IN-FLIGHT PROVISIONING AND DISTRIBUTION OF ATM INFORMATION

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Abstract

The approach presented in this paper describes a provisioning system for automatic digital distribution of relevant in-flight information via data link. Thereby, fewer voice radio communications are necessary between Airline/Flight Operations Centers and aircrafts which are currently used for keeping pilots up-to-date on relevant information. The system utilizes Air Traffic Management information exchange standards such as the Digital Notices to Airmen Event Specification and employs filtering to minimize the amount of data that has to be communicated via data link.

1 Introduction

One of the main objectives of Air Traffic Management (ATM) and Air Traffic Control (ATC) is to provide pilots with up-to-date information relevant for their current situation. Currently, the bulk of information is provided to pilots prior to flight using paper printouts. Communication of short-term changes and events is primarily conducted via voice radio. Increasing availability of air-to-ground data links provides a new channel for exchanging such information.

Different communication channels are used to provide relevant information to pilots to ensure safe flight operations. Pre-flight briefings inform about short to medium-term changes prior to departure. Relevant short-term changes that become known after departure are communicated via voice radio. This practice is not sustainable due to global rise in aeronautic operations and the resulting issue of frequency congestion. Systems that automatically provide pilots with relevant information can lead to a decrease in required voice radio communication, as information is transmitted via data link instead. This eases the burden on pilots and especially on air traffic operators, thus improving aircraft operations and flight management efficiency.

Pilots are informed via Notices to Airmen (NOTAMs) about temporary changes to flight conditions, e.g., temporary closure of a runway. To support the move to digital ATM, a digital NOTAM format has been defined by the European Organization for the safety of air navigation (EUROCONTROL) and the Federal Aviation Administration (FAA). The Digital NOTAM (DNOTAM) [1] format is based on the Aeronautical Information Exchange Model (AIXM) [2], which is one of several ATM data exchange models. Other models currently defined are the International Civil Aviation Organization (ICAO) Weather Information Exchange Model (iWXXM), for provision of relevant weather information, and the Flight Information Exchange Model (FIXM), for provision of flight plan information. These exchange models provide the foundation for System Wide Information Management (SWIM) [3]. The standardized formats and accompanying tool support will simplify the origination and publication of digital ATM information. In the future an increasing amount of information will be published as DNOTAMs, as well as in other exchange standards, while the latency between the occurrence of an event and its publication will decrease [4]. As an example, performance statistics of the EUROCONTROL AIS database already show an increase in published NOTAM information over recent years [5].

DNOTAMs can be displayed in the cockpit on an electronic flight bag (EFB). An EFB is a general purpose computing platform intended for cockpit-use that is able to read information from on-board avionics systems. A main goal of EFBs is to provide information digitally to replace current paper-based material, e.g., NOTAM printouts. Standards such as the DNOTAM specification facilitate visualization and data processing on EFBs.

An EFB is able to communicate with ground-based systems via data link. A data link connects two locations for the purpose of exchanging digital information. For air-to-ground communication several different data-link systems exist. Data link communication alleviates the problem of frequency congestion. However, limited bandwidth of data link connections still requires conscious usage [6]. In the context of this paper, a data link is a system that allows communicating ATM data and flight parameters, e.g., current position or on-board weather sensor data, between an aircraft (in-flight or on-ground) and a ground-based system. Technical details of this communication channel are not further detailed in this paper.

The approach presented in this work describes a distribution system for digital provisioning of relevant in-flight information. The proposed system utilizes existing services and technologies to realize automatic digital information exchange. Further, efficient handling of information exchange is achieved by utilizing advanced filter capabilities to minimize the amount of data that has to be communicated via data link.

Unlike currently available systems, our approach supports the automatic transmission of relevant ATM information to airborne aircraft. Thereby, fewer voice radio communications are necessary which has positive effects on air transport system efficiency. Additionally, the lowered burden on flight operators and consequently lower stress levels contribute to air safety.

This paper focuses on the provisioning and distribution of DNOTAMs. However, the same principles can be applied to other ATM data exchange models such as iWXXM or FIXM.

2 ATM Information Management

The main goal of Aeronautical Information Management is to provide *"the right digital Aeronautical Information, at the right place, at the right time"* [7]. This is necessary to maintain safety and efficiency of international air navigation, since a lack of, or erroneous, information can harm the safety of air operations.

The diffusion of performance-based navigation, airborne navigation systems, and data link systems has increased the importance of ATM information [7]. Current aeronautical information exchange, which is based on paper and teletype technology, in combination with voice radio is no longer able to satisfy the requirements of ATM [1]. Heavy reliance on voice communication leads to issues regarding read back clarity and frequency congestion [8]. Thus, new methods of information provision and management are required. ICAO provides guidance for this transition process to ensure uniform evolution in all regions around the world. This transition primarily focuses on the means of data distribution, while the scope of the distributed information is expected to mainly remain the same [4]. Improved data distribution is intended to support common situational awareness which is an enabler of collaborative decision making in ATM.

