IS THIS THE TIME AND PLACE TO FINALLY BACK UP GNSS?

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On February 12th, the White House released an Executive Order[1] to improve the US' critical infrastructure resilience on the Positioning, Navigation and Timing (PNT) services, mostly provided by the GPS (Global Positioning System). A week later, UK Science Minister Amanda Solloway announced the creation of a £36 million National Timing Centre to build a network of atomic clocks across the UK to backup GNSS (Global Navigation Satellite System) timing capabilities.

This recent political attention toward PNT is easily explained. Our whole modern industry relies on it, including emergency response systems, 4G/5G mobile networks, communication and broadcast systems, transport, high speed trading in the stock exchange and the energy grid. London Economics estimates the daily cost for the UK of a widespread GNSS failure to be above a billion pounds[2].

Of course, since those announcements, the aviation industry around the world is reeling from the shocks and aftershocks of the COVID-19 pandemic and its impacts. But it will recover, and the infrastructure problems will not go away. Is this the time and place to finally back up GNSS?

[1] Executive Order on Strengthening National Resilience through Responsible Use of Positioning, Navigation, and Timing Services, White House, Donald Trump, February 2020: https://www.whitehouse.gov/presidential-actions/executive-order-strengthening-national-resilience-responsible-use-positioning-navigation-timing-services/

[2] Economic impact to the UK of a disruption to GNSS, London Economics, April 2017: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/619545/17.3254_Economic_impact_to_UK_of_a_disruption_to_GNSS_-_Showcase_Report.pdf

GNSS AND NAVAID VULNERABILITIES

GNSS is the main navigation system and many new concepts of operation will rely on it. GNSS represents a critical single point of failure. GNSS signals are weak and vulnerable to unintentional interference, jamming, or even spoofing. For instance, the Middle East region is suffering from periodic GNSS outage as reported by the ICAO MID Office[3].

When GNSS isn't available, the current navigation (NAV) backups are ground NavAids (Navigation Aids), like DMEs (Distance Measuring Equipment). These use post WWII technologies, with very low spectrum efficiency. Some might find it surprising to learn that they are still identified with a Morse code. While very difficult to jam due to their strong signal, the current NavAids are not cyber secure and due to their spatial distribution, they can be limited in their support to PBN (Performance Based Navigation) or any new concept of operations.

COMMUNICATION CHALLENGES

In the aeronautical communication (COM) domain, a similar situation exists:

- The main voice communication Air to Ground (A/G) is a simple open analogue technology in VHF and HF, unchanged since 1948. In the last 10 years, EU VHF radios progressively switched to 8.33 kHz channel to improve capacity and spectrum efficiency[4]. However, the voice radio is still open, unencrypted, and makes it impossible to deploy flight centric operation with point to point communications and sectorless operations.
- VDL (VHF DataLink) Mode 2, primarily used for CPDLC (Controller-Pilot DataLink Communications), is a "modern" narrowband datalink technology that will reach its capacity limit in the next 20 years[5]. Whereas VDL2 is limited to a few kilobits per second, passengers on the other hand can enjoy inflight broadband services. Speed and bandwidth are not the only problems, in recent years, this system has been criticized due to its cyber-vulnerabilities, and its lack of modern Internet Protocol[6].

RADIO ANTENNAS AND GROUND STATIONS

The legacy NavAids, like NDB (Non-directional beacon), ILS (Instrument Landing System), VOR (VHF Omnidirectional Range) and DME, all require a specific frequency band, various equipment, and airborne and ground antennas. As a result, the average commercial airliner can carry around seven specialised navigation antennas, and as much as 20 when accounting for all the other CNS functions. Having different radio systems is adding redundancy but makes the aircraft and the ground equipment very costly, as well as difficult to engineer and to maintain.

