Lessons Learned: System Upgrade from a Basic Datalink Solution to an Integrated Electronic Flight Bag (EFB) Connectivity on Legacy Airliner Aircraft

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Abstract

Over the last 10 years there have been many improvements in the development and availability of high-performance hardware and software for data processing in the field of civil aviation. In addition, the transmission media (SATCOM, UMTS, ...) and their performance (bandwidth, data rates, etc.) have increased to a level that enables users in civil aviation to exchange information virtually in real time. On the basis of these developments, the challenges in the practical technical implementation as well as the accumulated engineering experience are to be analyzed, which enable an integrated solution for sustainable (ecological and economical) flight operations in the area of fuel consumption, mission planning, maintenance, passenger handling and ground handling.

1. STARTING POINT: A BASIC DATALINK ON LEGACY COMMERCIAL AIRCRAFT

Looking back 10 years ago, airlines show a wide variety of datalink usage in their legacy fleets. Some airlines, early adopters, already demonstrate a high and company-wide process integration of their datalink functions, typically achieved by a highly customized Aircraft Communications Addressing and Reporting System (ACARS) software in detail tailored to match the airline's needs, processes and IT interfaces.
At the same time, some other airlines only use the basic datalink functions or even still operate their legacy fleets without any ACARS capabilities at all. These basic functions typically consist of reporting flight times (OOOI = off-block-Out, airborne-Off, touchdown-On, onblock-In) to the airline ops control center or ops system and engine health monitoring (EHM) data to engine manufacturers. Some also use the exchange of freetext messages between respective departments and pilots, fault reporting and weather services. The weather services (METAR/TAF) are either contracted from an external source or are provided by the airline's flight planning system. Airlines with a starting point of only basic datalink usage tend to choose other means (Electronic Flight Bag - EFB, Electronic Technical Logbook - eTLB) for further process integration and digitalization, even in a non-connected aircraft environment.

Early adopters have already reached a high degree of process integration at times, where ACARS was the only possible way of communication. ACARS delivers comfortable process support for the pilots during all flight phases and at all times, only limited by loss of connectivity. There is active communication between pilots and various departments of the operator and airport stations. ACARS messages are often automatically exchanged with various airline ground systems, e. g. interfacing with the systems for flight planning, ops control, departure control, mro, invoice control, emission trading, crew management, crew payroll and data ware houses. The ACARS screens (cockpit frontend) and the message content have been highly customized to exactly match the airline's demand for information and the required structure of the system interfaces. Many business units benefit from the use or the content of ACARS messages, in real-time or for back office analysis, as widespread as ops control and dispatch, maintenance control, engineering, powerplant, flight ops, flight ops engineering, ground ops, passenger ground handling, crew control, cabin quality, legal and IT. This existing ACARS orientated IT interface structure needs to be considered in any business case for removing ACARS functions and replacing them by EFB or eTLB. This first chapter explains the starting conditions of our datalink project for the legacy aircraft fleet, to give the reader a principal understanding of the baseline setup.

1.1 Technical Description: Existing Hard- and Software

Datalink hardware and software on aircraft side strongly depend on the vendor and the aircraft manufacturer. On Boeing aircraft the datalink hardware manufacturer implies which ACARS software can be loaded. Main vendors are Collins and Honeywell, but there are also stand-alone solutions (e. g. DLINK by Spectralux Avionics) that provide basic functions combined with limited integration capabilities [1]. In contrast to this, the ATSU (Air Traffic Services Unit) of the considered Airbus (e. g. A320 Family) is capable of loading either Collins or Honeywell software which provides more flexibility and less integration challenges to the operator.
The software typically consists of a core software provided by the original equipment manufacturer (OEM) and a so called AOC ("Airline Operational Control") software. The latter can either be a standard version or a customized version reflecting the individual airline needs. The AOC software defines the pilot interface (layout & content as well as access & navigation through ACARS screens). Nevertheless, in order to be used for datalink communications, all defined uplinks and downlinks, standard or customized, have to be compliant to the ARINC AEEC standards 618/620. These standards apply to all datalink service providers (DSP) such as SITA, ARINC and also to regional service providers [2].
A contract with a DSP and its corresponding configuration in the DSP system is the prerequisite of being able to exchange datalink traffic end-to-end. The service providers configure parameters typically such as airline code, aircraft registrations and the airline system address in their DSP system network to ensure the end-to-end delivery of the datalink traffic. Without having contracted this service, traffic received by the DSP is trashed and not delivered to the airline (downlinks) or to the aircraft (uplinks) [3].
On aircraft side, the datalink scan mask configuration defines which service provider, represented by a certain VHF

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frequency per region, is addressed for datalink communications and at which priority. To ensure seamless datalink traffic without trashed messages, it is mandatory that the scan mask settings match to the contractual aspects.

