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Forum for Digital Flight:

Enabling Future Operational Concepts in the National Airspace System for All Airspace Users

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FOREWORD

This document was prepared by the Forum for Digital Flight and provided for use by the aviation community.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal advisory committee and develops consensus-based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;

- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;

- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and

- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration Technical Standard Orders and several advisory circulars.

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DISCLAIMER

EXECUTIVE SUMMARY

Ever since the advent of powered flight, aviation has experienced steady advancements in technology and operational safety, while at the same time benefiting from leaps that impact the ecosystem in profound ways. Aviation is on the threshold of tremendous change, with new technologies and new aircraft types driving diverse proposals for new operational concepts that hold potential to open the benefits of flight to more people in more places. With so many new technologies under development, there is a risk that the aviation community will diverge and miss an opportunity to harmonize these various concepts and to empower all operators – new entrants and incumbents alike.

The concept of Digital Flight has emerged as a way to maximize benefit across aviation stakeholders, while taking advantage of these developments. Digital Flight is an operating mode in which flight operations are conducted by reference to digital information, with the operator ensuring flight-path safety through cooperative practices and operator-responsible separation enabled by connected digital technologies and automated information exchange. Digital Flight is predicated on employing four essential elements: digital information connectivity and services (for maintaining a digital model of the operating environment for decision making); shared traffic awareness (for maintaining awareness of relevant traffic and intent for use in conflict management); cooperative practices (for governing the behavior of Digital Flight operations to ensure harmonized use of the airspace); and separation automation (for automating the separation function in flight path management).

Some proponents of Digital Flight have proposed formalizing this concept under a set of flight rules, building on the historical precedent that expanded visual flight operations during the early period of aviation to instrument flight operations as technology matured. The introduction of Instrument Flight Rules (IFR) enabled a dramatic expansion of aviation services and airspace use that Visual Flight Rules (VFR) alone could not support. Similarly, Digital Flight Rules (DFR) could be a set of regulations authorizing sustained Digital Flight as an alternative means of separation from all hazards in VMC and IMC, in lieu of employing visual procedures (i.e., VFR) or receiving Air Traffic Services (i.e., IFR). The principal operational benefits of DFR to new entrants and incumbent operators will be the combination of airspace access enabled by IFR with the operational flexibility enabled by VFR. By design, DFR operators will share the airspace with VFR and IFR operators without requiring segregation. As with VFR and IFR, prerequisite qualifications will be established for DFR operators and aircraft, including equipment, training, currency, and other requirements. A list of references is provided in Appendix A.

This RTCA Member Report provides a brief introduction of Digital Flight, a discussion of the use cases that enable users of the airspace, barriers, solutions, and a path forward for the community. A key principle underpinning this report, and every discussion around the topic of Digital Flight, is that the safety and efficiency of all aviation activities must be preserved and should be improved. The prospect of introducing Digital Flight offers the potential for significant value to the aviation industry, the airspace user communities, individuals such as pilots, controllers, and dispatchers, and the ultimate beneficiary of aviation: the general public.

ACKNOWLEDGMENTS

The Forum on Digital Flight would like to acknowledge the participation and contributions of several key members. The FAA's Info-Centric NAS CONOPS provided key concepts and motivation for discussions and ideas articulated in this report, especially with respect to ATC infrastructure and Third Party Service Providers. Likewise, NASA's Sky for All Vision provided a framework through which to consider all aviation users at the same time. NASA researchers David Wing, Ian Levitt, and Andy Lacher contributed substantially to the research that provides the foundation for this RTCA Member Report. RTCA hosted this Forum and provided the logistical support to its operation.

The Forum was organized into three subgroups; Operations, Aircraft Capabilities, and Third Party Service Providers. Brandon Suarez (Reliable Robotics), Anna Dietrich (Xwing, Inc.), Jim Williams (AURA Network Systems), Paul Johnston (Cirrus Aircraft), Bryan Barmore (NASA), Fabrice Kunzi (The Boeing Company), and Nadine Akari (The Boeing Company) all helped to organize the Forum.