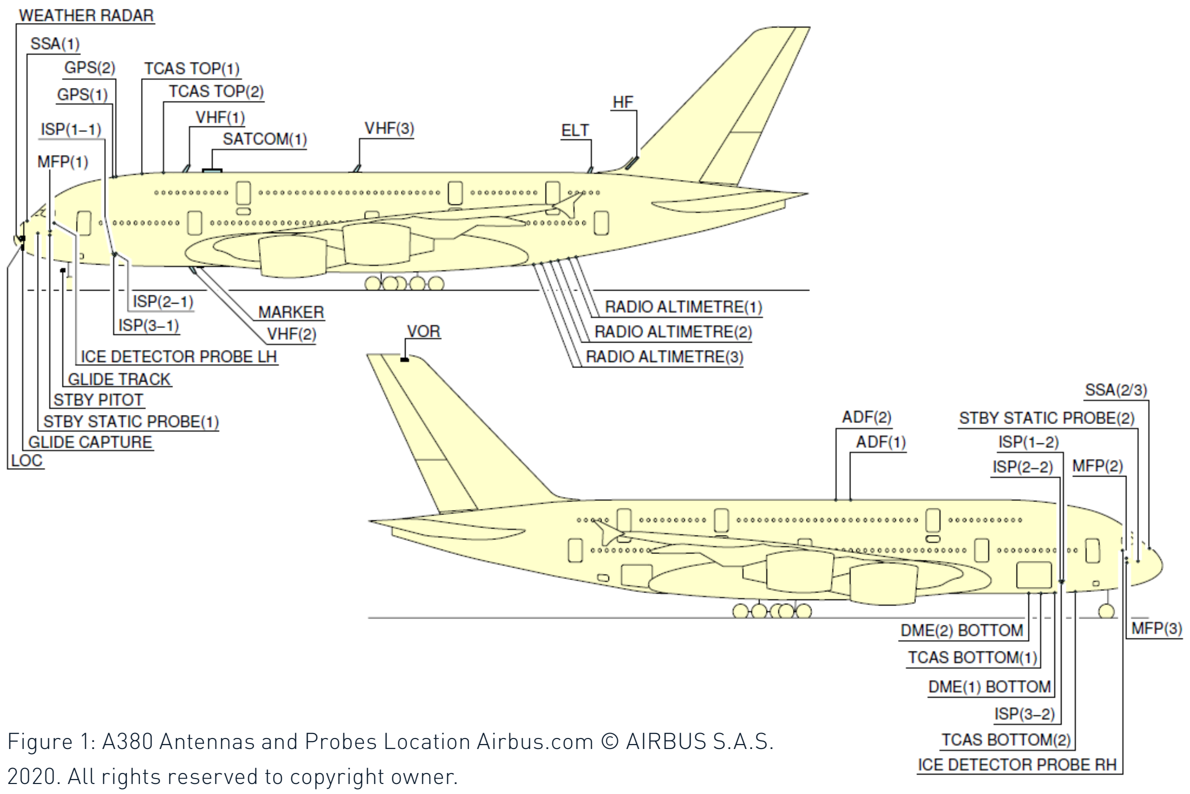

Figure 1: A380 Antennas and Probes Location Airbus.com © AIRBUS S.A.S. 2020. All rights reserved to copyright owner.

Although aviation remains safe and secure (so far), two major threats will affect the industry in the future. First, software-defined radio, and powerful low-cost radio systems are available to the public and any ill-intended person could interfere, deactivate or worse, divert these vulnerable systems from their purposes. Secondly, spectrum is a finite and fixed asset.

[3]RASG-MID Safety Advisory 14 (RSA-14), ICAO Mid Office, April 2019: https://www.icao.int/MID/Documents/2017/RASG-MID6/RSA%2014-GNSS%20Vulnerabilities.pdf

[4]Spectrum Efficiency is the information rate that can be transmitted over a given bandwidth in a specific communication system.

[5]VDL Mode 2 Capacity and Performance Analysis, SJU, 2015: https://www.sesarju.eu/sites/default/files/documents/news/SJU_VDL_Mode_2_Capacity_and_Performance_Analysis.pdf

[6]Controller-Pilot Data Link Communication Security, Andrei Gurtov, Tatiana Polishchuk, and Max Wernberg, Sensors, May 2018: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5982923/

SPECTRUM

Except for terrestrial cables, spectrum cannot be extended, augmented, or replaced with some alternative. Aviation uses 14%[7] of the total available spectrum, valued at an astonishing €1000 billion[8] due to its advantageous position, in the "Sweetspot" where speed and communication range are nicely balanced.

