The Essentials of

Datalink
Communications

The origins and course of Air-to-Ground Messaging

Contents

The **Technology** that **HR** Created

At one time in the not-so-distant past, pilots and other flight crew members were paid different rates for the time they were airborne versus the time they were performing ground operations. Events like aircraft pushback, taxi, takeoff, landing, and gate arrival were transmitted via voice over radio frequencies to operators who would relay this information back to the airlines. The pilots were responsible for self-reporting their own times and movements. Understanding that people can sometimes be forgetful, or worse, willfully manipulative, the major airlines began searching for a solution that tracked crewmember pay in a more structured and accurate way. Since time card machines weren't an option for the flight deck, they reached out to communication and engineering company ARINC for help with a solution.

ARINC's solution was an automated system, called the ARINC Communications Addressing and Reporting System, or ACARS for short, which sent short text data from the avionics of the aircraft directly to the ground-based entities through Very High Frequency (VHF) radio frequencies without any crewmember involvement. The aircraft was programmed to take advantage of switches and automation points on the aircraft, resulting in the creation of a set of messages referred to as the OOOI report. An OOOI report is any of four messages: Out, Off, On and In. Still in wide-scale use today, the OOOI report is any one of four messages generated by specific events on the aircraft.

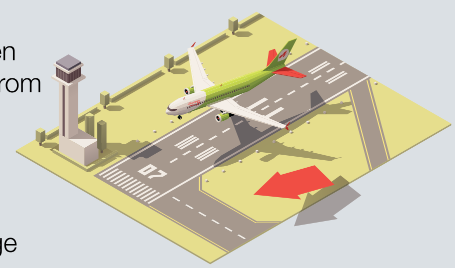
The events are:

Out:

The precise time when the aircraft is "pushed back" from the gate, or in other words, "out" of the gate, normally determined by discreet door sensors

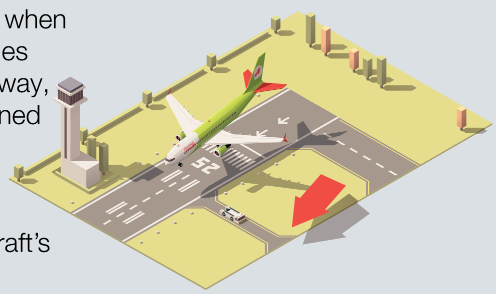
Off:

The precise time when the aircraft takes off from the runway, normally determined by a "weight on wheels" sensor built into the aircraft's undercarriage



On:

The precise time when the aircraft touches down on the runway, normally determined by the same "weight on wheels" sensor built into the aircraft's undercarriage



In:

The precise time when the aircraft arrives at the gate, normally determined by the same discreet door sensor used in the Out message

The concept of the OOOI message took hold quickly, and many of the airlines paid to have VHF ground stations installed at the busiest airports. Over the next few years, further applications were developed that took advantage of the ACARS protocol and other providers began to emerge with the ability to provide ACARS services, the most notable of which being the French company, SITA, a leading provider of international communication services for aviation.

Free-text messaging, flight plan uplinks, text weather, and position reports started to become commonplace. At some point after the initial launch, the acronym ACARS was officially changed to the Aircraft Communications Addressing and Reporting System, removing the reference to ARINC. The term ACARS remains in use, but most people in the aviation industry simply refer to it as "datalink."

The datalink system that was started to track crewmember hours for payroll purposes in the late 1970s continued to develop over the next 40 years, increasing its ability and service footprint. What was once limited to line-of-sight VHF towers at major airports, is now widely available in most locations.

This technical white paper will briefly review the evolution and fundamentals of datalink, the system that was truly created in response to a Human Resources problem, including its role in the modern-day flight operation and plans for its future.

Growing into an **Operational** Necessity

The OOOI message continues to this day to be one of the key features in the datalink service offering. However, shortly after the OOOI message was created, other message sets were developed to take advantage of this new static-free text transmission method. Flight crews and dispatch offices quickly became enamored with the ability to type out a message on a keypad or keyboard instead of trying to relay messages via voice on congested, noisy, and fatiguing voice radio transmissions. The new messages quickly improved accuracy, safety, and situational awareness.

