

EMERGING TECHNOLOGIES FOR FUTURE SKIES: AIRBORNE CAPABILITIES



SHAPING
OUR
FUTURE
SKIES

Acknowledgements

This paper was produced by the CANSO Strategic Technology Workgroup as part of a series examining emerging technologies. CANSO would like to thank the following experts and their organisations for their dedication and commitment in developing this document:

- Olivier de La Burgade, Thales
- Edward DeMello, Boeing
- Anthony MacKay, NAV CANADA
- Bernard Mouton, Airbus
- William Penhallegon, The MITRE Corporation
- Pascal Rohault, Thales
- Patrick Souchu, DSN

Contents

1. Introduction

1.1 General Description

The accelerating pace of technology is creating new opportunities for the airborne platform to play an increasingly important role in Air Traffic Management (ATM). Organisations such as Air Navigation Service Providers (ANSPs), government agencies, research companies, operators, and equipment manufacturers have, for years, been researching, developing, and deploying new flight deck-based capabilities to improve operational efficiency and safety in the air and on the ground. These capabilities enable concepts and operations with the potential to transform the role of the aircraft to a much more active participant in the management of airborne traffic in all domains and phases of flight.

Over the next decade and beyond, operations enabled by these capabilities promise more efficient trajectory management, including spacing and separation operations with fewer interventions needed by the ground, reduced climate impacts, improved communications, increased safety, and better decision-making by flight crews, air traffic controllers and dispatchers.

Airborne technologies are at various levels of maturity with respect to concepts of operation, availability of avionics standards, equipage, and operational deployment. Some of these technologies, such as Performance Based Navigation (PBN), Ground-Based Augmentation System (GBAS), and controller-pilot data link communication (CPDLC) already have well-established implementations and are planned for significant capability updates. Other technologies, for example Automatic Dependent Surveillance - Broadcast (ADS-B) In, 4D Trajectory Based Operations (TBO), and Digital Departures have already seen initial deployments and are expected to become increasingly mature and capable over the next decade. Future technologies, like Extended Project Profile (EPP) and trajectory negotiation applications, single pilot operations, and the technologies that will facilitate formation flight, may see initial operating capabilities before 2030 and will further revolutionise the role of the aircraft in ATM.

This document examines several of the key flight deck technologies and concepts that are expected to have significant impacts on ATM operations over the next decade and beyond. It describes the benefits, impact, and challenges for each, along with its state of maturity. Many of the applications included here are being developed in parallel and will be ready for deployment in similar timeframes. However, they are often not being matured in an integrated manner and in consideration for how they can be jointly implemented. As a result, ANSPs, manufacturers, and operators face a significant challenge in integrating these capabilities into flight deck and ground automation systems, developing enabling procedures, and training flight crews, air traffic controllers, and managers to incorporate them into their operations in a coordinated way.

CANSO supports the need for regional, if not global, governance with the adoption of these airborne capabilities (and the relevant counterparts on the ground) in order to foster operational harmonisation and cost effectiveness, along with an acceleration towards realising the significant benefits. With so many potential technologies becoming available, an overall airborne technology survey, such as that provided by this document, is an important step for ensuring effective deployments so that the on-going investments in the airborne platform will yield the promised benefits for the system as a whole.

1. Introduction

1.2 Background and Maturity Levels

Many of the technology applications described in this document are being developed for implementation under the Next Generation Air Transportation System (NextGen) and Single European Sky ATM Research (SESAR) programmes in the U.S. and Europe, respectively.

NextGen is administered by the Federal Aviation Administration (FAA). The SESAR Joint Undertaking (SESAR JU) is responsible for coordinating ATM relevant research and development efforts in the European Union (EU). It is a public-private partnership between the main public stakeholders (i.e. the European Union and EUROCONTROL), European air navigation services, and the manufacturing industry. The subsequent activities that require synchronised deployment as part of a 'Common Project' are administered by the SESAR Deployment Manager (SDM). These programmes are intended to modernise aviation systems to improve safety, efficiency, and interoperability not just across the Atlantic but globally in support of the International Civil Aviation Organisation (ICAO) Global Air Navigation Plan (GANP, Doc 9750) and its Aviation System Block Upgrade (ASBU) programme.

International deployments are intended to be harmonised through joint participation in standards organisations such as the Radio Technical Commission for Aeronautics (RTCA) and the European Organisation for Civil Aviation Equipment (EUROCAE). Once this standardisation is achieved, full interoperability is expected to be championed by CANSO, IATA, RTCA, EUROCAE, and ICAO to expand the technology adoption to aircraft and ATM systems built for worldwide use. The successful implementation of this process requires commitment from all members of the aviation community. The planning process at the global, regional and national levels should enable a well-understood, manageable and cost-effective sequence of improvements that meet user needs and culminate in a well performing air navigation system.

To be approved for installation and use on board an aircraft, airborne systems are typically defined through an RTCA/EUROCAE process that includes input from ANSPs, industry, users, and research organisations. The key documents that are produced in this process normally include:

- **Operational Service & Environment Description, Safety, Performance, and Interoperability Requirements (OSED/SPR/INTEROP)** documents that describe the operational use of the application, derive functional and possible system architectures as well as the required equipment performance to support operational objectives, and ensure the use of the equipment meets Target Levels of Safety.
- **Minimum Aviation System Performance Standards (MASPS):** As defined by RTCA¹, MASPS documents "...describe the system (subsystems / functions) and provide information needed to understand the rationale for system characteristics, operational goals, requirements and typical applications."
- **Minimum Operational Performance Standards (MOPS)** documents capture the minimum set of requirements that equipment designers must implement to ensure the system properly performs its intended functions.

The international standards described above for aircraft do not have necessarily an equivalent standard for the ground segment beyond DO-278A/ED-109 used by some ANSPs in their ATM equipment development. Many ANSP requirement definitions for ground systems that enable the use of proposed airborne applications are typically defined and implemented by ANSPs and their contractors.

The maturity level of a concept or system is usually defined by where it stands in the research and development process, the existence and testing or prototypes, avionics and ground system standards maturity, proximity to an Initial Operating Capability (IOC), product availability, and degree of implementation.

¹ [rtca.org/standards/standards-guidance-materials](https://www.rtca.org/standards/standards-guidance-materials)

1. Introduction

1.2 Background and Maturity Levels (continued)

This document generally classifies the maturity of each airborne tool in terms of the following three classifications:

- **R&D Initiative:** Whether a proposed concept or system is still in the early development stage, which may consist of concept of operations documents and draft air and ground equipment requirements. This phase may also include initial prototype development and testing. Though vendors may be planning product lines based on expected final requirements, regulator certification guidance and products are not yet available.
- **Industrial Product Development:** Here, the concept is mature and system requirements are either about to be or have been published, such that vendors can invest in product development with a reasonable expectation of regulator certification and approval.
- **Early Local Implementation:** A system reaches this stage when it achieves an IOC and is starting to be used during revenue operations in at least one location. Here, certified equipment has been installed on airframes and approved for certain operations. Ground systems have been modified as needed (or workarounds identified) and system users, e.g. flight crews and air traffic controllers, are trained to support the operations.

The concepts, technologies, and systems are described in the next section as Fields of Application, and include maturity assessments related to these levels of classification.

2. Fields of Application

2.1 Overview

Numerous concepts and technologies have been identified that will improve the safety and efficiency of air traffic management systems over the next decade. The operational objectives, benefits, enabling technologies, and maturity, are specific to each and are thus described on a per-application basis in this section. Some applications apply across domains and are grouped by their enabling technology. Others are grouped in terms of their operational domain. Groupings do not necessarily imply that the related applications will be deployed in similar timeframes. In addition, the applications often involve air and ground components and will thus be relevant to both airspace users and ANSPs. This document, therefore, does not attempt to categorise the applications as unique to either.

2.2 Four Dimension Trajectory Based Operations - 4D TBO

2.2.1 Description

4D Trajectory Based Operations represent a paradigm shift away from today's (radar)-sector-based operations. 4D TBO provides air and ground stakeholders a common view of the aircraft's trajectory, so that the flight can be managed as closely as possible to the airspace user's ideal profile, while optimising the flow of air traffic. Throughout the flight, detailed information about the future projected position of the aircraft is exchanged with all service providers en route. The trajectory is defined in four dimensions (4D) which are composed of the three geometrical dimensions (latitude, longitude and altitude), and time. The expected time at each waypoint, including both ATC and Trajectory Change Points, along the trajectory is estimated with high accuracy and reliability.

During the flight execution, 4D TBO Operations are enabled by message exchange using enhanced data link technology: multiple link types, including Broadband communications, and applications such as Automatic Dependent Surveillance – Contract (ADS-C) and Controller Pilot Data Link Communications (CPDLC) – and enhanced Flight Management System

capabilities, along with broadband IP based communications for dissemination of constraints and negotiation of changes. These technologies enable the aircraft to exchange real-time trajectory information with ATC and flight data processing systems.