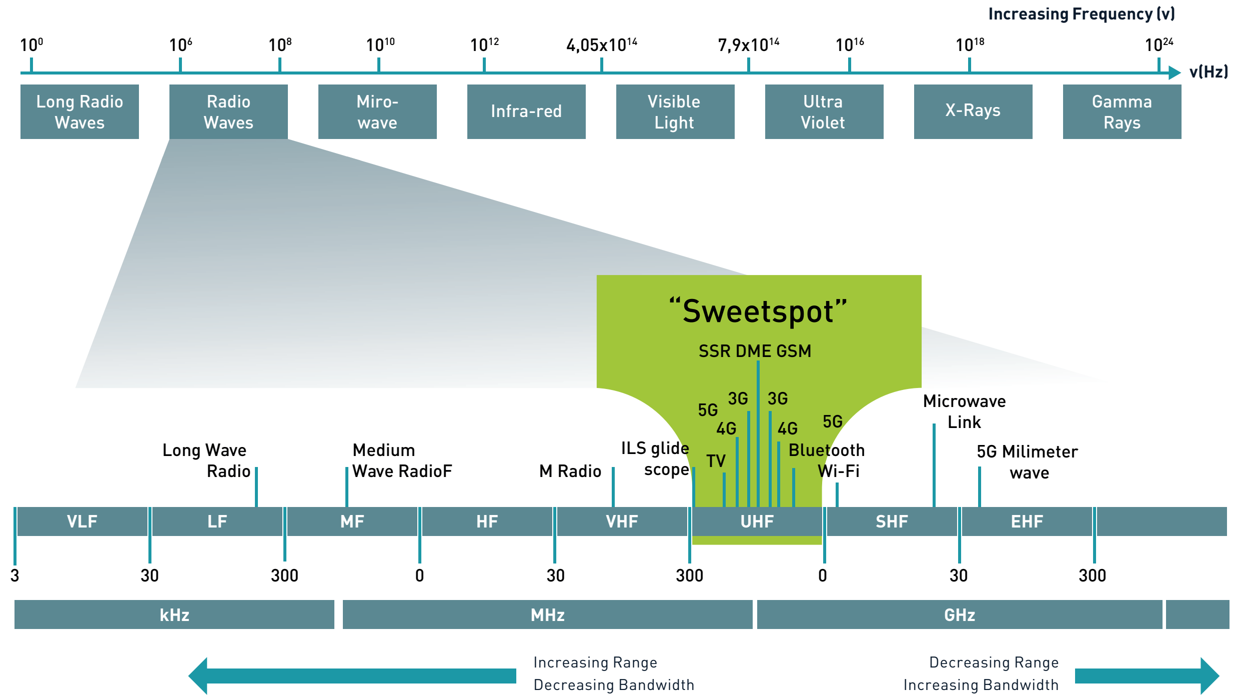

Figure 2 "Sweetspot" where speed and communication range are nicely balanced

Aviation ***needs*** to rationalise its use of this resource to ensure long-term access to suitable spectrum allocations for new CNS systems. Failure to tackle the situation proactively carries risks. Technological disparity can cause the industry to fall behind, reducing cooperation and synergy opportunities with other spectrum users. It:

- Prevents aviation benefiting from technological innovation in other fields.
- Reduces goodwill with spectrum management bodies to preserve the aviation dedicated spectrum.
- Becomes a barrier to the growth and development of aviation itself, including potentially the drone market.

[7] 14% from 87.5 MHz to 10 GHz Ofcom 2007

[8] WAC 2019, Integrated CNS, Roadmap &_Strategy, Aviation Spectrum, presentation by Jacky Pouzet, Head of ATM Communication and Frequency Coordination Unit, EUROCONTROL: https://www.sesarju.eu/sites/default/files/documents/events/wac2019/wac2019-day2-cns.pdf

WHY HAVEN'T WE ALREADY FIXED THIS?

This is not a new problem, or one that the industry is unaware of. The technology has been available for some time which could support rationalisation, so why hasn't this problem been solved already?

MARKET INCENTIVES AND AIRCRAFT LIFETIME

First, there are no market incentives for air navigation service providers (ANSPs) and airlines to make expensive investments in new ground infrastructures and aircraft retrofits. With an average lifetime of 25 years, commercial fleets take a long time to be renewed. This prevents the quick technology evolutions we are used to in other systems, like the average 2.5 years lifespan of mobile phones!

MOBILE EVOLUTION

Mobile usage and underlying technology are following an exponential curve[9]. Between 2010 and 2018, the wireless data traffic grew 73-fold in the US. In five technological generations, the spectral efficiency has improved from 0.46 bps/Hz in the 80's to 15 bps/Hz in 4G/LTE-Advanced and above 30 bps/Hz for the 5G technology[10 11]. To compare industries, even if the DME accuracy has improved in the last 60+ years, the original pulse-pair signal has remained unchanged. The last active MOPS (Minimum Operational Performance Standards) for Airborne DME Operation was published in 1985[12].

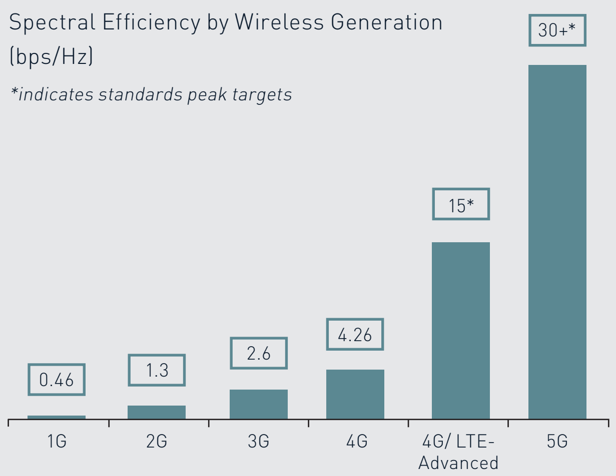

Figure 3: Evolution of the Spectral Efficiency of mobile networks

[9] CTIA 2019 Annual Survey

[10] Indian Institute of Technology Madras, Radha Krishna Ganti, Energy Efficiency in Cellular Networks

[11] CTIA, Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum

[12] RTCA DO-189, Engineering 360 website, powered by IEEE GlobalSpec: https://standards.globalspec.com/std/449164/RTCA%20DO-189

COMPETITION

Secondly, aviation spectrum is protected and not open to the highest bidder. This has led to a long-standing status quo of complacency and a lack of pressure to use the latest technologies for improved spectrum efficiency. Without competition and evolution, the actors are well installed and form local monopolies, further hindering any change.