The set of messages developed shortly after the OOOI messages became known as Airline Operational Control (AOC) and Airline Administrative Control (AAC) messages. AOC and AAC messages are unprotected, meaning they are not regulated by any operational authority other than to the extent necessary to comply with the technical specification for message creation. For example, the message formats themselves were designed to flow properly through the ACARS infrastructure, but the content of the messages is free-text or formatted text.

In addition to the OOOI reports, a number of AOC/AAC message sets were created and are still in use today, including the following examples:

- Incremental Position Reporting and Estimated Time of Arrival (ETA) Messages
- Text Weather (METARs/TAFs/NOTAMs/PIREPs)
- Graphical Weather Charts
- Pre-Departure Clearance (PDC) and Datalink Clearance (DCL) Messages
- Flight Plan Uplinks
- Oceanic Clearance Delivery (OCD)
- Terminal Weather Information for Pilots (TWIP)
- Digital Airport Terminal Information System (D-ATIS)
- Gate Notifications
- Fuel and Service Requests
- Free-Text Messages
- Maintenance Reporting
- Airframe Fatigue Reports
- Aircraft Engine and Health Reports
- Aircraft Weight-and-Balance Load Sheets and Trim Sheets
- Diversion Tracking
- Special Passenger Advice
- Other Fault and Abnormal System Status Reporting

Soon, Air Navigation Service Providers (ANSPs) and Air Traffic Control (ATC) facilities around the globe started seeing the benefit of voice-free communications. The accuracy and efficiency of AOC/AAC messages was needed in other critical messaging areas, like to issue clearances, diversions, position reporting, and other ATC functions. A new message set, called Air Traffic Control (ATC) or Air Traffic Services (ATS) messages was created. The most prominent example of ATS messages was coined under the term Future Air Navigation System (FANS). FANS messages are the current standard of safety of flight messages being transmitted over datalink.

FANS comes in many shapes and sizes, but the messages typically consist of two main components:

- Automatic Dependent Surveillance (ADS), which provides three-dimensional position data to ANSP and ATC agencies on the ground. ADS relays aircraft location, speed, and altitude and supplements traditional radio position reports and radar data. ADS technologies come in a few different “flavors,” but the datalink implementation is ADS-Contract (ADS-C), where the ATC host computer establishes a contract with the aircraft to report data at certain intervals
- Controller-Pilot Datalink Communications (CPDLC), which provides a two-way ATC communications between the flight crew and the ATC facility, reducing the use of traditional radiology. which is prone to error and lacks efficiency.

Unlike AOC and AAC messages, ATS messages are protected and therefore cannot be altered. All messages are built on approved templates that use standard text and nomenclature, and with ATS messages, no free-text messaging is available. If your request cannot be accomplished using the library of available requests or responses, you must revert to voice communications.

Figure 1:
Sample ATC Communications using Protected ATS Datalink.

In this example, the crew requests a climb to FL430, and is told to "standby" momentarily, then granted permission to climb to FL430. The crew reports leaving their current altitude (FL410) and when they are level at the new altitude (FL430).

Figure 2:
Sample Message using Unprotected AOC Free-Text.

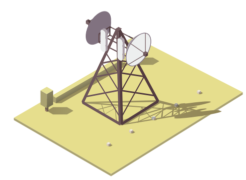
In this example, the crew has received a free-text message from their service provider, who is updating them on their handling arrangements and transportation.

Communications Mechanisms (**Networks**)

Datalink messages can be transmitted via four distinct networks. The first two, Very High Frequency (VHF) and High Frequency (HF), are ground-based radio mechanisms. The second two, Inmarsat and Iridium, are satellite-based technologies.

Most business jets are configured in such a way that the aircraft tries to communicate over VHF radio first, as it is the least expensive option, and if a VHF connection cannot be established, the aircraft will switch over and attempt to send the message over satellite. Even though aircraft can have both Inmarsat and Iridium antennas, which support a number of different functions, the aircraft can only be configured for one of the two satellite networks for datalink purposes. Business aircraft are typically not configured for HF datalink, because most have satellite connectivity and because HF datalink is very expensive.

