WHITE PAPER

THE LDACS AIR-GROUND DATALINK

An essential pillar for the digital transformation of Air Traffic Management

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Content

1 Executive Summary

The aviation sector is currently facing significant challenges, including coping with predicted increases in global air traffic and achieving ambitious sustainability targets in terms of emissions reductions. To succeed, organisations require a diversified strategy where one of the central goals is improvement of overall operational efficiency.

As a major efficiency enabler, the digital transformation of air traffic management (ATM) is the foundation for sustainable growth of aviation. In this evolving process, air-ground connectivity represents a significant bottleneck that can be resolved using high-rate datalinks as proposed in the European ATM Master Plan.

According to the plan, future air-ground connectivity architecture should be based on a multilink approach, where different types of technologies are used to address different modes of operation and to overcome datalink coverage and capacity limitations in specific areas.

These technologies must provide additional bandwidth and also deliver high operational performance. Moreover, the new datalinks must fit into the evolving roadmap for aviation data infrastructure, which includes Internet Protocol Service (IPS), plus support for instance traffic separation capability and security features.

LDACS (L-band Digital Aeronautical Communication System) is a high-throughput terrestrial datalink operating in the L-band that has been developed and validated through several years of joint effort from industry, ANSPs, and research organisations within SESAR and other national projects. Following intensive verification campaigns, which include flight trial sessions and compatibility tests with other avionic systems, LDACS is currently being recognised by ICAO and under standardisation by EUROCAE.

LDACS is now close to entering the operational deployment phase, where the benefits of its scalable, distributed and fully open technology will be visible at an early stage with its to integration with the current ATN/OSI infrastructure, acting as VDLm2 ‘booster’.

While meeting the operational safety requirements for ATM communications, LDACS also provides global interoperability and ensures sovereignty of ground infrastructure for increased control of airspace.

Thanks to the intrinsic characteristics of terrestrial, distributed architectures, LDACS provides a high level of resilience to potential intentional service disruptions and simplifies the deployment of the LDACS technology both on the ground side, where existing VHF radio stations can be reused with much less effort, as well as on the airborne side, where the installation in the aircraft can share antennas and cabling with existing VHF equipment.

As soon as steps to achieve the necessary technological maturity are concluded, deployment activities can start. These includes several validation activities that are currently being performed in the framework of the SESAR Program. A significant acceleration of the LDACS implementation process can be achieved with the support of incentive schemes, partially relieving ANSPs, airlines, CSPs and industry from the burden of initial investments, thus leading to an early gathering of the benefits of the new technology.

Similar scenarios, such as the introduction of CPDLC/ATN using VDLm2, tell us it is beneficial to first undertake the deployment on the ground and then on aircrafts. One of the key benefits of this strategy is that once the airlines get their aircraft equipped with the new technology, the ANSPs, the CSPs and the ground infrastructure is ready to provide the new service.

Additionally, since LDACS is a terrestrial distributed system, it is worth considering a gradual deployment, addressing first areas or regions with high-traffic congestion, enabling significant benefit at an early stage.

In conclusion, LDACS represents an essential pillar supporting the digital transition of aeronautical communications, and is ready to play a main role in the FCI multilink infrastructure in continental airspaces, which is essential to cope with the predicted traffic growth and to achieve of carbon-neutrality targets.

2 Scope

The whitepaper aims to provide an overview of the digital transformation that the aviation sector is currently facing and the supporting CNS technologies that are required. In the context of air-ground connectivity, the terrestrial-based LDACS technology represents one of the most promising and realistic options to support this modernisation process.

This document firstly presents LDACS technology, mainly focusing on the advanced level of maturity already achieved, on the supported services and on its major benefits for main airspace users.

Next, ANSPs, airlines and CSPs, who will be the main beneficiaries of the introduction of new CNS technologies, will highlight and explain the importance of LDACS and the role this terrestrial technology will have to play in supporting the introduction of new operational procedures.

The crucial aspect of the LDACS roll-out and deployment is then addressed, presenting various possible implementation options.

The whitepaper also provides an overview of cost and business models related to the introduction of LDACS, relying on data collected from available publications.

3 Evolution of Air Traffic Management

European aviation is targeting carbon-neutrality by 2050, with the EU proposing an intermediate target of a 55% reduction by 2030 compared to 1990 levels. ATM will be a key enabling factor in this initiative, with a drive to migrate to ever more data-driven and automated operations, supported by a modernization of technologies such as CNS. This will underpin the implementation of the Single European Sky, which is the baseline framework to achieve this target.

At the same time, ANSPs need to increase airspace capacity. European airports will be unable to accommodate approximately 1.5 million flights in 2040, which is equivalent to around 160 million passengers unable to fly, according to Eurocontrol's figures in 2018 (1). The Airspace Architecture Study suggests addressing the airspace capacity challenge in the medium- to long-term by combining airspace configuration and design with modernised technologies, decoupling service provision from local infrastructure, and progressively increasing collaboration and automation support. The SESAR ATM Master Plan also aims to develop and industrialise such technologies and future concepts, as well as to enhance collaboration between stakeholders, including across state borders and with aircraft, implementing initial system-wide information management (SWIM), and introducing network capacity and demand balancing measures.

Future airspace designs must be optimised for current and future network flows, making use of higher levels of automation and common ATM data services. This will ensure more efficient use of resources when responding to disruptions and peaks in demand, enabling greater flexibility and resilience. The introduction of service-oriented architectures, such as virtual centres, will enable dynamic and shared management of airspace and remote provision of ATS, meaning that sectors can be modified based on demand and airspace available, increasing capacity and, even more importantly, making efficiency a cornerstone for the implementation of Single European Sky.