STAKEHOLDER COORDINATION

States, ANSPs, airlines, airport, aircraft manufacturers, communications providers, system providers all have their own interests and perspectives when it comes to new CNS systems. This increases the difficulty in developing and maintaining a global CNS roadmap that would ensure a safe and cost-effective transition from one technology to another. While regional spectrum assignment can be done in the mobile industry, the intrinsically global nature of aviation must ensure worldwide interoperability.

DEPLOYMENT

Even once a roadmap is agreed, the deployment challenge remains. For instance, even with mandated CNS programmes like ADS-B or VDLM2 Datalink the equipage rates are still well below target. Initially set up for June 2020, the retrofit compliance date for ADS-B has been pushed back to June 2023 due to the pandemic. In September 2020, the EU27+4 registered EU fleet ADS-B equipage rate only reached 81%[16], lagging behind the Asian and US fleet above 90%. In June 2020, only 53%[17] of flight plans over FL285 are registered as VDLM2 and CPDLC capable. More aircrafts are equipped, but the actual share is mostly unknown as pilots and ATC do not trust the system yet[18].

THE HUMAN FACTOR

Since the first FAA-certified GPS unit in 1994, in less than 20 years the GNSS system has become the primary means of navigation. This shows that aviation can move fast when operational and commercial benefits are clear for all stakeholders. This is particularly the case for GA (General Aviation), for which changes often mean an additional cost without clear economic benefit. For instance, only 54% of US GA aircraft were equipped when the FAA ADS-B mandate rolled out in January 2020[15].

Aside from organisational, technological, and commercial hurdles, human factors have also to be considered for any critical change in aviation. Pilots are trained on and used to following NavAid Airways and GPS for navigation, and to communicate by VHF voice with ATCOs. This is the reason why the evolution of Navigation and Communication systems must be seamless with current systems or require an in-depth human factor risk assessment.

[13] SESAR Deployment Manager, ADS-B website: https://ads-b-europe.eu/

[14] CPDLC Mandate, Where Does The Aviation Industry Stand? Fokker White Paper: http://www.fokker.com/sites/default/files/media/Files/Services/CPDLC_WhitePaper_FokkerServices.pdf

[15] AOPA, "ADS-B off to smooth start, FAA publishes tiered enforcement guidelines", January 2020.

[16] ADS-B Equipage, Eurocontrol website. https://www.eurocontrol.int/service/adsb-equipage

[17] Data link Network Operational Status Report, Eurocontrol, June 2020 https://ext.eurocontrol.int/WikiLink/images/e/e5/2020-06_DL_Status_June2020.pdf

[18] CPDLC Mandate, Where DoesThe Aviation Industry Stand? Fokker White Paper: https://www.fokkerservices.com/news/blog/cpdlc-white-paper

WHAT ARE THE POTENTIAL SOLUTIONS?

To future-proof aviation and Performance-Based operating procedures, aircraft need:

- A broadband, IP-based datalink, capable of VoIP.
- A convincing, secure and cost-effective A-PNT (Alternative Position, Navigation and Timing) system as a back-up to the GNSS systems.

DATALINK

For the Datalink, the Multilink system is under development, composed of three new complementary IP-based datalink solutions: SATCOM (Satellite Communications) for oceanic and remote communication, LDACS (L-Band Digital Aeronautical Communication System) for continental ground communication and AeroMACS (C-band WiMax) for airport high bandwidth connectivity. They are being supported by new radio generation technologies: Software Defined Radio and Multiband antennas. These technologies enable the reduction of the actual number of antennas on an aircraft. In the medium term, LDACS could replace VDL Mode 2 datalink with its 50 to 200 times greater bandwidth. In the longer term, LDACS could also replace continental VHF voice with its VoIP capabilities.

GNSS BACK-UP

GNSS back-up in the short to mid-term is based on the selected (by-default) technology of the 70-year-old DME. Using the signal from multiple DMEs, aircraft can locate themselves with reasonable accuracy. In the US, with currently 924 GS (Ground Stations), 100 DMEs would be redundant and 176 additional DMEs would be needed for improving the accuracy around airports[19]. The other NavAids, NDBs and VORs, would be rationalized with a MON (Minimum Operational Network) and decommissioned in the long term. This solution, while attractive because of its cost-effectiveness, would not satisfy security and spectrum efficiency requirements.