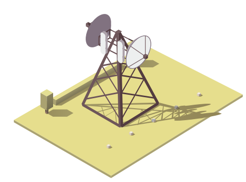
Ground-Based Mechanism #1



VHF

Connection Type: Line of sight very high-frequency radio transmissions
Usable Range: Up to 220 nautical miles
Service Area: Typically near airports and other highly traveled regions
Speed of Data: 2.4 - 31.5 kbps
Relative Cost: Lowest

Ground-Based Mechanism #2

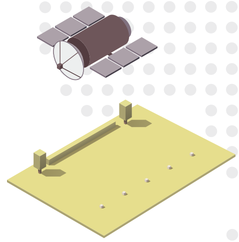


HF

Connection Type: Line of sight high-frequency radio transmissions
Usable Range: Up to thousands of nautical miles (due to ionosphere reflection)
Service Area: Typically over large bodies of water or vast rural terrain
Speed of Data: 1800 baud
Relative Cost: Highest

Satellite-Based Mechanism #1

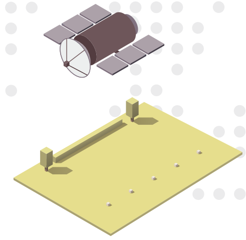
Inmarsat



Connection Type: L-Band satellite waves to/from inmarsat's geostationary satellite fleet
Usable Range: Up to thousands of nautical miles as long as the aircraft has an unobstructed view of the sky
Service Area: Worldwide between 83 degrees north and 83 degrees south latitude
Speed of Data: 4.8 - 10.5 kbps
Relative Cost: High

Satellite-Based Mechanism #2

Iridium



Connection Type: L-Band and K_a-band satellite waves to/from iridium's geosynchronous satellite fleet
Usable Range: Up to thousands of nautical miles as long as the aircraft has an unobstructed view of the sky
Service Area: Worldwide, including the polar regions
Speed of Data: 2.4 kbps
Relative Cost: Moderate

Since HF Datalink (HFDL) equipment is typically not installed on general aviation aircraft, we will omit any further discussion about that technology from this white paper. We are then left with some capable datalink transmission options for the business aviation fleet:

1. **VHF Radio**
2. **Inmarsat Satellite**
3. **Iridium Satellite**

1. VHF Radio

Datalink over VHF radio is still the most common transmission method, in part because of familiarity and aircraft equipage but also because of the low cost of entry for the equipment, its vast governmental and operational approvals, and its relatively low operational costs.

After VHF datalink was originally implemented in 1978, it continued to grow in popularity, and most production aircraft began receiving a dedicated radio to serve as the transmission mechanism for data-only ACARS communications. These analog messages operated on the VHF spectrum between 129-137 mHz, at a speed of approximately 2.4 kbps. Within two decades of its launch, the network began to reach its capacity in certain geographic regions due to limited VHF frequency availability.

A newer, faster, more efficient network protocol needed to be defined. This new network was also to use VHF radio waves as its transmission mechanism, but it was built to be more spectrally efficient and to meet the requirements for the delivery of Air Traffic Services (ATS) messages. The governing body of the International Civil Aviation Organization (ICAO) defined the specifications of this new technology in the ICAO Standards and Recommended Practices (SARPs), naming it the Aeronautical Telecommunication Network (ATN). More than anything else, ATN defines the applications and the protocols for the delivery of ATS messages.

ATN demanded more efficiency than what was then available for via analog VHF communications. To meet this demand for spectral efficiency, the VHF datalink providers created a new, bit-oriented air/ground VHF communication sub-network to improve datalink speeds, accuracy, and performance. This new digital network became known as VHF Digital Link (VDL). It boasted speeds up to 15 times faster than traditional analog ACARS and had a much greater band of frequencies available for communication. The datalink service providers began updating their ground equipment to support this newly improved VHF datalink protocol.