Moreover, flight-centric operations will also ensure that ATS methods gradually evolve from the management of sectors to the management of the trajectory of flights across a larger portion of airspace, thus enabling flexibility and overall, increasing capacity. Air traffic flow and capacity management (ATFCM) will evolve to enable the management of complete traffic flows in the network in a more collaborative and dynamic manner.

3.1 FCI overview

To achieve the strategic vision described above, the key enabler is to exploit digital data exchange throughout the ATM network including air to ground exchanges between ANSPs and airspace users, both routine and automated, as well as on-demand. The performance of such platforms therefore needs to be guaranteed such that the timeliness and capacity of the links is assured whenever they are needed, and under the conditions of increasing data demand.

This is the role of the Future Communications Infrastructure (FCI) concept, within which LDACS is a foundational pillar. LDACS is the preferred terrestrial infrastructure to provide high-capacity connectivity to aircraft within Terminal Manoeuvring Areas (TMA) and enroute airspace. This is illustrated in the figure below

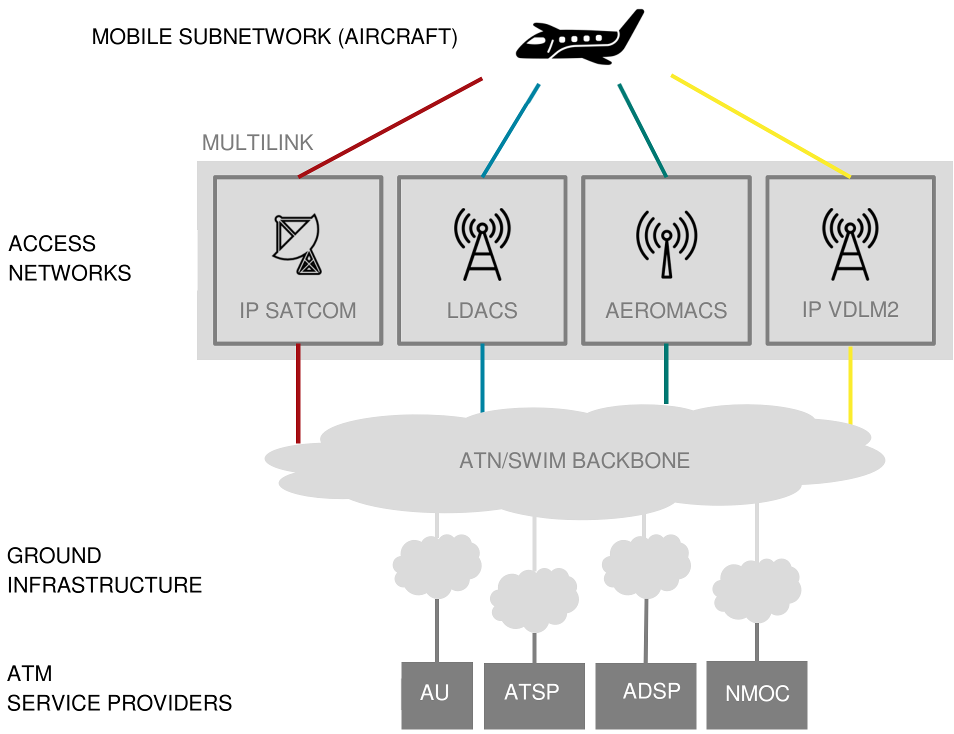


Figure 1 - Network topology of the FCI.

LDACS will carry the bulk of the ATC exchanges, with COTS technologies like Hyperconnected ATM providing offload capability at airport surface level, and SATCOM providing offload capability for all flight phases and connectivity in airspaces with no or limited ground infrastructure (e.g. oceans, deserts, large rural areas). It is therefore critical that LDACS be planned and implemented in a timely manner in order to be available as both ATC and non-ATC data demand continues to rise.

4 LDACS

4.1 Technology

The L-band Digital Aeronautical Communications System (LDACS) is a broadband and secure terrestrial data communications system for aviation, specifically designed by SESAR to meet the stringent requirements of air-ground communications for Air Traffic Control.

Operating in the aeronautical L-band (960 to 1164 MHz), LDACS is based on a cellular-like architecture that supports data throughput between 500kbps and 2.6mbps - nearly 200 times greater than existing capacity provided by VDL Mode 2 networks.

LDACS is based on the highly flexible, scalable multi-carrier technology OFDM (Orthogonal Frequency-Division Multiplexing) occupying a bandwidth of approximately 500 kHz per channel. Using an adaptive coding and modulation scheme covering QPSK up to 64-QAM, LDACS is highly spectrum-efficient and extremely immune from noise and interference induced bit errors.

The cellular approach for the LDACS ground infrastructure avoids co-channel interference problems as experienced during VDL Mode 2 data link deployment. Moreover, the use of a coordinated multiple-access scheme ensures a collision-free channel access with guaranteed low latency.

LDACS supports secure transmissions through built-in cyber-security means. It provides mutual entity authentication, it protects the confidentiality, integrity, and authenticity of messages, and it ensures availability and continuity of service.

LDACS offers the potential for extension towards a fully integrated CNS system. In fact, besides communications, it can offer both navigation and surveillance functionality as back-up service to legacy navigation and surveillance systems.

LDACS terrestrial aeronautical air-to-ground radio system enables IP-based data and voice communication between the cockpit and the ground. IP-based (IPv6) data and voice communication has been adopted as the standard by ICAO, EUROCAE and AEEC, with plans for it to be the basis for future air-to-ground data communication. It will provide efficient, secure, and high-bandwidth communication capability (voice and data), with embedded navigation capability standardised by ICAO.