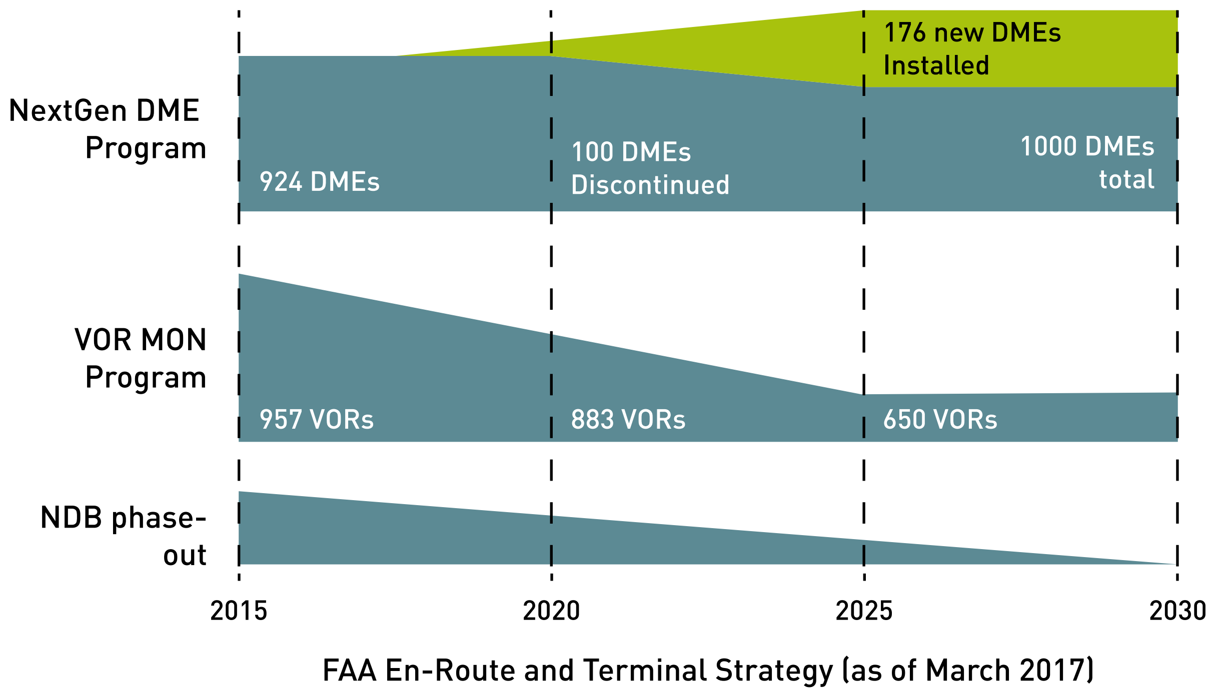

Figure 4 FAA En-Route and Terminal Strategy (as of March 17)

Many technologies are under consideration to replace the DMEs for the GNSS back-up functionality. Given GNSS developments and enhancements, it would be difficult to justify a brand-new standalone technology. The main choice is between an enhancement of DME systems (Multi-DME RAIM, eDME, Mosaic DME) or an A-PNT solution (LDACS-NAV, WAM-TISb, SSR mode N, eLORAN) taking advantage of synergies with other CNS technology or industry.

[19] FAA, Navigation Programs Strategy 2018

CHOOSING AN A-PNT SOLUTION

The reason why no long-term decision has been taken so far is that all these solutions have advantages and disadvantages, and none of them easily solves all the possible A-PNT needs. Moreover, the operational and commercial benefits of a back-up system to GNSS are very small, and the industry is reluctant to improve its spectrum efficiency.

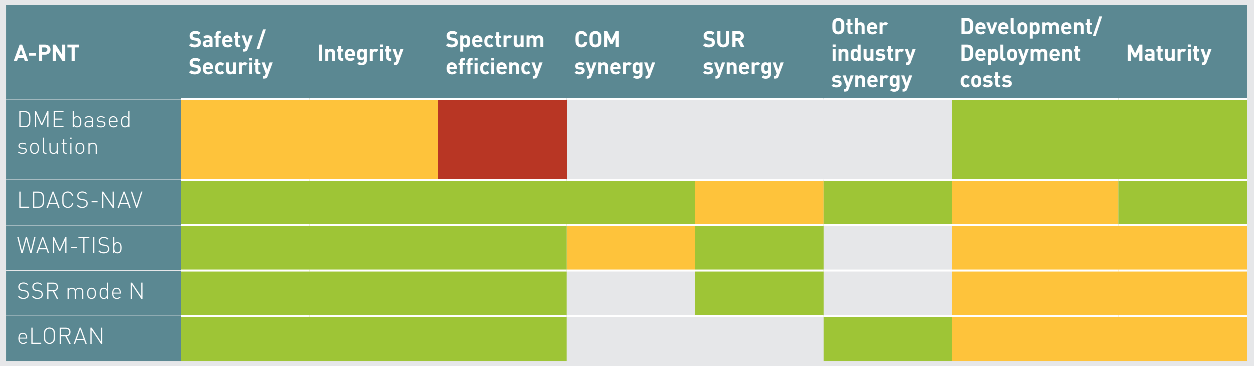

Figure 5: comparison of A-PNT solutions

However, the need for change is growing. The drone market is expected to explode with very diverse commercial applications in infrastructure surveillance, agriculture, last kilometres logistics and urban mobility. This additional traffic cannot be managed by the traditional ATM systems and an efficient and automated UTM (Unmanned Aircraft System Traffic Management) is currently under development. While the drone industry supports the use of licensed, unlicensed and spectrum sharing opportunities, there is an unresolved need for a dedicated spectrum for commercial, safety and mission critical applications[20].