The ADS-C datalink application is the vehicle for the aircraft system to transmit airborne trajectory prediction to the ground (mainly via the Extended Projected Profile report). It allows the ground to support many ATC functions (Flight plan check, conflict detection, conflict resolution, flow and sequencing tools) based on a better anticipation of aircraft behavior. System Wide Information Management (SWIM), through IP broadband links is used to share system constraints with airspace users, including the airplanes. Additionally, emerging applications that may be hosted external to the certified avionics system (i.e. not integrated in the FMS or CMF) equipment (e.g. on an Electronic Flight Bag [EFB]) may also be employed to provide and negotiate aircraft trajectories. These will be over broadband links, and may communicate with various ground entities to provide services in coordination with ATM.

With the help of automation, users are constantly watching for opportunities to further improve efficiency and asking for changes when opportunities arise. They can also minimise disruptions by planning ahead. When necessary, the controller can instruct more complex route modifications (i.e., affecting the route potentially within the upstream ATC airspace) to the flight crew via CPDLC messages (ATS-baseline 2, or B2). After acceptance by the flight crew, a new ADS-C EPP message would be automatically generated by the aircraft system and shared with the Ground system, thus closing the loop.

One of the many applications that may be used for absorbing Terminal Maneuvering Area (TMA) delays is the use of RTA clearances over optimised flight profiles. The more recent avionics compliant with §DO-236D can meet time constraint within 10 sec accuracy, while ATCO can use the a/c downlinked ETA min/max to send informed RTA clearances.

2. Fields of Application

2.2.2 Benefits

The 4D TBO will improve airspace capacity and efficiency by allowing better coordination between air traffic controllers and airspace users, including aircraft (thanks to information exchange facilitation), while enhancing safety, thanks to:

- Increased predictability
- Earlier resolution of disruptions
- Less vectoring and holding patterns resulting in less fuel burn and delays
- Aircraft flying closer to its optimal trajectory

It will also improve traffic handling for controllers (fewer spurious conflicts, situations well known in advance, reduced workload) and will help in reducing excess CO₂ emissions and costs for airlines.

2.2.3 Maturity

Initial application of 4D TBO has been used extensively during the SESAR Projects PEGASE (on ferry flights), DIGITS (on revenue flights) and now ADSCENSIO. An initial RTA capability is also available in many FMS installations, though updated requirements for a standardised RTA capability are currently being defined in RTCA DO-236D. In addition, projects in the US and Asia including the Boeing ecoDemonstrator, FAA 4DT and Multi-region TBO, have been researching the application of TBO in real-world demonstrations. Overall, 4D TBO is considered to be at the *Industrial Product Development* stage.

2.2.4 Impact

The 4D TBO allows improved trajectory predictions of ATC systems, which support in particular conflict detection functions. It can enable controllers to better build the sequence of arriving aircraft considering each aircraft's ETA window at a metering point.

4D TBO also has the potential to enable significant environmental benefits and is a key area in the expected contribution of ATM to aviation CO₂ emissions reduction.

2.2.5 Challenges

The B2 application is certified on approximately 100 Airbus single aisle and wide body aircraft. Boeing aircraft are not equipped with B2, and likely will not be until it's mandated. The challenge is getting a meaningful number of equipped aircraft, developing the applications on the ground that provide benefits given the costs of upgrading (especially without using B2 CPDLC), having communication networks that can handle the increased capacity and speed necessary, handling mixed equipage B1/B2, and ensuring that all ground systems are functioning prior to the mandate. Another challenge is the deployment of tools on the ground and procedural changes within ATM and ATC to fully exploit the aircraft capabilities in applications such as:

- Optimisation of Climb and Descent Profiles
- Onboard Vertical Conformance Monitoring /Alerting
- Conflict Detection
- Sequencing Management
- Demand and Capacity Balancing
- Complexity Management
- Dynamic Airspace Allocation
- Consistent capability deployment across ground systems in EPP processing, including operational concept definition at a system requirements level
- Trajectory brokering functionality between ATC ground systems, given the step-wise deployment
- Uplinking CPDLC messages supporting TBO, since B2 CPDLC is not yet mandated in Europe or in Australia
- Handling mixed equipage environments given the smaller percentage of equipped aircraft
- Slower/uneven deployment roll-out by ANSPs around the world
- Capacity constraints of current deployed technology

2. Fields of Application

2.3 Performance Based Navigation (PBN) Approach Operations

2.3.1 Description

PBN Approach Operations discussed here will consider two different types of approach operations that are dependent on GNSS; Required Navigation Performance Approach (RNP APCH), (LNAV, LNAV/VNAV, LPV), and Required Navigation Performance Approval Required (RNP-AR). APV (Approach with Vertical Guidance) is divided into procedures with altimetry based Barometric VNAV (APV) and Geometric based SBAS vertical guidance. The following table provides differentiating information.

PBN Type	GNSS Augmentation	Vertical Guidance Type	Approach Design	ATC Impact Air	ATC Impact Ground
RNP APCH and RNP-AR Approach (LNAV/VNAV) Type A $\geq 250'$	Internal Aircraft Integrity Monitoring	Barometric Altimeter Based	Linear obstacle clearance areas for lateral and vertical	Efficient approach operations in terrain or airspace constrained airports Established on RNP (EoR) operations	No limitations protecting ILS beam forming areas (no ILS critical or sensitive area) During RNP APCH Operations Increase airport throughput
RNP APCH (LPV) Type A $\geq 250'$ Type B, CAT I $< 250', \geq 200'$	Space Based Augmentation (SBAS) (WAAS/EGNOS) ¹	GNSS Geometric Based	Angular obstacle clearance areas for lateral and vertical (similar to ILS)	Efficient ILS like approach operations to APV-I or CAT I minima	

¹ Other SBAS systems are in development or early operational stages. Australian SBAS, ASECNA SBAS, GAGAN (India), BDSBAS (China), MSAS (Japan), SDCM (Russia), SACCSA (South America).

RNP and RNP-AR approach operations require no ground monitoring, as the accuracy, integrity and continuity of the system is either internal to the aircraft or, in some cases, provided by SBAS. SBAS requires ground monitoring stations within the service volume that provides GNSS corrections over large geographic areas.

2. Fields of Application

2.3.2 Benefits

RNP APCH, including SBAS based APV-I & CAT I, approach procedures may reduce air traffic and terrain separation standards, improving airport access and increasing traffic throughput. Airport throughput is increased as ILS CAT I protection areas need not be protected for ground operations. Aircraft holding for take-off can be closer to the runway and spacing on final approach can be reduced as aircraft exiting the runway will not interfere with the ground-based approach guidance radio signals.

With LPV (SBAS APV-1) approaches, ILS like operations may occur on precision certified runways, without ILS ground equipment installed on each runway end (lighting and runway marking requisites are the same as for a Precision ILS CAT I approach). LPV offers more resilience at airports where it is implemented, by providing CAT I ILS type approach limits to more in-to-wind runways, reducing operational disruption due to low ceilings and reduced visibility. Moreover, RNP APCH procedures (SBAS and Baro-VNAV) make possible the deployment of approaches with vertical guidance to non-precision and non-instrument runway ends with associated minima for non-precision and non-instrument runways.

RNP and RNP AR enable stable approaches in difficult terrain environments and in environmentally sensitive areas through the inclusion of multiple RF flight legs, removing the constraint of straight-line approach paths required for conventional navigation aids like ILS and VOR. Environmental benefits can also be expected through noise and CO₂ emissions reductions, especially when combined with CDA/CDO, as described in section 2.7.2.

2.3.3 Maturity

RNP APCH (LNAV, LNAV/VNAV) and RNP-AR are widely available and in use. The MASPS and MOPS are well defined for RNP APCH and RNP-AR aircraft equipage with most major avionics manufacturers providing RNP enabled FMS equipment. The USA and Canada currently have well developed RNP APCH (LPV) RNP-AR approach procedures, and Canada has adopted EoR, where two aircraft can be cleared simultaneously for approaches to parallel runways from their respective downwind legs. Using RF (radius to fix) legs, the aircraft is considered on final approach in the downwind, and transitions from the downwind turning to final approach at approximately 3nm from the runway threshold.

RNP APCH (LPV) is at the *Early Local Implementation* stage of maturity in some parts of the world and very mature in others. Areas served by WAAS (USA, Canada, Mexico) and EGNOS (Europe) have thousands of APV-LPV approach procedures currently in use. The European Commission has mandated LPV as the main CAT I approach type by 2030. The MASPS and MOPS are well defined for LPV aircraft equipage, with most major avionics manufactures providing LPV enabled FMS equipment. Aircraft Original Equipment Manufacturers (OEMs) historically have been split on the applicability of RNP (LPV) vs RNP (LNAV/VNAV) and RNP-AR, with regional aircraft (100 seats and smaller) being well equipped with LPV while traditional narrow body and wide-body aircraft opted for LNAV/VNAV and RNP-AR. That gap is now narrowing with some regional aircraft being LNAV/VNAV, LPV and RNP-AR equipped and some narrow and wide-body aircraft offering LPV in addition to RNP-AR.

2. Fields of Application

2.3.4 Impact

The impact of PBN enroute and approach operations reduces reliance on the ground segment (conventional navigation aids) for navigation. In the enroute, track segments no longer need to go in straight lines for great distance. States can eliminate local airspace definitions and requirements in favor of ICAO-PBN defined airspace requirements, simplifying international operational certification for air carriers.