1.1 Challenges: Interface Definition, Encryption, customized Software, Specifications & Documentation

Most challenges for a typical datalink implementation are related to limited or missing documentation or deviation from international standards. Another key element is the availability of expert knowledge in the company in terms of datalink, corresponding avionics and technical aspects (e. g. IT related topics).
While the ARINC 618/620 standards, once purchased, describe the general format of a message in the network, they do not help to understand message content of a customized AOC software. Customization is not only limited to message content. A highly customized AOC software may be exactly tailored and even linked with the corresponding ground system and coding in the aircraft. In such cases, using the same AOC software with a different ground system leads to loss of functionality, and interfaces or parts of coding are no longer met. This could either be an encryption of datalink messages that require the decryption algorithm in the corresponding ground system, or functions that differ from the international standards in order to meet optimized content from the individual ground system. Once replacing the ground system, those ACARS downlinks are not compliant to communicate with common sources such as databases for weather services (e. g. METAR/TAF) or digital ATIS or ATC clearances. If documentation is limited or not provided at all, especially how functions are implemented in the ground system or any other hidden functionality, it is a major challenge to cover these changes without a loss of functionality.
It also needs to be considered that for an amendment of AOC software, a corresponding back office tool is required or alternatively changes can be requested from the manufacturer. Both require expert knowledge and training as well as detailed datalink expertise either for handling AOC software changes inhouse after having purchased the corresponding tool or for submitting a detailed specification for the required change requests. Rather long lead times (typically in the order of several months) and financial impact have to be considered here as well.
Within the sector of the back office work, challenges arise in that way, that the hard- and software must be capable of processing the amount of bidirectional data for detailed analysis. Therefore interfaces to back offices quickly can become a bottle neck, if not developed from the beginning according to the operator's requirements.

2. DEVELOPMENT & INTEGRATION PROCESS TOWARDS TARGET CONFIGUTATION

Chapter 2 introduces general requirements and guidelines to the different aspects of a connectivity network and datalink application during the development and integration process.

2.1. Definition of Datalink Requirements for efficient Airline Flight Operation

Requirements for efficient datalink management cover several aspects, such as the capabilities (e. g. data transfer rates, coverage) of the ground system as well as DSP support quality (e. g. 24/7 vs. email contact only), but also organizational aspects in terms of documentation and knowledge and also the overall approach for implementation. The following table shows vital requirements for a successful datalink implementation.

FULL DATLINK TRAFFIC ACCESS
Access to the datalink traffic not only at end points (pilot front end, end user back office) but also easy access to all unformatted uplinks and downlinks in raw format for analysis. Messages that are directly routed outside the system need at least to be supplied as a copy to the system. It is recommended to keep the traffic not only for a few months but for up to 3 years.
FULL CONTROL
Full control of administration & configuration of datalink traffic in order to directly control distributions, formats, processes and to guarantee short reaction times.
EFFICIENT SYSTEM
A datalink ground system that is intuitive, easy to use and capable of handling (ad hoc) changes in a fast and efficient way is an essential benefit. Administration should not require programming skills, but should be carried out by configuration of rules, permissions and formats. Any change needs to become effective at once without any system restart or a deployment schedule (*configuration/change management during life operation*)
INTUITIVE/ STANDARDIZED INTERFACES
The ground system has to manage traffic from both/all DSPs, seamlessly for various media (VHF, VDL, Satcom, HF), ideally also supporting multiple-airline usage. For message delivery to end users and IT systems, typical technical adapters such as Message Queuing (MQ), Secure File Transfer Protocol (SFTP), email, telex messaging etc. should be available.
FAULT TOLERANT SYSTEM OPERATIONS
Stable operations and fallback lines are mandatory to avoid outages in traffic flow, which may lead to operational, costly irregularities. Outages must be covered by message queueing and redelivery.
24/7 DSP SUPPORT
A 24/7 support is mandatory for all issues of operational impact where immediate actions on short notice are required. It is important to receive an adequate near-time incident reporting of any DSP services in degradation or outage, not only post-incident reporting.
DSP CONSULTING
Technical experts from DSP work with various airlines and providers. This is an excellent source for guidance and recommendations when facing new technical requirements, mandates, avionics or aircraft. Technical consultancy and proactive support by DSP experts should be guaranteed.
OPERATIONAL & TECHNICAL KNOWLEDGE
Datalink knowledge for aircraft and ground is crucial. It needs to be company knowledge, not only personal knowledge. The datalink team is shared responsibility between Flight Operations (Technical Pilot), Engineering (Avionic Engineer) and IT (Ground System Administrator). It is crucial to read specifications and understand the datalink traffic in order to derive conclusions, e. g. maintenance actions or improvements of services or configuration.

DETAILED DOCUMENTATION
All relevant specifications, own decisions, experiences, test plan & test cards, results as well as datalink configuration setup. In order to ensure organizational learning, it is crucial to understand the root cause of test cases & system behaviour and draw conclusions for further system development. Detailed documentation is a vital basis for sustained in house knowledge.
WORKING GUIDELINES
For any implementation, serious operational impact has to be avoided. This can be covered in an incremental or step-by-step approach such as testing one aircraft, in back office, on ground, inflight before applying it to the fleet. Each testing step needs to be completed successfully before moving to the next one.