Whilst the picture is different today in the wake of the Coronavirus pandemic, just a few months ago ATM was suffering delays and inefficiency. The system was overloaded. The rationale still exists to improve connectivity, share digitalised ATM information to all stakeholders, ready for when the recovery begins. In all this, the highest level of cybersecurity is needed across the chain of information to ensure the participation of the military.

If we look at the most mature solutions, the DME/DME and the LDACS-NAV are the main options, and they represent a real dilemma:

[20] Drone Alliance Europe, "Drones, UTM and Spectrum – A review" 2016: http://dronealliance.eu/wp-content/uploads/2016/06/Spectrum-Allocation-White-Paper-Drone-Alliance-Europe-fin.pdf

DME/DME

Today, DME/DME represents the best GNSS back up and offers great coverage of the EU territory. In the 80's, all the new DME standards improvements failed to convince the industry. So, the 1MHz spacing pulse pair has remained unchanged since the 50's[21] and represents an outdated, inefficient navigation method with low accuracy compared to GNSS.

Nevertheless, potential enhancements to the DME system have been proposed. A first possibility would be to improve the signal, thereby improving accuracy. Without requiring signal modifications, other improvements would allow the detection of more than 2 ground stations, or even the RAIM (Receiver Autonomous Integrity Monitoring) capability.

- The advantage of this solution is it is already based on an available network and only small improvements need to be made to the signal and to the FMS (Flight Management System). This is clearly the minimum effort and cost option.
- Regarding standardisation activities, EUROCAE (WG-107 and WG-85) and RTCA (SC-227) are working together on the standardisation of the use of DME to support RNP 1 and even RNP 0.3.
- The drawbacks are that to reach a reliable RNP PBN 0.3, additional distance measurements are required, especially at low altitudes, and more DME facilities might be needed. For instance, in Germany, less than 20% of the airspace at FL100 can deliver the RNP 1.0 requirements.[22] Currently in Germany, the DME network is showing some high utilisation with more than a hundred aircraft visible for some ground antennas. Given the limit is between 100 and 200, the demand for air traffic could overload the DME system in the future.
- This solution does not provide a secured, integrated CNS and does not improve the spectrum efficiency of this legacy technology.

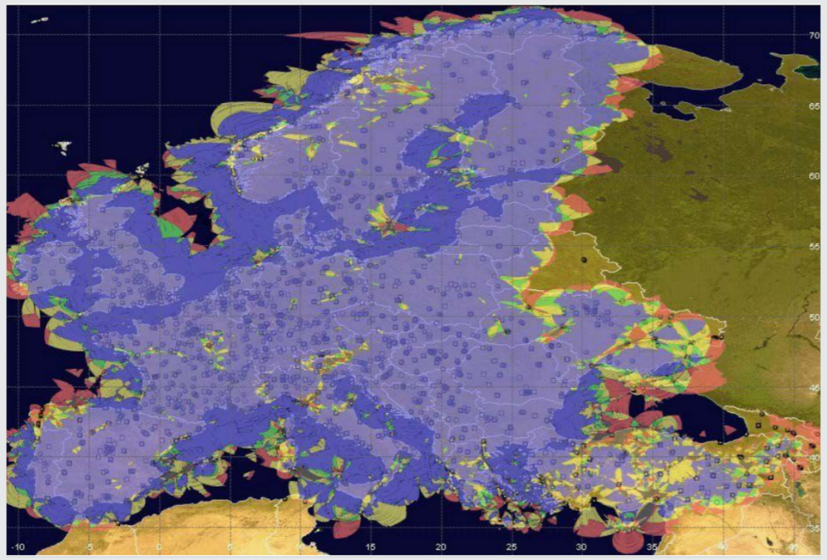

Figure 6: DME/DME RNAV Coverage at 19'500ft AMSL ©EUROCONTROL

[21] PNT: What comes after DME, 20th IFIS Papers, ICASC.

[22] DLR, "Placing LDACS-Based Ranging Sources for Robust RNP 1.0 Accuracy En-Route" 2017: https://elib.dlr.de/130751/1/BattistaKumarOsechas_RobustRNP1.pdf

LDACS-NAV

LDACS-NAV is a built-in capability of the LDACS1 communication technology. It is a modern technology based on OFDM (Orthogonal Frequency-Division Multiplexing), organised as a cellular network and sharing a lot of common features with 3G-4G.

LDACS-NAV works by detecting signals of opportunity within the communication exchange to multilaterate the signals from at least four ground transmitters and calculate an airborne position. The frequency is ingeniously placed in the L-Band, between each DME frequency and is built with interference mitigation algorithms. It also minimizes out-of-band radiation, to protect DME.