In the approach segment, optimised lateral paths can, in some instances, be constructed to avoid noise sensitive areas, hazardous terrain and constrained airspace, reducing community impacts while increasing safety and efficiency. ANSPs will need to undertake controller training to manage mixed equipage with aircraft on RNP tracks versus tactical vectoring in constrained areas. RNP-AR procedures allow for aircraft to meet stabilised approach criteria without the requirement for a long straight-in final approach.

ANSPs will be able to reduce navigational infrastructure costs through the decommissioning of traditional ground-based navigation aids to a minimum operational network (MON) level, where RNP APCH (LNAV/VNAV), RNP-AR and RNP APCH (LPV, with SBAS) become primary mode of operation and ILS - VOR/DME - DME/DME become backup modes of navigation within a minimum operating network in case of GNSS unavailability.

2.3.5 Challenges

RNP and RNP APCH implementation (PBN) plans vary between States, ANSPs and airports. There is also a lack of RNP certification on some older regional aircraft due to, for example, the lack of IRUs. The application of incentive structures, such as Best Equipped Best Served, may increase RNP equipage.

PBN approach procedure definition expertise will be required to expand worldwide RNP APCH (LNAV/VNAV), RNP-AR and RNP APCH (SBAS). Having mixed equipage aircraft arriving to the same airport can increase traffic management complexity in the TMA and needs to be managed to achieve expected benefits.

While LPV (SBAS APV-I) approaches will provide navigation aid accuracy, integrity, and continuity for precision like approaches to more runway ends, LPV CAT I (Type B) with possible minima of 200' AGL, will be limited by, airport, runway certification and lighting to meet precision runway requirements to all runway ends, and costs in some regions.

Robustness of GNSS PBN based approaches of all types in regions with high ionospheric activity presents an issue of availability of service, particularly during highly active times or in regions with daily ionosphere activity, such as near the magnetic equator. In these regions, dual-frequency multi-constellation improvements may provide sufficient availability and robustness, but ILS may remain a required backup mode for precision approach in some regions. As reliance on GNSS increases, the importance of protection of the radio frequency spectrum becomes critical due to the low-power characteristic of satellite signals. Radio frequency interference can disrupt GNSS approach operations for days or weeks until the source can be found and mitigated, further supporting the need for ILS and other conventional navigation aids as permanent backup capabilities.

Different aircraft OEM philosophies on future navigation capabilities has segmented aircraft equipage in the past between RNP (LPV) and RNP (LNAV/VNAV) solutions. These previously competing navigation capabilities within different aircraft types appear to be converging to allow for all PBN approach types in the near future.

2. Fields of Application

2.4 GBAS-based (GLS) Approach Operations

2.4.1 Description

GBAS provides very precise GNSS corrections through a local ground monitoring station subsystem typically covering a service volume of airspace for one airport.

Navigation Type	GNSS Augmentation	Vertical Guidance Type	Approach Design	ATC Impact Air	ATC Impact Ground
GBAS Approach	Ground Based Local Area Augmentation (GBAS)	GNSS Based Geometric	Angular obstacle clearance areas for lateral and vertical (like ILS)	Efficient ILS like approach operations to all runway ends with future CAT III minimums	No limitations protecting ILS beam forming areas (no ILS critical or sensitive area) During RNP APCH Operations Increase airport throughput

2.4.2 Benefits

GBAS-based approach procedures have different air traffic and terrain separation criteria. Airport throughput is increased as ILS protection areas need not be maintained during GBAS approaches for ground operations. Aircraft holding for take-off can be closer to the runway, and spacing on final approach can be reduced as aircraft exiting the runway will not interfere with the ground-based approach guidance radio signal.

With GBAS approaches, ILS like operations may occur on precision certified runways without ILS ground equipment installed on each runway end (lighting and runway marking requisites are the same as for an ILS approach). A single GBAS can accommodate approaches to all runway ends and offers more resilience at airports where it is implemented, by providing ILS type approach limits to more in-to-wind runways, reducing operational disruption due to low ceilings and reduced visibility. GBAS offers the ability for advanced procedures like displaced threshold and multiple different glideslopes, either for obstacle clearance or noise abatement benefits. Operational costs for GBAS are lower in part due to reduced flight inspection cost.

2.4.3 Maturity

GBAS Cat II/III is at the *Industrial Product Development* stage. Multi-Mode Receivers available on narrow- and wide-body aircraft have been in use to enable GBAS operations under limited trials in the United States and elsewhere. Five GBAS manufacturers produced prototype GBAS stations to support trials and requirements validation. Certification of a Cat III capable GBAS is being pursued and is anticipated in the coming years.

GBAS Cat I is at the *Early Local Implementation* stage of maturity. Countries implementing GBAS (Russia, USA, Australia, Germany, Japan, for example.) have several stations currently in use. Thousands of narrow and wide-body aircraft offer GBAS Cat I capability as standard or optional. GBAS Cat I facilities have the potential to also offer use in Category II conditions subject to local operational approval on a case-by-case basis.

2. Fields of Application

2.4.4 Impact

GBAS based approaches provide for ILS like approaches operation to CAT I, II and III minima without costly-per-runway ground infrastructure and limitations.

ANSPs will be able to reduce navigational infrastructure costs through the decommissioning of traditional ground-based navigation (in this particular case those involved in the supporting of conventional approach procedures) aids to a minimum operations network (MON) level where GBAS become primary approaches and ILS and other systems become backup modes of navigation.

2.4.5 Challenges

While GBAS approaches can provide navigation aid accuracy, integrity, and continuity for precision approaches with minima 200' AGL and lower, as with ILS, airport, runway certification and lighting then become the limiting factor for precision approaches to all runway ends.

Robustness of GBAS based approaches of all types in regions with high ionospheric activity presents an issue of availability of service, particularly during highly active times or in regions with daily ionosphere activity, such as near the magnetic equator. In these regions, dual-frequency multi-constellation improvements may provide sufficient availability and robustness, but ILS may remain a required backup mode for precision approach in some regions. As reliance on GNSS increases, the importance of protection of the radio frequency spectrum becomes critical due to the low-power characteristic of satellite signals. Radio frequency interference can disrupt GNSS approach operations for days or weeks until the source can be found and mitigated, further supporting the need for ILS and other conventional navigation aids with a minimum operating network as permanent backup capabilities.

Different aircraft OEM philosophies on future navigation capabilities has segmented aircraft equipage in the past. These previously competing navigation capabilities within different aircraft types appear to be now converging to allow for all approach types in the near future.

2.5 Airborne ADS-B in Applications

Airborne applications enabled by Automatic Dependent Surveillance-Broadcast (ADS-B) In technology promise significant capacity and efficiency benefits beyond what is achievable with ground systems alone, especially when integrated with Trajectory-Based Operations (TBO). The major applications being developed for nearer-term deployment are described in this section.

2.5.1 Description

Beyond basic situation and traffic awareness, several ADS-B In applications for airborne phases of flight are currently being developed and deployed. They include the following.

- **In-Trail Procedure (ITP)**, which enables flight crews to optimise their flight level when not otherwise possible in oceanic, non-radar airspace.
- **Cockpit Display of Traffic Information (CDTI)-Assisted Visual Separation (CAVS)**, which allows for the continuation of current visual approach and pilot-applied visual separation procedures after a lead aircraft is temporarily lost in conditions such as haze. The CDTI supports the visual separation task and initial traffic visual acquisition out-the-window and CDTI correlation is required.
- **CDTI-Assisted Separation (CAS)**, which builds on current-day pilot-applied visual separation and CAVS operations to single runways to allow for the continued use of visual-like separation between successive departures or arrivals in conditions where flight crews cannot identify or maintain out-the-window visual contact with a lead aircraft. Here, the CAS-capable aircraft can be operating in weather conditions that do not allow for the conduct of visual operations and the controller will have knowledge of CAS-capable aircraft and use aircraft identification when identifying the lead aircraft. Unlike CAVS, initial traffic visual acquisition out-the-window is not required.
- **Interval Management (IM)**, which describes a set of beneficial operational applications in which the flight crew of a trail aircraft follows flight-deck generated speed commands to achieve or maintain a spacing objective specified by a controller.

2. Fields of Application

2.5.2 Benefits

Each individual application has a specific benefits mechanism, though the overall operational goal is increased capacity and efficiency, especially in high density airspace. The Oceanic ITP application saves time, fuel², and emissions by enabling aircraft to more consistently fly at their optimal altitudes. It also allows aircraft to avoid turbulent altitudes. The CAVS and CAS applications increase resilience in low visibility conditions by allowing for near pilot-applied visual separation-like capacities when visual operations would either not be possible or would have otherwise been suspended. The Interval Management applications result in precise, inter-aircraft spacing relative to another aircraft. It improves spacing consistency by enabling more frequent trajectory adjustments than possible with a ground system alone, which results in increased arrival throughput. ATC and flight-crew workload may also be improved with fewer ATC instructions during high-workload portions of the flight thanks to the added airborne functionality and ground-based automation system to support the ATCO.