2.2. Connectivity: Media, Data & Interfaces

Bi-directional datalink messaging via the DSP network needs to be contracted by one or both of the main global service providers (ARINC, SITA). The benefit of having contracts with both providers is given by differences in their VHF coverage range. While most terrestrial regions are covered by both providers, there are still areas where only one of them provides coverage. It is therefore crucial to match the DSP's coverage regions to the operator's expected flight program.

Figure 1 SITA VHF worldwide Coverage [3]

Cockpit satcom data/voice services (currently Iridium or Inmarsat) fill the coverage gap and ensure (nearly) global coverage. For satcom services, a contract with one of the DSP is sufficient. Required hardware (e. g. antenna and satcom data unit - SDU) needs to be installed on the aircraft. HF data services are offered by ARINC only and have widely been replaced by satcom.

ACARS data from all these media sources is seamlessly delivered by the DSP to the airline ground system. The parameters in the so-called DT Line of each ACARS downlink, specified in ARINC 620 standard, contains information which DSP has delivered the message and which media and ground station has been used for delivery. The communication service line ("DT line") consists of DSP Identifier, the satellite or ground station identifier, the message reception time stamp and a message sequence number [4]. The following table explains some examples for DT lines found in ACARS downlinks:

DT	**QXS**	**FRA1**	**080938**	**M04A**
DT	**QXT**	**IGW1**	**081310**	**F23A**
DT	**QXT**	**EUA1**	**080934**	**F43A**
DT	**DDL**	**H03**	**081240**	**S10A**
DT	**DDL**	**KEF**	**080828**	**F29A**
-	DSP identifier	Reference station	Time stamp	MSG Sequence number
			DDHHMM	-
QXS = SITA VHF *QXT* = SITA Satellite based network *DDL* = ARINC		*FRA1* = ground station *EUA1* = ground earth station INMARSAT *IGW1* = IRIDIUM Gateway H03 = HF datalink (HFDL) ground station		

Table 1 Sample message data format

Analyzing the DT line for an aircraft reveals beneficial information about which DSP and which media has been used and may even assist in technical troubleshooting. It helps to differ between general datalink connectivity issues or satcom related issues. It also helps to explain that certain ACARS services are not working, if the wrong DSP has been used where such services have not been contracted. The next table reviews basic characteristics of different media.

MEDIA	Provider	Frequency & Bandwidth
VHF	SITA, ARINC	2-30 kbit/s, limited coverage
SATCOM	IRIDIUM, INMARSAT	L-Band (1616-1626.5 MHz), ~350kbps, better global coverage L-Band (1545-1547 MHz), ~430 kbps
HF	ARINC	~300 bit/s, global coverage
UMTS	-	Max. ~42 Mbit/s (HSPA+)
WiFi	-	Low GHz, ~3.3 Mbit/s (public)

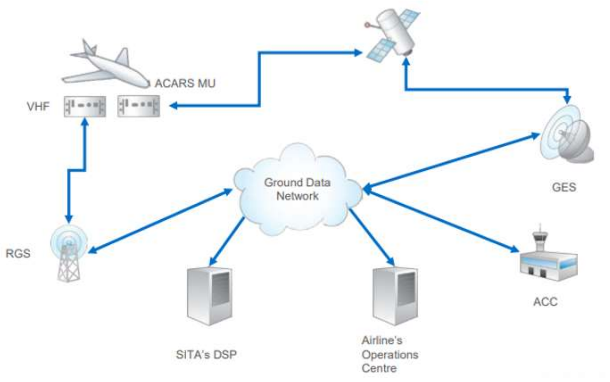
Table 2 General Media characteristics [5] [19]

2.3 Data Processing

The end-to-end data processing consists of a transformation from the pilot facing front end via raw message format of the downlink displayed in the ground system to the final format received by the end user recipients.

The AOC software loaded in the aircraft defines the front end menu and screens, but also defines how the content is transformed into a message downlink received by the ground system. The ground system defines how the message is reformatted and to which recipient it is distributed in which format. For uplinks, the ground system defines the message formats, that are required by the individual aircraft avionic configuration.

Customized uplinks may even be reformatted after having been received by the aircraft, e. g. by fixed text templates, text labels or font size modifications which are not visible in the uplink itself. The link between uplink format and processing on aircraft side is a customized SMI (Standard Message Identifier). In order to supply the correct uplinks, it is crucial to have a documentation of the relationship between a customized SMI and its processing on aircraft side. The same applies to cases where special coding in the ground system is linked to a special downlink message type. A successful implementation in a customized environment without having proper documentation or at least given examples is almost impossible.



RGS = remote ground station, GES = ground earth station

ACC = air traffic control center

Figure 2 Sample Data Routing & Processing [3]

2.4. Prioritisation of Datalink Functions

Datalink functions may be either of operational importance (e. g. weather hazards, ATC clearances) or supply data for back office analysis (e. g. emission trading, fuel billing). Some of them replace voice communication or paper-based processes (e. g. Controller Pilot Datalink Communication (CPDLC)). Based on the fact that (quasi) real time data may have the highest flight operational importance the following table presents a principal prioritisation of datalink functions to be integrated in an incremental process into flight operations.

