of the harmonized architecture

Harmonized Architecture

The harmonized architecture defines the role and scope of each standards package relative to the other packages in the context of a generalized network computing protocol stack. The standards generally fall into two categories. AAtS and SC-206 standards cover both application and services - middleware functions (and corresponding requirements). In an AAtS context, AGIE and OGC standards mainly cover re-usable services - middleware functions that multiple end-user applications can leverage to reduce cost, improve integration, and lower development effort, as well as increase operational efficiency and interoperability. AGIE standards can also cover some application functions in the context of non-AAtS applications and information exchanges.

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The harmonized architecture identifies areas of standards overlap and gaps with regard to intended use, end-user applications needs, and key business requirements. It utilizes a layered design pattern to show how different application, services, and middleware functions interface and interact, as well as where related, critical but out-of-scope functions fit. The architecture is characterized through a system level view in which functional components are distributed in nominal topologies between the information providers and consumers. The system level view identifies key functional features that are common across the standards and shows where they might be allocated to provide an efficient and harmonized AAtS implementation.

High-level System Architecture

The high-level system architecture described and recommended in this report expands the scope of the harmonized architecture to include other relevant industry and aviation standards as well as other air-ground architectures. The recommended architecture is developed by expanding from the standalone FAA/NAS AAtS architecture to incorporate a perspective based on industry standards-based solutions as well as a global perspective. It provides a basis for initial global interoperability discussions.

Conclusions and Recommendations

As documented in this report, the goal of the AAtS harmonization project to "harmonize standards and concepts within the AAtS trade space" was accomplished through coordination amongst multiple standards team members and other activities. The following conclusions were reached and recommendations developed:

Conclusions

1. A harmonized architecture based on AAtS with SC-206, AGIE and OGC standards is achievable and provides a framework for deploying AAtS as a multi-domain solution.
2. Harmonization across these three standards in the AAtS architecture allows the benefits of the capabilities from each standard to be realized in a consistent implementation.
3. The AAtS architecture as defined in IGD v3.0 is too constraining to fully reflect the capabilities and benefits of the harmonized architecture.

Recommendations

1. Recommend incorporation into future updates of the AAtS IGD of an enhanced and broader architecture and environment based on the harmonization team review comments and recommendations.
2. Recommend the development and testing of a harmonized solution (prototype).
3. Recommend follow-on harmonization efforts to include other key industry standards.

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OGC® Aircraft Access to SWIM (AAtS) Harmonization Architecture Report

1 Introduction

1.1 Scope

This OGC® document describes the Aircraft Access to SWIM (AAtS) harmonization architecture developed by a team funded by the FAA and led by the Open Geospatial Consortium (OGC). The architecture harmonizes:

- [AAtS] Aircraft Access to SWIM concepts;
- [SC-206] RTCA aeronautical information services (AIS) and meteorological (MET) information data link service committee concepts and standards;
- [AGIE] Air-Ground Information Exchange A830 standards; and
- [OGC] OGC encoding and services standards as well as architectural perspectives.

It identifies areas harmonized in common for all four standards packages, areas harmonized across two or three standards and unique areas of each standard that either require further harmonization or impede full harmonization.

1.2 Purpose & Objective

The purpose of the harmonization effort has been to leverage the strengths of distinct but related standardization efforts in order to improve the scope, scale, and interoperability of aircraft-ground data communications under the auspices of the FAA AAtS concept and program.

The objectives of this report are to:

- Describe the challenge of harmonizing disparate standards and a layered architecture methodology for addressing it.
- Apply the harmonization methodology to three principal standards or standards packages relevant to AAtS (SC-206, AGIE, OGC)
- Recommend a new high-level AAtS system architecture incorporating SC-206, AGIE, OGC, and other standards.

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1.4 Revision history

Date	Release	Editor	Primary clauses modified	Description
1 July 2014	0.10	Johannes Echterhoff	all	Moved content of report version "I" to OGC ER template, including updates as discussed during the June meeting.
7 July 2014	0.11	Matt de Ris	6.5.3	Reorganized the OGC mapping sections to include a higher level discussion of multiple topologies
21 July 2014	0.12	Johannes Echterhoff	throughout	Updates as discussed during telcon on July 14, merged edits and comments from Robert Klein
4 August 2014	0.17	Johannes Echterhoff	Executive Summary	General revision and removal of project summary content to a separate document.
10 August 2014	0.2	Joshua Lieberman	all	General editorial reworking and polishing
29 August 2014	0.5	Joshua Lieberman, Johannes Echterhoff	6.5	Response and Update following August F2F Meeting
3 September, 2014	0.6	Joshua Lieberman, Johannes Echterhoff	Various	Editorial updates and sync with 14-086

1.5 Future work

In the course of carrying out the work presented in this report, a number of opportunities for valuable follow-on activities were identified:

- Testing and validation of the recommended AAtS architecture through one or more prototyping activities (see OGC document 14-086);
- Extension of harmonization down into lower architectural layers (transport, data link);

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- International outreach and harmonization with other SWIM and AAtS systems that are being designed and developed;
- Development of business value propositions for additional stakeholders (for example, value for aircraft operators);
- Identification and development of additional use cases for aircraft-ground communications
- Development and testing of additional OGC standards and standard profiles relating specifically to aviation and AAtS, such as a Data Management Services (DMS) specification.

1.6 Foreword

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

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

2 References

The following documents are referenced in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

- ARINC 830 *Air/Ground Information Exchange (AGIE)*
- FAA *Aircraft Access to SWIM (AAtS) Implementation Guidance Document (IGD) v3.0*
- FAA *Aircraft Access to SWIM (AAtS) Concept of Operations (ConOps) v1.0*
- RTCA DO-340 *Concept of Use for Aeronautical Information Services (AIS) and Meteorological (MET) Data Link Services*
- RTCA DO-349 *Architecture Recommendations for Aeronautical Information (AI) and Meteorological (MET) Data Link Services*
- OGC Document 14-086 *AAtS Harmonization Project Summary*

3 Conventions

3.1 Abbreviated terms

AAtS Aircraft Access to SWIM

ACARS	Aircraft Communications Addressing and Reporting System
ACD	Aircraft Control Domain
ADS-B	Automatic Dependent Surveillance - Broadcast
AGIE	Air/Ground Information Exchange
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
AISD	Airline Information Services Domain
AIXM	Aeronautical Information Exchange Model
AMQP	Advanced Message Queuing Protocol
ANSP	Air Navigation Service Provider
AOC	Airline Operation Center
ARINC	Aeronautical Radio, Incorporated
ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATM	Air Traffic Management
ConOps	Concept of Operations
DLS	Data Link Service
DLSPF	Data Link Service Provider Function
DMS	Data Management Service
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
FIS	Flight Information Service
FIXM	Flight Information Exchange Model
FOC	Flight Operations Center
GDLM	Ground Data Link Manager
GDLP	Ground Data Link Processor
GDLPF	Ground Data Link Processing Function
GML	Geography Markup Language
HF	High Frequency
HTTP	Hypertext Transfer Protocol
IFE	In-Flight Entertainment
IGD	Implementation Guidance Document
IP	Internet Protocol
LLWS	Low Level Wind Shear
MAGIC	Manager of Air Ground Information Communication
MET	Meteorological
MIAM	Media Independent Aircraft Messaging
NAS	(US) National Airspace System
NESG	Network External Secure Gateway
NWS	National Weather Service
ODLM	Onboard Data Link Manager
ODLP	Onboard Data Link Processor
ODLPF	Onboard Data Link Processing Function
OGC	Open Geospatial Consortium
OGC WFS	OGC Web Feature Service

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PIESD	Passenger In-flight Entertainment and Services Domain
PIREP	Pilot Report
PODSD	Passenger Owned Device Services Domain
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SESAR	Single European Sky ATM Research
SOA	Service Oriented Architecture
SWIM	System Wide Information Management
VDLm2	VHF Data Link mode 2
VHF	Very High Frequency
VLAN	Virtual Local Area Network
WXXM	Weather Information Exchange Model
XML	eXtensible Markup Language

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4 Architecture Overview

This chapter provides an overview of the approach taken towards a harmonized AAtS architecture.

4.1 Harmonization Problem

AAtS, SC-206, AGIE and OGC standards, architecture, use cases and business value propositions have mostly been independently developed. Overlaps have not been identified and they have not been designed to work together in concert. The AAtS harmonization effort is intended to identify and recommend fixes to harmonization issues between these standards. One aspect of AAtS harmonization is ensuring the standards can work together in one or more common architectures.

The primary goal is to define a harmonized architecture that describes an AAtS implementation environment which leverages capabilities from each of the relevant standards as applicable. The architecture must depict the value discovered by the harmonization effort for common and unique areas that accentuate the value of each specific standard. This includes key application capabilities, infrastructure services and functions of AAtS, SC-206, AGIE, and OGC.

A key tool in the development of harmonized architectures is the use of system layers or levels with well-defined interfaces between them that serve to separate concerns and technology choices in one layer from those in another. At an application level there are AAtS and SC-206 harmonized functions along with gaps and differences in functionality or requirements. At the service level there are AAtS and SC-206 lower-level functions harmonized with AGIE and OGC infrastructure services.

The major issues in harmonizing the application level of AAtS with SC-206 within the prototype context are:

1. The harmonization scope limits SC-206 use cases. It only covers IP data link capable uses (no air-air and broadcast services).
2. AAtS does not show non-SWIM ground sources in its architecture.
3. AAtS focuses on non-safety critical (i.e. category 2) use cases.

The major issues with harmonizing the service level of AAtS and SC-206 functions with AGIE and OGC standards are:

1. AAtS-type (combined AAtS and SC-206) use cases and architectures do not account for implementation in a larger aviation environment, e.g. cabin, maintenance, non-AAtS flight operations.
2. AAtS and SC-206 are written and viewed from regulatory and flight deck perspectives whereas AGIE and OGC are written and viewed from commercial and multi-domain perspectives.

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These standards each have separate application space, intended uses, and technical architectures. The first task is to define what these are and how they relate to each other. See Figure 1 below. The second task is to focus on the architecture aspects useful to harmonization.

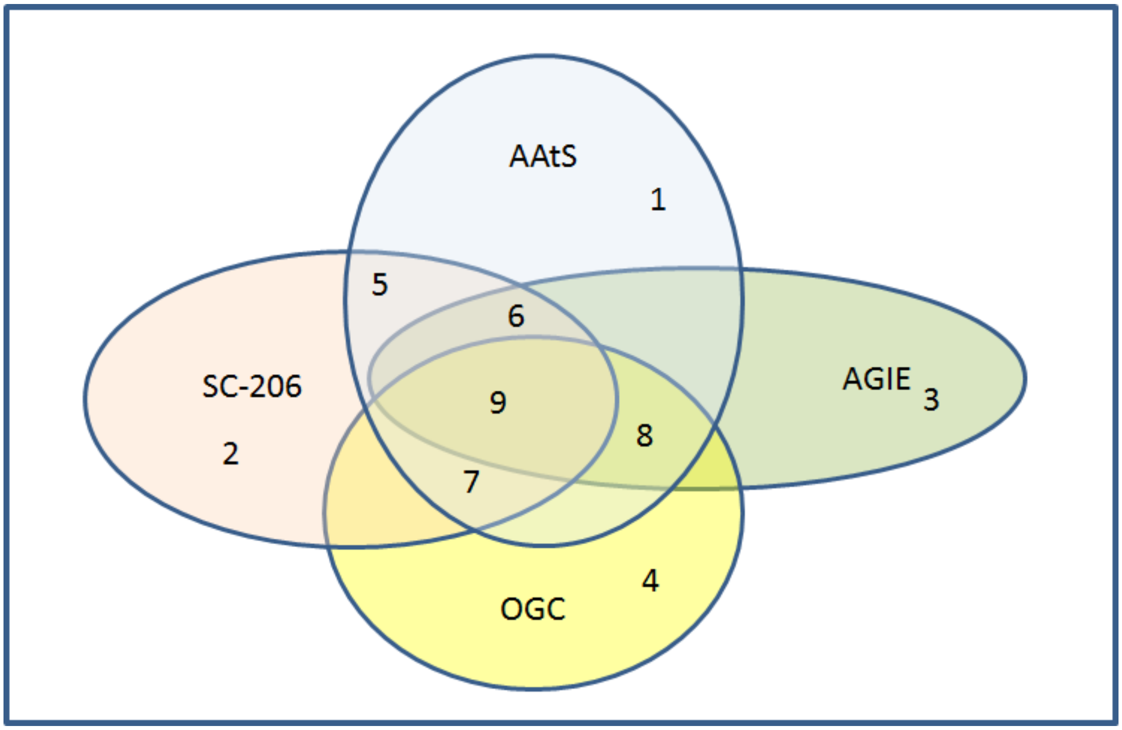

Figure 1 - Venn diagram of the applicable standards space

Figure 1 describes the coverage of each standard within a space defined by application functionality vs intended use in order to illustrate overlaps and gaps between them. The following describe key areas of overlap in the diagram.