A list of organizations that participated in the Forum can be found in Appendix E.

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1 VISION

Digital Flight is a proposed new operating mode for all airspace users, complementing and adding to the existing operating modes of visual and instrument flight rules (VFR and IFR) and providing for cooperative integration in all airspace. Under new regulations (Digital Flight Rules, DFR) that set requirements for its sustained use, qualified operators employ Digital Flight to enhance their airspace access and operational flexibility in all visibility conditions without segregation from incumbent operations.

1.1 OPERATIONAL

There are many ways to operate aircraft in non-segregated airspace today, including special sets of rules for unique operations (e.g., Part 101 for unmanned free balloons). Historically visual flight rules enable very flexible operations where safety can be achieved with natural human vision, while instrument flight rules enable access through all weather conditions where pilots must rely on systems to safely control their aircraft and navigate through the airspace. Today's IFR operations still rely on the rate and capacity of human decision making as well as flight segments where human vision is critical to maintaining a high operational tempo. As digital processors are increasingly used in aviation, digital information exchange becomes ever more central to the safe operation of aircraft throughout the airspace and introduces the opportunity to surpass human-centered limitations and thereby increase airspace capacity and operational tempo in all visibility conditions. A new operational construct that is built to leverage this data and enable these benefits is needed; this is called Digital Flight.

1.2 PRINCIPLES

The core principle at the foundation of Digital Flight is increasing the safety of aviation. Other principles that are maintained through this report include:

- The introduction of Digital Flight operations should not impair or infringe upon existing airspace operations;
- Digital Flight operations should not impose new requirements on operations conducted under VFR or IFR;
- Digital Flight operations should be fully interoperable with VFR and IFR operations;
- All aviation use cases should be able to make use of Digital Flight as an operating mode and the enabling technologies to enhance safety;
- Digital Flight operations can occur with a pilot onboard, remote pilot, remote supervisor, or other novel crew complement concepts that ensure continuity of operational authority;
- Digital Flight should reduce or maintain – not increase – the current workload for air traffic controllers; and
- Digital Flight should serve an enabling role in the operationalization of innovative, efficient, safety-enhancing technologies today and far into the future.

1.3 AUDIENCE

To the extent possible, this report assumes an educated aviation audience and seeks to reference other sources, without recreating content. While this report is being written in the

United States, and many references throughout are U.S.-centric, it is intended for a global audience. Some readers will have to adapt the details described for their domestic airspace system, especially as it relates to airspace design and management. This report does not contain definitions; the reader is encouraged to read the referenced material. This report does not seek to explain the U.S. NAS nor the aviation ecosystem. The reader is encouraged to read resources from the FAA and other stakeholders on those topics. This report is also written with the assumption that the reader is generally familiar with airspace operations today and their benefits or limitations.

2 BENEFITS

The introduction of Digital Flight seeks to benefit both new entrants and incumbents in the aviation ecosystem. A wide variety of benefits can be achieved in terms of safety, security, and efficiency. This section is organized by benefit; however, many of these benefits and uses cases will overlap. This section is not meant to be a comprehensive or exhaustive list.

2.1 IMPROVED SAFETY

Commercial Transport Aviation[1] is the largest segment in air transport and it is the safest form of transportation that exists today. This safety record is critical to retaining the Public's trust in the aviation ecosystem. For the benefits of aviation to reach more people in more places, however, safety should be improved in other segments of the system. A safety benefit can be realized in **personal, business, and commercial small aircraft operations**[2] with the application of new digital technologies and the introduction of a Digital Flight operating mode. The advanced automation that enables Digital Flight can reduce pilot workload, significantly reduce accidents, and enable scalable passenger-carrying **Advanced Air Mobility (AAM)**[3].