LDACS offers improved communications performance to overcome the deficiencies of current aeronautical communications systems. It provides:

- Data link connectivity as well as digital voice
- High-rate data communications with at least 550 kbit/s up to 2.6 Mbit/s
- Low-latency transmission through coordinated channel access
- Simultaneous traffic management of ATS and AOC services ensuring immediate access for safety-critical services through service priority management.

4.2 Benefits of LDACS

The LDACS technology with its above highlighted characteristics and features provides several important benefits for all airspace users.

Open framework

- **Fosters market competition**: Users can select different data service providers without the need to change the avionic bay and avoiding the costs of recertification of the aircraft.
- **Ensures global interoperability**: LDACS infrastructure can be deployed in any part of the world without any regional difference or limitation.
- **Minimise equipment required in the avionic bay**: LDACS requires a single airborne device to communicate with any service provider in any region of the globe. This avoids proliferation of multiple equipment in the aircraft.

Distributed terrestrial, cellular architecture

- **Robustness**: as a distributed system with no central single point of failure, LDACS ensures high resilience to failures or to intentional local interference.
- **Scalability**: ground infrastructure can grow on demand to meet increased traffic demand with the simple installation of additional ground devices at existing stations where necessary. In high-density areas containing multiple airports and numerous aircraft, LDACS cells can be reduced in size to optimise performance.
- **Sovereignty**: each country or region can have full control of its critical ground infrastructure for the control of its national airspace.
- **Efficient reuse of ground infrastructure**: existing VHF ground station locations can be reused to install LDACS ground stations. This protects large investments in building and energy infrastructure, as well as avoiding the considerable time and expense involved in finding and developing new sites. As LDACS operates in a different frequency band to existing radio infrastructure, it can be deployed at existing radio sites without the risk of interference.
- **Ease of deployment in the avionic bay**: the installation in the aircraft can share antennas and cabling with existing VHF equipment.
- **Ease of maintenance**: users can take advantage of coverage from neighbour sites during repairs, reducing downtime.

Performance

- **Support of ATS/B2 services**
- **Support of future ATS/B3 services**: Exceeds RCP130 requirements by far and with provision to fulfil future RCP (for instance RCP60 is currently under development), LDACS provides sufficient performance margins to support future services (ATS/B3) including full 4D trajectory-based operations (TBO) and flight-centric ATM.
- **High throughput**: LDACS provides data throughput up to 2.6 Mbps—up to 200 times higher than the throughput of the current system.
- **High continuity of service:** LDACS is a datalink exclusively dedicated to aeronautical communications, ensuring a guaranteed bandwidth.
- **Low latency**: due to the intrinsic characteristics of terrestrial-based infrastructure, LDACS achieves latency below 100ms, making it suitable for safety-critical real-time applications for ATC operations.
- **Data traffic prioritisation**: LDACS technology can manage different categories of data traffic and assign different Quality of Services. This enables effective traffic prioritisation for ATC and AOC

services, allowing users to reliably transfer large amounts of essential operational data (such as engine and maintenance data, graphical weather information) without delaying time-sensitive ATC data traffic.

- **Integration of CNS**: thanks to a significant increase in bandwidth, LDACS can provide additional features such as navigation and surveillance data to aircraft, thus offering the potential for a fully integrated CNS system.
- **Data security**: LDACS uses a dedicated Public Key Infrastructure with end-entity certificates to grant access to trusted users only via a secure mechanism. A chain of trust enables secure transmission of voice and data communications, ensuring the highest degree of protection to avoid any service disruption.
- **Flexibility**: The LDACS technology can support both the integration into the existing ATN/OSI network, to overcome VDL Mode2 criticalities in the short term, and IPS-based FCI multilink architecture in the future.

4.3 LDACS roadmap

4.3.1 Development and validations

The L-band Digital Aeronautical Communication System (LDACS) has reached a significant level of maturity, as evidenced by its extensive specification, verification, and successful application in various scenarios. This chapter delves into the key aspects that demonstrate the maturity of LDACS.

LDACS has been extensively specified and verified in multiple national and international research projects (SESAR, Cleansky), involving leading aviation stakeholders from industry, academia, and regulatory bodies. These projects have played an important role in refining the system and ensuring that LDACS meets the highest standards of performance, reliability, and cyber-security, making it a robust solution for aeronautical communication.

The usability and applicability of LDACS have been demonstrated in two flight trial sessions, where it successfully supported various ATM applications such as 4D trajectory management, CPDLC and flight plan exchange. These trials have provided valuable insights into the system's operation in real-world scenarios and have confirmed its readiness for deployment in the aviation industry.

LDACS maturity is progressing fast and is nearing readiness for deployment. Several manufacturers have developed LDACS-compatible airborne and ground radio prototypes that should be easily integrated into existing and future aircraft and ATM infrastructure.

LDACS has been designed to coexist with legacy L-band systems such as DME, MODE-S, MODE-C, ADS-B, and TCAS. Several measurement campaigns have already been conducted to prove this compatibility, demonstrating that LDACS can be integrated together with existing technologies in aircraft as long as it is appropriately decoupled and has the characteristic duty cycle.

LDACS is not only a standalone communication system, but also a key enabler for the future Internet Protocol Suite (IPS) infrastructure that will support seamless and secure multilink connectivity for ATM. LDACS solutions have been integrated into the IPS architecture in several projects and the multilink functionality has been tested and validated.

The International Civil Aviation Organization (ICAO) and EUROCAE have been working on aviation standards for LDACS for several years. These ongoing standardisation efforts underscore the system's maturity and its acceptance as the future standard for aeronautical communication.