VDL has become the flagship due to its superior technology, but the traditional analog VHF datalink still exists today and is widely used across the globe, especially in areas void of VDL ground stations. Analog VHF datalink operates with the service name POA, an abbreviation for “Plain Old ACARS.”

2. Inmarsat Satellite

The aviation sector soon started to require connectivity in more distant places, and the installation of VHF ground stations did not keep up with the demand. High-Frequency Datalink (HFDL) existed, but the link speed was slow, the reception and clarity of the signal was prone to errors, and the service could be prohibitively expensive. Aircraft manufacturers started to take note of how their counterparts in the maritime world kept their ships in communication while at sea, effectively operating in large, unmanaged swaths of unpopulated Earth. The shipping industry had started to outfit their vessels with satellite equipment, which gave them the ability to make communication with a number of satellites recently launched by a non-profit intergovernmental organization known as the International Maritime Satellite Organization, or INMARSAT. The group had recently launched a number of geostationary satellites into low-earth orbit at 22,236 miles (35,786 km) above the Earth’s surface in an effort to improve communications in unpopulated and rural areas, as well as improve aeronautical safety. (In the mid-1990s, many nation states that were part of the INMARSAT steering committee refused to invest in improvements and modernizations of the satellite fleet, which ultimately led to the privatization of the company.)

Inmarsat began offering their spectrum to the aviation community under trade names like Aero C, Aero H, Aero H+, and Aero I (all of which later became known as Classic Aero Services). They continued to evolve these technologies over the years, reaching a maximum link speed of 10.5 kbps, which was sufficient to send Short Burst Data (SBD) messages to and from the ground. Once the industry began to openly accept Inmarsat equipment and the adoption rate was climbing, Inmarsat made sure its network was capable of carrying the most important datalink message types – those relating to the safety of the flight – thus, earning itself the esteemed honor of being the first satellite provider certified to transmit said messages without using traditional radio spectrum.

Inmarsat continually grew its satellite constellation over the years, improving bandwidth and performance. Today, Inmarsat operates 11 satellites in low-earth geostationary orbit (they are fixed above a reference point on the globe and do not move). Most of their older satellites operate on the L-band spectrum, but their newest satellites, the Inmarsat-5 (I-5) constellation, operates on the more efficient and speedy K_a-band.

3. Iridium Satellite

In the 1990s, the Motorola Corporation was the principal financial backer of what was thought would be the “next big thing” in the telephone marketplace: satellite telephone services. Specifically, communications via the Iridium satellite constellation, a network then comprised of 66 geo-synchronous satellites operating at an altitude of approximately 483 miles above the Earth’s surface and moving quickly in defined parabolas at the speed of approximately 16,689 miles per hour (26,858 kilometers per hour), making a complete orbit of the planet every 100 minutes.

Iridium was touted as the first global communications network. As long as you had access to the sky, you had connectivity. The selling point of truly global connectivity was also the problem: you had to be outside to make or receive a telephone call. On top of that, the devices were large, clunky, expensive, and not user-friendly. Ultimately, the “next big thing” ended up being decommissioned and ultimately filing for U.S. bankruptcy protection.

Shortly thereafter, a private equity group purchased the company and revived its operations. The company shifted its focus from the end consumer to different markets, including the maritime and aeronautical sectors, and gained success quickly. Soon thereafter, a group of engineers patented the ability to send Short Burst Data (SBD) messages via the Iridium satellite network at a link speed of 2.4 kbps, providing an alternative satellite network that could be used to send and receive datalink messages. Iridium’s popularity soared in the aviation sector, namely because of its low cost of entry into the equipment market, true global coverage, and its usage fees being less than its Inmarsat counterparts.

Like with Inmarsat, aircraft manufacturers began installing Iridium satellite equipment on aircraft, and since Iridium is SIM card based and easily expandable, people began provisioning one channel (SIM card) for voice and dedicating a second channel (SIM card) for datalink communications. In July 2011, the Federal Aviation Administration (FAA) of the United States certified Iridium for use in certain safety of flight communications, including emerging Future Air Navigation System (FANS) technologies.

So, Iridium is cheaper and has a better coverage area. Why would we even consider choosing an Inmarsat solution?