On a wider scale, SWIM labels joint efforts of EUROCONTROL and the FAA to completely change the paradigm of how ATM information is managed along its lifecycle. SWIM consists of standards, infrastructure, and governance enabling the management and exchange of ATM information [9]. In this context, Service Oriented Architecture (SOA) is designed to be the main concept for exchanging ATM information.

As previously mentioned, relevant standards in the context of SWIM and ATM are AIXM, iWXXM, and FIXM. AIXM is used for exchanging aeronautical information such as information about aerodromes, navigation aids, and airspaces. DNOTAMs are defined as an extension of the AIXM model and are used to communicate temporary changes to aeronautical features. This includes, e.g., runway or

aerodrome closures, or temporary airspace restrictions. iWXXM focuses on different kinds of weather information such as Airman's Meteorological Information (AIRMETs), or weather reports like SPECI or METAR. FIXM provides a standard for the representation and exchange of flight and flight plan information. Additional information exchange standards could emerge in the future.

3 Aircraft Access to SWIM

The Aircraft Access to SWIM (AAtS) initiative launched by the FAA aims to provide a link between aircrafts and SWIM services during all flight phases. This allows aircrafts to provide data to other SWIM participants and to consume data distributed by them. By providing near real-time access to this shared data, common situational awareness between flight crews, ATM, and Airline/Flight Operations Centers (AOCs/FOCs) can be established [4]. To achieve this, current systems which heavily depend on voice communication have to be transformed.

AAtS is not a specific implementation to create the actual link to the aircraft, but defines operational and technical requirements for this link [8]. The main purpose of the AAtS concept is to define a bi-directional data link which connects aircrafts and ground operation centers to exchange relevant information. This includes the provision of aeronautical, weather, and operational flight information to flight crews during all flight phases. In the concept of AAtS, aviation authorities such as the FAA or EUROCONTROL provide the appropriate data access enabled by SWIM to approved service providers [10]. These providers decide how to transmit their information to end-users and which end-users are served. Analogously, aircraft systems also provide access to relevant data to service providers and aviation authorities via data link. This includes both automated and manual input data.

Limitations of data link usage have to be considered when applying AAtS. Some of the problems associated with heavy use of voice communication are also prevalent for communicating over data link. Analogous to frequency congestion of radio channels, data link communication has limited bandwidth. Seker et al. [6] report on potential performance issues with respect to AAtS communication. Careless use of data link communication might lead to increased latency and temporary breakdown of communication. Therefore, it is necessary to distinguish relevant from irrelevant information to avoid unnecessary bandwidth cluttering.

4 In-Flight Distribution System

The presented approach for an in-flight provisioning and distribution system for digital ATM information represents a possible application of the AAtS concept. A main characteristic of this approach is that the system can be integrated into the SWIM architecture by utilizing SOA. A focus of the described system is to identify and digitally exchange relevant ATM information to reduce dependency on voice communication for keeping pilots up-to-date. At the same time the system supports targeted information exchange to prevent unnecessary air-to-ground communication and vice versa.

4.1 System Architecture

The proposed architecture of the system exemplified for DNOTAM information is depicted in Fig. 1. The main components are multiple 'ground systems' and 'EFB systems'. A ground system maintains and provides information for multiple flights and has access to currently published DNOTAMs indicated by the 'DNOTAM publisher' component. A 'filter system' is available both on EFB systems and as part of ground systems. This filter system is able to filter ATM information, e.g., DNOTAMs, based on spatial, temporal, and semantic (e.g., relevant for the specific aircraft) dimensions. Ground and EFB systems can exchange information through data link (in-flight), or through local network connectivity (on-ground).

The depicted DNOTAM publisher component represents a service that publishes DNOTAM information. However, this component can also represent other services
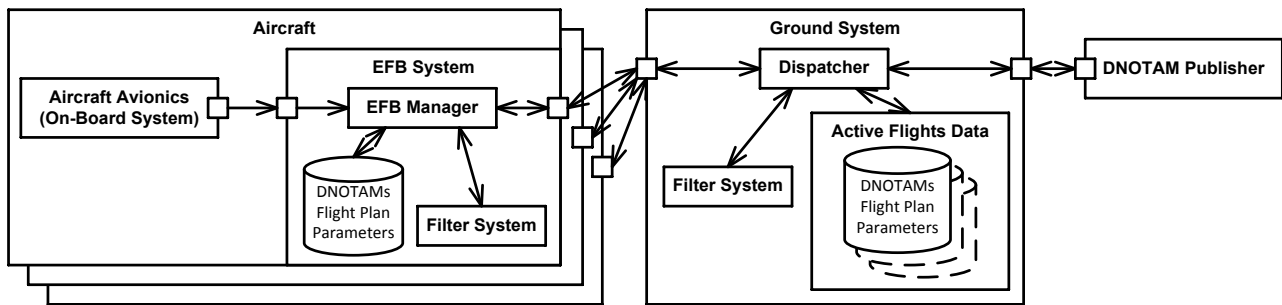
Fig. 1. System architecture

publishing other kinds of information. Multiple ground systems are subscribed to one or more publishers, depending on the kind of information and the structure of the publishing service. Certain information is published by a centralized service (e.g., DNOTAMs), while other kinds of information are published in a decentralized manner (e.g., weather reports).