The maturity of LDACS is reflected in its thorough specification and verification, successful flight trials, availability of compatible prototypes, compatibility with legacy systems, integration into future infrastructures, and ongoing standardisation efforts. As the aviation industry moves towards more advanced, reliable, cyber-secure and efficient communication systems, LDACS stands out as the robust and future-proof ground-based data link solution.

4.3.2 Standardisation

LDACS is currently under standardisation within ICAO. The standardisation process started in October 2016 with the establishment of the ICAO Project Team Terrestrial Data Link (PT-T) under the ICAO Communications Panel (CP). LDACS draft SARPs and guidance material has been developed since then. Based on this, the LDACS Proposal for Amendment (PfA) for Annex 10 Vol III has been prepared and it is expected that it will be endorsed by CP in June 2024. The endorsement will trigger the start of the formal LDACS standardisation process. As the formal ICAO standardisation process takes a considerable amount of time, the LDACS PfA is foreseen to become effective in 2027.

In parallel, standardisation within EUROCAE was initiated in early 2022. EUROCAE WG-82 is currently working on the development of MASPS (Minimum Aviation System Performance Standards) and MOPS (Minimum Operational Performance Specification) to assist with LDACS standardisation.

Within the European SESAR 3 Project, which started in 2023, LDACS has been further matured. In particular, the LDACS avionics architecture has been defined, enabling integration of LDACS into aircraft avionics. Avionics architecture should be available by end of 2024 and is expected to be submitted to the AEEC (Airlines Electronic Engineering Committee), which will initiate standardisation of onboard integration of LDACS.

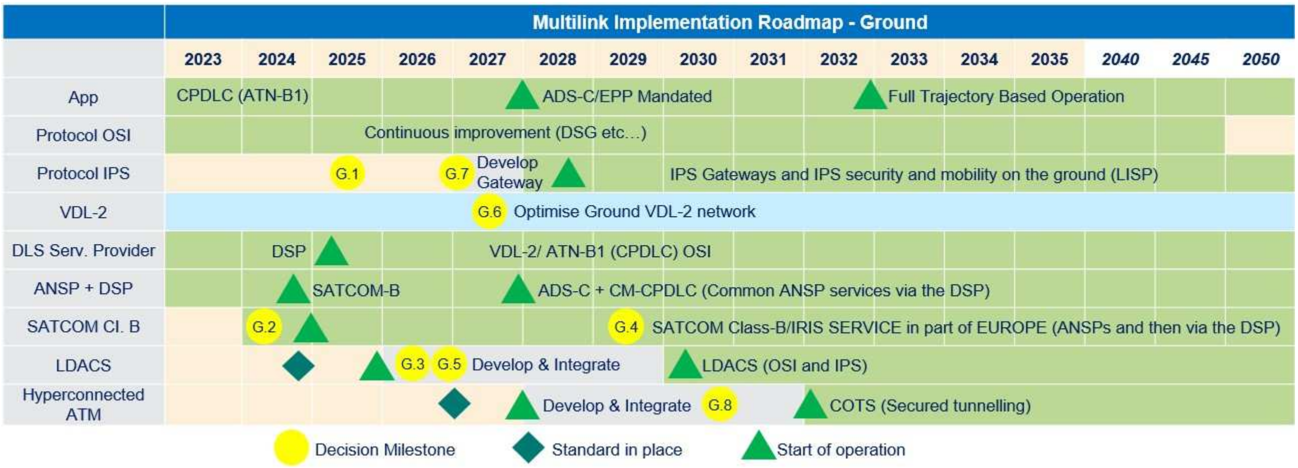
4.3.3 LDACS within the FCI roadmap

The SDM released the Multilink Implementation and Air / Ground Application (ADS-C/EPP) Roadmap 2023 in July 2023. This document aimed to develop a complete roadmap for the development and implementation of a European datalink infrastructure meeting performance needs for Air Traffic Services (ATS) and Airline Operational Control (AOC) Services from the present day until 2035, considering the perspective and the needs of future services or functionalities, such as, Trajectory Based Operations (TBO).

At the time this roadmap was developed, the SDM together with a group of Datalink experts assessed which new datalink technologies / solutions (besides VDLm2) could become available over time that offered a sufficient performance level and maturity to begin rollout for the purpose of ATM and AOC information exchange. That assessment led to the proposal that the following three datalink technologies / solutions be integrated as part of the multilink roadmap:

- SATCOM Class B: an ATM service based on Aeronautical Mobile Satellite Service SATCOM Class B (since Iris is the most advanced candidate service, it is represented in the roadmap).
- LDACS: a terrestrial-based radio access technology designed for aeronautical air-to-ground communication, i.e., optimised for aviation needs. It is defined for OSI and IPS protocol stacks. In this regard, this technology should be considered for the wide concept of Multilink for OSI and for IPS. Specifically, for IPS, it represents a sound native mobility solution.
- Hyperconnected ATM (COTS): use of public non-safety commercial communication systems (such as broadband Ka or Ku satellite systems, 4G or 5G).

One of the most important outcomes of this document was the proposed Multilink implementation roadmap that is included in the figure below. The proposed roadmap tackled different aspects and topics: ATM application, OSI protocol development and timeline, IPS protocol development and timeline, VDLm2 at present and future expectations, Datalink Service Provision (DSP) timeline and, finally, the foreseen timeline for the current and future air/ground technologies.