2.5.3 Maturity

RTCA Special Committee (SC) 186 Working Group (WG) 4 and EUROCAE WG-51 Sub-Group (SG) 3 have been working for over a decade to document requirements for ADS-B In applications. Avionics requirements for ITP were first published in the Aircraft Surveillance Applications (ASA) MOPS version DO-317A/ED-194, and CAVS was added in DO-317B/ED-194A. The ASA MOPS document has since been updated to DO-317C, and the FAA is currently examining whether the CAS application can leverage these standards without any changes. In 2020, RTCA published Flight-deck Interval Management (FIM) Safety and Performance Requirements (SPR) (DO-328B/ED-195B) and the FIM MOPS (DO-361A/ED-236A) to enable IM benefits in a variety of environments. The FAA is updating the Technical Standard Order (TSO)-C195b to include the IM capability and reference the most recent version of the IM MOPS. The CAVS and ITP applications are available today; ground system functionality enabling CAS and IM operations is yet to be deployed.

As an overall roadmap to current and future application implementation, an ADS-B In deployment strategy document has been published by the Equip 2020 Industry and FAA Working Group and is publicly available. Also, in 2020, ICAO published a second edition of the Manual of Airborne Surveillance Applications (Doc 9994), which supports ASA implementation and summarises guidance material related to the standards and recommended practices. It includes descriptions for each of the various applications, the benefits, and implementation considerations for stakeholders.

Airbus, Boeing, and various avionics companies offer products that support one or more of these applications, though not always current with the most recent standards. For example, the FAA-certified Aviation Communication & Surveillance Systems (ACSS) SafeRoute+ equipment, which will be used for the 2021-2023 ADS-B In Retrofit Spacing (AIRS) Evaluation, includes a DO-317B/ED-194A-compliant version of CAVS. It also includes an ITP capability and an initial version of the IM application, covering a sub-set of the capabilities defined in DO-361A. American Airlines is in the process of equipping their entire fleet of Airbus A321 aircraft with SafeRoute+ equipment. Other vendors, such as Honeywell, have developed prototype equipment for ADS-B In flight tests, such as NASA's Air Traffic Management Technology Demonstration-1 (ATD-1) flight test in 2017. In addition, a flight test conducted by United Airlines and Alaska Airlines at San Francisco and Tucson International Airports in 2019 demonstrated the feasibility and benefits of an IM arrival application termed Paired Approach.

The CAVS and ITP applications have been approved by the FAA and guidance is available via Advisory Circular 90-114B. The FAA has also modified the Advanced Technologies & Oceanic Procedures (ATOP) automation system to make ITP operational at all US Oceanic Centers (i.e., Anchorage, New York, and Oakland). CAVS and ITP are therefore at the *Early Local Implementation* stage. IM will require more significant ground system changes than CAS and both are at the *Industrial Product Development* stage.

² During operational trials, the FAA and United Airlines estimated that aircraft equipped with ITP saved an average of 670 lbs. of fuel on transatlantic flights and 521 lbs. of fuel on transpacific flights.

2. Fields of Application

2.5.4 Impact

The impact on ATM to implement the airborne ADS-B In applications ranges from minimal (CAVS) to significant (IM). The individual impacts are as follows.

- **CAVS:** The impact of CAVS operations on ATM is minimal because operations are designed to be conducted in a way that is transparent to controllers. No changes to navigation, communications, or ground automation are required.
- **ITP:** The impact of ITP on ATM for US-based operations is currently minimal (while being under assessment in Europe) because avionics products are currently available to users and the procedure is operational at all US Oceanic Centers.
- **CAS:** The impact of CAS operations on ATM is minor-to-moderate because controllers will need aircraft capability display indicators and awareness of active CAS operations. Additionally, for maximum benefit, CAS operations must be accounted for in ground-based schedulers when metering operations are in effect.
- **IM:** The impact of IM operations on ATM is significant because IM operations require ground automation support, such as integration into scheduling systems and en route and terminal display systems. Procedural changes will also be required to achieve maximum benefits. However, some tactical IM operations are envisioned to be possible with aircraft capability display indicators alone.

ADS-B In message requirements (as specified in DO-350A/ED-228A, developed by RTCA SC-214/ EUROCAE WG-78 in conjunction with SC-186/WG-51) have not yet been implemented as part of B2. While capable, this specification will likely need additional validation and updating prior to implementation. There are also other ancillary systems that will be impacted on the aircraft, as well as the need for ground automation support.

2.5.5 Challenges

Though some limited ADS-B In operations have already been certified and deployed, one primary challenge to widespread ADS-B In implementation remains operator equipage. To demonstrate the benefits of the IM, CAVS, and CAS applications, the FAA, American Airlines, and avionics manufacturer ACSS are planning the AIRS Evaluation at selected facilities in the US National Airspace System (NAS). American Airlines A321 equipage has begun and ADS-B In operations will take place over at least one year to gather data and evaluate benefits. Results are expected to be available in 2024 and should help other potential users develop business cases for equipage. In addition, during operational trials, ITP requests by flight crews and acceptance by controllers were initially low. Various contributing factors have been identified by the FAA and users and Equip 2020 has since indicated that more equipage is increasing the use of the ITP application.

Going forward, regulators will need to work with vendors and users to upgrade installed equipment to bring it in line with the latest standards and eliminate the need for ground systems to manage equipment variants.

The other major challenge for application deployment beyond CAVS and ITP is implementing enabling requirements into ground systems. In the US, the FAA is on a path to add en route and terminal display features to indicate capable aircraft and is planning further system updates to support more complex applications. The timeframe and funding for these deployments, however, are subject to change as agency and operator budgets and priorities evolve over the next decade. Challenges to worldwide implementation are likely similar.

2. Fields of Application

2.6 Data Link Communications

Data Comm is a group of technologies modernising communications between air traffic controllers and pilots. Traditionally radio voice communications are used to pass clearances, requests and flight information between air crew and controllers. Radio broadcast voice communications are prone to readback/hearback errors, frequency congestion and call sign confusion errors.

Data Comm provides the ability to transmit flight plans, clearances, instructions, advisories, flight crew requests, flight plan conformance reports and other essential messages automatically or on request dependent on the nature of the information or critically of the message. A key factor in the expanded usability of Data Comm for services like TBO is the ability to load complex clearances into the FMC. This not only reduces chances for transcription errors but also links the aircraft and ground automation in ways that are impossible or impractical to do by voice.

Data Comm began in the late 1980s as ACARS which was primarily used as data communications between an airline's operation center and its aircraft. As the use of the equipment was expanded to include ATS, FANS-1 and FANS-A were developed to evolve to FANS-1/A+ (although notionally referred now to FANS-1/A). Europe developed the LINK 2000+ trial, pioneering Data Comm on ATN (Aeronautical Telecommunications Networks) instead of ACARS, paving the way to full deployment with the ATN-B1 (Baseline 1) CPDLC mandate (above FL285). Next step is ATS-B2 (Baseline 2) supporting additional applications (4D-TRAD, IM, DCL, D-ATXI, for example) with expanded CPDLC messages set and ADS-C that supports the exchange of trajectory information. Future updates will include moving to ATN using Internet Protocol Suite (ATN/IPS), which updates the legacy network protocols for both ATN and ACARS-based applications and provides the transition path to native internet protocol-based safety applications. Additionally, off-board systems such as Electronic Flight Bags (EFB) may be used to exchange information between aircraft and ground system, and can be used for enhanced services.

³ easa.europa.eu/en/downloads/137252/en

Apart from future updates on transmission protocols, the current HF/VHF data links cannot provide broadband services now or in the future due to various reasons including the lack of available radio spectrum. This drawback is becoming a limitation to enhanced ATM operations, such as TBO, 4D trajectory negotiations, and other enhanced services (i.e., B3, EFB).

Future data-link technologies like SATCOM Class B or A or LDACS (L-band Digital Aeronautical Communications System) are envisaged to overcome identified VDL Mode 2 shortcomings. SATCOM class B such as INMARSAT SwiftBroadband/Iris and Iridium NEXT constellation (Iridium Certus service) is at a level of maturity considered as ready for deployment to support the Baseline 2 ATS requirements, SATCOM Class A will be augmenting the current Class B systems for future aviation performance requirements (referred to as Baseline 3 ATS requirements).

A joint white paper by the European Aviation Safety Agency and the Federal Aviation Administration, in collaboration with Boeing and Airbus, entitled "Future Connectivity for Aviation" and published in November 2022 offers a jointly proposed vision for the future aviation connectivity landscape which is based on the combination of aviation specific solutions (VHF datalink and higher performance L-band SATCOM) that will offer guaranteed safety and performance with commercial, non-aviation specific solutions that are expected to provide high capacity and economic efficiency.³

2.6.1 FANS-1/A

2.6.1.1 Description

FANS-1/A consists of CPDLC, ADS-C and Airways Facility Notification (AFN, a logon capability) applications. FANS-1/A originally started operations in 1995 in oceanic areas. The global footprint and usage of FANS-1/A continues to grow, including in domestic airspaces such as the US as well as oceanic and remote airspaces. A key feature of FANS-1/A is the integrated nature of the CPDLC application, which allows single button push loading and execution of uplinked route clearances. This supports advanced services such as initial TBO.