A ground system maintains information about multiple flights and their corresponding EFB system. This information includes the flight plan corresponding to a flight, information about the DNOTAMs, and other kinds of information that have been loaded to the flight's EFB system. Further, a ground system keeps track of the flights' current position and other related parameters which are received from the individual EFB systems. This aircraft-specific information is essential for minimizing data link communication as it allows a ground system to decide whether a new DNOTAM is relevant for the corresponding flight. The 'dispatcher' monitors currently published aeronautical information. Whenever new information is published, the dispatcher utilizes the filter system to check for each maintained flight whether the information is relevant. Usually, the dispatcher will push the new information to the EFB systems of the managed flights for which it is relevant. The specific communication mechanism used can differ based on the use-case and operational requirements. A more detailed discussion on communication mechanisms is provided in Section 5.

The ATM information distributed by the ground system is displayed to the pilots on the EFB system. An EFB system can be realized by a specifically designed device, or a general purpose device such as a tablet PC or a smartphone. Independent of the specific realization, it provides an interface for pilots to display ATM information. Sophisticated systems can be used to classify and prioritize the transmitted information to facilitate their digestion, as shown, e.g., by Zimmer et al. [11] and Steiner et al. [12].

The 'aircraft avionics' component represents the aircrafts' integrated on-board system. In the proposed architecture, the EFB system reads information from the aircraft avionics. This includes, for example, the current position of the aircraft. An 'EFB manager' component operating within EFB systems is responsible for keeping the ATM information up-to-date. Further, this component is responsible for information visualization and the communication of the aircraft-specific data, retrieved from the aircraft avionics, to the ground system. Information received from the ground system is maintained in a local database on the EFB system. This database includes information about the current flight, i.e., the flight plan and current flight parameters. Additionally, the database maintains other ATM information items such as DNOTAMs or weather messages. A local filter system available on an EFB system is used as a fine-grained filter for information in the database. In contrast to filter systems in ground systems, the filter systems in EFB systems allow to filter for a subset of the available information. This enables the reduction of displayed information, e.g., only displaying information relevant to the current flight phase. Sophisticated EFB systems, such as [11, 12], require this capability to facilitate information digestion.

4.2 Information Provisioning Process

To achieve the intended benefits by providing targeted information, the information provisioning process has to be examined. The process is exemplified using DNOTAM information only, since the same principles can be applied analogously to other standardized ATM information exchange formats.

The process starts with registering a new flight to a ground system. As part of this registration, the intended flight plan including the planned flight route, flight times, and aircraft are provided to the associated ground system.

Depending on the users' context the proposed ground system might be implemented in different ways. In [4] three different usage contexts are identified. For airlines, the ground system can be associated to the AOC. For large supported General Aviation (GA) operators the ground system can be part of the contracted FOC. For non-supported GA flights the functionality of the ground system can be provided directly as electronic pay-for service.

Independent of its actual context, prior to the start of an operation, the ground system determines the set of relevant DNOTAMs for the flight by utilizing the filter system. Based on the filed flight plan, the ground system determines the query that is necessary to acquire the relevant DNOTAMs and uses the filter system to calculate the result set. An example of such a filter system is the SemNOTAM system [13], which is able to filter DNOTAMs based on temporal, spatial, and semantic dimensions. To cope with minor deviations from the flight plan, this set might also contain DNOTAMs in a larger area and/or timespan around the planned trajectory. The filtered information is subsequently loaded to the EFB system. This loading process can either be conducted manually, e.g., through an USB device, or through terrestrial network connectivity.

The ground system periodically checks for new published DNOTAMs and transmits them to the flights for which they are relevant. For each new DNOTAM the system determines, using the filter system and the locally available information, for which active flights the DNOTAM is relevant. If a DNOTAM is relevant for a flight and if it has not already been loaded onto this flight's EFB, the DNOTAM is transmitted via data link. This represents information that currently would have to be communicated via voice radio.

In the cockpit, the EFB system and the local filter system can be used to readout specific information, e.g., within a radius of the current position. This local filter system is applied to the information maintained on the EFB system. Due to this local filter capabilities, the initial information set that is loaded to the EFB system will usually cover a broader extent of information than actually displayed. For example, to cover possible delays a time buffer of three hours after the planned flight times might be applied for initial loading of NOTAM data. However, in the cockpit the system would be able to filter for the active DNOTAMs based on the actual time and a smaller spatial buffer.