Applications

There are five areas in Figure 1 that relate to application capabilities and features of the standards that the team identified as necessary to harmonize. In this case “applications” refers to unique functions, capabilities, requirements and unique non-re-usable services. That is special software required to meet the unique end user application demands. Both AGIE and OGC provide services and non-AAtS infrastructure functionality to support a larger scope than that defined by AAtS.

1. AAtS unique – this area contains all the unique AAtS functions and requirements. This includes flight information (in addition to SC-206 AIS and MET) functions, data and requirements.

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2. SC-206 unique – this area contains all the unique SC-206 functions and requirements. It includes any safety critical applications and requirements, and non-networks (IP-like) communications (such as air-air, broadcast).
3. Non-AAtS AGIE supported – this area contains all the AGIE supported applications that are non-AAtS. This includes cabin, maintenance, software delivery, passenger entertainment, and other such applications.
4. Non-AAtS OGC supported – this area contains all the OGC supported applications that are non-AAtS, for example built environment, defense & intelligence, emergency response & disaster management.
5. AAtS & SC-206 common – this area contains all the common AAtS and SC-206 functions and requirements, for example regarding AIS and MET information.

Services and Middleware

Four service or middleware areas are considered key areas. In this case, services or middleware refers to functionality that supports the end user applications and is generally either a software level "service" or "re-usable middleware software".

6. AAtS AGIE services – this area contains all the AGIE-only supported services and middleware functions.
7. AAtS OGC services – this area contains all the OGC-only supported services and middleware functions that support AAtS and SC206 that are not AGIE.
8. AGIE OGC services – this area is about the realization of communications and services with AGIE and OGC protocols in general, without specific relevance to either AAtS or SC-206.
9. AAtS, SC-206, AGIE & OGC common services – this area contains all the services and functions that both AGIE and OGC support for AAtS and SC-206.

The AGIE standard focuses on Internet Protocol (IP) transport and network capabilities. In principle, OGC standards are transport protocol agnostic; however, they are typically bound to IP-based protocols.

While AAtS has not yet specified a transport mechanism, there appears to be a consensus that it will rely on IP at some point in the future. SC-206 as currently represented also supports aviation-based, non-IP transport mechanisms and data links including VHF, HF, ADS-B and non-IP satellite communication links. Many of these data links bear no resemblance to modern day ground-based networking and are more like legacy radio communication links leveraging true broadcast where the sender broadcasts a message blindly and any suitably equipped destination may receive it.

4.2 In the Large

Both AGIE and OGC are defined as industry standards. OGC standards in particular specify information and service models that are used across multiple industry domains.

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AAtS utilizing OGC standards may therefore be able to leverage infrastructure services that are not aviation-specific but still re-usable for aviation purposes, reducing infrastructure service costs. AGIE is an aviation-specific standard but one designed to support a range of aviation domains, of which AAtS applications are only a small part. AGIE supports traffic management for essentially all onboard data communications applications. This is important because the requirements and scope for each onboard application (including those in both SC-206 and AAtS) are defined only for its specific standalone functionality. Each independent application on each airplane competes for scarce and costly air-ground bandwidth from airline networks or even from networks that support both aviation and non-aviation users (e.g., Inmarsat, Iridium, etc.). This is especially true for Internet Protocol (IP) systems because IP has been configured to function globally using only "greedy" bandwidth management algorithms. AGIE's and OGC's cross-domain holistic perspectives are unique in the aviation industry. Both support solutions that address the need for communication and services "in the large" – see Figure 2 and Figure 3.

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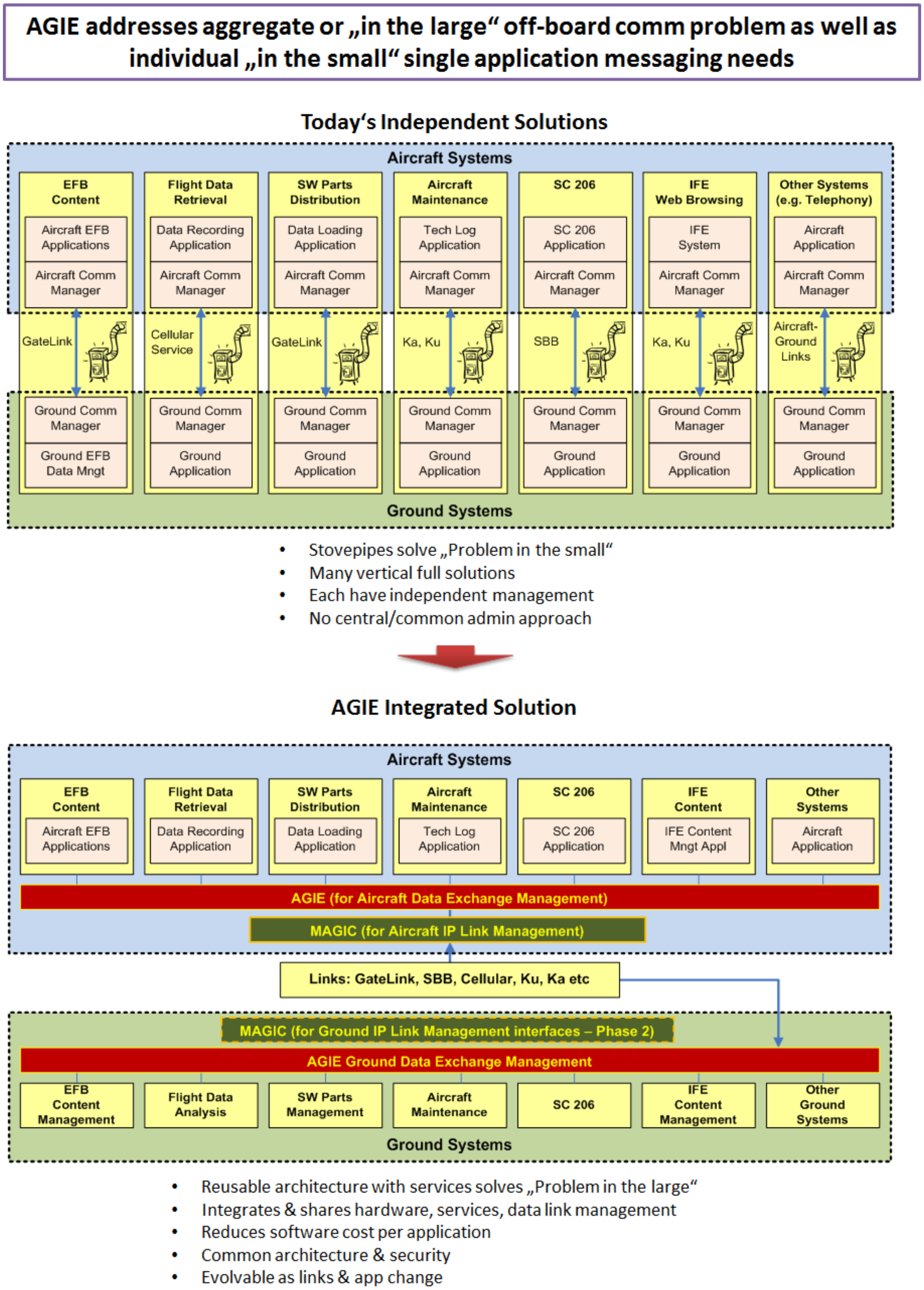

Figure 2 - AGIE example of "In the Large" Context

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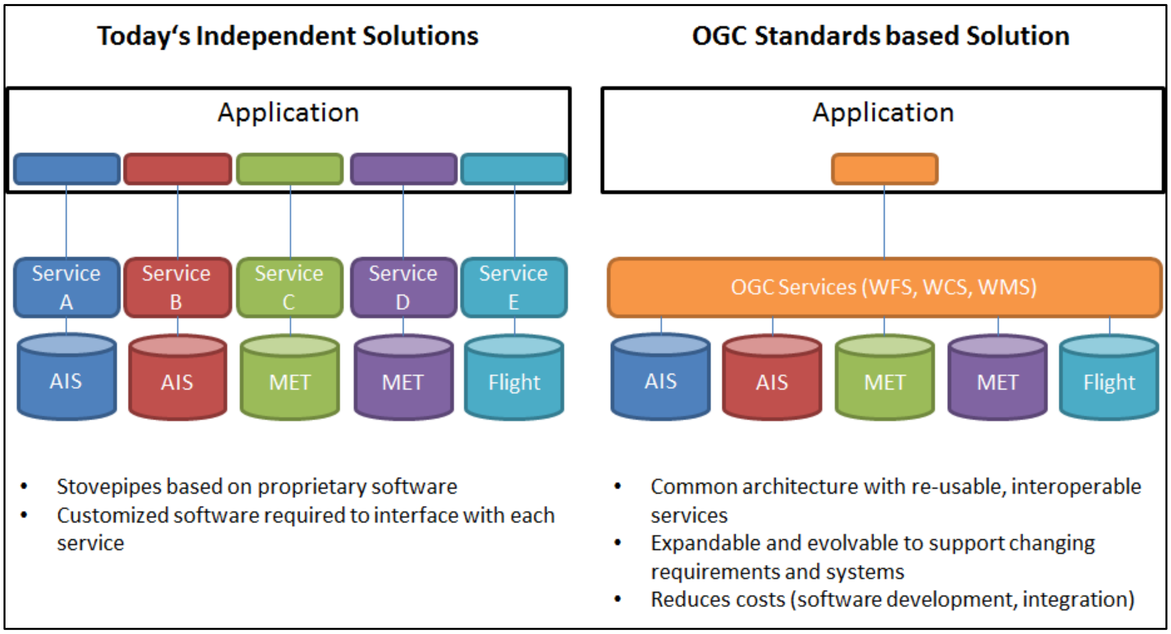

Figure 3 – OGC example of "In the Large" Context

Today's air-ground environment, as characterized in both AAtS and SC-206, consists of many stove-piped applications or application suites which compete with each other for bandwidth on the air-ground links and are developed and integrated independently. This is normal for IP-based applications and how the Internet has been designed to work. On the Internet all applications are independently developed, deployed and operated. Each application is "greedy" in claiming all the bandwidth it can use. IP applications use a "ramp rate" and "maximum packet size" to request bandwidth. An application starts with a small request, ramps up at a defined rate until it can't increase further, then backs off one step. On the ground where most performance issues are caused by congestion, applications compete in relatively large (huge in an aviation context) resource pools, and there is little need for coordination between applications. During periods of congestion, the Internet routing infrastructure automatically throttles application bandwidth, and manages actual allocations to equally greedy applications. Greedy works because each application requests as much bandwidth as it can use and requests are resolved very quickly.

In the air-ground data link environment, however, Internet congestion rules don't work as well. Performance issues are not always caused by congestion, but more often by limited bandwidth, or by latency such as from global distribution and geo-stationary satellite delays, or just by poor quality on the links due to atmospheric interference. Re-allocating bandwidth to an air-ground route may take tens of seconds, rather than micro/milliseconds with ground-side Internet. It is not always possible to determine what causes latency and dropped packets nor what dictates the final throughput limits that IP packets see on a network. When such delays and bottlenecks are combined with automatic

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bandwidth throttling algorithms that assume congestion, it may only further reduce the bandwidth available for a client or application suite. Throttling one aircraft's request under a mistaken congestion assumption may then simply allow non-flight operational users (passengers), or another aircraft (possibly a competitor's!) to greedily consume the freed-up bandwidth. Worse, if every aircraft makes greedy requests, bandwidth may instead be allocated to non-aviation users (i.e. oil rigs, cruise ships, off-shore gambling) on data link services that obtain revenue from more than just aviation flight operations (i.e. almost all commercial air-ground data link services).

Only a centrally managed and operationally distributed system – one based for example on AGIE plus Manager of Air-Ground Information Communication (A839 MAGIC) or other specification for centralized management - that is knowledgeable of all bandwidth demands, all air-ground path options, and associated rules for both uplink and downlink priorities can overcome these limitations. Such a system would allow SC-206 over IP and AAtS to operate with appropriate delivery priorities in the context of all onboard data delivery and messaging requests (air-to-ground and ground-to-air), all available data links, and actual available bandwidth. Figure 2 provides an example of how AGIE + MAGIC might support management of these data flows and resources "in the large".

4.3 Architecture Objectives

A harmonized architecture has been developed in order to enable the FAA and industry to quickly evaluate how AAtS can leverage harmonized features, topology and approach, as well as to show the value of AAtS for implementing a harmonized solution in airplane platforms and services. In order for AAtS to be successful it must embrace industry practices for development, certification/approval and operations. This involves cost-effective software development, re-use of components, interoperability (for both development and operations), sharing of real-world data link resources, and harmonized operations in aircraft maintenance and operational environments. An objective, therefore, of the FAA harmonization effort with AAtS and SC-206, AGIE, OGC, and this document is to portray a common architecture that leverages as many existing services and functions as possible.