Priority/Functions	Examples
Prio 1 - Basics • establish (bidirectional) communication • ensure systems fault/health monitoring • basic data	- *Freetext* from/to operator's departments (replaced by SATCOM voice?) - FANS/CPDLC according to mandate - Engine condition monitoring, Warning & Fault Reporting - Weather Request & Uplink (METAR/TAF) - OOOI Flight Status Monitoring (Out/Off/On/In)
Prio 2 – Efficiency • replace voice information by data • replace manual data entry by automated data • support ontime flight operation	- Slot Uplink, Digital ATIS Request & Uplink, - Loadsheet Uplink - (Re-)Route & Wind Request & Uplink - Departure/Oceanic Clearance - ETA Reporting - Communication from/to operator's stations
Prio 3 – Process Optimisation • replace paper-based processes • supply data to other IT systems • aircraft tracking backup	- (Re-)Fuel Reporting - Delay Reporting - Flight Log Reporting - Door Opening Times - Position/Progress Request & Report
Prio 4 – Comfort • passenger info • additional communicaton channels • collection of meteorological data	- Connecting Flights Gate Info for Passengers - ACARS messages air-to-air - ACARS messages to telex addresses - ACARS messages to company email addresses - Meteorological data

Table 3 Prioritisation of Datalink Functions

2.5 Integration and Test

Guidelines for integration and test have initially been derived from the efficient datalink requirements (see chapter 2.1) and follow a general "Keep it simple" approach. In detail the following techniques were utilized to follow this approach:

Keep it simple	
Incremental/step-by-step	Not all at once, to better understand and analyse system behaviour
From easy to complex	Start with the basic functions and develop from there
Prioritization	What is really important at the relevant level of integration?
Detailed Documentation	Document root cause and system/network architecture & behaviour

Table 4 Integration & Test Guidelines

In particular detailed documentation sets the basis for building company knowledge and finally establishing a learning culture for the future. Under all circumstance it must be avoided, that knowledge is solely related to individuals.

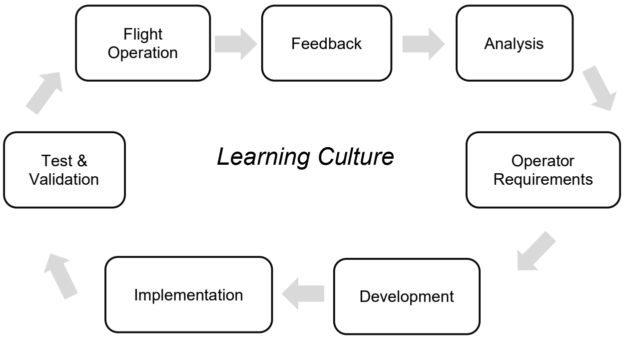


Figure 3 Learning Culture Process

Before looking at some further details the general set up of integration as well as validation & test processes is shown. As mentioned above an incremental approach was chosen. The below process was integrated in the learning culture set up as it was utilized during upgrading single aircraft followed by an complete fleet expansion upgrade.

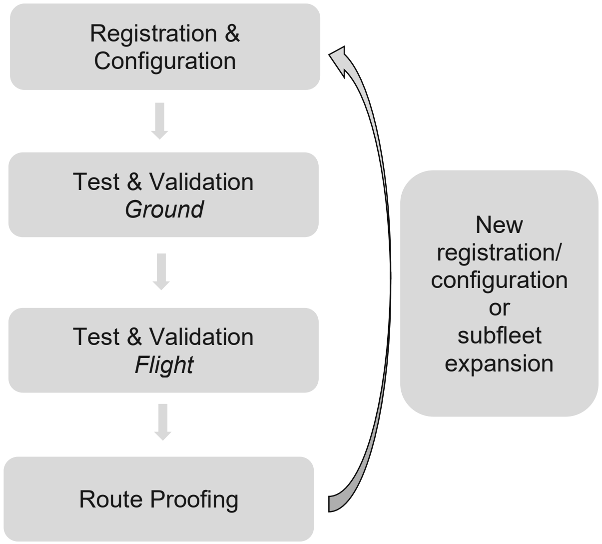


Figure 4 General integration process

Operational Requirements and their impact on system capability have to be understood as a prerequisite for development and implementation. Tests have to be prepared by defining what should be tested, how it should be tested, how the result can be proven, and which results are expected. New configurations in the ground system can be validated at first inside the system, then in one aircraft on ground and finally during operations inflight. The feedback derived from the test and validation step needs to be documented, analyzed and leads to a new set of requirements. The whole documentation process needs to be archived to ensure that gained knowledge will not be lost.

A guideline is to focus on the most important functions and requirements first, implement basic solutions and postpone enhancements or complex workflows to a later stage. Implement smaller steps and set them live, monitor them and react by readjustments. For a successful approach of keeping steps simple, it is still crucial to develop an understanding for technical and functional details in order to keep the right things simple in the right way.