The green triangles indicate the start of operations milestones. The LDACS timeline clearly indicates that based on the current development of LDACS, operations can start around 2030. It must be noted that this roadmap is for the ground implementation, meaning that airlines may start operations a bit later, as happened for CPDLC/ATN over VDLm2 where ANSPs started operations in 2018 and airlines started two years later in 2020.

4.4 Services over LDACS

Performance requirements for CNS systems are becoming increasingly complex and demanding, Moreover, they need to be considered as part of an integrated common infrastructure, where air and ground systems are treated in a unified concept of operations. LDACS is one of the few new-emerging technologies that ensures secure and safe air-ground data communications, which make LDACS a potential candidate to achieve the convergence of navigation and surveillance services.

LDACS will provide efficient, secure, and high bandwidth communication capability in all phases of flight, supporting the higher ATM performance requirements and the air traffic services evolution. In particular, the 4D trajectory management operational concept must be facilitated by a reliable, scalable, modular and efficient data link technology.

Here is a list of the main service that can be run over LDACS:

- COM capabilities:
    - ATN-B1 (CPLDLC)
    - ATS-B2 (ADS-C), future ATS-B3
    - AOC
    - Digital voice
    - Secure connectivity to the flight deck (EFB)
- NAV capabilities:
    - APNT solution
    - RNP 1.0 and even RNP 0.3
- Supported operational concepts:
    - Full 4D trajectory-based operations (TBO)
    - Flight-centric ATM
    - Single-pilot operations

4.5 Deployment scenarios for LDACS

4.5.1 Overcoming short-term VDLm2 limitations

The LDACS Transition Concept (LTC) allows LDACS air-to-ground communications to be integrated into the existing ground infrastructure, It would thus bring the core benefits of this technology without requiring any change for ANSPs.

LDACS can support safety-critical services, thanks to its compliance with operational performance and safety requirements. It is a fully scalable and high bandwidth system, offering an important advantage in terms of cost-efficiency in contrast to other Data Link systems. LDACS will offload the current VDL-2 infrastructure for both AOC and ATC services, and it is considered an ideal solution to support future high-throughput services.

This step provides:

- A way of adding LDACS to forward-fit aircraft, prior to the availability of IPS avionics.
- A solution for retrofitting LDACS to aircraft which do not support IPS (and still using OSI). This would cost less than upgrading to both IPS and LDACS,so it may be attractive to airlines even when IPS avionics do become available.
- A way of adding LDACS if there is not yet a deployed ground IPS infrastructure.

4.5.2 Long-term solution for future communication infrastructure

In addition to the short-term need to overcome VDLm2 limitations on existing ATN/OSI and ACARS-based data links, where LDACS as a capacity provider can shift traffic in congested areas with high traffic density from VDLm2 to LDACS, LDACS is ideally suited to meeting the requirements of future applications.

As an A/G data link, it establishes resilient connectivity between the airborne IPS system and the ground infrastructure to enable reliable end-to-end connectivity between safety-critical applications.

LDACS is positioned for seamless integration into the forthcoming communication infrastructure: the Aeronautical Telecommunication Network (ATN/IPS).

Equipped with IPS capabilities, the LDACS airborne radio seamlessly operates with the standardised Common IP Radio Interface (CIRI), facilitating the exchange of information with airborne IPS systems, thus ensuring seamless and efficient communications in a multilink environment.

On the ground, the LDACS access network is connected to the IPS backbone network via the A/G boundary router. This router announces the accessibility of the connected aircraft to the ground infrastructure. The air-ground boundary router also ensures local network mobility within the LDACS access network using Proxy Mobile IPv6 (PMIPv6).

Within the LDACS access network, the A/G Mobility Interface Proxy (AGMI Proxy) undertakes the task of managing aircraft link preferences in a multilink environment. This critical information is subsequently relayed to global mobility and multilink solutions.

An important part of LDACS integration is establishing a reliable Public Key Infrastructure (PKI). The PKI plays a central role in the validation, distribution, and management of LDACS certificates, which are essential for ensuring mutual authentication between LDACS airborne radios and ground subsystems.

This seamless integration of LDACS into the future communication infrastructure promises improved reliability, safety, and efficiency for A/G communication in aviation.

5 The need for LDACS and its role

5.1 ANSPs' perspective

ANSPs serving high density airspace today rely most heavily on CPDLC for operational efficiency. They are facing operational limitations from non-optimal performance caused by increasing usage of data links from the post-pandemic increasing traffic. A similar situation will be also faced in the future by ANSPs managing regions with a strong air traffic growth ratio.

VDLm2 (continental airspace datalink) should reach capacity crunch in 2028-2030 due to the prolonged increase in traffic and new ATC/AOC data requirements. When you also consider the need for increasingly time-critical ATS exchanges, the situation will soon become very challenging. With this in mind, VDLm2 is considered by ANSPs as an intermediate solution until future wideband technologies like SATCOM and LDACS are available.

Space-based SATCOM technologies are already deployed that meet the required ATM communication performance-based standards. SATCOM is already an important component of aviation communications, especially for oceanic airspace. First pre-commercial flights over continental airspace are in progress and this will lead to an expansion of continental services for ANSPs in the near future.

Terrestrial-based LDACS technology is foreseen by ANSPs as a wideband and cyber-secure data link service for primary or backup means of continental operation and as a successor of VDLm2. Standardisation of LDACS is expected to be finalised in 2024, with first services available by 2028.

It is expected that both satellite systems and LDACS will be deployed to support the future multilink aeronautical communication needs as envisaged by the ICAO Global Air Navigation Plan (GANP) and Eurocontrol Future Communication Infrastructure (FCI). Both technologies have their specific benefits and technical capabilities, which complement each other. In addition, multilink can reduce the operational impact of interference and jamming threats.