Changes to the flight plan of an active flight require the system to transmit the DNOTAMs which are relevant for the changed flight plan. It is assumed that the new flight plan is made available both to the EFB system and to the ground system. Whenever the ground system receives a new flight plan for an active flight, the relevant DNOTAM set is determined as for a new flight. Only relevant DNOTAMs that have not already been sent to the EFB are transmitted to the flight via data link. This prevents unnecessary or duplicate transmissions.

5 Communication Mechanisms

In the FAA AAtS Data Exchange report [10], three different scenarios for data communication, 'continuous distribution', 'event triggered', and 'request/reply', are delineated which can be used in the presented in-flight provisioning and distribution system. In this section the effects of applying these different mechanisms to the proposed architecture for data exchange between in-flight aircrafts and ground systems are described. In contrast to [10] where these mechanisms are viewed only in the context of downlink communication, we review them for communication in general.

Continuous distribution denotes that information is continuously sent at a predetermined update rate. Conceptually this might be realized as a publish/subscribe service, as already described in the Information Service Reference Model (ISRM) under the name of Integrated Digital Briefing Service (IDBS). In the context of our proposed system, this mechanism is suited for the communication of flight parameters, such as the current position, from the aircraft to the ground system. In this case, the ground system acts as subscriber to information published by the aircraft. The aircraft system pushes the flight parameter and other aircraft-specific information to the ground system at a fixed interval.

In contrast to continuous distribution, event triggered communication sends information as it is created through automated processes. As previously described, the ground system monitors published DNOTAM information. Therefore, publication or detection of a new DNOTAM might represent an event which triggers further processing. In the case of our system, the event detection would trigger the filter process on the ground system, determining for which of the registered flights the new DNOTAM is relevant. After this, the system would initiate the transmission of the DNOTAM to those aircrafts. The aircraft system has to acknowledge the reception of new information. Depending on the kind of information it might be necessary to additionally require an active acknowledgement from the pilot crew.

In the request/reply mechanism, the communication is only initiated when explicitly requested. A request in the context of the proposed distribution system might be a change of the filed flight plan. If the flight plan is changed, the aircraft can request the existing DNOTAM information relevant for the updated flight plan. As previously described the ground system will respond with those DNOTAMs that are relevant to the updated flight plan that are not already available on the EFB system.

6 Related Work

Few related work addresses provisioning of NOTAMs to and communication with EFBs apart from the technical realization of data link communication. Notably, Zimmer et al. [11] and Sindlinger et al. [14] of Jeppesen research report on a rule-based system for in-cockpit NOTAM notification on an EFB. The described system uses business rules to define the flight phase in which a NOTAM is relevant. The system also supports different notification levels using different intensity levels of aural alerts and display signals, based on the type of information received. In contrast to the system proposed in this work, the Jeppesen system uses proprietary data exchange formats, which are not based on DNOTAM.

Several commercial service providers are leveraging the widespread availability of smart mobile devices with internet access to provide information services to pilots (e.g., [15, 16]). These services primarily focus on support for GA pilots. They operate outside the SWIM infrastructure and utilize existing data link technologies or the fact that conventional mobile internet connectivity can be available when operating at low flight altitudes.

Evans et al. [17] provide a usability study for EFBs. They report on a user study with pilots in which the usability of displaying different kinds of ATM information on EFB systems has been conducted. Pilots rated the usability and acceptability of EFBs well due to the power of graphical representation, but offered suggestions for improvements. Among others, they highlighted the fact that messages should be filtered and tailored to the specific flight so that only relevant information is displayed.

This drawback is bridged by the SemNOTAM project [13], during which the approach discussed in this work has been developed. In SemNOTAM an intelligent querying and filtering system for DNOTAMs is developed. This system allows filtering DNOTAMs for an interest specification (i.e., a flight plan) and enriching DNOTAMs with additional information such as a priority or the flight phase the information relates to.

7 Conclusion & Future Work

In this paper we have presented how Aircraft Access to SWIM might be leveraged to improve ATM. We proposed a system architecture consisting of a ground-based component maintaining several flights and corresponding information with each aircraft operating a corresponding EFB system. Due to the availability of information concerning the maintained flights in combination with utilizing filter systems it is possible to reduce the amount of information that has to be communicated. As a result, the usage of data link communication bandwidth is kept to a minimum. We further touched on the different AAtS communication mechanisms and discussed their role within the proposed system.

Future work includes a proof-of-concept prototype of the proposed system. In a first step, this prototype will be limited to provisioning and distribution of DNOTAM data, as a corresponding filter system for DNOTAMs already exists.

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