From an implementer's perspective (airline, airframe developer, avionics supplier, regulator, air navigation service provider (ANSP), data link service provider) the objective is to show a harmonized overall solution. From the perspective of an industry standards developer, the objective is to show a feasible approach to implementing their standards together in larger context.

4.4 Architecture Approach

The selected approach has been to define a harmonized architecture from two perspectives:

1. Architecture layers and services interaction
2. System architecture or component topology

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Given the close mappings between AAtS and SC-206, the focus has been on harmonized aspects of the AAtS and SC-206 problem space. In this vein, harmonization components have been defined as a set of functional capabilities/requirements from one or more standards packages brought together to define a "new" and "harmonized" component. However, critical capabilities and functions relying on only single standards are also briefly described.

One aspect to this approach has been developing a simple but powerful prototype architecture. The prototype architecture, while intentionally simplified, provides a useful concrete view that could potentially be implemented. A description of the prototype architecture can be found in the Project Summary document.

5 Harmonized Layered Architecture

This section describes the layers, protocol interactions, and scoping of each of the four standards packages. It also discusses critical but out-of-scope standards, services, and functions. Most of the harmonization accomplished in this effort has taken place in what is described in the ISO OSI model as the "Application Layer". This is because AAtS, SC-206, AGIE and OGC standards rely on lower ISO layer functions and requirements but do not cover them except in specific cases not described here where the complexity and drawbacks of tighter vertical integration are deemed necessary.

5.1 Layer Interactions

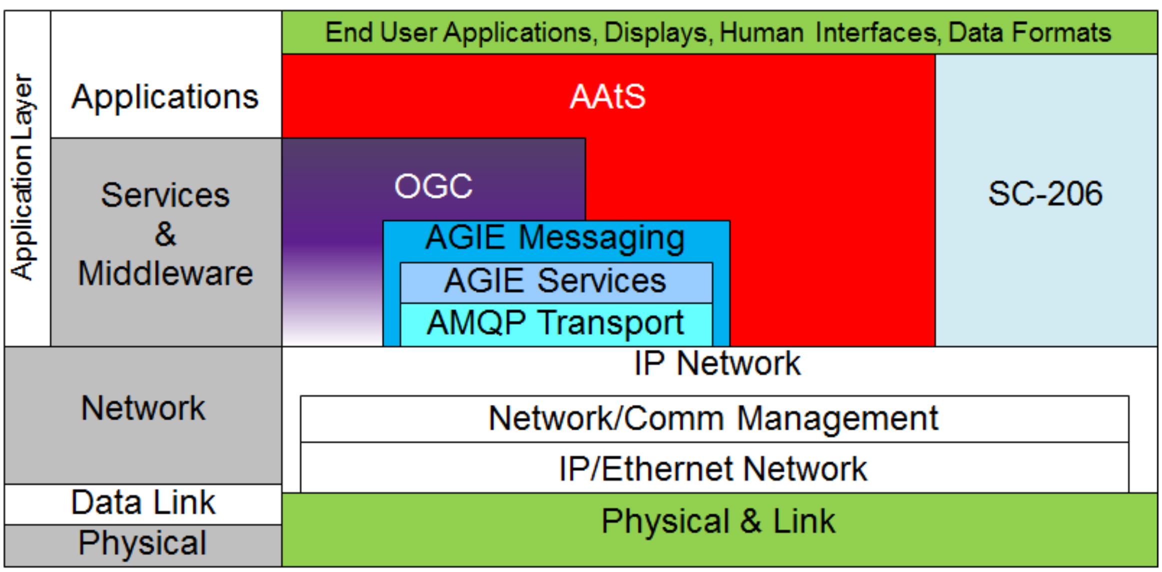

Figure 4 - Harmonized Layers

As shown in Figure 4, applicable AAtS, SC-206, AGIE and OGC functionality can be assigned to the Application layer between the end user (human or system) applications layer (displays, control, data formats) and the network layer. For simplicity, only the following layers and sub-layers are defined and considered here:

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1. Application Layer – defined as the ISO application layer.

2. Application Sub-layer – this upper part of the Application layer encompasses unique and non-reusable software and hardware functionality provided to support specific business and technical application needs. Included in this scope are application capabilities defined by AAtS and SC-206. End user specific application features, such as displays, controls, data formats, etc., are out of scope for both AAtS and SC-206 as well as this harmonization effort; however, a portion of AAtS and SC-206 "services" can be considered application-specific "business services" rather than reusable "software services".
3. Services and Middleware Sub-layer – the lower part of the Application layer focuses on reusable functions and "software services". This layer includes most of the AGIE and OGC capabilities as well as software services and infrastructure functions in AAtS and SC-206.
4. Network Layer – the Network layer is defined here to include all of the network layers in the ISO stack. This includes IP layer (network), TCP layer (transport), and various network control and management layers. It also includes Ethernet or an equivalent data link layer. All of these layers are usually combined seamlessly in a modern IP Router/Switch.
5. Data link and Physical Layers – the layers below the Network layer carry out physical and bit-level transport. These are only of interest to harmonization in that air-ground data links have unique capabilities and limitations in these areas. These include: Ka/Ku-band satellites, L-band Inmarsat ACARS, and broadband VHF/HF/Iridium ACARS. Certain minimally harmonized SC-206 features pertain to these generally non-IP capabilities; others are out of scope for this effort.

Figure 4 positions key harmonization standards and adjacent critical functions within the defined layers.

6. AAtS and SC-206 - are positioned throughout the Application layer. There is a small component of each that pertains to end user applications (by standards body agreement) and a small component of SC-206 that pertains to non-IP communications has been considered in this harmonization effort.
7. OGC – is shown supporting the Services and Middleware sub-layer, with emphasis on Services. This includes functions both harmonized with AGIE (as messaging) and standalone without AGIE.
8. AGIE – is shown occupying a portion of the Services and Middleware sub-layer. Originally this was termed a transport sub-layer; this is not fully accurate but does in some sense describe the primary AGIE messaging capabilities. AGIE is shown

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both working with OGC and in a standalone capacity. AGIE is further delineated into:

a. AGIE messaging – the overall AGIE functionality.
b. AGIE service layer – an AGIE sub-layer that performs message management, decision making and housekeeping.
c. AMQP transport – an AGIE sub-layer that performs the actual data transport between AGIE servers and clients. AMQP interfaces directly with the network and IP layers, primarily using TCP/IP.

5.2 MIAM and ACARS Considerations

Non-IP transports positioned below the Application layer (although not shown in Figure 4) that have been considered in this effort include:

1. MIAM – ARINC 841 Media Independent Aircraft Messaging is a key Airbus and SITA capability being rolled out for Airbus A-350 timeframe.

2. ACARS – Aircraft Communications Addressing and Reporting System is critical because the only real aircraft data communication system today for safety and non-safety critical applications for FAA and most of the globe is ACARS. ACARS is limited in performance but globally available and certifiable for some safety related uses with operational mitigation.

Note: VHF,VDLm2 – VHF Data Link mode 2 (VDLm2) is a physical medium (but really also a data link layer) and is the primary global data communications link for aircraft. Inmarsat "classical satcom" falls in the same category with a very large penetration rate among airlines. ACARS works well over any of these links. Media Independent Aircraft Messaging (MIAM) is an early subset of AGIE functionality to be implemented 2-5 years before AGIE. It does not perform client-server functions; instead it works point-to-point from an onboard MIAM server to a single ground-side MIAM server.

ACARS, on the other hand, is supported by nearly every ANSP globally and installed on nearly every commercial airplane produced in the last decade. Upgrades to VDLM2 have increased VHF ACARS efficiency. Inmarsat and Iridium are both going for safety certification with IP-based offerings, although those offerings still attach to most applications on most aircraft via legacy non-IP/non-Ethernet aviation interfaces. This provides a limited but widespread ACARS-over-IP capability.

MIAM has some very important benefits for consideration.

1. MIAM is emerging in the very near-term

2. MIAM compression greatly enhances ACARS/VHF and satcom bandwidth

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3. MIAM guarantees ATC performance under all MIAM loads

4. MIAM increases message size to 50KB from 3.3KB.

5. MIAM is defined to integrate directly into AGIE in future AGIE deployments

6. MIAM allows redirecting information exchange from aviation data links to IP based commercial data links by means of a MIAM convergence algorithm.

The MIAM concept also includes an update to ARINC 620 which is termed “ACARS-B” or “ground ACARS”. This is significant as it allows use of larger (possibly XML based) messages in common, industry defined (ARINC 620) message formats. This will be key to rolling out AAtS and SC-206 for interoperability and sharing across multiple information providers, information consumers, and data link / data management service providers. AIXM, WXXM, and FIXM and air-ground derived subsets, for example, may be considered for future ARINC 620 formats.

MIAM allows AGIE to use a non-IP data link with MIAM-over-ACARS. This capability has been agreed to by multiple AEEC committees but is not included as part of the initial standard. (MIAM) defines an ACARS convergence algorithm that allows native IP devices to communicate over the ACARS data link. These algorithms allow efficient and controlled access to the limited ACARS data link. AGIE and MIAM sub-committees have coordinated how this can/will be accomplished in the near-term. This allows MIAM to become a proxy between AGIE server (AMQP broker) and ACARS. However, it requires an adaptation to the AMQP implementation to transport messages over ACARS between specified AMQP brokers. While this feature has value and has been approved, no implementation details are captured in the current version of the standard.

6 System Architecture and Topology

This section provides a system architecture view for each of the standards, as well as a view for the harmonized system architecture. AAtS and SC-206 have very similar system architectures and may potentially be deployed similarly, although data sourcing varies considerably from one to the other. AGIE and OGC provide software services that can support AAtS and SC-206 functionality but also support non-AAtS related applications. AGIE-based systems provide message handling functions and services that are applicable to portions of both AAtS and SC-206 but also to other aviation domains such as cabin, maintenance, non-AAtS related flight operations, software parts delivery, and in-flight entertainment (IFE) head-end messaging. OGC standards enable interoperable systems that manage and process geospatial information across many domains, such as aeronautical, weather, flight and terrain data. The focus in the sections below is on aspects of the standards relevant to AAtS applications. Other applications are shown only for context. First the standalone system architectures are presented, and then various harmonized perspectives are layered over the standalone system views.

AAtS and SC-206 system architectures may be compared quite directly as follows:

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- Information Sourcing:
  - Primary ground information source (and consumer of downlink information) is the NAS via SWIM for AAtS. There is no specifically defined primary information source (and consumer of downlink information) for SC206.
  - Private/public sector data is a non-SWIM source of information for SC-206 but not a part of the nominal AAtS architecture.
  - AAtS architecture is directed at enterprise-level implementations whereas the SC-206 architecture takes into account local non-enterprise-level system implementations as well.
  - Overall, SC-206 recognizes global and non-SWIM ground infrastructure components beyond the NAS SWIM to which AAtS architecture confines itself.
- AAtS and SC-206 both include a ground-side server component for filtering and processing. The SC-206 component is GDLPF while for AAtS it is DMS. SC-206 describes concepts for a government funded component option as well as a commercial entity similar to DMS.
- Both AAtS and SC-206 are data link agnostic but contain functions for data link services. The focus in terms of harmonization is support for commercial data links (IP plus ACARS).
- AAtS and SC-206 both cover onboard aircraft systems. SC-206 concepts describe installed and mobile devices, while AAtS covers onboard functionality. Human-machine interfaces and associated end user applications are considered beyond the scope of both standards.
- Differences in application scope supported by each standard (AIS, MET & FIS vs. only AIS and MET) have no impact from a system architecture perspective.

6.1 AAtS System Architecture

AAtS has defined a system architecture made up of six top level components, two of which are NAS/SWIM components and four of which are commercial components unique to AAtS.

Figure 5 - AAtS System Architecture View (Source: FAA AAtS IGD)

NAS Data Service Provider is a NAS component that provides information for weather, aeronautical data and ATM data. In the case of bi-directional data flow this component also ingests data sent from the aircraft (such as turbulence data and PIREPS). The NAS SOA Service Provider component transports the NAS data from internal NAS services using SWIM Core Services to other SWIM nodes via SWIM SOA service interfaces. This information is also provided to external non-NAS consumers (or providers in bi-

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directional flow) via the Network External Secure Gateway (NESG) through pre-defined SWIM SOA-based services.

In the context of AAtS, Data Management Service Provider (DMS) components also connect with the NAS SOA Service Provider via the NESG. AAtS considers that DMS and other external AAtS components will be provided as commercial non-FAA-funded services. The DMS queries / filters NAS data, and sends the appropriate data to aircraft and airline systems based on operator configured logic. The Aircraft Operator / Aircraft System is a peer component to the DMS and is the primary client (downlink or uplink) for exchanging data with the DMS. The DLSP is the air-ground data link service used to transport data between the DMS and the aircraft. While shown on par with the other components, it actually implements lower level transport functions. The External Access to DMS Provider is a set of functions used by the operator to configure, manage and control the AAtS system for its intended use.