2. Fields of Application

2.6.1.2 Benefits

Many different operations and services are supported with FANS-1/A, and since it is a mature technology there is a large equipage base (e.g. around 6000 equipped aircraft operating the US). This means that new services will benefit many airspace users. Oceanic and remote areas use CPDLC and ADS-C to provide communication and surveillance functions, resulting in decreased separation. Additionally, FANS-1/A can work over multiple subnetworks, including VHF Mode 0, VHF Mode 2, legacy narrow-band satellite and broadband satellite.

Current services include Departure Clearance (DCL) as deployed at US airports, various enroute clearance and position-reporting services provided throughout the world. The US DCL involves integrated FANS-1/A CPDLC clearances through (push to load), which is different than most other PDC-type services. Note: In Europe DCL service via ACARS based on EUROCAE ED-85A is provided as a direct exchange between Airport Tower and crew on many airports (e.g. Most of French major airports, LHR, EDDF).

FANS-1/A is well past the *Early Local Implementation* stage.

2.6.1.3 Impact

The impact on ATM is large. Implementing FANS-1/A reduces risk for regulatory and operational implementation of future data link by providing a known consistent messaging platform from which to start. Early benefits from services are realised and usable by a large, readily-available equipage base as the system is widely supported across different aircraft manufacturers and aircraft types. Although in service for a long time, there are still significant operational benefits from FANS-1/A.

2.6.1.4 Challenges

FANS-1/A is not recognised as providing the expected level of performance for high density traffic. For this reason, FANS-1/A aircraft are exempted from CPDLC mandate in Europe, this implies that these aircraft do not benefit from CPDLC services across Europe.

2.6.2 Baseline 1 and Baseline 2

2.6.2.1 Description

Baseline 1 (B1) and Baseline 2 (B2) are ATN-based applications. B1 was the original CPDLC application used in Europe, and consists of CPDLC and the Context Management (CM, logon function) applications. B1 had a reduced CPDLC message set and aircraft implementations largely do not support integration into the FMC which means no TBO-type operations are supported and is not considered further here. B2 is an upgrade of B1, and has CPDLC, ADS-C and CM applications. B2 CPDLC features support many new services such as 4D Trajectory Management (4DTRAD), Advanced Interval Management (A-IM), Digital Taxi (D-TAXI), and other services. B2 ADS-C includes new capabilities such as EPP reports and events monitoring.

2.6.2.2 Benefits

The new services defined as part of B2 will provide many new benefits, some of which were described in previous sections on TBO and IM. However, in order to get benefit from B2, there needs to be careful consideration of how to implement the service from both the ground and aircraft perspective.

2.6.2.3 Maturity

B1 well past the *Early Local Implementation*. Stage; B2 is at the *Early Local Implementation*. Stage, largely limited to European trials.

2.6.2.4 Impact

The impact on ATM is large. B1, while still in service only in Europe, will eventually be superseded by B2. However, the current European mandate only specifies implementation of ADS-C/EPP capabilities on the ground systems, including the introduction of a Common ADS-C server function. Nevertheless, it is expected that ground systems will progressively take benefits of B2 CPDLC from B2 equipped aircraft as a consequence of the ADS-C mandate for more advanced trajectory negotiation application.

2. Fields of Application

2.6.2.4 Impact (continued)

B2, implemented as a package including all applications, can provide the backbone of many advanced services, and is a key enabler for TBO and IM. Other services possible include D-TAXI and enhanced DCL. Using B2 with other tools such as arrival and departure managers will further provide value.

2.6.2.5 Challenges

While there are many potential benefits to B2, there must be a consistent implementation approach. This necessitates well-defined benefits to help with the implementation business case. While certainly capable as an application set, there are some potential issues:

- Aircraft equipage rate and numbers will lag for some time
- Changes to the B2 standards (planned completion for 2023) will likely require changes to existing implementation. The issue and imperfections with B1 bring about negative user experience and perception. These B1 issues, and also user perception, need to be fixed first, else the ATC users will not leverage full benefits of B2 aircraft capabilities
- Ground automation updates must be implemented in order to extract benefits from B2; this includes not only the messaging components but also the flight data processing that uses the messages. This must also be consistent across neighboring ATC centers
- The full benefits case of specific B2 services will need to be defined in order to encourage further implementation
- B2 currently will only operate in Europe over VDLM2. Plans for SATCOM support are in place with an EASA certified service targeted by September 2023. Satcom equipage update and full performance advantage is TBD although equipage rate is planned to slightly accelerate when the multilink deployment roadmap is agreed later this year and when per-commercial flights (as part of the IRIS project) are finalising the performance demonstrations

- The timelines for European implementation of B2 do not match those for the rest of the world: transition and providing value across mixed equipage will need to be defined
- Due to some of the advanced processing features of B2, legacy aircraft may be excluded. As airframes fly for many years, this will preclude a significant number of aircraft from B2 benefits. The FAA does not currently plan to implement OSI
- The cost of B2 systems, particularly for advanced services such as DRNP and IM, is unknown and will likely be very expensive. Committed ground deployments using those services will be needed and mechanisms for coordinated ground and air deployments will be needed, as well as further operational concept development

Implementation of B2 CPDLC is necessary to get the full value from B2; partial implementation (e.g. only using EPP) will limit the benefits (TBO requires route uplinks to full enable 4D trajectories, and those uplinks need to be directly loadable into the FMC for many reasons. Without that CPDLC capability, how are complex route changes given to and input into the FMC).

2.6.3 ATN/IPS

2.6.3.1 Description

The ATN/IPS is an emerging network standard that is intended to eventually replace ACARS and ATN/OSI network protocols. ATN/IPS is based on internet technology and provides updates such as security, mobility, and multilink capability. Additionally, ATN/IPS was designed so that end-user applications such as CPDLC do not need to change and also specifies a gateway capability to aid in transition and not force users for immediate upgrade. It also supports FANS-1/A, B1/B2 and ACARS-based applications. Message uplink/downlink time are largely subnetwork dependent (i.e. a FANS message over VDLM2 performs the same as a B1 message over VDLM2). IPS will bring more capability to the network level.

2. Fields of Application

2.6.3.2 Benefits

Providing a more modern infrastructure more closely aligned with existing internet standards has many advantages:

- Moves away from aviation-specific, legacy aviation-unique protocols
- Much wider technical base to draw on
- Reduced development and lifecycle costs
- Widely available COTS products
- Provides a transition capability without requiring end users to immediately change
- Provides the infrastructure for future high bandwidth, native IP applications (e.g. B3)
- Is the agree-upon end state for networking technology by ICAO, Industry, and US-EU

2.6.3.3 Maturity

ATN/IPS is at the *Industrial Product Development* stage. Standards are nearing completion, and some have been published already. Additionally, red-label level flight testing has been performed with multiple vendors participating.

2.6.3.4 Impact

ATN/IPS will have a medium impact on ATM. For the near term, the change will be essentially invisible to most end users, as the applications using ATN/IPS won't change. However, as more new applications that move beyond the existing CPDLC and ADS-C constraints are introduced (e.g. high data rate trajectory negotiations), ATN/IPS will provide the network technology and infrastructure necessary for support.

2.6.3.5 Challenges

There are a number of challenges that remain:

- Ensuring ground gateway capability to allow ATN/IPS equipped aircraft to operate in different environments (e.g. ATN/OSI)
- ATN/IPS will need to be included as an acceptable means of compliance for various airspaces

- The standards are nearing completion but have not yet been completed
- ATN/IPS introduces new concepts like link and network layer security, which will need careful consideration from a management and operation perspective
- Ground deployment programmes are needed for implementation

2.7 Other En Route and Arrival Applications

This section describes other applications that enhance ATM operations in the en route phase of flight and during arrival and approach operations.

2.7.1 Formation Flight

2.7.1.1 Description

Wake Energy Retrieval (WER) is the principle that migration birds use to save energy and, when applied to aviation, offers a significant potential for reducing fuel burn and emissions in airline operations. Through formation flight, a follower aircraft will retrieve the energy lost by the wake of a leader aircraft, by flying in the smooth updraft of air it creates. This provides lift to the follower aircraft allowing it to decrease engine thrust and therefore reduce fuel consumption in the range of 5-10 per cent per trip.

2.7.1.2 Benefits

Formation Flight is projected to reduce fuel burn by 5-10 per cent during long-haul trips, along with the corresponding CO₂ and NOX emissions. Flight testing, including that by NASA, has confirmed instantaneous fuel burn reductions of over 10 per cent. Airbus flight tests, have generated results which are consistent with both academic theories and reported testing of industry bodies.

2. Fields of Application

2.7.1.3 Maturity

Numerous industry bodies and research organisations have studied WER and there is a significant body of literature available on the procedure and benefits. With respect to an actual deployable system, however, the formation flight application is at the *R&D Initiative* stage of maturity.