The modernisation of air traffic management towards Trajectory Based Operations (TBO) in real time requires an efficient air-ground datalink system, which must be supported by FCI with sufficient and scalable capacity to accommodate current and future operational datalink services and to automate data exchanges between air and ground ATM components and actors.

The datalink applications and service enhancements that are planned as part of the ADS-C/EPP are expected to be implemented by the end of 2027 in accordance with the CP1 Regulation and within the wider global ATS-B2 context beyond the scope of the CP1 Regulation.

These new applications must be supported by the right performance (bandwidth, low latency, security, and reliability) and be delivered with the appropriate technologies for their benefits to be delivered incrementally.

Multilink services are the preferred way and the long-term vision by ANSPs to enable the transition from today's narrow band to high-speed data link systems.

Based on a high-level business case study recently conducted by Eurocontrol, Multilink technologies (SATCOM, LDACS, COTS 5G/6G) enabling new upcoming ATS B2 applications will deliver a positive NPV of €4.7bn (8%) discount rate, 2023-2050) and environmental savings of around 6.8m tons of CO_2 emissions. An implementation delay of 5 years (either ground or airborne) would halve the above-mentioned financial return and significantly reduce environmental savings.

Overall, LDACS will ultimately be the successor to VDLm2 in the continental airspace in the medium term, i.e., 5 to 10 years from now.

LDACS is designed to cope with the stringent requirements of the new ATC services and to provide capacity to cope with the increasing traffic both for ATC and AOC purposes. Multilink will consider LDACS one of its main pillars based on the characteristics and performance provided by this technology and will allow the prioritisation of traffic based on multilink policies that still have to be agreed.

ANSPs strongly encourage the finalisation of standardisation, in order to give LDACS a global relevance. Together with the achievement of final maturity steps, this will extend the acceptance of the technology and the awareness of its benefits also from stakeholders outside of Europe.

5.2 Airlines' perspective

Although VDLm2 meets and will continue to meet specific operational needs, airlines consider implementation of new secured high-bandwidth communication technologies key to enabling safer and more sustainable operations. To achieve this, airlines fully support the multilink concept which allows you to select the most suitable system depending on operations, aircraft type or age, costs, etc.

SATCOM Class B is currently the most mature FCI solution, although performance and availability are yet to be demonstrated. However, it is only applicable for certain types of new aircraft, with no retrofit capability. Installation and operational costs are a concern. Due to the limited number of providers, there is a risk to service continuity. Airlines believe that a robust terrestrial communication technology is a must to complement satellite systems.

With regards to installation and communication costs, SATCOM solutions have always been more expensive than terrestrial systems, which was only justifiable when flying outside terrestrial coverage (oceanic or remote).

Geostationary constellations will, compared to LDACS, fail to provide a complementary PNT source.

Hyper Connected ATM promises to make use of COTS systems already installed in aircraft, making it of interest for new communication opportunities with low investment. But its development is challenging. It is not expected to be the main and sole onboard communication system, so it will have to be complemented by another communication system.

The ongoing Hyperconnected ATM Research activities foresee a safety link back-up for ATM applications over COTS. That could be VDL in some regions but needs higher performance in other regions requiring SATCOM or LDACS installations.

If no oceanic or remote airspace link access is required, LDACS technology looks very promising for airlines for several reasons.

First, in the current and future context of a global disrupted GNSS environment, due to multiple crises and vulnerabilities, the availability of a robust ground-based infrastructure, potentially supporting GNSS PNT back-up, appears to be a must for robustness and national or regional sovereignty for airlines. Future communications shall not rely solely on satellite systems. LDACS is the only ground system being standardised by ICAO today, in line with global targeted IPS protocol.

LDACS brings some important benefits and open opportunities for airlines: high performance (low latency, RCP60), high-capacity secured IP communication, preservation of aviation spectrum, opportunities for EFB/AOC and digital voice.

Besides these promising communication capabilities LDACS could support NAV domain robustness (APNT - GNSS back-up).

Combining the Communication and Navigation Domain and potentially in the future also the Surveillance domain is a huge step to improve spectrum efficiency and the first step towards integrated CNS.

It could also allow avionic rationalisation, reducing the number of onboard equipment for the first time in history (since we observed an increase in number of onboard communication systems continuously over the last few decades).

From a deployment point of view, LDACS ground infrastructure could be collocated and mutualised with ground VDLm2 infrastructure that is already deployed, for a progressive, natural, and resilient evolution of VDLm2 towards FCI technology.

On airborne side, it is assumed that impact on avionic equipment could be low. Adaptation of existing radios and antenna optimisation may open the way to retrofits, which could significantly increase the rate of adoption for FCI technologies, and consequently accelerate operational and environmental benefits.

It can be concluded that airlines prefer implementations that support complementary applications as well as AOC and ATC communication in continental airspace. For SATCOM, this would be AOC and ATC Link access in oceanic or remote areas. Where the operation does not require such extensive coverage, LDACS should provide the most benefits thanks to the ongoing research and development activities in all three CNS domains, AOC and ATC datalink, Voice communication, complementary PNT and back-up surveillance.

Additionally, the commercial dimension is relevant. LDACS will allow a multi-provider infrastructure supported by a single aircraft installation and as such will ensure competition and open markets.

For all these reasons, airlines support the acceleration of LDACS development, in the context of multilink phase-in.

Next step should be the speeding up of avionic development to test a commercial aircraft prototype within the best achievable lead time. Airlines also encourage all relevant bodies to consider interoperability worldwide.