6.2 SC-206 System Architecture

The SC-206 system architecture depicts a number of entities but the two key components are the Ground Data Link Processing Function (GDLPF) and the Onboard Data Link Processing Function (ODLPF). Most SC-206 information is considered to flow from ground sources to the aircraft; however, there is some air-to-ground information flow as well. Conceptually, the SC-206 architecture also includes provisions for air-to-air data flow but the harmonization effort has not focused on this.

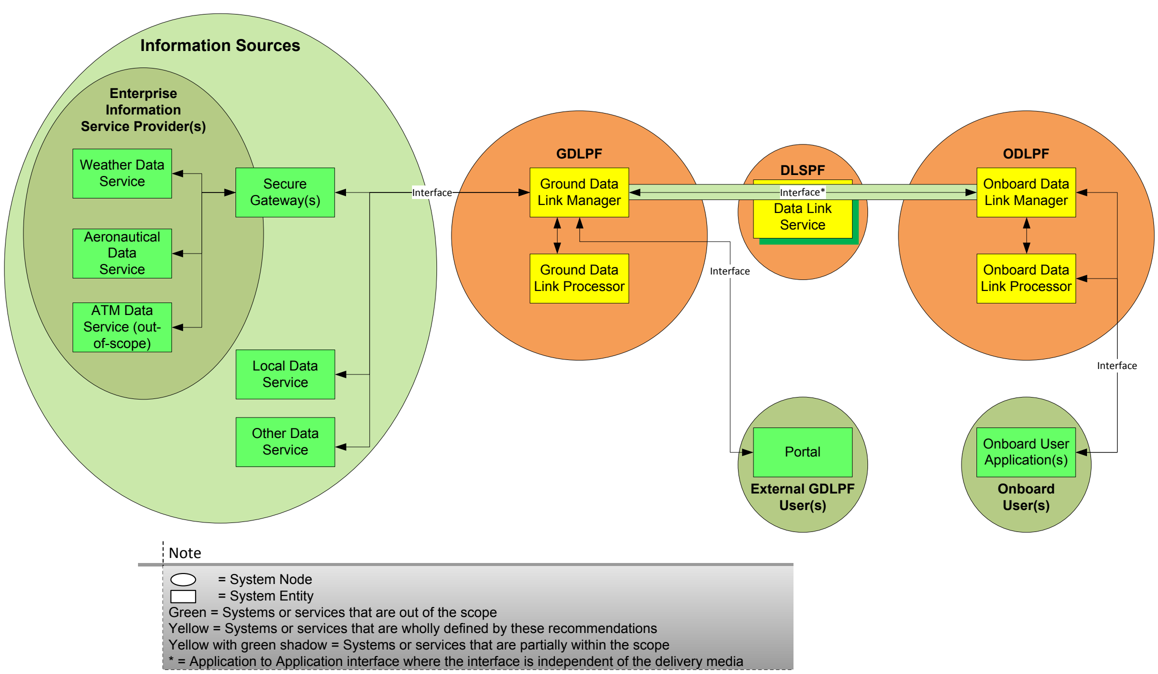

Figure 6 - SC-206 System Architecture View (Source: RTCA DO-349)

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In the SC-206 system architecture, information originates from an information provider, whether on the ground or in the air. Data flow, filtering and general management are handled by the principal system components (GDLPF/ODLPF). Information source types covered in this architecture include:

- **Enterprise Information Source:** A ground-based program, commercial entity, or system that represents the system endpoint environment for enterprise-level data sourcing and dissemination. This environment may contain a variety of data and node abstractions representing the ground entities that are providing source information services. Access to such environments is typically through secure gateways. Examples of Enterprise Information Source(s) include:
  - The FAA's NAS SWIM infrastructure;
  - SESAR's SWIM infrastructure;
  - National Weather Service (NWS) infrastructure/ground entity;
  - Large approved commercial data warehouses and processing centers.
- **Local Data Service:** This is an abstraction for scenarios where information is originated and transmitted with low latency in close proximity to an event. Potential future examples include:
  - Digitized ASOS transmissions;
  - Streamed near-real time RVR status;
  - Low Level Wind Shear (LLWS) digital transmissions; and
  - Wake vortex data transmissions.
- **Other Data Service:** This is an abstraction for data and information sourcing not covered by the above examples. It might include such things as:
  - State AIP dissemination infrastructure.

Most of these sources are considered to be commercial non-SWIM non-NAS data sources (or consumers) that are not funded by FAA.

The primary ground-side component in the SC-206 architecture is the GDLPF. It processes information from available information sources and sends appropriate data to the aircraft. Both governmental and commercial GDLPF functions are considered within the architecture. This allows commonality, for example, across commercial FAA DMS' and ANSP-provided SESAR components.

Information can be transported to/from the aircraft by way of various physical data links. The aircraft hosts an ODLPF function that stages all of the data for the aircraft systems and processes, then stores and forwards it to/from the onboard systems as shown in Figure 7. Of note: portable systems are shown on the ground as "Off-A/C Equipage" and onboard as "portable devices".

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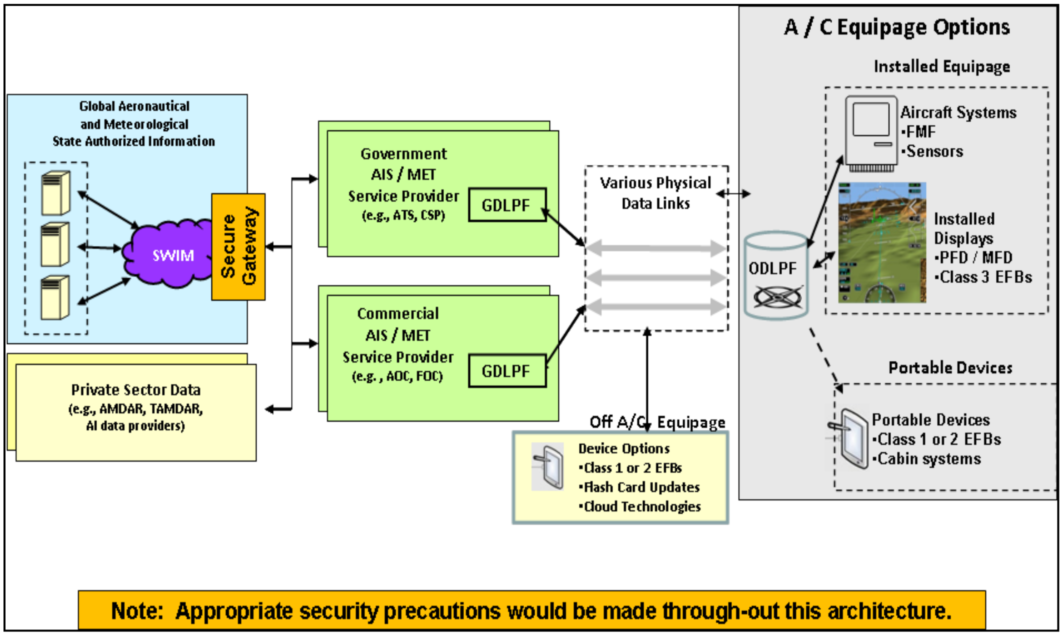

Figure 7 - AIS and MET services physical architecture (notional) (Source: RTCA DO-340)

6.3 AGIE System Architecture

AGIE primarily supports message delivery between aircraft and ground systems; however, it also supports ground-ground messaging so that airlines can stage large files to globally distributed locations. AGIE also supports onboard messaging between different applications on the same aircraft without routing via air-ground data link, in order to reduce air-ground data link costs.

The principal AGIE components are AGIE servers and AGIE clients. The AGIE architecture consists of one or more fixed ground-side servers that connect dynamically with AGIE onboard servers. The connections are dynamic as accessibility and addressing change continually: aircraft move geographically, and access varies with the availability of air-ground data links. AGIE clients are software interfaces implemented by or on behalf of end user applications so that they can exchange data with the local (host) AGIE server. Communication between two applications generally follows the path (see Figure 8):

> source application → source client → source host
> → (optional intermediate storage and processing server)
> → destination host → destination client → destination application.

AGIE servers are logical components and may be hosted as a single server or as functions distributed across multiple physical components. One set of functions required on a ground AGIE server is termed “Primary Server”. This performs system configuration and control and is the access point for the admin client and application. Each AGIE

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component consists of two functional layers. The service layer provides messaging and infrastructure services to applications, while the AMQP layer provides lower-level transport services.

A basic AGIE topology would consist of a single ground server hosting all ground-side functions and a single onboard server on each aircraft. A more complex topology might add multiple globally distributed ground-side servers sharing AGIE functions, providing higher availability, lower latency, and reduced cost. The simplest possible AGIE topology might consist of a single ground-side server and only onboard clients. While less efficient than server-server links, it could be of value in mixed or GA fleets where some aircraft carry AGIE onboard servers but others only support mobile onboard clients. This architecture might be suitable for aircraft with passenger in-flight entertainment (IFE) based air-ground data links but no substantial onboard computing resources beyond tablet-based EFB's.

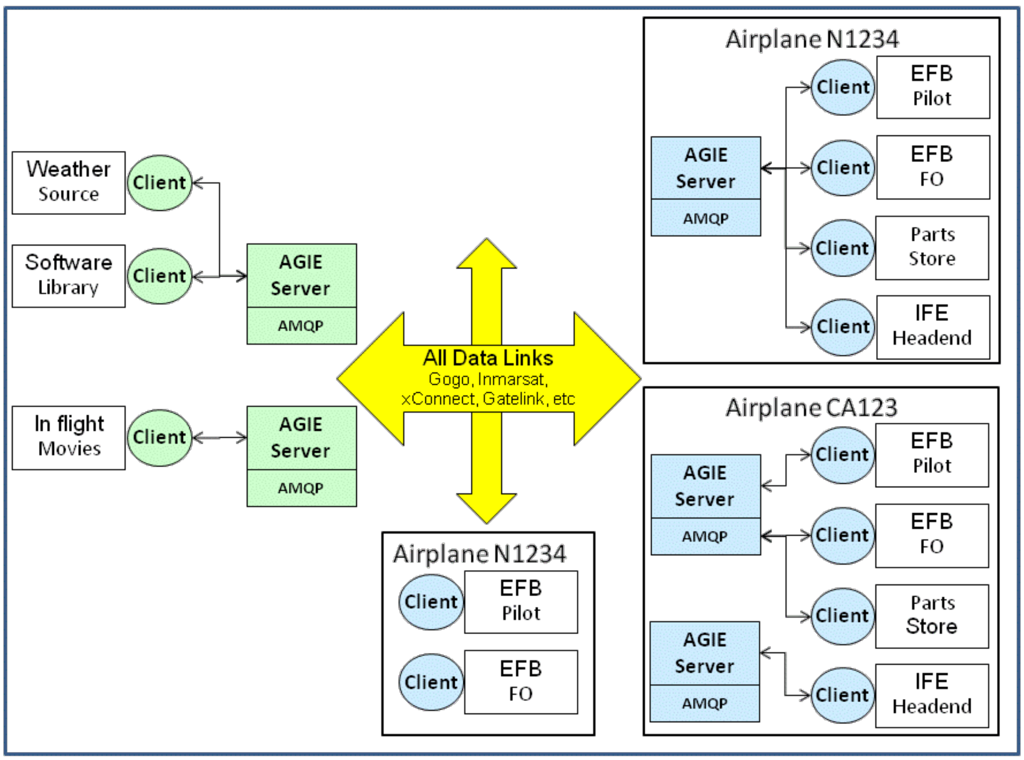

Figure 8 - AGIE Topology with Multiple Servers

The most sophisticated AGIE topology would be one that employs multiple isolated sub-networks or partitions. These partitions would allow admins to configure secure, separate domains with limited and well-controlled interaction. This might be useful for ATM applications, where there are onboard passenger and cabin services needing to be isolated from the flight deck and avionics systems in order to maintain security necessary for regulatory approval. Sub-network isolation could be physical or logical or both depending on security and regulatory considerations. Physical separation could involve separate hardware and software servers and clients, separate air-ground data links or

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channels within a data link (or separate air-ground control VLANs c.f. ARINC 792). Logical separation could involve software functions, limited access between clients and servers and/or servers and servers, AGIE node visibility limits, message type limitations, data link access restrictions, or methods for public association.

Typical aircraft environments or domains are defined in ARINC 664 Part 5, including: Aircraft Control Domain (ACD), Airline Information Services Domain (AISD), Passenger In-flight Entertainment and Services Domain (PIESD) and Passenger Owned Device Services Domain (PODSD). ACD typically consists of safety approved avionics; AISD consists typically of EFB's and other flight operations equipment that may or may not be safety critical (such as most new IP-enabled flight operations devices). PIESD typically comprises a full passenger entertainment system and may include seat-based cabin services as well as air-ground connectivity. The bulk of IP-enabled air-ground communications is in fact managed by or provides services to PIESD. Each domain has unique rules, and security requirements and considerations. Cross-domain functionality such as represented by AGIE will typically support applications in more than one domain. In the example below, security rules require AGIE to support each domain separately in order to maintain "provable domain separation".