2.7.1.4 Impact

Enabling the formation flight concept has a significant airborne component, in that the leading and trailing aircraft systems need to be modified to allow automatic formation flight. Airline involvement is paramount, as the lead and trail must be aligned for rendezvous and safe separation before the procedure can begin. The ground component is also significant in that ATC procedures to manage flights engaged in this procedure must be designed, along with ATCO tool creation/modification (e.g., changes to Short Term Conflict Alert in Radar Controlled areas and coordination of aircraft entering and exiting formations) and the proper ATC controller and flight crew training. Formation flight also has the potential to provide more aircraft access to preferred oceanic tracks between participating city pairs, increasing oceanic capacity and efficiency.

2.7.1.5 Challenges

Deploying an automatic formation flight procedure requires the development of a Concept of Operations (CONOPS) document that includes considerations for Airline operations, ATM, ATFM and other aircraft manufacturers. ATC operational procedures for oceanic or participating long haul flights must then be defined and ICAO and authorities must federate industry to define an applicable regulatory framework.

2.7.2 Continuous Descent Approach/ Operations (CDA/CDO)

2.7.2.1 Description

There are two main airborne capabilities supporting CDO.

The first one is the Descent Profile Optimisation (DPO) that consists in having a steeper descent profile than the basic one in the FMS database, optimised with regards to real aircraft performance, and computed with reduced 'idle (thrust) margins'.

The second one is the Continuous Descent Approach (CDA) function within the FMS, which enables an aircraft to manage an optimised continuous descent vertical profile from Top of Descent (TOD) with no decel level-off. This function computes a complete vertical flight profile of the descent and provides to the pilot some cues for aircraft configuration extension (flaps) to fly this profile.

2.7.2.2 Benefits

By avoiding level-offs and keeping the aircraft thrust close to idle, CDO improves flight efficiency by reducing fuel burn, with a corresponding reduction in CO₂ emissions. Studies have shown that these operations may enable fuel savings of up to 4000 kg per approach, depending on aircraft type and other factors, over traditional step down approaches.³

In addition, by suppressing the decel level-off (CDA function), these operations will contribute to reduced noise.

2.7.2.3 Maturity

CDO implementation strategies are actively being developed by ANSPs. CDO has been deployed on a limited basis at facilities around the world, including airports in the UK, Hungary, and Kenya. Therefore, the maturity of CDA/CDO is at the *Early Local Implementation* level.

Both DPO and CDA airborne capabilities are available as options on most large aircraft. CDA airborne capabilities are available as options on all aircraft with VNAV.

³ ICAO Doc 10013, Operational Opportunities to Reduce Fuel Burn and Emissions, 2014.

2. Fields of Application

2.7.2.3 Maturity (continued)

PBN arrival procedures are an enabler to CDO to facilitate the design of procedure in complex TMA. Trials have been made in Paris CDG with new RNP1 procedures called PBN to ILS.

2.7.2.4 Impact

The main impact on ATM is that CDO requires anticipation and agreement of the (optimum) TOD between both the flight crew and controller, and that ATC should then allow the descent to be continuous up to the IAF. This may require some specific coordination between sectors to have adapted transition levels.

CDO has also a potential to enable significant environmental benefit by reducing excess fuel burn and associated emissions. Increasing CDO rates is an important contribution of ATM to aviation CO₂ emissions reductions and the industry's climate goals.

2.7.2.5 Challenges

One barrier to implementation is that not all ANSPs have approval for anticipated separation, which decreases the effectiveness of CDA/CDO due to multiple altitude restrictions being provided to guarantee vertical separation. Additionally, conformance monitoring within the ground system may be required to ensure aircraft FMC descent windows are matched with published constraints on the procedure. And finally, individual controllers will need to avoid unexpected vectoring clearances to not alter the vertical profile.

Arrival procedure design should consider aircraft performances to extend CDO as much as practical.

2.8 Surface Applications

The applications in this section are primarily focused on enhancing surface operations.

2.8.1 D-Taxi

2.8.1.1 Description

Current D-TAXI messages in ARINC 622/623 message sets could be used to send taxi clearances and routes textually to ACARS and directly to the Electronic Flight Bag (EFB) on the aircraft. It would function as an electronic "Follow the greens."

ATN-B2 (Baseline 2) supports D-TAXI applications with expanded CPDLC messages set that could be more easily integrated in the avionics.

2.8.1.2 Benefits

Decreased radio congestion at major airports and clarity of taxi route instructions reducing the chance of the wrong taxi clearance being written down and wrong execution of the route.

2.8.1.3 Maturity

D-Taxi is at the R&D Initiative stage. It has been trialed in some SESAR projects that have shown potential applications in the pre-taxi phase, but it was perceived as more challenging during taxiing or before landing due to data-link and pilot reaction time.

2.8.1.4 Impact

Improved safety and efficiency with a decrease in taxiway and runway incursions due to a pictorial shared mental model between the ground controller and the aircraft.

2.8.1.5 Challenges

Common standards where ANSPs do not follow the current 622/623 message set and integration challenges with the EFB where an Aircraft Integration Module (AIM) or Aircraft Interface Device (AID) is not present.

2. Fields of Application

2.8.2 SURF-A

2.8.2.1 Description

Applications leveraging ADS-B In technology have also been identified to increase safety on the airport surface. The Surface Alerts, or SURF-A, Safety Net application receives and processes ADS-B messages from surrounding traffic and provides a flight deck-based warning to flight crews in case of collision risk in all situations close to the runway: take-off, landing, line-up and runway crossing.

2.8.2.2 Benefits

Safe surface operations is one of the highest challenges for aviation safety, and major aviation bodies have long identified the risk from runway incursions as a major safety issue. SURF-A is intended to protect equipped aircraft in all conflict situations close to the runway and reduce runway collision risk by at least 70 per cent (based on the targeted detection rate).

2.8.2.3 Maturity

The DO-317C/ED-194B standard published in 2020 contains requirements for basic surface situation awareness application, and an SPR for the surface alerting capability was published in 2010 as part of DO-323⁴. The SURF-A application is under active development and Airbus intends to begin offering it for installation on the A320/A330 aircraft families in 2023. Therefore, the maturity level of SURF-A is considered to be at the *Industrial Product Development* stage.

2.8.2.4 Impact

The impact on ATM from implementing the SURF-A application is primarily a significant increase in safety during runway operations. The airborne impact is limited, though pilot training and aircraft manuals will

need to be updated. The ground impact is also expected to be minimal as the flight crew use of SURF-A will be largely transparent to ATC. However, controllers may want to be informed of the existence of this on-board safety net.

2.8.2.5 Challenges

The effectiveness of the alerting algorithm that underlies the SURF-A application relies heavily on high-accuracy ADS-B data quality supported by high quality and accuracy positioning data for the participating aircraft and airport survey. When holding 200 feet back from the runway edge, any discrepancy in positioning data could cause nuisance alerts for aircrew. Enabling technologies of SBAS or GBAS may be required.

2.8.3 Brake to Vacate/Brake to Exit

2.8.3.1 Description

Runway Occupancy Time (RoT) is a constraining factor for airports operating near maximum capacity. Having a means of optimising deceleration could both reduce RoT and reduce brake wear. Brake-to-Vacate (BTV) has therefore been developed as an AUTO-BRAKE mode that automatically manages aircraft braking to exit a runway on a selected taxiway exit. The procedure involves the pilot, while still in flight, selecting an exit taxiway (through Airport Navigation system) using predictive assessment of braking distance. Then, on the ground, BTV actively adapts the braking level, delaying braking if possible, to reach the selected exit as efficiently as possible.

Boeing's Brake to Exit (BTE) system is a similar system with a different name. BTE adds new safety features like optimal runway exiting and brake-to-exit, which will allow a pilot to tie an airplane's rollout and stopping distance to a specific runway exit.

⁴ DO-323 also contains requirements to provide "indications" to flight crews when a collision hazard exists in the course of normal operations. The surface situation awareness application that includes both indications and alerts is referred to as SURF-IA. At the time of publication, there do not appear to be any current efforts to market a full SURF-IA application.

2. Fields of Application

2.8.3.2 Benefits

More reliably predictive taxiway exits provide the controller extra confidence in applying airborne separation for minimum spacing operations on final. There may also be some cost reduction for airlines by optimising braking energy/temperature, thus reducing brake wear and improving Turn Around Time (TaT).

2.8.3.3 Maturity

The BTV/BTE application is at the *Industrial Product Development* stage, deployed on the A350, A380 and B777X aircraft.

2.8.3.4 Impact

Operational efficiency is enhanced by reducing Runway Occupancy Time (RoT) at landing and making it deterministic. This is through allowing for a defined ground sort and optimum flow of traffic to and from the runway.

2.8.3.5 Challenges

Airports, air operators and ANSPs will have to work collectively to designate the preferred runway exit taxiways for the selected operation considering the location of airspace user stands, and weather and runway conditions. LVOP operations may be limited to specific exits, periods of runway contamination may be limited to one or two exits etc. Shared expectations and functionality will be key to successful adoption.