While it is true that Iridium is an excellent low-cost alternative to traditional Inmarsat service offerings, there are still a number of factors that could influence your decision. A few questions should be asked when contemplating Iridium vs. Inmarsat, including the below:

1. What equipment does your aircraft have? If you don’t have Iridium equipment, you must be willing to add or change the hardware onboard, which could come at a significant cost.
2. Does your aircraft have an internet connection? Iridium only supports Short Burst Data (small packets of text), and will not support internet connectivity.
3. Does your Iridium transceiver support more than one SIM card? If it does, you can dedicate one to data-only transmissions and link it to the datalink system; if it doesn’t, you will have to choose if you are willing to give up your voice/ fax connection in order to use the single channel for datalink.
4. Do you use any datalink applications that are not yet approved for use over Iridium connections? Does your Iridium setup provide you with all the necessary safety of flight requirements?

Again, there is no right or wrong answer to these questions. Selection of equipment is an important part of future-proofing your aircraft and your investment. Technologies will continue to evolve; it is important to pick the right one for you and your operation.

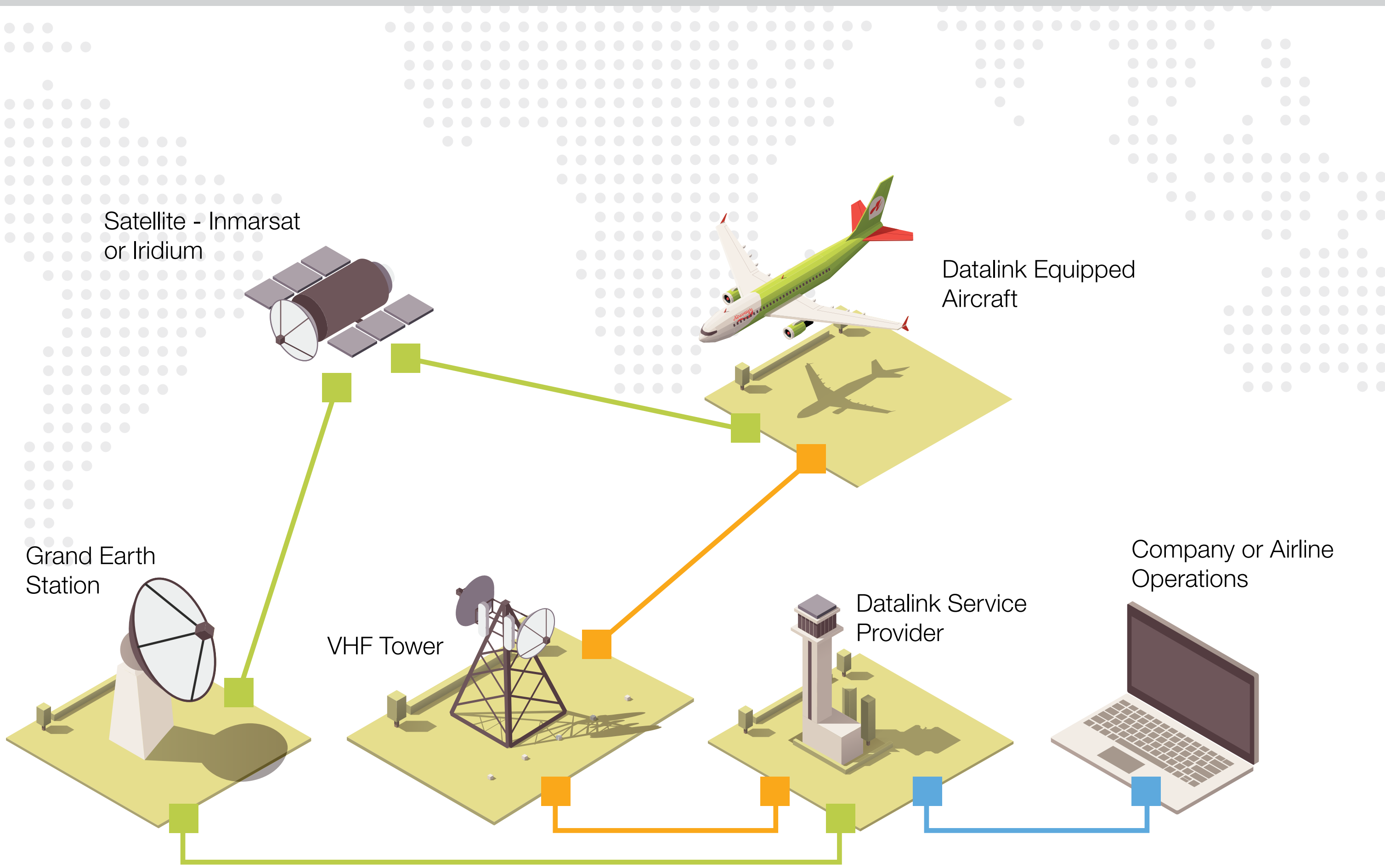


Figure 3:
Diagram showing datalink communications.

I have an Iridium connection dedicated solely for datalink communications. It's worldwide and I don't notice a speed difference between VHF and Iridium. Why do I need the VHF connection?

You might not. In the early days of satellite communications, the price was the main factor for not making the satellite the preferred service. However, as satellite connectivity prices continue to drop (sometimes at near parity with their VHF counterparts), service providers are beginning to offer a number of satellite-only options. The aircraft can be configured to prioritize satellite over VHF (and vice versa), or it can easily be told not to attempt the VHF connection whatsoever.

However, there is one main drawback to eliminating the VHF connection; aircraft will be unable to participate in many ATN Future Air Navigation System (FANS) initiatives, due to the fact that a VDL connection is a requirement for many airspaces and implementation zones. For example, any aircraft that is configured in a satellite-only manner will not be allowed to operate over FL285 in Europe beginning in 2020.

Therefore, selecting Iridium as a primary (or singular) communication network, is indeed a viable option; but you need to weigh all of the pros and cons of that action before you make the transition. The good news is that if you ever want to switch back to VHF or a medley of VHF and satellite, it typically only requires a few minutes' worth of work to reconfigure the priorities in the aircraft's datalink system.