Tests should cover several aspects: initial tests should be performed in order to familiarize with the functions and the corresponding message formats and content and how this is linked to the frontend facing the pilot: which function and which data entry lead to which message format and parameter? How is it possible to distinguish between different message types and to which extent is this required? As a result of this familiarization phase, the message types, parameters and content options are understood and implemented in the ground system.

The next step considers formats and recipients: Which recipients require to receive which message type and how should the content be presented? This applies to back office users as well as for interfaces of IT systems. Distribution rules and formats need to be tested and validated in this step and confirmed by recipients. The same applies to uplinks taken into consideration the individual format requirements of the aircraft avionics.

In case of encrypted messages, it is important to understand the mechanism of encryption: This can be done by comparing encrypted raw data with the final decrypted format received by end users or IT systems. If encrypted and decrypted versions of the same message have the same length and also the same character pattern, encryption may be based on a simple character replacement procedure. Knowing which character has been replaced by which delivers a translation table that can be used for en- and decryption.

2.6. Change of Datalink Ground System

As access to traffic and understanding the traffic is a key element for any preparation phase, it is very important to have a copy of all traffic as soon as possible in the new ground system. Setup of the system configuration can then be done based on the actual traffic data. Individual functions can be activated in the new system for test purposes for a certain time period or flight or aircraft. As a result of this preparation phase, message reformatting and message distribution rules have been configured in the new system and have been thoroughly tested on a case-by-case basis.

After completion of the preparation and test phase, the actual cutover takes place when the new system becomes the leading system. In order to reduce the risk (e. g. operational irregularities) as much as possible, the cutover was carried out in an incremental way aircraft by aircraft. In the first step, the new system was made leading system only for one initial aircraft registration with a respective hard- and software configuration. After the transfer of this aircraft, the traffic was closely monitored and analyzed for a period of 1 - 2 weeks. Any observed errors were corrected by documented root cause analysis. After that, all other aircraft of the same aircraft type and avionic configuration were successively transferred. After the completion of the first subfleet, one aircraft of the next subfleet (e. g. different avionic configuration) was transferred and observed before the remaining aircraft of this group were moved as well. The same procedure was followed for all other subfleets.

In order to remove individual aircraft from the previous system and manage them completely in the new system, a coordinated cutover between all parties was necessary. It was important to ensure that no messages were lost and double deliveries (redundancies) were to be avoided. During the test and preparation phase of several months, all downlinks had already been routed in parallel to the current and the new system. The current system was the master system and was responsible for message distribution. Since the message distribution could not simply be stopped there for the individual aircraft to be transferred to the new system, the cutover for each aircraft essentially consisted of stopping the downlink delivery to the current system and at the same time setting the message distribution active in the new system for this aircraft only. The downlink delivery to a ground system can only be terminated by the Datalink Service Provider (e. g. SITA) as part of a configuration change. These changes must be requested a few days in advance, only take place on certain days of the week and are carried out within a time window of several hours, typically not in the local European time office hours.

It must also be ensured that data deliveries from third-party systems, e. g. slot messages or load sheets, for the respective aircraft are only delivered to the new system when the cutover has taken place. This usually requires administrative activities (e. g. new system addresses) in these third-party systems, which must also be synchronized with the cutover time.

None of these steps require any preparation or action inside the aircraft, so there was no requirement to allocate maintenance tasks or align ground times. However, it is recommended to inform all stakeholders such as flight crew, ops control center and maintenance in advance to make them

aware in case of any unexpected datalink or connectivity issues.
After having completed the transfer of all aircraft, some remaining adjustments had to be carried out. The essential one was that the backup datalink service provider also had to readjust its delivery to the new system. Since it was not possible to change this aircraft by aircraft at individual cutover times, this was completely changed immediately after the transfer of the last aircraft. As a config change was required for this, the request had to be submitted with a leading time of several days. The actual configuration change takes place outside our local time office hours.

Subsequent contractual and billing-related reworking was carried out with the provider of the previous system, so that no more costs could occur due to mislead messages, e. g. in case of manual uplinks still being sent to the previous system. The associated system and telex addresses were also finally deactivated and deleted. All rework was completed within approximately 3-4 months with basic datalink knowledge.

2.7. Change of Datalink Service Provider (DSP)

If the datalink ground system and the datalink service provider are changed at the same time, a few different aspects have to be considered. Once again it is advisable to have a copy of all downlinks set up for the new system as early as possible. If there are contracts with both service providers in place, the exchange between ARINC and SITA networks is technically possible, but additional costs may arise for forwarding messages as ground telex from one network to the other.
The new provider has to configure every aircraft in its system and requires detailed aircraft information such as registration, Mode S Address and ACARS capabilities (VHF, VDL, Inmarsat Satcom, Iridium Satcom) for this. The new provider is able to configure the aircraft already in advance based on VHF and VDL capabilities. This is done in a configuration change and needs to be requested a few days in advance. It is not possible to prepare and activate the satcom configuration when at the same time it is still in use with the previous provider. This needs to be taken into account during the actual cutover procedure.
For VHF/VDL services, the actual cutover is easy: by simply changing the aircraft scan mask settings from the former to the new DSP frequencies relative to geographical position, message traffic to the new DSP network and the new system is being enabled and traffic to the former network and the previous system is stopped.