- This solution is spectrum efficient, cybersecure, doesn't require any additional frequency assignment, is scalable and adaptable to the local needs. Given LDACS is almost certain to be implemented in COM to replace VDLM2, using this capability would be an easy choice for NAV.
- This technology is modular, and some additional features can be easily implemented to add value for different stakeholders. Features like Air-to-Air ranging[23], Surveillance, or enhancing DFMC GBAS are possible. Also, additional navigation information can be easily transmitted, like TBO (Trajectory Based Operation), and 4D trajectories.
- The technology is mature and currently at the standardisation and industrialisation phase, both Frequentis AG and Leonardo SpA have built fully functional and interoperable prototypes. LDACS was tested by DLR, the German Aerospace Centre, in March 2019. The flight campaign showed all the major capabilities in practical scenarios, with industrial demonstration equipment.[24] The horizontal positioning error was measured under 10m, so the LDACS-NAV would easily meet the RNP 0.3 requirements.
- The flight test data is contributing to the validation of ICAO SARPs (Standards and Recommended Practices) and is the first truly iCNS system recognised by ICAO. Within the ICAO Communication Panel, a standardisation group has started work on LDACS.

The best roll-out scenario will come from the VDL Mode 2 infrastructure. With a multi-mode LDACS/VDL avionics, no additional antennas or connectivity is needed. This will enable the progressive relief of VDL Mode 2 and ensure immediate use and revenues from LDACS.

For navigation, the LDACS-NAV will first be used to augment the DME system. In Germany, DFS evaluated that, combined with the DME network, 17 LDACS ground station enable a robust RNP 1 over the country and 89 stations allow an RNP of 0.3[25]. This progressive implementation of LDACS-NAV will provide a lot of flexibility to serve the local demand. For instance, three LDACS stations combined with DME or five or six standalone LDACS stations can fulfil RNP 0.3 accuracy around a major national airport like Munich or Frankfurt[26]. In the longer term, the DME stations can be replaced progressively by LDACS ground stations.

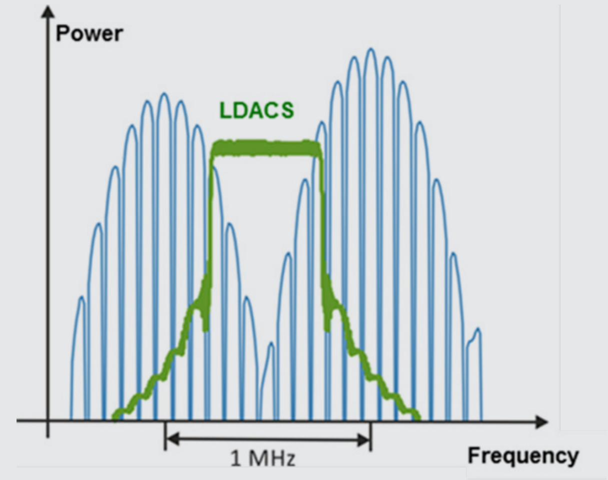

Figure 7: LDACS inlayed between DME frequencies ©DLR

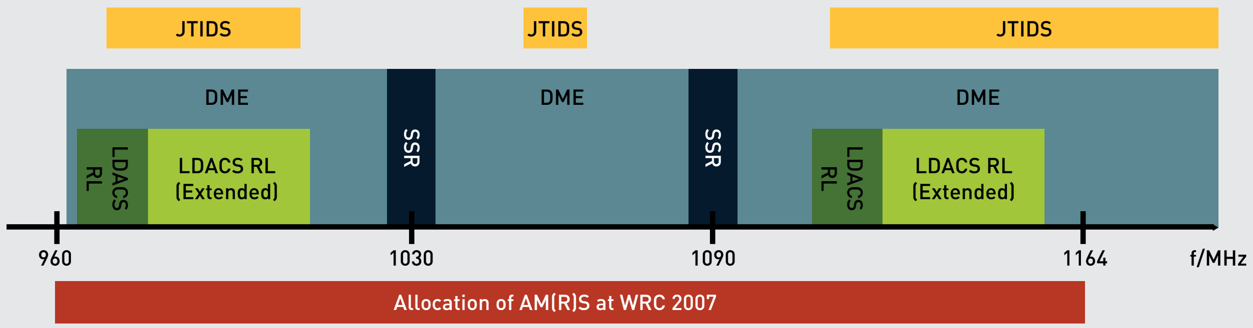

Figure 8: Proposed frequency assignment for LDACS forward link (FL) and reverse link (RL)[27] ©DLR

[23] Oceanic APNT Using Air-to-Air Ranging, DLR and EUROCONTROL, November 2019

[24] ICAO Working paper, Communication panel – data communications infrastructure working group, "LDACS White Paper – A Roll-out Scenario", October 2019.

[25] DLR, "Placing LDACS-Based Ranging Sources for Robust RNP 1.0 Accuracy En-Route" 2017: https://elib.dlr.de/130751/1/BattistaKumarOsechas_RobustRNP1.pdf

[26] DLR, "Demand-Based Placement of LDACS Ground Stations to Achieve RNP 0.3 Accuracy for APNT" 2017 : https://elib.dlr.de/111153/1/ION_ITM_2017_RACHIT_KUMAR.pdf

[27] FL: Ground to Air, RL: Air to Ground. The light green represents possible extension bands. JTIDS: military Joint Tactical Information Distribution System. SSR: Secondary Surveillance Radar.