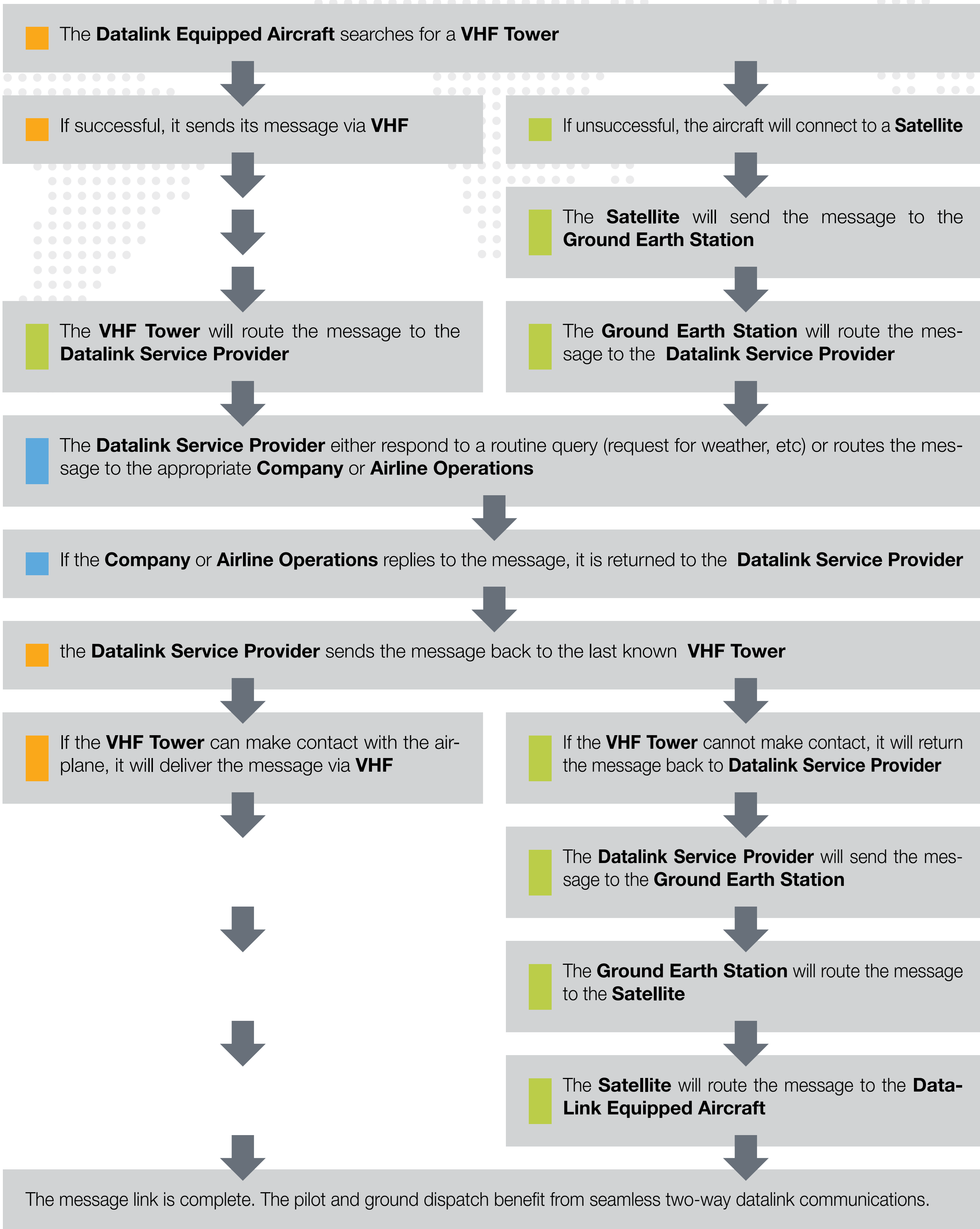


Figure 4:
A flowchart of datalink communications.

Upcoming **Regulations**

Due to the operational benefits in terms of efficiency and safety, datalink has moved from a nice-to-have technology to a required piece of equipment in many airspaces around the globe. Datalink initiatives will enable true performance-based separation minimums and improve the efficiency of air traffic management operations. This in turn will provide more efficient routings in terms of time and fuel and lowering the overall cost of navigation and surveillance services. For operators to continue operating in preferred airspaces at optimal levels, their aircraft will need to be fitted with the prerequisite equipment, and certain approvals and certifications will need to be obtained.

Here are some of the most common datalink mandates in effect today, as well as those scheduled for the future:

FEBRUARY 2013

North Atlantic Track System (NATS) – Partial Implementation
To fly the most optimal center tracks in NATS airspace between FL360 and FL390, the aircraft must be FANS-equipped.

FEBRUARY 2015

North Atlantic Track System (NATS) – 2A
To fly any of the tracks in NATS airspace between FL360 and FL390, the aircraft must be FANS-equipped.

DECEMBER 2017

North Atlantic Track System (NATS) – 2B
To fly in any of the North Atlantic Region between FL350 and FL390, the aircraft must be FANS-equipped.

JANUARY 2020

North Atlantic Track System (NATS) – 2C
To fly in any Minimum Navigation Performance Specification (MNPS) airspace throughout the entire North Atlantic Airspace at FL290 or above, the aircraft must be FANS-equipped.

FEBRUARY 2020

Link 2000+ (Single European Skies or SES)
To fly in Eurocontrol airspace (Europe) above FL285, aircraft must be FANS-equipped, specifically using "Protected Mode" Controller Pilot Data Link Communication (PM-CPDLC), which is ATN datalink using a VDL connection.

Many other nations and airspaces have FANS mandates in place as well, including certain high-traffic airways in China and Asia. The best way to determine compliance with datalink mandates is to talk to your maintenance facility, your service provider, your local regulatory authorities, and your flight planning team.