5.3 Communication Service Providers' perspective

LDACS could be a strong technology in the medium- to long-term roadmap for aeronautical communications. It brings both a substantial enhancement in bandwidth, offering at least 50 times the capacity and improved latency compared to the existing primary aviation dedicated terrestrial networks, namely VDLm2. The high-level characteristics of this system are suited to the increasing demands of air-to-ground communications, fulfilling the need for high capacity, high-rate data and digital voice communications.

On the effort to deploy and upgrade the ground network, CSP see this as a relatively business as usual activity. In fact, the following considerations regarding the deployment steps of LDACS in the ground infrastructure apply:

- Benefit from the re-use of existing sites and locations
- Benefit from existing premises and lease agreements with airports
- Benefit from existing facilities in these locations; power, AC supply, etc.
- Benefit from re-use existing station connectivity (likely with bandwidth upgrades) where possible
- Add LDACS radios and RF components.
- Re-use all ground-ground datalink ecosystem e.g., ATN backbone and Gateways / ACARS Gateways / IP Gateways / interconnectivity to ANSPs / interconnectivity to Airlines (and other ecosystem third parties)

Advantages of LDACS:

- **Enhanced performance**: LDACS provides a significant increase in bandwidth, promising a low-latency network that is more efficient than existing aviation networks.
- **Deployment**: It is compatible with existing VDLm2 infrastructure, allowing for cost-effective deployment by collocation with existing VDLm2 ground stations, reusing some existing ground station infrastructure and premises.
- **Complementary**: LDACS fits into the wider communications ecosystem, including Hyper Connected Air Traffic Management (HyCATM), as an additional Air-to-Ground communications network. It is expected to carry both Controller Pilot Datalink Communications and operational communications.

- **Quality of Service**: With a built-in message prioritisation mechanism, LDACS ensures managed Quality of Service (QoS).
- **Security**: The use of Public Key encryption facilitates the authentication of all participants.
- **Open ecosystem**: Supports a multi-Communication Service Provider model, providing the end-user community (i.e., air space users and air space controller) with choice of supply.

Challenges and considerations:

- **Maturity:** LDACS has built good traction with many key industry stakeholders and via many forums, however the airborne component maturity is lagging, and needs stronger endorsement from both Air Framers and avionic manufactures. For LDACS to come to fruition an avionic development stream needs to be accelerated, and the typical linefit availability lead time to market must be compressed as much as possible.
- **Deployment timeline**: The groundwork for LDACS can be swiftly established once the necessary radios are available. A European network could be operational within two years from radio availability, but linefit avionics could take an additional five years post airframers' decision to proceed.
- **Operational readiness:** LDACS could be operationally ready between 2030 and 2035, contingent on its acceptance by the aircraft communications community – in particular endorsement from airspace users and airframers. From a ground network perspective, the cohabitation and re-use of VDLm2 infrastructure and locations could facilitate a rapid deployment scenario.

LDACS is a forward-looking technology that could play a key and central role in the evolution of the aeronautical communication ecosystem. Its potential benefits are significant, including high bandwidth, low latency, and enhanced security. The endorsement from airframers and avionics vendors and the maturity of the airborne component is key in securing a timely path to linefit availability and large-scale adoption.

Communication Service Providers believe that the LDACS concept should be matured further, so it can progress to becoming a viable option for the next generation of aviation dedicated terrestrial networks. We believe at this stage LDACS should be viewed as a complementary network technology, compatible with both existing aircraft communications networks and future networks, including but by no means limited to new generation satellite services and Hyper Connected ATM.

5.4 ACDLS perspective

In Europe, the ATS Common Datalink Services (ACDLS) initiative brings together the breadth of European ANSPs to jointly govern the deployment of Datalink, migrating to services from a single Datalink Service Provider (DSP) entity by 2026.

The ACDLS is already established and has been set up through the signing of a Memorandum of Co-operation (MoC) by ANSP stakeholders, which sets out how a DSP will be governed in technical and economic terms.

The establishment of a DSP provides for an important harmonised service platform, through which the deployment of LDACS can be facilitated and delivered in the most cost-effective manner possible to all ANSP users. Once the DSP is in operation, the common provider will be able to plan for LDACS deployment on a Pan-European basis, which will bring great benefits in comparison to how VDL M2 was adopted. LDACS based services can be managed in a harmonised way across Europe from the start for all users, and the charging mechanisms employed will be balanced according to user needs. LDACS will be included within the service portfolio of the DSP as soon as the technology is mature and ready to deploy.

6 Deployment

6.1 Deployment and service models

It can be expected that LDACS ground infrastructure and interfaces will be deployed as a third-party supplied communications service, from the perspective of ANSPs, in the same way that VDLm2 and SATCOM services are managed today.

It is also expected that LDACS can be deployed in a complementary manner to VDLm2. This means that LDACS can be deployed iteratively through integration of VDLm2 and LDACS networks, while maintaining the required datalink service levels throughout using both infrastructures. In this way the transition period from VDLm2 to LDACS may be long in duration, but savings can be made incrementally throughout the period. VDLm2 ground stations can be decommissioned over time once LDACS is established in a geographical area.

On the airborne side, the rate of deployment for LDACS capable avionics is a crucial factor. This rate of equipage must be managed closely to manage the ground transition effectively while maintaining service levels. In this way, the acceleration of LDACS avionics is a key enabler to the transition and the realisation of both operational and deployment cost benefits.

Deployment on the airborne site will be facilitated through design, as the avionics and antenna implementations will be integrated into existing avionics infrastructure.