Automation of flight controls and flight path management can lead to a decrease, and in some cases an elimination, of the most common causes of aviation accidents today and enable new concepts such as **Simplified Vehicle Operations (SVO)**[4]**.** SVO, including Simplified Flight Controls[5], is a form of human-systems teaming that promises to not only improve aviation safety but also allow more people to experience the benefits of aviation. While there does not need to be a dependency between the implementation of SVO and Digital Flight, the combination of the two concepts ha the potential to increase the utility and safety of both. Many of the technologies and capabilities that enable SVO are enablers for Digital Flight and the benefits of Digital Flight can motivate a migration towards SVO. Adoption of these types of advanced capabilities in **General and Business Aviation** can be facilitated by regulators through resource allocation, performance-based regulations, and accepting mission- and aircraft-appropriate pilot training requirements. These safety-enhancing and market-expanding technologies can also be encouraged or incentivized by insurance companies and other stakeholders in the aviation ecosystem with long-term interests in improving safety and increasing the number of pilots. Digital Flight expands the benefits of SVO-equipped aircraft by enabling operations in high density and complexity airspace.

2.2 FLEXIBLE OPERATIONS THROUGH CONTROLLED AIRSPACE

Digital Flight operations will occur through all classes of airspace; both controlled and uncontrolled, both where ATC services exist and where they do not. The most benefit can be gained by enabling more flexible operations through large volumes of airspace that are actively managed or positively controlled by ATC: in the U.S. that is Class A, B, C, and D

[1] https://www.cast-safety.org/

[2] Hook, et al. "Exploring the Potential of Automatic Safety Systems in General Aviation" IEEE 2023

[3] https://ntrs.nasa.gov/citations/20220006225 , FAA definition: "The terms "advanced air mobility" and "AAM" mean a transportation system that transports people and property by air between two points in the United States using aircraft with advanced technologies, including electric aircraft or electric vertical take-off and landing aircraft, in both controlled and uncontrolled airspace."

[4] GAMA, Transitioning to Electric Vertical Takeoff and Landing (eVTOL) and Other Aircraft Equipped for Simplified Vehicle Operations (SVO), 2020

[5] FAA, Modernization of Special Airworthiness Certification, Notice of Proposed Rulemaking, 2023

airspace. These anticipated benefits include streamlined operational control, more efficient flight paths, and increased accuracy of interactions with ATC. While IFR aircraft require a clearance to enter Class E airspace, ATC is not actively managing VFR flights in either Class E or G in the U.S.

Digital Flight can enable flexible **Urban Air Mobility (UAM)** operations with or without an onboard pilot around major metropolitan areas (e.g., through Class B airspace) at scale without requiring traditional IFR separation services. The digitization and sharing of intended and real-time flight paths through Class B airspace, for example, can give both pilots and controllers more information with which to make timely decisions. With increased flexibility, UAM operators could increase operational density and complexity relative to initial operations under VFR or IFR and with or without a pilot onboard.

Digital Flight can enable **General Aviation** operations through Class B and Class C airspace with the same efficiency that they occur in Class D or E. This can lead to more airspace being available to General Aviation activity and lower workload for ATC. By sharing real-time flight path intent with ATC and proactively avoiding major arrival/departure flows, , more flexible use of that airspace could be possible for all users.

Digital Flight can enable operators pursuing **small package delivery using UAS** who desire to operate in and through Class B and Class C airspace **Beyond Visual Line of Sight (BVLOS)** of their remote pilots. These operations have pioneered the capabilities (e.g., UTM/USS) that are being built upon for Digital Flight but these operations remain largely segregated (e.g. below 400 ft AGL) rather than integrated into the airspace.

Digital Flight can bring greater levels of safety and more access to **Aerial Work** operators, such as agricultural spraying, surveying, infrastructure inspection, and a variety of public safety missions, through all visibility conditions. The flight paths required for these activities are typically more complex than for air transportation, involving frequent turns and a variety of patterns that cannot be defined using published transit waypoints, which often makes them unsuitable for IFR or control by ATC.

2.3 FLEXIBLE OPERATIONS THROUGH INSTRUMENT METEOROLOGICAL CONDITIONS

When weather conditions degrade or suddenly change, operational tempo and efficiency at an airport or in a given volume of airspace are often significantly reduced. By leveraging operators' Digital Flight capabilities, such impacts could be mitigated without requiring enhancements to ATC systems or ATM procedures.