2.8.4 Braking Action Computation Function

2.8.4.1 Description

Runway excursions are the highest air transportation source of accidents, comprising 22 per cent of accidents between 2010-2014 and contributed to \$5,429M of hull loss between 1985- 2010. To reduce these excursions, the aircraft can be used as a sensor for an objective measure of braking action. This Braking Action Computation Function (BACF) involves computing the RWY State result on board the aircraft (ATSU) and providing the result to ground stakeholders via ACARS communication and

dedicated ground infrastructure. The Runway Condition Code is then disseminated by ATC to upcoming aircraft.

2.8.4.2 Benefits

The BACF will provide objective, timely and regular reports of actual contaminant effect on aircraft stopping distance, accurate anticipation of RWY performance degradation and no need for RWY closure for contamination measurement. It will also achieve the benefits described previously for BTV. It also improves operational efficiency by serving as an enabler for informed tactical and strategic decisions and helps flight crews in their PIREP elaboration.

2.8.4.3 Maturity

The BACF application is at the *Industrial Product Development* stage.

2.8.4.4 Impact

BACF will enhance safety through optimum spacing on final for ground conditions and enhanced airport runway optimisation. The ground impact is expected to be minimal as contamination results are disseminated by ATC to inbound aircraft. The airborne impact could be minimal if the pilots are informed via the existing ACARS communication system in a timely manner.

2.8.4.5 Challenges

Timely flow of runway reports is a challenge within existing runway condition reporting procedures. Currently, in most locations, the authority for the runway condition reports lies with the airport operator as do decisions to close runways based on conditions. ANSPs are generally the conduit via which information is passed to flight crew via either the ATIS, D-ATIS or direct from the Airline SOC to the aircraft via ACARS. Agreements respecting the authority under which the aircraft reported data will be used would need to be accepted by states, airports, and operators. While this is presented as a challenge, it is also an opportunity to greatly enhance safe contaminated runway operations.

2. Fields of Application

2.9 Mobile Applications

EFBs and Avionics Interface Devices (AIDs) provide the underlying hardware and data-processing platforms to implement capabilities that can enhance ATM efficiency and safety.

The systems enable 'mobile applications,' which can aid controllers and flight crews in making strategic decisions for more efficient operations. Several potential applications are described in this section.

2.9.1 Trajectory Negotiation Applications

2.9.1.1 Description

Trajectory Management incorporates user preferences (e.g. preferred speeds or speed limits), either at the AOC planning stage (dispatch) or with ATC during a flight, into trajectory determination and modification processes. AID-enabled connectivity to ground based systems then enables Trajectory Intent Sharing among all airspace users.

2.9.1.2 Benefits

Trajectory Management applications can provide additional situation awareness information and guidance, beyond that provided by existing installed avionics, to achieve the desired trajectory. This can help determine conflict free trajectories, optimised for individual aircraft performance, that enhance safety with minimal manual intervention from ATC. This leads to improved flight efficiency, with associated reduced fuel burn and CO₂ emissions reductions. Additionally, speed to change or market with development cycles for EFB devices allows for more rapid integration of airborne tools.

2.9.1.3 Maturity

Trajectory Negotiation applications are still at the *R&D Initiative* stage of maturity.

2.9.1.4 Impact

Trajectory intent sharing among all airspace users, both piloted and autonomous, enhances ATM planning and execution.

2.9.1.5 Challenges

Trajectory Negotiation applications will require the sharing of more information than is done today (e.g. airspace configuration, traffic flows, additional constraints, etc.) to establish a common operational view between pilots and controllers. Otherwise, there is a risk of overloading ATC if requests for better trajectories are not appropriate.

Regulatory procedure changes will also be needed, which will require research into how to determine an acceptable flight deck integration solution, considering flight crew workload, controller acceptance, and what is necessary to obtain airworthiness certification for mobile devices. Implementation decisions for enabling technologies will also need to be made, especially with respect to common communication systems.

2.9.2 Vertical and Lateral Profile Optimisation Applications

2.9.2.1 Description

These applications provide optimised vertical and lateral cruise profiles to flight crews on their EFB. They take benefits from the fact that the EFB can access Open World data (EFB is not part of safety critical avionics – no strong protection required, no certification). They also make use of the high EFB performance processing capabilities, allowing significant amounts of data to be processed in real time. For example, these applications can notably have access and process very detailed MET data that cannot be uploaded and processed by critical avionics (FMS) today. They can then provide to the flight crew a wide range of 'what if' trajectories corresponding to different criteria (e.g. fuel burn, CO₂, climatic impact, flight time), in order to support any trajectory update from pre-flight briefing to landing.

2. Fields of Application

2.9.2.1 Description (continued)

Four individual optimisation applications have currently been identified:

- **Climb Optimiser (vertical)** provides improved vertical climb profiles to the flight crew, optimised in terms of fuel burn and CO₂ emissions
- **Cruise Optimiser (vertical)** provides improved vertical cruise profiles to the flight crew, optimised in terms of fuel burn, CO₂ emissions, and time
- **Climatic Footprint Optimiser (vertical/lateral)** provides improved vertical and lateral cruise profiles to the flight crew, optimised in terms of climatic footprint, including CO₂ and non-CO₂ emissions (e.g. contrails)
- **Strategic Met Deviation Optimiser (lateral)** provides improved lateral profiles to the flight crew, optimised in terms of bad weather avoidance

2.9.2.2 Benefits

These applications optimise climb and vertical and lateral cruise profiles in terms of reduced flight time and fuel burn, with the corresponding reduction in CO₂ and non-CO₂ emissions. This will improve flight efficiency and reduce a flight's climate footprint. The Strategic Met Deviation Optimiser also optimises a flight's profile in terms of weather avoidance to enhance flight safety and efficiency.

2.9.2.3 Maturity

Profile optimisation applications are at *Early Local Implementation* stage and other advanced functionalities are still at the *R&D Initiative* stage level of maturity.

2.9.2.4 Impact

Optimised trajectories may be different from what controllers are used to allowing today. These trajectories may have vertical and lateral profiles with almost no straight-in segments, so that most current ATM clearances (FL, heading, etc.) would not be adapted anymore.

Furthermore, these trajectories would be different from one aircraft to another as their performance are different. Controllers may therefore need to manage the traffic enabling these differences, when it can be done without degrading safety and capacity.

2.9.2.5 Challenges

Not all ANSPs have approval for anticipated separation, which decreases the effectiveness of an Open Climb due to multiple altitude restrictions being provided to guarantee vertical separation. Also, conformance monitoring within the ground system and the airborne system may be required to ensure aircraft FMC climb windows are matched with published constraints on the procedure. Aircraft performance due to Takeoff Weight (TOW) and atmospheric conditions are harder to model for climb operations.

Additionally, these applications will help pilots fly close to an optimised trajectory, which might not be fully compatible with conventional ATM (e.g. cruise FL clearances, offset clearances, etc.). New types of clearance may need to be defined.

2.10 Foundational Airspace Enabler: True North Reference

With the advent of digital aircraft and ATM systems all sharing data under SWIM, a standardised heading reference system is required. In today's current operation using a magnetic heading reference system, aircraft systems, airports, approaches, and ATM systems are using multiple disagreeing variation and declination values across aircraft systems, airport reference, approach design and surveillance systems.

2.10.1 Description

Modern aircraft avionics systems, airport documentation, approach design and ATM digital systems all complete navigation and surveillance calculations with reference to True North based on the latitude and longitude grid of the Earth. Then given the position (lat/long/date) of the operation underway, Magnetic variation tables are consulted within the systems to provide the end user with the navigation or surveillance track converted to degrees magnetic.

2. Fields of Application

2.10.1 Description (continued)

As these magnetic conversion tables are released in five-year EPOCHs and are not required by regulation to be updated across aviation systems, discrepancies between aviation user segments occur reducing the accuracy, integrity, continuity, and stability of the operation being conducted. Where direct machine communications occur, unexpected discrepancies of even a minor nature can magnify into larger systems issues. Remaining on a magnetic heading system introduces navigational discrepancies dependent on the MAG VAR EPOCH used by each affected ATM and Aircraft system for each system interaction. By switching to a common True North System, all users will be using the same heading/proposed track values for flight plan conformance and checking.

2.10.2 Benefits

Currently, aircraft operators, airports, ATM systems and individual state AIPs must be continually updated to reflect the current magnetic variation value for aircraft systems (IRU, FMS, SVS etc.), airport (runway alignment), ANSPs (airway track, approach tracks, nav aid declination, surveillance systems etc.) to maintain a correct magnetic north reference. Many air operators, ANSPs and airports do not maintain systems and publications with up-to-date magnetic variation values due to the cost involved. This results in aircraft airworthiness directives and operations bulletins limiting PBN approach and CAT II/III operations and ANSP NOTAMs removing navigation aids and procedures from service until re-aligned. Switching to True North Operations would eliminate this need to update each aviation system, saving money while ensuring all users will be using the same heading/proposed track values for flight plan conformance and checking.

2.10.3 Maturity

True North reference operations are currently conducted within high north and south latitude regions of the world and during oceanic operations by some air carriers. All of Canada's Northern airspace is designated as a True North Heading Reference area for all conventional, PBN and surveillance operations.

Generally, aircraft that are IRU equipped or using modern Attitude Heading Reference System are capable of True North Heading Reference operations. Canada is currently developing a concept of operations to be followed by an implementation plan with the assistance of IAIN for presentation to ICAO following statements in the 12th and 13th Air Navigation Councils.