Figure 5 Sample scan mask [6]

There is no need of any coordinated action with the service providers in the moment of cutover. However, the aircraft needs to be on ground for the maintenance action of changing the scan mask to be carried out.
For transferring Iridium satcom aircraft from one provider to another, the new provider has to supply new SIM cards that need to be installed in the aircraft. The SIM card exchange needs to be scheduled in the maintenance plan. After having exchanged the SIM cards in the aircraft, the new provider needs to be contacted for activation of the SIM card. This kind of activation with the new provider had been possible on short notice within hours. However, activation with the new provider is only possible when the previous provider has released the corresponding IMEIs (International Mobile Equipment Identifier) [7]. The former provider required written information about the scheduled satcom deactivation at least one week in advance and it was not expected to update the time window afterwards in case of rescheduled maintenance due to operational reasons. Aligning operational changes to the maintenance window and having given the fixed timeframe for deactivation with the former provider was a challenge in order to avoid operational impact.
Deactivation and reactivation is not necessary for moving Inmarsat aircraft from one DSP to the other. Nevertheless, the former DSP needs to be informed at least one week in advance. Once the aircraft is ready for transfer, a request of transfer from the former DSP PSA (PSA = Point of Service Activation) to the new one needs to be submitted [8]. The new DSP confirms that they accept to be PSA for that aircraft and contacts Inmarsat to carry out the transfer. After successful transfer, the customer is informed by the new DSP that the change has been completed. All these actions can be performed within one day.

2.8. Fleet Expansions with different Datalink Solutions

As onboard datalink equipment cannot easily be exchanged, additional aircraft that come from previous owners and enter the fleet, are always a challenge in terms of integration and harmonization, especially if a formal documentation of the ACARS software is not available. Typical challenges are:

- different manufacturer (Honeywell vs. Collins vs. Stand-alone)
- different satcom systems (Iridium, Inmarsat) or no satcom system
- given AOC SW, no ability/knowledge/budget to change and align
- some parameters not supported in datalink interfaces

As a result, fleet expansions can lead to an uncomfortable mixed environment of hardware & software configurations. Pilots then have to be familiarized with different datalink frontends, and on the ground system administration side, the challenge is to align all aircraft given differences to a harmonized output towards back office users and IT systems.
It is recommended to register the new aircraft as soon as possible with the Datalink Service Provider in order to ensure to receive the downlinks in the ground system as soon as registration, airline ID and Mode S address have been updated in the aircraft.
We also found it very useful to take photos of all datalink screens that are accessible in the aircraft; these photos enhanced general system/interfaces awareness for the non-pilot engineers. As a next step, in a coordinated test between cockpit and ground, all ACARS screens were tested and filled with data and as many manual downlinks were sent as possible. At this point it is very crucial to have a

detailed documentation to align what has been done in the frontend in the aircraft (which screen filled with which data) and what has been the resulting downlink format and content that was received in the ground system. This should be supported by a predefined test plan, by photos of data entries and ideally by aligning actions via mobile phone in parallel (when aircraft is on ground). However, aircraft-generated messages such as OOOI cannot be tested and prepared in this way and need to be considered as soon as the aircraft will move.
Based on these tests that have evaluated the capabilities and options, a concept was derived how pilots have to use these ACARS reports in order to provide as much data and content as possible that is required to support established processes on ground. As a result of this approach we were able to introduce functions which originally were not supported by the new software by simply defining how to use (or „abuse“) existing reports. Being error-prone and not comfortable for the pilots, it at least was a way to support ground functions and interfaces without any additional cost for software or interface modification. A key element in this process were the tools and functionality given by our ground system. With a huge tool-set provided for data reformatting and message processing, it was possible to transform downlinks of various different formats into one common format to be delivered to the end users or IT interfaces. For example, a freetext downlink to ops control may be received in various very different downlink data formats generated by the different ACARS software in use. Making use of the tool set in the ground system, they all could be reformatted to one and the same format before being distributed to the final recipients (customizing raw data format for end user interface). Different message formats for the same downlink functions are therefore not visible to end users.

3. OPERATIONAL USE CASES & BENEFITS

Chapter 3 highlights datalink solutions and applications to aircraft operation on ground and in flight. In particular their impact on sustainable and efficient operating modes is shown.

3.1. Impact on sustainable, economical and safe Operation

The following chapters show a more detailed impact of connectivity and datalink capabilities on flight operation. In principal one can divide the impact of data into three general sectors of aircraft operation: 1. Flight Safety 2. Flight Operation 3. Ground Handling. However many data have impact on more than one sector and therefore can be categorized as more important than others, depending on the operators requirements. As a consequence those data should be prioritized during integration-, test- & validation phase.