LDACS-NAV REMAINING QUESTIONS

Given all these positive points, LDACS-NAV seems like the perfect solution. But some questions remain unanswered. To provide one hundred per cent coverage to European airspace above FL100 for COM purposes, around a hundred ground stations are needed, depending on the range (60-120 nmi) and optimisation process near airports[28].

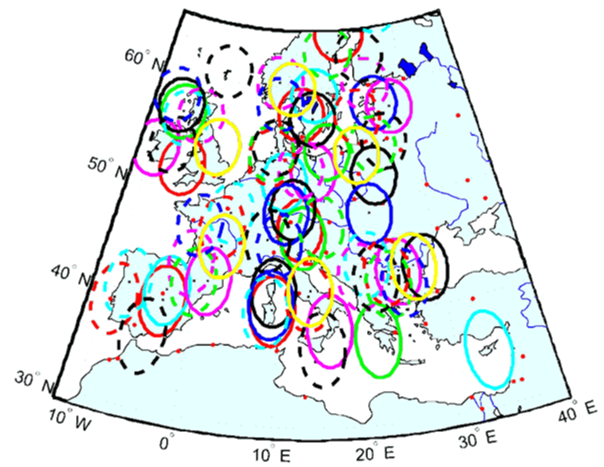

Figure 9: DME compliant LDACS Deployment in Europe[29] ©DLR

CELL PLANNING

However, to reach a good NAV performance, the requirements would be far more stringent. Indeed, the tests for the NAV performance were realised in a much smaller 65x44km (35x24 nmi) rectangle[30] outside Munich and maintained a good GDOP (Geometric Dilution of Precision)[31]. The tested cell size had an effective range of 130 km[32].

To fully validate the LDACS-NAV concept, further studies and large-scale demonstrations must be conducted to evaluate the performance of this system over a larger area. Specifically, a cell planning study is needed to evaluate the number of ground stations needed to cover the European Union, with and without the support of the DME network and with the RNP 0.3 and RNP 1 requirements.

COST-BENEFIT ANALYSIS

A detailed cost/benefit analysis (CBA) study must be undertaken to evaluate the cost of an EU-wide LDACS-NAV network, taking into account:

- The manufacturing and deployment costs of ground stations, identifying whether colocation with current DME equipment is suitable or not, and the potential economies of scale generated by more than a hundred ground stations.
- The different costs of ground stations depending on their range and bandwidth. The specific costs of a navigation-only ground station.
- The equipage costs of a multi-mode LDACS/VDL avionics, identifying whether it can support the NAV functionalities or not.
- The equipage costs of a dedicated avionic system.
- The long-term benefits of decommissioning the legacy NavAids.
- The direct operational benefits to provide a reliable, low latency and cost-efficient communication and navigation network for all aviation stakeholders, including secured proprietary information for airlines and aircraft manufacturers, and including full 4D trajectory-based operations and flight-centric air traffic management for ANSPs.
- The benefits of having a back-up system in case of a localized or generalised GNSS failure.

If the CBA study, with the cell planning study, suggests a positive economic advantage to implement the LDACS system compared to the current system or the other potential A-PNT solutions, then European Institutions could select LDACS as the official long-term A-PNT solution in the CNS Roadmap & Strategy and enable the SESAR Operational Concept high-level goals. This would help accelerate the standardisation and industrialisation activities to resolve the current lack of redundancy in our CNS systems.

[28] FEASIBILITY OF LDACS1 CELL PLANNING IN EUROPEAN AIRSPACE Felix Hoffmann, Ulrich Epple, Michael Schnell, Uwe-Carsten Fiebig German Aerospace Center (DLR), Wessling, Germany 2012

[29] The different colours indicate different LDACS frequency assignments.

[30] L-Band Digital Aeronautical Communications System Flight Trials in the National German Project MICONAV

[31] GDOP express the need to spread in space the ranging ground station to increase accuracy.

[32] LDACS Implementation and Validation, LDACS.com

CONCLUSION:

What can be concluded from both the US and European programmes on A-PNT is that the options available are clear, but it is very difficult to identify a strong favourite due to missing global decision mechanisms and supporting metrics.

Clearly, minor evolutionary enhancements of DME would be the simplest option for navigation. But it is quite possible that such a choice would continue to exacerbate compatibility challenges in the L-Band, therefore leading to a dead-end street when considering the overall CNS context. By contrast, ICAO is working on the LDACS-NAV concept, and could provide a complete, integrated-CNS, secure and future proof A-PNT solution, which must be tempting.

Can (and should) aviation maintain its low spectrum efficiency impunity and keep the same navigation system for a century? Or is it time now for the industry to invest for the future, get rid of the burden of legacy NavAids, and slowly but surely catch up with the rest of the communications industry?

Contact us to know more about the future of aviation.

WWW.EGIS-GROUP.COM

Follow Egis on:

Egis
15, avenue du Centre
CS 20538 - Guyancourt
78286 Saint-Quentin-en-Yvelines Cedex
France

Authors: Maxime de Villers, Andrew Burrage & Philip Church

contact.egis-avia@egis.fr