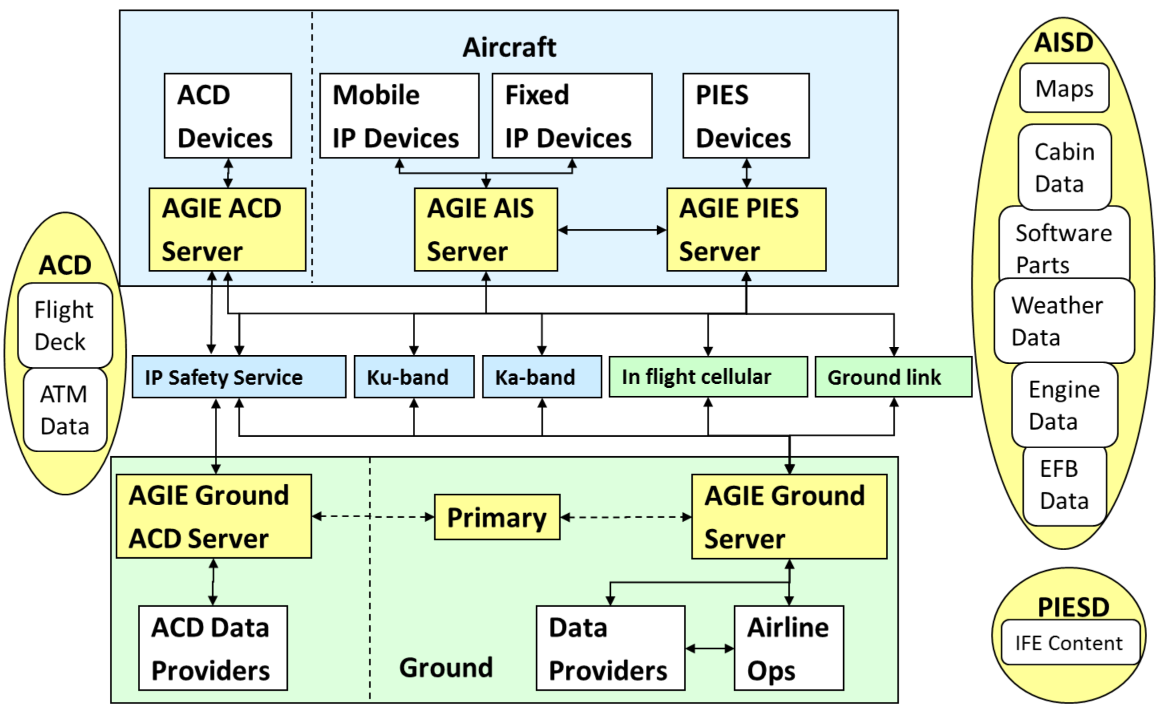

Figure 9 - Partitioned AGIE Architecture

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6.4 OGC System Architecture

OGC standards provide support for a wide range of use cases involving geospatial information, and thus have multi-domain applicability, e.g. Aviation, Defense & Intelligence, Emergency Response & Disaster Management, Energy & Utilities, Land & Infrastructure, Meteorology, etc. Since both the data types and the client applications usually vary from domain to domain, however, the standards are typically implemented in systems that serve specific domains.

OGC standards generally fall into one of two groups: geospatial information encodings on one side, and service interfaces on the other. The former specify how geospatial information is to be modeled and encoded for exchanging between systems, while the latter specify how relevant information can be discovered, processed, and disseminated in a conformant system. With respect to the Aviation domain, OGC service standards support:

- Discovery of information and services that meet an application's or user's needs;
- Access to and dissemination of geospatial information:
    - as feature (vector) and/or coverage (raster) data;
    - filtered, projected and transformed by client request;
    - portrayed using pre-configured or client-specific styles and symbology, provided as pre-created map tiles or rendered on-the-fly;
    - delivered upon request or whenever relevant information is available;
- Execution of common processing tasks, such as computing the geometry of aeronautical features and creating customized maps for inclusion in pre-flight information bulletins;
- Securing service access to ensure integrity and confidentiality of information.

Within a distributed system, OGC standards are applied as interfaces between system endpoints to enable the exchange of information in a way that enhances both functional and information interoperability. In an aviation system, for example, interfaces to SWIM systems and other data providers could be based on OGC standards such as the OGC Web Map Service, Web Feature Service, or Web Coverage Service) for convenient and reliable information access. OGC service interfaces support rich functionality to query and process geospatial information (for example: aeronautical, weather, flight, and terrain information), so that standards-based clients can receive the information they need when they need it without the need to support multiple vendor or technology-specific application programming interfaces (API's).

6.5 Harmonized System Architecture Mapping

6.5.1 SC-206 to AAtS Mapping

The AAtS architecture and the architecture defined by RTCA SC-206 are very similar: their concepts and functions often map directly to one another.

Table 1 shows SC-206 system architecture terms mapped to/from AAtS terms.

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Table 1 – Mapping Architecture Terminology (SC-206 to AAtS)

SC-206 Architecture Terminology	AAtS Architecture Terminology
Aggregate – Ground/Ground (External Portal to GDLPF)	Aggregate – Ground/Ground (External Portal to DMS)
Aggregate – Ground/Ground (GDLPF to External Portal)	Aggregate – Ground/Ground (DMS to External Portal)
Aggregate – Ground/Ground (GDLPF to Source)	Aggregate – Ground/Ground (DMS to NAS)
Aggregate – Ground/Ground (Source to GDLPF)	Aggregate – Ground/Ground (NAS to DMS)
Aggregate – ODLPF In	Aggregate – Air/Ground (Uplink))
Aggregate – ODLPF Out	Aggregate – Air/Ground (Downlink)
Data Link Service Provider Function (DLSPF)	Data Link Service (DLS)
Enterprise Information Service Provider(s)	NAS Service Provider(s)
External GDLPF User(s)	External Ground DMS User(s)
GDLPF Data Cache	DMS Data Cache
Ground Data Link Manager (GDLM)	Manage DMS
Ground Data Link Processor (GDLP)	Process DMS Data
Ground Data Link Processor Function (GDLPF)	Data Management Service (DMS)
Maintain GDLPF Security Services	Maintain DMS Security Services
Maintain ODLPF Security Services	Maintain Aircraft Access to DMS Security Services
Monitor / Report GDLPF Performance	Monitor / Report DMS Performance
Monitor / Report ODLPF Performance	Monitor / Report Aircraft Access to DMS Performance
ODLPF Data Cache	Aircraft Access to DMS Data Cache
Onboard Data Link Manager (ODLM)	Manage Aircraft Access to DMS
Onboard Data Link Processor (GDLP)	Process Aircraft Access to DMS Data
Onboard Data Link Processor Function (ODLPF)	Aircraft Access to DMS
Provide Data Link Service	Provide Aircraft Access to SWIM
Provide Data Link Service Provider Function	Provide Data Link Service
Provide External GDLPF Portal	Provide External Ground DMS Portal
Provide Ground Data Link Processor Function	Provide Data Management Service
Provide Onboard Data Link Processor Function	Provide Aircraft Access to DMS
Provide Source Originated Information	Provide NAS Service
Source Originated Information	NAS Originated Information

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6.5.2 AGIE to SC-206 System Architecture Mapping

Mapping to the AGIE system architecture is complicated by the many options available for AGIE deployment. For the purposes of this report, a typical AGIE installation has been assumed, with a few variations based on prominent options (Figure 10).

Near-Term: In the near-term it is assumed that NAS systems will not employ AGIE as a messaging system due to SWIM contracts and FAA program constraints. Under this assumption, the ground-side configuration is very simple with only a single ground AGIE server for an entire airline (though only one aircraft is shown). Ground-side AGIE clients are implemented on the GDLPF and inside of the MET and AIS data sources, as well as on ground-based Class 1 or 2 EFB's. While what is depicted is a single AGIE Ground server in the baseline system, an AGIE server could be employed to handle SC-206 functions in/for the GDLPF in addition to the other airline AGIE ground servers. In addition to the basic SC-206 ground-side components, AOC/FOC and other airline operations are depicted as sharing information using the same ground-side AGIE server[1]. The aircraft-side is also depicted as a single AGIE server with AGIE clients on the airplane systems (FMF, etc.) and portable devices (EFBs, etc.).

Depicted in blue lines is an example of a partitioned AGIE system with an onboard AGIE server and client in the cabin area, and an In Flight Entertainment (IFE) system such as from Panasonic managing its own data-link for passenger information services. The red-line connection to the cabin client would be deactivated in this scenario. In a partitioned system the onboard server would be limited in its server-server connectivity, as well as in its client visibility. In such a case the onboard cabin server would be connected to a cabin ground AGIE server connected in turn to ground AGIE cabin domain clients. The ground client red-line would again be deactivated in this flow.

AGIE would route traffic between the onboard server(s) and ground server(s) using all IP data links available based on admin configuration of priorities, costs and regulations. Even though connection arrows are shown as bi-directional, association between air and-ground could only be initiated by the aircraft equipment.

Note that portable devices are depicted on both the aircraft and the ground on the assumption that they are continually being carried back and forth but clients only associate with a single host server at a time. Onboard-only clients never associate with ground servers and ground-only clients never associate with an onboard server while mobile clients may switch their association.

[1] The AGIE Ground Server could also be deployed in a commercial GDLPF in a manner similar to the government GDLPF. This emphasizes that multiple deployment options are possible.

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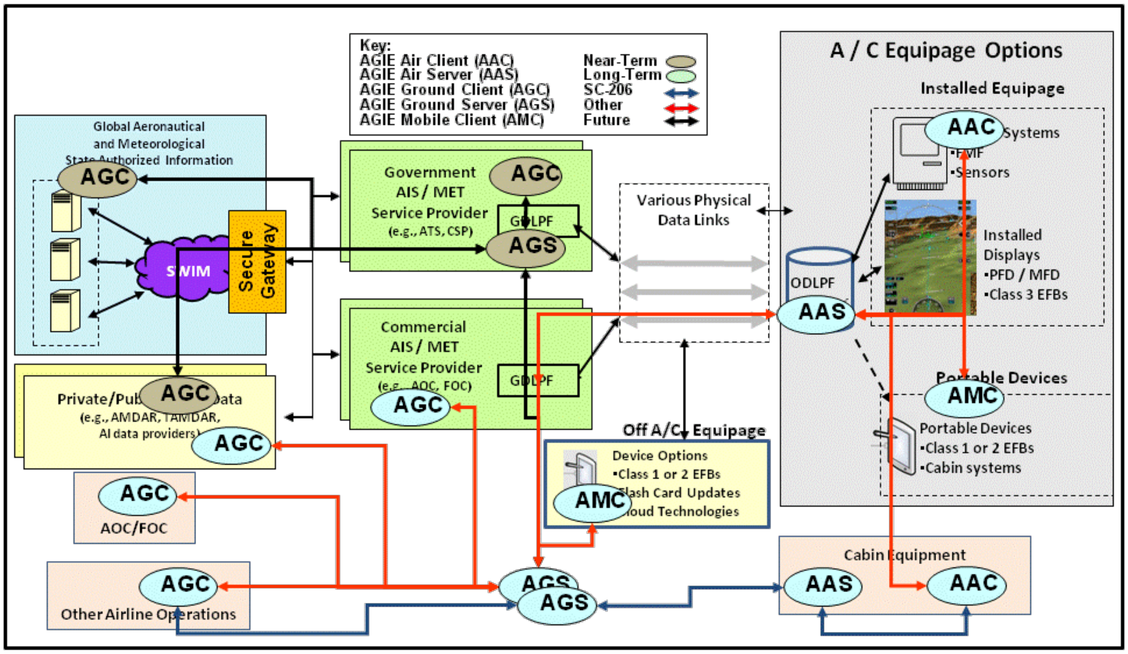

Figure 10 - AGIE to SC-206 System Architecture Map

Long-Term: In the long-term, if AGIE is successful and SWIM contracts are modified to recognize AGIE, many ground-side information sources and consumers could become AGIE-aware. One could conceive of additional elements on the NAS side that connect to AGIE ground clients. Depicted in Figure 10 is a possible future state (black connectivity and gray bubbles) with a NAS ground-side AGIE server and associated ground-side AGIE clients connected to it in an isolated NAS AGIE sub-network dedicated to NAS ground-side information messaging. The value to NAS would be the opportunity to leverage a larger commercial ecosystem of AGIE-ready data sources and consumers.