Strange Side Effect of Regulations: ATN Only Avionics

With the compliance clock for datalink equipage continuously counting down, some aircraft and avionics manufacturers have decided that the most direct route toward compliance is to build equipment that only supports the required datalink message sets. Some manufacturers are now producing ATN-only avionics, leaving out the AOC and Airline Administrative Communication (AAC) message types. A customer can purchase an aircraft that complies with all FANS mandates, including Automatic Dependent Surveillance – Contract (ADS-C) for position and CPDLC for voiceless ATC communications but not have the ability to send or receive any free-text messages, uplink a flight plan, or obtain weather.

This trend will likely continue as in-flight connectivity continues to be on the rise, with more aircraft being outfitted with internet connectivity at speeds hundreds of times faster than the low-link speed of traditional ACARS. Many feel that if their aircraft has an internet connection, they can get better and more detailed information from their mobile device than from their datalink service provider.

It is true that in a connected environment, superior products and services are available on the internet. Why send a short burst data message with limited characters when you can send an email, text, or WhatsApp message? Why rely on limited graphical weather capabilities when you can get animated, high-definition graphics on your phone, tablet, or computer?

However, what do you do when you don't have an internet connection? What happens if you do not have a satellite phone on board? Would you be comfortable not having the ability to send a free-text message to the ground asking about weather conditions or arrival information? How about not having the ability to uplink the flight plan directly to the FMS?

There is no right or wrong answer for this, as each operator is different. However, if you are faced with the decision of ATN-only avionics in the future, it is well worth discussion and analysis.

The Future of **ACARS**

As onboard technologies continue to expand and satellite connectivity prices continue to drop, more aircraft will be equipped with advanced communications equipment, specifically items that provide in-flight internet access. ACARS in its traditional sense is held back by the relatively low speed of the data connection. Even the "fastest" connection, VDL, tops out at a maximum throughput of 31.5 kbps, which is roughly half the speed of dial-up modem from the early 1990s.

The next step in the datalink evolution will most likely take advantage of Transmission Control Protocol (TCP) and Internet Protocol (IP), collectively TCP/IP methodologies, effectively changing the delivery mechanism from outdated text packets to rich, expandable content delivered via the internet and onboard WiFi systems.

This functionality, becoming known as ACARS-over-IP, is currently in development with the major datalink service providers and avionics manufacturers. One of the earliest examples of ACARS-over-IP is the mechanism used to convert flight deck information into Short Burst Data packets, which are transmitted over the Iridium network, as described earlier in this document.

In 2015, Hawaiian Airlines became the first commercial carrier to operate flights using ACARS-over-IP technology. Their aircraft were configured to translate data from the avionics to TCP/IP packets, which were shipped over Inmarsat's high-speed network.

ACARS-over-IP technologies have many superior benefits as compared to their predecessors, with link speed being the primary advantage. IP connections to the aircraft are expected to reach 15 Mbps within the next year or so, which will yield an exponentially high increase in the Kbps rate for both POA ACARS and Inmarsat's Classic Aero connections.

Additionally, one of the main advantages is offering a great deal more flexibility and convenience by hosting ACARS and ACARS-like applications on smart phones, tablets, and laptops aboard the aircraft, instead of on small, restrictive avionics boxes and screens.

However, on the other side, one of the major concerns of ACARS-over-IP is the security threat. Today, ACARS messages are transmitted completely independent of any IP pathways. They are segregated communications tunnels, with no overlap. With ACARS-over-IP, you run the risk of infecting the ACARS network with malicious code, viruses, or dedicated attacks, since the ACARS unit is passing operational messages on the same WiFi network on which the passengers are surfing the internet. Datalink service providers and avionics manufacturers are being very careful about exposing critical flight networks to open internet traffic.

One thing is clear: the need for datalink connectivity in the aircraft is on the rise. ACARS equipage has grown exponentially since the technologies were introduced nearly 40 years ago and is currently installed on 18,000-plus aircraft that send an average combined total of 40-45 million datalink messages per day. Compounded with the fact that datalink use is now being mandated around the globe, it is more important than ever to make sure your aircraft is equipped, and your crews are properly trained to take advantage of the technology that Human Resources created two generations ago.

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