Many regional flights depend on visual procedures (e.g., visual approaches) to achieve shorter routes and flight times, and **Regional Air Mobility (RAM)**[6] use cases desire to maintain that operational flexibility through IMC and without a pilot onboard. This is especially important for small airports in uncontrolled airspace, where IFR procedures can be particularly burdensome and timely service is critical to the use case.

Without natural human vision onboard, **Uncrewed Aircraft System (UAS) and Remotely Piloted Aircraft System (RPAS)**[7] operations in controlled airspace will initially rely on IFR, however, most instrument procedures still contain one or more visual segments. Digital Flight can enable operations with the flexibility of VFR by introducing digital procedures that are compatible with visual procedures. Similarly, the use of UAS below

[6] https://sacd.larc.nasa.gov/sacd/wp-content/uploads/sites/167/2021/04/2021-04-20-RAM.pdf

[7] For the purposes of this report, these terms are considered equivalent. RPAS is the term used by ICAO.

minimum IFR altitudes could be essential to unlocking their full operational potential, especially for operations where operational flexibility and predictability are important. Hazard avoidance capabilities aligned with Digital Flight, such as **Detect and Avoid (DAA)** systems, could be critical to enabling this flexibility.

Digital Flight can enable flexible high-tempo **Business Aviation** operations in and out of airports without local ATC services. The burdens associated with airspace where ATC must apply procedural separation (e.g., one-in-one-out at airports without surveillance coverage to the ground), can be alleviated with existing technology applied in new ways.

Digital Flight can benefit **Commercial Aviation** by facilitating operator preferred trajectories and reduced separation standards, especially in Class A when widespread weather reduces en route capacity. The primary way in which much of the general public interacts with aviation is through the commercial airline industry. While operations under IFR support the highest level of safety on the FAA's Safety Continuum, Digital Flight can maintain that level of safety while increasing access, predictability, on-time performance, and operational flexibility, which positively impacts both the operators and flying public.

2.4 HIGHER DENSITY AND MORE COMPLEX OPERATIONS IN UNCONTROLLED AIRSPACE

Historically, airspace where high density (e.g., around airports) or more complex (e.g., flights under IFR) operations take place have been designated as controlled airspace (i.e., Class A-E) and provided structure through applying Air Traffic Services. More recently, especially as new entrants use airspace that is not heavily trafficked, operations in uncontrolled airspace (i.e., Class G) have increased but with Third-Party Service Providers (3PSPs) filling the role traditionally played by ATS.

Digital Flight can benefit **small UAS operating Beyond Visual Line of Sight (BVLOS)** by facilitating the traditional safety-critical Communication, Navigation, and Surveillance (CNS) services through 3PSPs. Digital Flight supported by 3PSPs, which could be an evolution of UAS Traffic Management (UTM), can enable the integration of sUAS into airspace shared with aircraft with a pilot onboard.

Both **Urban Air Mobility (UAM) and Regional Air Mobility (RAM)** use cases can benefit from intent sharing to increase operational tempo and complexity at traditional airports and heliports as well as facilitating dynamic and interoperable operations at new infrastructure, such as vertiports. Especially with RAM operations to/from airports in communities outside of urban areas, where there is a lack of CNS/ATM infrastructure, Digital Flight can provide a way to integrate into airspace predominated by visual operations, such as a visual traffic pattern.

Digital Flight can increase the tempo and density of **General Aviation and Business Aviation** operations at non-towered airports, especially in weather conditions that historically would significantly reduce throughput.

2.5 COOPERATIVE OPERATIONS

Cooperation among aviation users occurs today in a variety of ways, but primarily through ATC (e.g., traffic flow management), pre-coordinated procedures (e.g., formation flight), and/or voice communication (e.g., non-towered airport operations). More extensive use of cooperative methods can increase safety and lead to higher density of heterogenous operations.