6.2 Cost models and impacts

6.2.1 Cost model for airspace Users

Concerning the OPEX Cost for ATC services, it is expected that the cost of LDACS implementation will not have a direct impact on airlines, rather they should be recovered by ANSP via enroute charges paid by airlines (as for VDLm2 services). It is important that this recovery mechanism via enroute charges is agreed and implemented from the early days of service.

OPEX AOC costs/benefits are considered in the business case for LDACS decision making. It is therefore important that AOC over LDACS costs shall be competitive compared with current VDLm2 costs. Airlines should still have the choice to select the appropriate technology for their various AOC services, independently from the link used for ATC.

Costs for aircraft equipage and extra charging are a concern for airlines and may jeopardise or discourage initiatives. Early movers may not have benefits from the use of LDACS in the early years of adoption.

Appropriate incentive mechanisms should compensate for the initial negative impact on business and boost adoption by airlines and ANSPs, such as EC funding or route charge modulation

6.2.2 Cost model for ANSPs

Related to the expectations around ground deployment above, it is further anticipated that the charging model for LDACS based services will follow the same framework as existing datalink third-party services. Currently, VDL M2 and planned SATCOM charged services are paid for through the enroute route-charging mechanism, focusing on cost recovery from airline customers.

The introduction of LDACS services in Europe is likely to be supported by a certified COM provider, whether this would be an existing provider or a newly established one. This factor would be incorporated into charging for the service, and it is also likely that LDACS-based services would be charged as integrated services with other datalink technologies from the ANSP perspective. Again, as discussed earlier, the introduction of a DSP single provision entity for Europe will act to simplify this service provision and charging mechanism for users which would also bring significant benefit as additional technologies such as LDACS are brought online.

6.2.3 Cost model for CSPs

It is expected that LDACS, as an additional air-ground data service, would fit well into the existing business model and that the cost model will remain in line with current policies, i.e. via ANSPs through the enroute route-charging mechanism and directly to airlines for their use of AOC services.

6.3 Need for incentives

Typically, any new technology that comes to the aviation industry is expensive and requires effort to deploy.

On one hand, the aviation market is limited compared to other widespread markets for citizens, e.g., mobile telephony, IP connectivity, etc.; on the other hand, it usually requires complex changes to both ground systems and onboard aircrafts. This is why there is a clear need for financial support and even incentives once the technology is considered mature and has been validated.

In Europe, the SESAR Programme is the technological pillar of the Single European Sky, which aims to improve ATM performance by modernising and harmonising ATM systems through the definition, development, validation, and deployment of innovative technological and operational ATM solutions. When a new technology is presented and reaches a certain level of maturity, it is also included in the European ATM Master Plan. It defines the operational changes that are required, providing an estimated roadmap for the implementation of these new technologies. This is clearly the case with LDACS, which was included from the very beginning in the SESAR Programme.

Once the technology is validated by SJU, the essential deployment of operational functionality is included in the so-called Common Projects supported by dedicated SESAR deployment governance and incentive mechanisms. Being part of a Common Project implies that it is binding according to the European Regulation, but it also implies that financial support can be obtained through CEF (Connecting Europe Facilities) funding.

Based on the experience of various CEF Calls, incentivisation is clearly necessary to support changes and include new technologies that improve and optimise ATM service provision. Otherwise, stakeholders, namely, ANSPs and airspace users, cannot raise the required investments to commission the new services and functionalities through specific technologies. Keeping in mind that these new services and functionalities will enhance the Single European Sky by making it more cost-effective, safer and more sustainable, measures should be taken to alleviate this cost burden. The current Common Project One (CP1) is a good example of this. It has a positive business case based on the window of opportunity for which it has been developed. By accomplishing the ATM Functionalities (AFs) included in the CP1, the aviation community will be able to achieve the long-term objectives of the SES in terms of reducing CO_2 emissions, increasing safety, and coping with increasing traffic expected over the coming years.

In conclusion, LDACS as a core technology to implement TBO needs incentives, and probably the most suitable mechanism to do that would be through the Common Projects scheme aforementioned.

7 Conclusions

LDACS is a new datalink technology, part of the FCI multilink architecture, which plays an essential role in air-ground connectivity for continental airspaces.

Its maturity has made significant progress during several SESAR programmes in the last few years and will soon approach the readiness level required for deployment.

Validations also include flight test campaigns and interference tests, which have proved LDACS compatibility with other L-band systems in aircraft.

Standardisation at ICAO and EUROCAE are currently in progress and are expected to be completed in line with the FCI Roadmap.

LDACS is a secure, scalable, high-performance and spectrum efficient data link providing:

- broadband connectivity
- very low latency
- application priority management, mitigating the capacity and performance issues VDL is currently facing
- cyber-security
- a complementary PNT source
- support for future integration of NAV and SUR services, that contribute to increase spectrum efficiency.

Moreover, the terrestrial and distributed nature of LDACS technology ensures:

- the national or regional sovereignty of ground infrastructure for increased control of airspace.
- an easy, flexible, on demand 'where needed - when needed' deployment of ground infrastructure with reuse of existing VHF Stations.
- existing business and cost models still apply.

LDACS is an open standard framework that ensures:

- global interoperability
- access to different service providers through a single piece of airborne equipment
- provider interoperability

Integration into the avionic bay is also expected to be very simple, leveraging the sharing of RF infrastructure with existing VHF devices.

The gap to deployment readiness is constantly and progressively reducing through the continuous joint effort of different players in the aviation community within different SESAR projects.

With an additional boost from potential incentive schemes, the progress can be significantly accelerated and make LDACS technology available very soon, for the benefit of the whole aviation world and providing a concrete contribution to the achievement of targeted sustainability goals.

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Many thanks to the people below listed, who actively contributed to the creation of this whitepaper.

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