In public discussion sustainable and economic operation is often rated contradictory. However from the authors' experience in airline operation sustainable and economic operation are a winning combination for the benefit of both. Many parameters have positive influence on sustainability as well as economy of aircraft operation. The most important aspect is the reduction of any kind of emissions during aircraft/flight operation. A reduced fuel usage is the prime driver of this goal; not only reducing direct operating costs to operators but also reducing the environmental impact.

3.2. Connectivity Requirements

As a prerequisite to efficient operational usage of connectivity structures and its associated datalink applications two major aspects must be assured. One is an establishment of an ultimate reliable and dependable connectivity network as well as respective datalink structures. The other aspect is a dependable front end solution not only in back offices but primarily in the cockpit environment, where crews must interact with, to support efficient and sustainable flight operation. Nowadays some kind of an electronic flight bag (EFB) is state of the art. EFBs are either part of the cockpit hardware or are installed as modifications on basis of e. g. supplemental type certificates (STC), minor changes; incorporation of "bring your own device" (BYOD) idea [9].

Figure 6 Sample Electronic flight bag (EFB) [10]

It must be noted that it is important to check the intended EFB hardware against the cockpit environment as well as the robustness in daily operation. Some key elements are touchscreen functionality, brightness control due to different sun angles, impact of cosmic radiation on EFB hardware elements like processors (e.g. if a lot of northern polar routings are anticipated), and in general EMI & EMC aspects.

3.3. Realtime Data for Inflight Operations

One major aspect is the availability of recorded atmosphere data (mainly wind, temperature, pressure), which are downlinked to meteorological forecast institutions to predict local and global weather and climate for a lot of more stakeholders than only aviation industry. Predictions for agriculture, sea travel, civil protection, … are vitally important. The Aircraft Meteorological Data Relay (AMDAR) project of the World Meteorological Organization (WMO) is probably the most important application [11]. As an example during times of greatly reduced air traffic (like the pandemic year 2020), also the reduced amount of sensed atmospheric data by aircraft deteriorates the quality of local & global forecasts [12].
A direct consequence of above weather predictions is the availability of inflight weather data (e. g. forecast for airport weather, atmospheric wind & temperature data, …), which allows the flight crew/dispatch department to optimize the lateral & vertical profile of the intended routing with reference to reduced fuel usage. The selection of the cruising flight level can be optimized based on most favourable wind components and temperature profiles (ISA deviations); as an example a cruising level 2000 ft below the optimum level can increase fuel consumption by approx. 1.5 t on a 10 hours flight depending on aircraft performance data. Wind/temperature data updates are currently available every 6 hours, which primarily affect long haul flights.
A second huge impact to sustainable & economic flight operation can be seen in the achievement of establishing

datalink services for an improved airspace usage and structure (e. g. CPDLC, North Atlantic High Level Airspace datalink requirements). Automatic 3d position data (in future 4d data), speed and routing information as well as pilot controller communication via datalink allow air traffic control to utilize reduced aircraft separation and optimized routings based on a more detailed situational awareness over air traffic flow in respective sectors [13] [14] [20].

As a third example the topic of inflight entertainment has started to change in recent years. The negative weight impact on fuel usage by inseat video hardware (e. g. monitors, wiring weight can be estimated with approximately 1.5kg per unit depending on configuration) and in addition the workload impact on maintenance (e.g. change broken units) shows more and more disadvantages compared to the utilization of the passenger's private portable electronic devices [9]. These have nowadays all some kind of WiFi, bluetooth connectivity, which can be utilized to stream entertainment contents or on board sales possibilities. Therefore there is a potential of weight reduction in this sector; as a general rule of thumb you can estimate 20-30 % of equipment weight one must provide as fuel weight to carry the respective equipment for one hour in cruise flight.

As an ever more important becoming aspect is the availability of maintenance relevant data (automatically) linked down to respective departments (e.g. system data like temperatures, pressures, flow rates, system cautions/warnings). These data are becoming more and more important in establishing predictive (preventive) maintenance with the goal of reduced hangar times and optimized system performance. As a side note to above topic the relatively new approach of establishing digital twins is mentioned, which are dependent on data input to optimize the capability of system performance prediction [15] [16].

3.4 Realtime Data for Ground Operations

In contrast to datalink applications during inflight operation (e.g. satcom, VHF/VDL), ground operations offer a higher variety of usable connectivity setups (e.g. WiFi, UMTS, LTE,…) within the airport environment. Advantages are usually lower costs and higher available data rates than inflight. This should impact the operator's decision to set up a priority of data transfer. Data not related directly to flight operations (e.g. fuel billing, crew duty times), can be exchanged on ground in a more economical way. This also supports the avoidance of the maximum data rate/bandwidth bottle neck in flight.

Within the airport environment typical (realtime) data handled are air traffic control & airport services related information like slot times, de-/anti icing sequences, ATC clearances etc. These information are usually communicated via cockpit interfaces, which are electronic flight bags nowadays or legacy ACARS MCDUs (mode control display units). These data have in common to optimize the aircraft ground handling flow and in a worst case scenario to keep aircraft on ground to avoid costly (related to fuel emissions/costs and flight delays) inflight delays like holding or delay routings. As an example related to emission avoidance for a typical wide body airliner, one hour of auxiliary power unit (APU) operation on ground (electricity & air conditioning) requires approximately 80-100 kg of fuel compared to ~ 4500 kg/h engine fuel consumption during inflight holding.