2.10.4 Impact

Referencing a heading source that remains constant and stable over time reduces the level of effort air operators and ANSPs must expend to continually update systems for no new additional operational benefit. Scarce resources can be focused on value added initiatives instead of time-consuming maintenance.

2.10.5 Challenges

While many operations could be conducted under a True North Heading reference system today, switching the global aviation heading reference system will require careful planning and implementation during any transition phase.

2.11 Single Pilot Operations

The continuous improvement in automation availability and reliability (in part due to the high level of investment in automotive and information technology industries), the development of digital technologies, and the increasing robustness of artificial intelligence, pave the way for more autonomous systems and, overall, more autonomy. These new technologies introduce new operational concepts, such as Single Pilot Operations (SPO), Reduced Crew Operations (RCO), High Altitude Pseudo-Satellites (HAPS) operations, and partially or fully autonomous operations, with the potential for safety and efficiency benefits. The evolution of the operational concepts in the flight deck will be accompanied by a parallel transformation of ATM.

2. Fields of Application

2.11.1 Description

Single Pilot Operations (SPO) consist of allowing a pilot to manage the flight in stand-alone, without any flight crew assistance, during some or all flight phases. These operations will be supported by several airborne capabilities, as current large commercial aircraft are not designed to be operated by a single pilot.

There are two approaches of SPO, requiring different impact of airborne capabilities:

- The first is to allow SPO only during some cruise periods, that is to say in non-critical phases of flight, when the flight crew workload is low in cruise under normal conditions. In that step, if the (single) pilot in command is incapacitated, the aircraft is able to detect it and maintain the aircraft safely in cruise until the time the pilot resting is back in the flight deck;
- The second consists in having the aircraft operated by one pilot during all flight phases, including critical phases such as take-off and landing. This requires significant evolutions in terms of airborne capabilities, such that a significant accommodation will be required. In that step, if the (single) pilot in command is incapacitated, the aircraft is able to detect it, divert the aircraft and make it land safely in automated mode on a pre-defined diversion airfield.

2.11.2 Benefits

SPO in Cruise reduces flight crew costs by reducing the number of augmented flight crew members that need to be aboard a long-haul flight. For example, if Flight Time Limitation regulation is adapted there is a need for fewer 'augmented' flight crew. This may mean two pilots instead of three or four, for one flight.

Full SPO, i.e. covering all flight phases, reduces flight crew costs by suppressing one pilot out of the two-pilot conventional crew in short-medium haul flights, and by further reducing the number of flight crew members that need to be aboard a long-haul flight.

2.11.3 Maturity

SPO applications are still at the *R&D Initiative* stage of maturity.

SPO in cruise capabilities are scheduled to be available from 2025 in some long-haul large aircraft.

SPO all flight phases' capabilities will probably not be available before 2030 (with an exception being turbo-props cargo freighters that could benefit from lighter certification requirements).

2.11.4 Impact

In normal conditions, it should be transparent to ATC that an aircraft is in SPO and the level of safety should not be reduced. The aircraft should behave the same in terms of maneuvers, communications, and response time to ATC instructions.

In instances where the pilot flying is incapacitated, specific ATM operations have to be defined to manage, within the current air traffic, the aircraft which will fly a deterministic trajectory:

- In SPO in cruise, these specific ATM operations should just manage the aircraft the next 20 to 30 minute period until the time the pilot resting has returned to the flight deck
- In full SPO, these specific operations have to cover the rest of the flight including the landing phase, affecting ATM up to approach and airport traffic control

2.11.5 Challenges

Deploying SPO requires the development of a CONOPS that includes considerations for Airline operations, ATM, ATFM and aircraft manufacturers. Then, ATC operational procedures for pilot incapacitation must be defined and ICAO and authorities must federate industry to define an applicable regulatory framework.

3. Conclusions and Recommendations

Technology on board aircraft has always had important implications for air traffic management and leveraging that technology will be critical to future capabilities. The benefit of airborne and ATM technology is not derived from the technology itself but rather the application of the technology and its integrated capabilities.

The various airborne technologies, capabilities and applications described in this paper have great potential to improve safety, capacity, flight efficiency, and to reduce costs and the environmental footprint of aviation. However, they are not often being matured in an integrated manner and in consideration for how they can be jointly implemented. ANSPs, manufacturers, and operators, therefore, face a significant challenge in integrating these capabilities into flight deck and ground automation systems, developing enabling procedures, and training flight crews, air traffic controllers, and managers to incorporate them into their operations in a coordinated and more interconnected way that justifies investment.

This section summarises some of the key benefits and implementation challenges, and provides high-level recommendations to guide effective deployment of new automation capabilities, such that the on-going investments in the airborne platform will yield the promised benefits.

Some of the key fields of application being readied for deployment in the near-to-midterm include:

- **4D TBO:** There is a great potential for a paradigm shift in terms of traffic management with 4D trajectory capabilities enabling optimisation of flight profiles, strategic deconfliction, and automation. 4D TBO promises to improve operational efficiency and reduce cost and emissions. But challenges remain with the deployment of tools in ATM and procedural changes in order to fully exploit the aircraft capabilities in applications

- **PBN and GBAS:** Performance Based Operations (PBN) departure, enroute and approach operations, have great potential to improve operations as an enabler of TBO, especially in terms of new approach capabilities and CDO/CDA. It can also enable decommissioning of traditional ground-based navigation aids down to a minimum operation network. Challenges to deployment centres on diverse implementation strategies among States, ANSPs and Airports, and different aircraft OEM philosophies on future navigation capabilities. Previously competing proprietary capabilities appear to now be converging with cross OEM standardisation.
- **ADS-B In:** Airborne ADS-B In applications have the potential to significantly improve ATM efficiency, but their deployment is not yet widespread. The primary challenge remains operator equipage and, in some cases, enabling ground systems. Surface ADS-B In applications have significant potential to reduce runway collision risk, though may depend on additional enabling technologies such as SBAS or GBAS to ensure accurate sub-meter positioning
- **Data Comm:** Avoids the potential for voice communication errors and frequency congestion by enabling the transmission of routine and essential messages and flight plan conformance monitoring within a 4D TBO environment over a data link. Cost, technology maturity, and differences in US and European ANSP operational needs are challenging deployments.

Other areas such as Mobile Applications, Formation Flights, and Single Pilot Operations are less mature, but promise significant efficiency and environmental benefits. ANSPs should maintain ongoing awareness of their development and encourage developers to consider their integration with other air and ground technologies and procedures.

3. Conclusions and Recommendations

Despite the rapid pace of technological advancements, many barriers remain in deploying new applications to airborne platforms. Some of these include, but are not limited to, the following:

- ANSPs, States and individual air operators having insufficient knowledge about the applications, including benefits, technological maturity, performance, and operational limitations
- Lack of governance frameworks addressing common technology deployments
- Long processes to deploy new technologies on a large variety of aircraft types and forward-fit/retrofit cost benefit challenges. This includes challenges regulators face in developing new frameworks to certify new technologies where there is a lack of regulation or proven standards
- When RTCA/EUROCAE-type standards are not available, the result can be multiple, non-interoperable technology solutions
- The need for ANSPs to identify and accommodate non-equipped and equipped aircraft in the same airspace for extended periods of time during transition phases of operations
- Incentive to equip when benefits are more for airspace efficiency or where individual operators may not see the business case to justify equipage in an acceptable timeframe. A lack of equipage also makes it challenging for ANSPs to justify ground investments
- Lack of synchronisation between interoperable airborne and ground capabilities implementation when there is not a common mandate. Often a chicken and egg situation occurs with business case for adoption: there is often no benefit for ANSP to implement functionalities that can be used only with a very limited number of flights, and respectively, there is no benefit for airlines to equip if the ground side is not ready to enable use of these functionalities
- The overall investment environment given COVID era financial losses

Overcoming these barriers will require communication and coordination among ANSPs, OEMs, aircraft operators, state regulators and airports. It is, therefore, recommended that the community continues to take a proactive approach to:

- Improving awareness of new airborne capabilities and giving operators a forum to coordinate and express their priorities
- Continuing efforts to develop governance frameworks addressing common technology deployments to foster better coordination at regional and global level evolutions of ground and airborne systems
- Achieving common standards and regulations across different regions
- Deploying additional strategies to incentivise equipage, especially when the benefits are more at the ANSP level, and the ROI timeframe is challenging for individual operators to justify
- Focusing on how to integrate many of these technologies such that they can achieve their operational objectives when applied in the same environment
- Examining the potential to apply less-expensive commercial technologies (COTS) instead of costly, aviation-specific solutions and programmes
- Executing field trials to prove the viability of certain concepts and validate the expected benefits
- Synchronising aircraft and ground system deployment through common mandates for some airspaces or shared incentive mechanisms when possible
- Evaluate technology-leapfrogging scenarios as an opportunity for ANSP to overcome long and expensive deployment roadmaps. Instead of implementing small and incremental innovations, organisations with different contexts and backgrounds could receive direct benefits by deploying ground systems with new capabilities