6.5.3 OGC Mapping

The nature of the capabilities that OGC services provide allow for multiple tiered and concurrent levels of various functions. Since the standards focus on interfaces and high-level information exchange formats rather than platforms or internal implementation details, they can be implemented as interactions between components arranged in many system configurations and topologies. The addition of interoperable messaging capabilities such provided by AGIE can result in an even wider variety of possible implementation topologies to satisfy different implementation requirements. Examples of multiple interfaces include:

- Multiple filtering levels – OGC services can be used at a variety of points for filtering, such as in multiple stages of data provisioning chains, allowing increasingly selective data subsets to be staged towards end user applications in order to balance bandwidth requirements with rapid access. Example scenario:

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- The DMS makes an information request to OGC-enabled SWIM services which return a geo-filtered response dependent upon the DMS client region and domain needs. This response is then stored internally for servicing multiple airborne clients

- The aircraft makes an information request to the DMS. The DMS responds using its internal data cache with a further geo-filtered response unique to the needs of the requesting aircraft. This response may then be stored onboard for reuse.

- Various onboard systems make information requests based on their particular requirement (e.g., weather, AIM, location based, etc.) to fulfill operational needs.

- Smaller datasets are rendered into maps specifically styled for each application via onboard portrayal services, while larger datasets can be requested as relatively small map images from ground-based portrayal services using the same map request interface

Note: the above example assumes that each “stage” will store or cache the received information in some manner for reuse and redistribution with further relevant filtering possible

- Distributed discovery – OGC interfaces for registering, finding, and binding to services and their content offerings can be implemented wherever services are being made available dynamically to clients. Service and content discovery can follow a star pattern, where for example a catalog service implemented as part of a DMS cascades search requests on to catalog service interfaces implemented by each of the components that supply data to it. Discovery can also follow a similar pipeline pattern to that of multilevel filtering, where the NAS, DMS, and onboard servers each provide an OGC catalog interface that supports searches for services and content staged to and available at that time from that component.

- Processing workflows – components implementing OGC services and encodings can be linked into distributed workflows to cover a significant range of the service functionality needed to work effectively with any geospatially characterized information, including search / discovery of datasets by location, provision / selection / transformation of feature data in numerous forms and formats, custom map image styling / portrayal, transactions such as inserting and updating feature data, and processing tasks such as data integration, routing, or imagery analysis.

How these services map internally and against the other services is described below.

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6.5.3.1 OGC to SC-206 System Architecture Mapping

Without assuming a specific implementation architecture, OGC standards can be mapped into specific subsets of the SC-206 architecture. This means that specific functionality of components built for this architecture can be realized using OGC standards. It does not remove the need for custom code to process information appropriately within an SC-206 component since that is not now covered by OGC specifications[2].

OGC standards could be implemented as service interfaces of the GDLPF and ODLPF, and also as features of internal modules of these system entities (see Table 2 and Table 3).

Table 2 – Mapping OGC Standards to SC-206 GDLPF Functions

OGC Standards	SC-206 GDLPF Functions
CSW-ebRIM registry, FES, Pub/Sub, SLD/SE, WCS, WFS, WMS [+ AIXM, WXXM, FIXM]	1.2.4 Process ground subscriptions / information requests
CSW-ebRIM registry, ISO 19115	1.2.5 Provide data provenance
PubSub, FES, [+ OASIS WS-Topics, W3C XPath]	1.1.4 Maintain / provide data synchronization between ground and aircraft users
PubSub, FES, [+ OASIS WS-Topics, W3C XPath]	1.1.5 Manage AIS & MET data link service technical rules
GeoXACML, [+ OASIS XACML]	1.1.2 Maintain GDLPF security services
GeoSPARQL [+ W3C OWL, RDF, SKOS, SPARQL]	1.2.1.1 Provide semantic mediation
FES, WFS, WCS	1.2.1.4 Provide ground data filtering

[2] The situation could be improved if a technical specification were created defining the functionality to be realized for a specific component (component interfaces plus processing between interfaces). In the OGC Testbed 9, for example, two independent but interoperable prototypical implementations of a DMS/GDLPF were developed that realized a large portion of DMS/GDLPF functionality. Such a specification would support the development of standards-based, interoperable commercial-off-the-shelf DMS/GDLPF components and reduce the need for proprietary custom software.

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Table 3 – Mapping OGC Standards to SC-206 ODLPF Functions

OGC Standards	SC-206 ODLPF Functions
CSW-ebRIM registry, FES, Pub/Sub, SLD/SE, WCS, WFS, WMS [+ AIXM, WXXM, FIXM]	3.2.4 Process onboard subscriptions / information requests
GML, O&M [+FIXM, WXXM]	3.1.1.3 Perform data acquisition
GeoXACML, [+ OASIS XACML]	3.1.2 Maintain ODLPF security services
GeoSPARQL [+ W3C OWL, RDF, SKOS, SPARQL]	3.2.5 Provide data transformation
FES, WFS, WCS	3.2.3 Provide onboard data filtering

There already is a significant amount of OGC support for discovering, managing and distributing aeronautical and weather data, but other types of information could also be supported, such as flight and terrain information.

NOTE: unless only an image representation of geospatial information is of interest, there are some constraints regarding data encodings. AIXM and WXXM are encodings based on GML and other OGC standards that are used for data exchange in SWIM environments. In multiple system implementations and demonstrations OGC services have been proven to work with these encodings. The OGC Web Feature Service (OGC WFS) for example utilizes AIXM and WXXM as data encodings when used to access aeronautical and weather information[3].

OGC standards and technology have also demonstrated significant support for security and data transformation/mediation functions. When incorporated in the GDLPF and ODLPF, OGC standards could support a major subset of the information processing requirements. They provide interfaces for accessing and inserting information (e.g. aeronautical and weather), which could then be invoked by client software in aircraft systems and portable devices. Figure 11 depicts in more detail how OGC standards can be mapped to data exchange interfaces at GDLPF and ODLPF as well as elsewhere in a harmonized architecture. Client software – for example on mobile devices – could also use OGC service interfaces to retrieve and insert information. Client software would not have to implement OGC standards and GDLPF and ODLPF could support other interfaces and data formats. However, if GDLPF and ODLPF were already to utilize OGC standards within the harmonized architecture, there would be significant benefit in directly leveraging this functionality within client software as well. Likewise,

[3] The OGC WFS standard requires that a conformant server work with feature data modeled as a GML application schema and served in one or more compatible encodings.

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implementation of GDLPF would be simplified if information sources also implemented OGC standards for encodings and service interfaces.

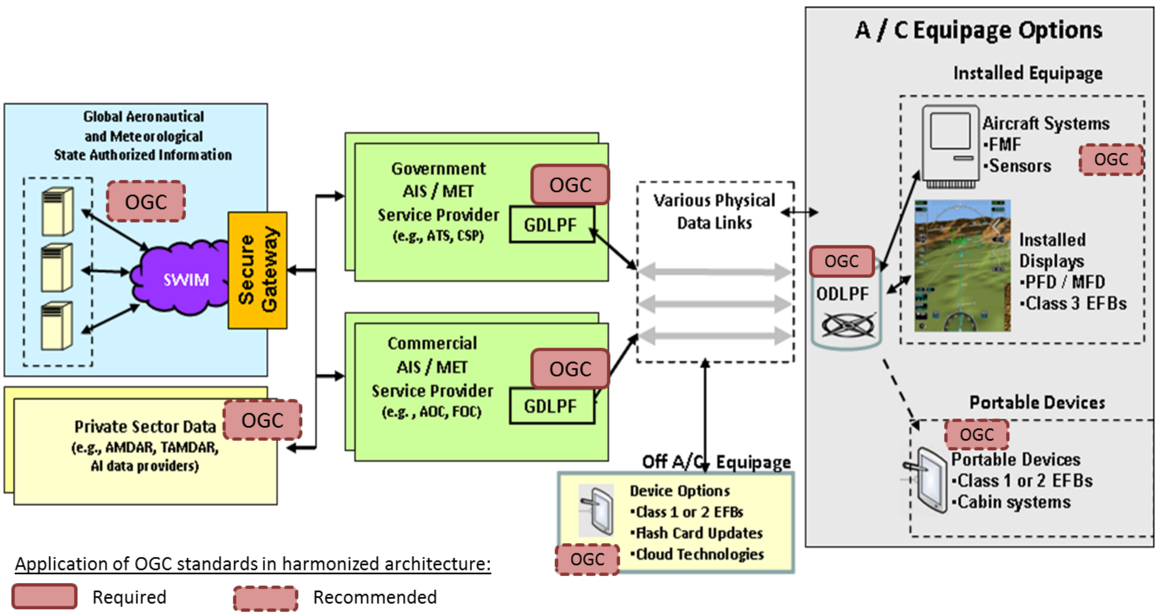

Figure 11 - OGC to SC-206 System Architecture Map

6.5.3.2 OGC to AGIE Mapping

OGC services are defined as transport protocol independent so that they may leverage any transport protocol for which a suitable protocol binding has been defined. A protocol binding defines how system endpoints can be addressed, and also how the messages and message exchange patterns defined in the standard (e.g. datagram, request-response, and publish/subscribe) are realized with a given protocol. OGC services bindings are commonly defined for HTTP and SOAP. SOAP is a messaging protocol that is itself transport protocol independent, and thus can be used on top of specific transport protocols (like HTTP and AMQP) as long as a SOAP binding is in turn defined for it. Within the harmonized architecture developed here, OGC services are envisioned to leverage AGIE message bindings. There is some overlap between SOAP and AGIE message handling functionality, so OGC services could either be bound directly to AGIE for all message handling functions, or via existing OGC SOAP bindings such that SOAP-handled messages would be transported in turn via AMQP.

7 Recommended High-level System Architecture

A new harmonized high-level system architecture has been developed from the standards analysis and mapping presented above. It is recommended that the new architecture

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become central to AAtS IGD V4.0 and form the basis for initial global interoperability discussions.

The new architecture is the result of expanding the AAtS and OGC harmonization scope (as defined in Phase 1 OGC documents) to include any/all relevant industry and aviation standards as well as air-ground architectures that share operational data, data formats, architectural elements, or computing and networking resources (e.g. ground or onboard computing and networking resources and air-ground data links). The initial OGC-led harmonization work was "up leveled" to a higher level of abstraction and widened within the scope described above to include non-AAtS and non-NAS unique services at a global level.

As a first step in portraying development of the new architecture, the US FAA/NAS AAtS architecture (Figure 14) has been redrawn (Figure 15) with more generic and re-usable components as a baseline to which new components, sub-components and connections derived from the industry standards harmonization work in Phase 1 are then added (Figure 16). The scope of the architecture is expanded further by considering a global scenario in which a US domestic aircraft flies internationally (Figure 18). This progression is presented in system-wide topology diagrams that depict the data and information flows and critical interactions between system components. The communications protocol layers that support the architecture are presented in Figure 17 to show how and where industry standard services and solutions fit into an emerging aviation network environment where components interact through open protocols rather than within a "black box".

The evolution of a recommended architecture is intended to convey how basic AAtS FAA concepts can be realized in a larger context, as well as to recognize what industry sees as key technical and business interactions and emphasize the need for international coordination. Ideally this will empower industry partners and global regulators to engage in discussions leading to a deeper understanding of the architecture and an international consensus that supports integrated AAtS capabilities for international flights of US and foreign carriers.

7.1 Standalone FAA/NAS AAtS Architecture

This section summarizes the key elements of the top-level FAA NAS-centric AAtS architecture as defined in AAtS IGD v3.0. Below is a new form of depiction that is the basis of expanding to a global harmonized context.

Figure 12 is drawn directly from the FAA AAtS IGD v3.0 document. It depicts the high level FAA/NAS-centric AAtS architecture from an AAtS-centric and standalone point of view, including the following system components:

> **NAS Data Service Provider** – represents FAA NAS services that provide (and for downlink consume) AAtS information. The focus for AAtS is on "advisory" or "non-trajectory controlling" information for **weather**, **aeronautical** and **ATM** services. It is shown in green indicating it is managed and funded by FAA.

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NAS SOA Service Provider – represents FAA managed and provided functionality. SWIM is shown as "**SWIM Core Services**". Also shown is the Network External Secure Gateway (**NESG**) which is the secure access and data/information exchange interface/PoP to all non-FAA/government partners for exchanging data/information within the SWIM and bi-directional AAtS scope. These elements are also managed and funded by FAA. It is important to note that while NESG is shown only connecting to the DMS Provider, it does connect to aircraft operators and other ground systems that require access to SWIM, in addition to the AAtS usage shown in this diagram.