Another aspect of ground operations is the optimized handling of cargo and passengers by the use of online data exchange (e.g. electronic loadsheet, cargo loading information, dangerous goods handling, (de-)boarding times). Replacement of paper related processes, reduction of physical distances overcome by ground personnel, ad hoc replanning challenges etc. can be handled more efficiently by making the required information available to qualified personnel on the spot. E. g. for security reasons baggage will usually not be loaded as long as a passenger has not boarded, which on the other hand can avoid lengthy (delay producing) search processes for luggage of no-show passengers.

Another example are ad hoc airline revenues (like cargo, luggage, passengers), which can be loaded for improved aircraft cruise center of gravities (c. g.) by utilizing quick data exchange between ramp handling personnel and load sheet departments. Depending on the respective aircraft performance documentation, an aft c. g. shift of 1% for cruise flight can save some decimal percentage of fuel consumption per hour.

In a last area during ground operations the utilisation of connectivity on technical aircraft handling is briefly highlighted. The introduction of electronic technical log books (eTLB) allows the maintenance personnel to remotely document maintenance as well as technical servicing & repair (e.g. ramp/ETOPS checks, etc.). No exchange of hardcopies or other paper processes are required. Big amount of data can quickly be exchanged and analysed for system status & performance monitoring. Online software updates or resets are possible.

4. SUMMARY & LESSONS LEARNED

This chapter summarizes facts & experiences which are considered as most important driving factors for successfully implementing datalink structures and usage.

4.1. Experiences & Working Guidelines

To the project team it was of utmost importance, that effective working principles and guidelines were established *prior* launching the datalink implementation project. In retrospective the most important aspect to be called is the "Keep it simple" approach. Or to put it in other words "…make everything as simple as possible, but not simpler" [17]. One can achieve this by applying techniques like: Incremental Build Up, From Easy to Complex, prioritization and integrated test & validation procedures. Sometimes techniques/guideline do not appear simple at first. But their real value often shows up further down the project road or even later during update or troubleshooting processes during flight operation. One of these guidelines is the permanent, detailed documentation of system design, behaviour and root causes. As previously mentioned, detailed documentation keeps the knowhow within the organization and avoids "brain loss" in case individuals leave the organization. Repeating mistakes, generating Aircraft on Ground (AOG) times due to lack of documentation and therefore lack of knowhow is much more expensive than establishing documentation procedures from the beginning.

Another benefit was the fact, that we could keep the number of project members small. If you have one/two highly capable and knowledgeable members from each of the flight operations department (e. g. technical pilot), the avionics department (e. g. engineer) and IT department (datalink focus) you can keep chains of communications as well as decision finding straightforward. It is also assumed beneficial, if the amount of departments/persons you have to report to is kept at a minimum. Based on a lean project structure you can concentrate on the technically and operationally important aspects. Above expert can act as multiplicator to other involved departments as required.

4.2. Connectivity Benefit

Connectivity is and will be the basis of future data processing and analysis related to an efficient and sustainable airline flight operation. As previously already mentioned there are several main sectors in which you can categorize the use of data. The more or less endless stream of generated data in these sectors (e.g. flight safety, flight operation, ground handling), allows the operator to track and analyse the performance not only of a single aircraft but of all (sub) systems (e.g. engines, hydraulics, position, atmosphere) as well as other stakeholders which are participating in flight operation. Trend monitoring, statistical analysis, digital twins concept are only some of the already applied techniques to analyse data and feedback the results into a sustainable & efficient flight operation (see also circle of learning culture Figure 3).

4.3. Future Development

With modern highly connected aircraft in mind and with reference to the experience during the project one key element will be the interface to and capability of data processing applications. Modern aircraft like Airbus A350 or Boeing B787 generate several thousands of sensed data records per hour. It must be assured that these amount of data can be handled in an efficient way. For operators it is costly to introduce new IT departments with the required hard- and software as well as the specially trained manpower. On the other hand the OEMs of new modern aircraft offer customized products to handle aircraft data in real time (e. g. Airman Airbus, Gold Care by Boeing). The same aspects apply for other fields where generated data can be used in a beneficial way. These fields are but not limited to cargo & passenger handling, airspace management, on board sales, (predictive/preventive) maintenance.
Steady improvement of data sensing and processing by e. g. the application of Near Field Communication (NFC) technology, QR Codes, will increase the amount of available data. The benefit of these data can only be assured if the capability of analyzing hard- and software is equally developed and made available (see also Big Data Technology [18]). Therefore it is equally important for an operator to carefully judge the two possibilities of in house data processing (raw data handling) vs. by the OEM prepared raw data directly suitable for data analysis. In any case it should be avoided that the processing capability is the bottle neck of data analysis.
A last topic to be considered is the question about the proprietary claims of own data. Who (e. g. OEMs) is allowed to use own data for analyzing them?

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