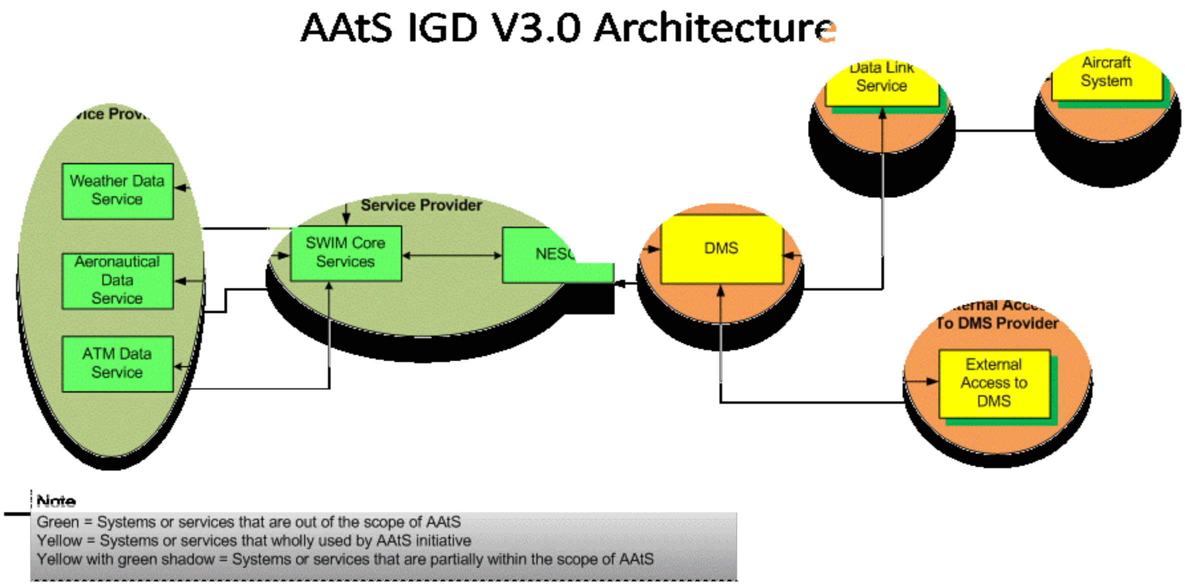

Figure 12 - AAtS IGD v3.0 Architecture

DMS Provider - represents the key ground-based component and business concept introduced by the AAtS architecture. The DMS provider is manager of the **DMS** system. The DMS system is the interface between the SWIM SOA systems (via NESG) and aircraft (via air-ground datalink). The DMS also connects to airline operator portals for managing DMS configuration. DMS is a non-FAA funded and managed component supported from aircraft operations funding sources.

Aircraft Operator – represents the airline or other aircraft operations that are responsible for flying/operating the aircraft. The only element shown is **Aircraft Systems.** Aircraft Systems contain all of the onboard elements of AAtS and the onboard systems required to exchange AAtS data/information via air-ground data links. It also includes the flight crew! It does not include built-in or mobile display systems or top-level flight operations applications. Mobile devices (iPad or tablet

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enabled EFBs) used for operational purposes by flight crew as well as aircraft fixed devices are included within this component.

DLSP – Represents the air-ground data link service provider. The key element here is the air-ground **data link service**, which consists of the air-ground data link, onboard data link equipment and functions, and ground-side data link equipment, functions and gateways.

External Access to DMS – represents the airline portal (likely as an AOC or FOC) that is used to configure, manage, monitor and control DMS operations. This component manages information and data exchange between NAS/SWIM and the aircraft systems/flight crew.

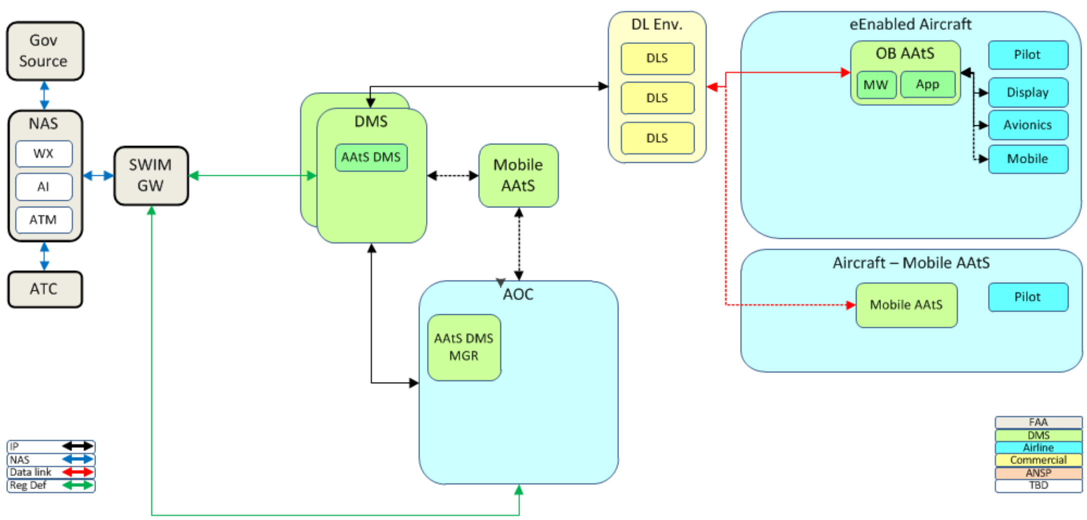

Figure 13 – Standalone FAA/NAS AAtS Architecture

Figure 13 is a streamlined depiction of the FAA standalone AAtS architecture shown in Figure 14. AAtS IGD v3.0 provides much more details than required for this report, but should be consulted for the detailed functionality and meaning of each component. Some component names have been modified as well for clarity. In this and the diagrams following, only technical definitions and components are explicitly considered. Service providers and other business actors are implied but not shown in diagrams. Diagram elements shown are as follows:

NAS – represents “NAS Data Service Provider and NAS services”. Attached are shown **other government sources** and **FAA ATC** components. The NESG is simply named “SWIM GW” or “SWIM Gateway”. All NAS internal connections are shown as “NAS defined” and not-IP based. SWIM-to-industry links are shown as “Regulatory defined”, for SWIM they are IP based with ground rules for security that provide access, security, point-of-presence, and other key attributes.

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DMS – represents the same DMS, however an internal component named "**AAtS**" is shown to allow growing the DMS functionality in the following diagrams and discussions.

AOC – represents the airline or aircraft operators interface to AAtS for DMS management (External Access to DMS). It is assumed to be the airline AOC or FOC or equivalent for GA operations. It is shown as an **AAtS DMS Manager** here and is included as a sub-component of the AOC.

Mobile – represents mobile devices. These are implied and discussed in AAtS IGD v3.0 but are not shown in their diagrams. Mobile devices are shown attached to either airplane or ground (AOC) and migrate over time. This is important to understanding operational use of and security considerations for AAtS as envisioned by FAA.

Data Link Environment – represents the multiple **data link service** options provided by data link service providers. The environment is shown to allow comprehension that there may be more than one data link and service per aircraft and certainly more than one for any DMS.

Onboard AAtS – is represented as two separate components as defined below. They represent the IGD's "Aircraft Systems".

- **eEnabled Aircraft** – represents an aircraft that is configured to be AAtS enabled and for which onboard fixed AAtS functionality exists. This allows full AAtS business value and all operationally defined AAtS data exchanges. Some of these require onboard systems to perform localized information exchange, storage, filtering and redistribution. The **Onboard AAtS** is depicted to include: (1) **software services** and (2) **onboard applications**. Software services include re-usable onboard AAtS infrastructure functions while AAtS applications provide AAtS (and possibly SC-206) uniquely defined functionality. It is key for software services to be re-usable for more than just AAtS. Also depicted are **pilot, displays, avionics**, and onboard hosted **mobile** devices. These are introduced as part of the AAtS standalone architecture but are not part of IGD architecture as they are not considered part of the management space of the AAtS organization (same for SC-206).

- **Aircraft with Mobile AAtS Only** – represents an aircraft that does not support any fixed AAtS functionality. AAtS functions are limited to those applicable to **mobile** devices only accessed by a **pilot** directly from a data link (likely managed for passenger connectivity reasons.

Connections – are represented as follows.

1. NAS: Internal NAS connections defined by NAS and non-standard

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2. RegDef: External NAS (NESG) connections defined by NAS regulation and defined as IP with constraints

3. IP:

   a. Ground side IP connections which may be Internet or private IP networks.

   b. Internal aircraft connections which are IP over Ethernet or IP over wireless.

4. Data link: Air-ground data links using RF methods, but sharing data via IP at the network level. Though non-IP protocols may be used they are not considered baseline capabilities in this discussion and architecture.

Responsibilities – are represented as follows.

1. FAA is shown as gray
2. DMS is shown as green
3. Aircraft operators are shown as blue
4. Commercial services are shown as yellow
5. Other ANSPs and non-FAA SWIM's are shown as mauve
6. Unknown or TBD is shown as white

7.2 Industry Harmonized FAA/NAS AAtS Architecture

This section now expands on the standalone FAA/NAS AAtS architecture to include an industry standards based solutions perspective. It describes a broader scope that includes AAtS functionality in a "real-world" environment of today's solutions and systems that are likely to share resources and data/information with AAtS functions, systems or sub-system components. The scope is still FAA/NAS-centric, representing the environment for a US domestic operator flying US domestic flights.

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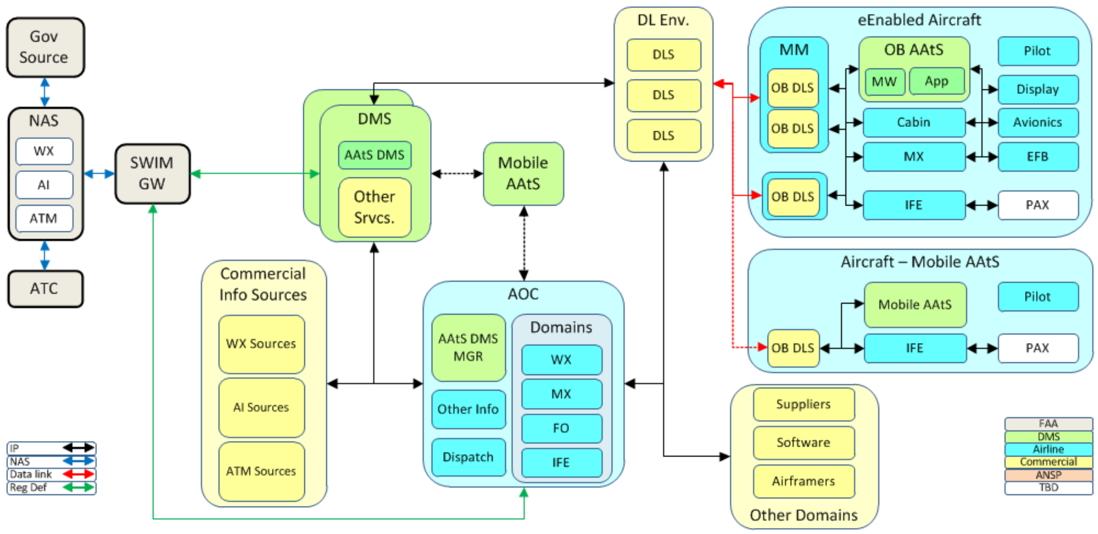

Figure 14 – FAA AAtS Harmonized Architecture

Figure 14 depicts the standalone FAA/NAS architecture harmonized with industry standards and industry/commercial solutions that exist or are emerging. Key changes are described below.

Commercial Information Sources – represents commercial sources of information in addition to just SWIM/NAS information (sources implies sinks/consumers as well). These are commercial entities attached to the DMS and AOC via IP links that provide similar, enhanced or other data for flight operations. This information may overlap and/or augment SWIM NAS information. Further it may be processed like the DMS will but by a separated commercial vendor. It is shown with **AI, ATM** and **weather** products.

Mobile device – is represented connected to both AOC and DMS in this architecture. That is the DMS may perform data exchange with mobile devices via AOC (airline enterprise connectivity) or via DMS Internet access directly. This is especially likely for smaller airlines and GA operations that don't have a complex, globally reaching enterprise environment.

DMS – contains a new sub-component **Other Services**. These other services provide additional business value beyond and above AAtS defined services and may be in any operationally relevant domain. FAA mentions the likely need of this capability to make the DMS providers' business cases close.

AOC – contains several new sub-components. **Other information** provides for non-NAS information to be exchanged with the aircraft from commercial sources but in AAtS domain. **Dispatch** is a key AOC/FOC sub-component that is discussed in IGD but not shown in diagram. The concept of collaborative decision making is now depicted on this diagram with ATC, pilot and dispatcher. Other (non-AAtS) domains

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are shown in AOC for completeness for DMS, airline operations and resource sharing purposes. Shown are: **weather**, **maintenance, flight operations** and **passenger in-flight entertainment** functions.

Other Domain Information Sources – is represented as a new component that brings in key players from non-AAtS domains for information exchange. Depicted as examples are other information and equipment **suppliers**, **software** suppliers and **airframers**/OEMs.

eEnabled Aircraft – is represented with additional sub-components. An onboard message manager (**MM**) is shown to manage one or multiple externally (non-AAtS) managed **onboard datalink services**. Two are shown to depict MM in multiple domains (i.e. ACD and AISD separated from PIESD MM). Also shown are **cabin**, **maintenance** and **IFE** functions and IFE passenger (**PAX**) components. These are important aspects of the AAtS context as they drive the business benefits as well as security and onboard networking and resource architectures.

Aircraft Mobile AAtS – also includes sub-components of a non-AAtS managed **onboard data link service** and IFE and **Passenger** connectivity.

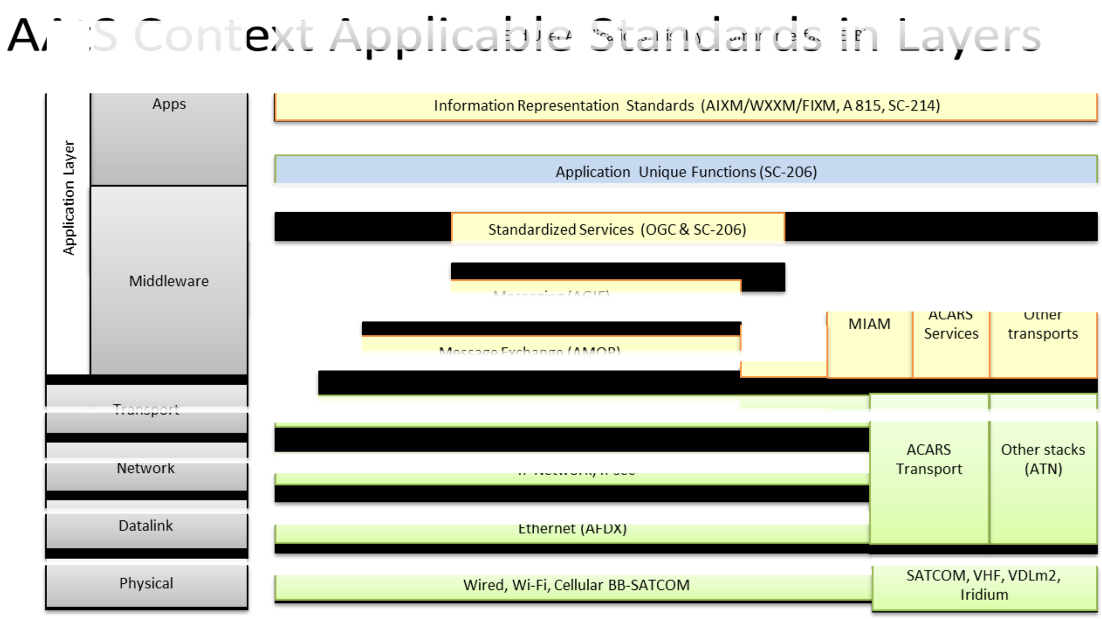

Figure 15 – AAtS Layers

AAtS Layered Standard and Solutions – industry standards and solutions are migrating (albeit only lately in aviation) to cooperating solutions. The old fully vertical product (black box) is giving way to industry solutions that provide infrastructure-style functions and services for aviation applications to build on. This allows re-use of equipment, software, certifications/approvals and security features. Examples of this are: ARINC-

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830 AGIE, ARINC-791 Ka/Ku-band solutions, EFB, NIS security, and data link network services.

Figure 15 shows an example of some of the industry standards and solutions evaluated by this harmonization effort and provides a general perspective on where these functions, services or layer-specific solutions might fit in the vertical stack of computation and data exchange protocols. Also represented are existing and emerging non-native-IP solutions that are applicable to the AAtS harmonized context. The intent is to provide a framework for industry standards developers and aviation solution providers to map their products and components into the AAtS harmonized architecture. This is essential for realizing a cohesive architecture that encompasses application needs in multiple aviation domains.

7.3 Globally Harmonized AAtS Architecture

This section expands on the industry harmonized FAA/NAS AAtS architecture to include a global perspective. It describes a broader scope that includes AAtS functionality in a worldwide environment with international flights requiring sharing of and data linking via international partners, both commercial and ANSP/regulatory.

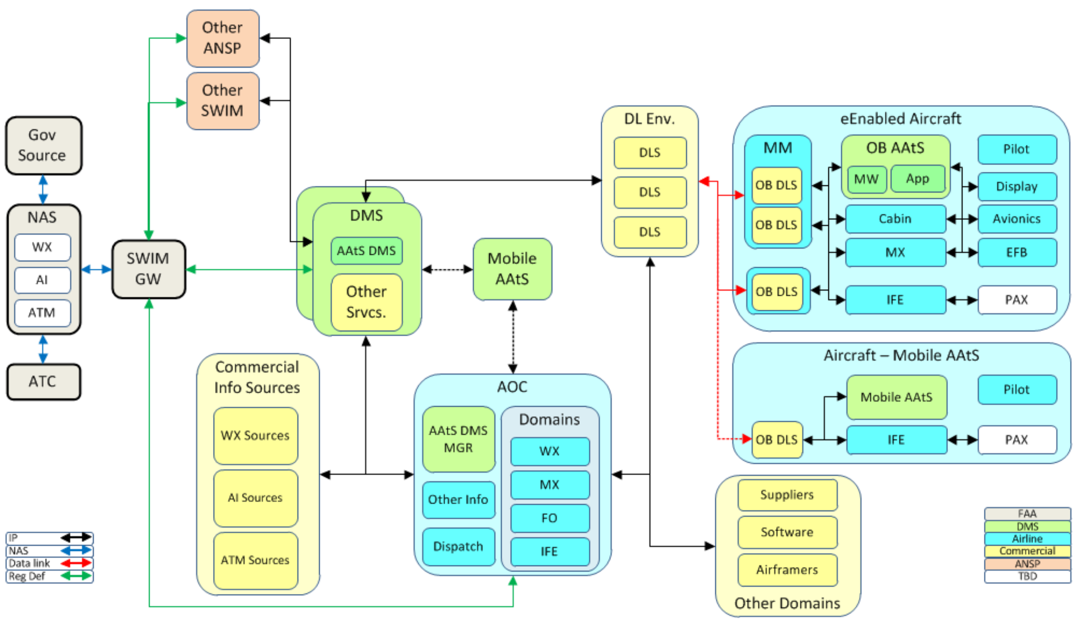

Figure 16 – FAA/NAS AAtS Architecture in Global or International Context

Figure 16 shows the industry harmonized FAA AAtS architecture in a global context, as might be leveraged by a US domestic aircraft flying internationally and needing to exchange global information. It is the recommended architecture for AAtS IGD v4.0.

Only two additional components are added to the industry harmonized FAA/NAS architecture: **Other ANSP** and **Other SWIM**. These are shown as being accessed and

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exchanging information either directly with another SWIM or with multiple DMS access points. Also represented are multiple DMS providers and DMS's.

Other SWIM – represents international SWIM solutions beyond just FAA/NAS SWIM. These are SWIM or network-centric SOA based solutions for non-US domestic and non-NAS information exchange. It is envisioned that these external SWIM's will provide information for flight operations that extend beyond the present NAS scope and domain.

Other ANSP - represents international ANSP solutions beyond just FAA/NAS SWIM and other international SWIM's. These are non-SWIM or non-network-centric, non-SOA based solutions for non-US domestic and non-NAS information exchange. It is envisioned that these external ANSPs will at least in the near-future be non-SWIM compliant. International operations will still require international data exchange before global SWIM solutions become viable, though, given FAA's intent to lead AAtS capabilities in a global context and provide for collaborative decision making via SWIM by 2018.

Connectivity – there are several ways inter-SWIM (e.g. inter-SWIM and SWIM-to-ANSP) information exchanges may be accomplished. Only two are described in this document they are (1) ground-based SWIM-to-SWIM exchange, and (2) DMS-to-multiple-SWIM exchange. Other options such multiple aircraft-to-SWIM stacks were considered but determined to be inadvisable or impractical.

- **SWIM-to-SWIM information exchange** – is the preferred option with maximum benefits and few drawbacks from a DMS, aircraft operator, equipment provider, and airframer perspective. It is not, however, considered attainable in the reasonably near term for global international operations, since it would require rolling out and coordinating global SWIM capabilities across the entire world. In this approach all information would be sourced, vetted, validated and managed by individual SWIM's in a cohesive global SWIM SOA information space. A DMS, aircraft, or AOC would just connect to its local SWIM and have access to all global operational information.

- **DMS-to-multiple-SWIM information exchange** – is the second best but most feasible option. Each DMS would determine the regions of the globe it must support and connect directly to the SWIM's or ANSP's or commercial services for those areas. Each DMS in this case would have a considerably more complex role brokering between multiple SWIM instances, but each aircraft and airline AOC would only need to implement a single connection to its selected DMS. While this does not provide a seamless global information fabric per se, it does allow the complexity to be managed by the DMS provider and focuses on the DMS providers' business cases and solutions, which could more easily be tailored to the operators they support. One consideration in terms of sharing information between FAA AAtS/NAS-SWIM and (for example) Euro-SWIM might be differing rules for what data are to be contained in SWIM. This might drive different DMS functions and requirements depending on the location of the supported airline operators and airline operations. SWIM-SWIM exchanges would be more likely to assume similar data catalogs for each SWIM.

8 Conclusions and Recommendations

The focus of this project has been to bring new perspectives in architecture, standards implementation, and functional scope to the FAA's AAtS concept, identify gaps and conflicts, then work towards both updates for the relevant standards and an updated AAtS architecture in order to achieve a more harmonized and interoperable solution for air-ground information exchange.

This report presents the results of this work and makes specific recommendations for consideration and adjudication by policy makers, government, and industry to ensure a fully operational and harmonized AAtS architecture. Additionally, a recommended high-level AAtS system architecture has been included to provide guidance for update of the AAtS IGD (e.g. v4.0).

The true measure of success for this work will be its ability to drive stakeholder consideration, public policy, standards formulation, and requirement baselines that lead towards a fully functional and fully scoped harmonized AAtS architecture. The harmonization efforts reported here have already resulted in both operational standards and documents that are more closely aligned and have minimal direct conflict on key attributes and requirements. Members of the harmonization effort engaged and actively participated in the development and cross-pollination of standards work products. RTCA's DO-349 and ARINC's AGIE 830 specification were materially changed through these efforts which would not have occurred without them. Some alignment still needs to be achieved, as documented in this report, for example some AGIE alignment with OGC standards and subsequent mapping of both to AAtS/SC-206 functions still requires further work. This work would benefit immensely from the implementation experience of prototype development.

At a minimum, however, the efforts reported here have led to a better understanding of the relationships between AAtS, SC-206, AGIE and OGC and no roadblock to common usage of these standards has been identified. As a result of this work and the resulting harmonized architecture, aircraft operators implementing AAtS will be able to leverage prevailing industry standards to deploy and participate in AAtS more easily, less expensively, and with lower risk.

8.1 Conclusions

An in-depth analysis of existing AAtS documentation was performed as part of this harmonization effort including the AAtS Implementation Guidance Document (IGD) v3

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and the AAtS Bi-Directional ConOps version 1.0. The analysis resulted in a set of detailed and specific recommendations and comments by industry intended to assist in the maturation of the AAtS concepts and guidance provided by the FAA. This analysis together with the results of work in this project as a whole, has led to the following conclusions:

1. A harmonized architecture based on AAtS with SC-206, AGIE and OGC standards is achievable and provides a framework for deploying AAtS in a multi-domain solution.
2. Harmonization across these three standards in the AAtS architecture allows the features of each standard to be implemented together in a consistent system.
3. The AAtS architecture as defined in IGD v3.0 is too constraining to fully reflect the capabilities and benefits of the harmonized architecture.

8.2 Recommendations

Another result of the project activities reported here was a set of recommendations for further work to improve AAtS-related standards, documents and concepts. While the standards from which the recommended system architecture was developed are more harmonized now than they would have been otherwise, there remains considerable work to undertake. Recommendations for further work include:

1. Recommend revision of the AAtS IGD v3.0 based on the team review comments and recommendations as well as the recommended system architecture presented in this report. As discussed previously, the team has performed a detailed industry based review of the guidance found in the AAtS IGD V3. Updated implementation guidance will provide value to all stakeholders involved in deploying an AAtS solution. The industry representatives within the team recommend the adoption and incorporation of team input that includes the following concepts:
    - Non-SWIM data sourcing inclusion in the architecture of AAtS
    - A role for safety critical applications within the AAtS trade space
    - Updates to the AAtS architecture to reflect the larger environment, facilitate more recognizable industry business value, and support more achievable global interoperability
2. Recommend development and testing of a prototype implementation of the harmonized architecture – a prototype is necessary to show industry value as well as technical readiness in a harmonized AAtS solution that leverages industry standards as well as to spur industry adoption. Prototyping efforts often lead as well to industry practices that motivate additional standards development.
3. Recommend follow-on harmonization work covering additional industry standards – while the work performed under this effort was worthwhile and has resulted in significant progress towards achieving interoperable solutions, it cannot be considered complete or comprehensive across the industry or even the complete AAtS architecture. Within the constraints of a realistic budget, it is recommended that further work investigate harmonization issues with ARINC

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841 MIAM, ARINC 839 MAGIC, selected EFB standards, and others as recommended by the RFI workshop and Tiger Team participants.

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