Novel vehicles such as **High Altitude Platform Systems (HAPS)** could use Digital Flight to operate in 'Class E above A' where a mix of slow-moving aircraft can cooperatively share airspace with supersonic aircraft. New Entrants, such as HAPS, have the capability to innovate and pioneer new operating modes when the benefits unlock their operational concepts. Digital Flight would benefit non-transiting HAPS operations by facilitating "exception-centric" supervisory management from a remote operator. Although not a pre-requisite, high altitude airspace also offers a low density environment to test new traffic management concepts.

Digital Flight could alleviate inefficiencies around **Metroplex** airspace where a mixture of operational speeds can make merging and spacing traffic flows between primary and secondary airports and heliports difficult. This is especially important for new entrants, such as **UAM**, whose operators seek to integrate into busy airports. As one of the essential parts of Digital Flight, digital communications can enable more accurate and timely communications and by replacing voice communication and could free up radio frequency spectrum resources for further utilization.

Digital Flight can increase operational density in **Oceanic Airspace**, which can lead to improved fuel-efficient high altitudes routes and flexible operations at lower altitudes. This could greatly benefit **Commercial Aviation** by facilitating the best use of optimal altitudes and routes. Traditional CNS/ATM services are not widely available at lower altitudes over the High Seas, making this airspace that can greatly benefit from Digital Flight, for example in **UAS** operations. The continuation of Digital Flight into international airspace and across borders points to the need for global harmonization through ICAO.

As an evolution after remotely piloted operations, Digital Flight can enable Multi Aircraft Control (also known as **m:N operations**), which is important for the long-term scalability of **UAS, UAM, RAM, and HAPS** operations, by increasing automation within the operating environment, while reducing pilot workload. Increasing the level of automation of airborne aircraft functions will be necessary but a new operating mode that, for example, does not rely on two-way voice communication will be critical for m:N operations. These same capabilities could also be used to enable a Remote or Virtual Co-Pilot into General Aviation and Business Aviation.

3 ENABLERS

Enabling Digital Flight does not require a technological revolution, but it does require many segments of a diverse aviation ecosystem coming together to use and integrate existing technologies and capabilities in new ways. Aviation benefits from general technology trends that have produced high performance computing in reduced form factors, mobile connectivity with digitized radios, and robust data transmission networks. Not all use cases will need all the enablers discussed in this section, nor will all use cases derive all the potential benefit that Digital Flight can facilitate, but by working together, everyone can benefit in unique ways that would not otherwise be possible.

3.1 DIGITAL INFORMATION CONNECTIVITY AND SERVICES

Users of the modern National Airspace System (NAS) create, ingest, disseminate, and use a tremendous amount of data and information. The majority of the safety-critical data remains in analog form (e.g., ATC instructions over VHF voice) and the use of digital forms remains confined to secondary or efficiency-enhancing use cases with the onboard pilot remaining the ultimate interrupter, final authority, or safety backup. While there are notable exceptions (e.g., Ground Based Augmentation System [GBAS]), a key enabler for Digital Flight is the increased use of digital connectivity and data services in safety-critical applications. When humans consume information, rather than data, the underlying data is not bound by human readability or interpretation. A key driver is the need to maintain a digital model of the operating environment to facilitate shared decision making, which may require access to more precise, timely, and localized data than is available today.

The FAA has made significant investments in its **System Wide Information Management (SWIM) infrastructure.** The FAA intends to expand its ability to offer secure microservices as a way to increase the utility of this system for more NAS users. The FAA, and other ANSPs, will continue to play a critical role to centralize and disseminate digital sources of high integrity data. The secure use of SWIM for safety-critical applications will be an enabler for Digital Flight and certain new features (e.g. low latency dissemination) may require government investment to facilitate upgrades and enhancements.

While traditional Air Traffic Management (ATM) will remain the backbone of commercial transport aviation flying under IFR, the FAA and other global ANSPs are exploring **eXtensible Traffic Management (xTM)** concepts to facilitate rapid deployment of new air traffic services to new airspace entrants and for new operations. This has occurred first with UAS Traffic Management (UTM), which is already facilitating the integration of UAS operations in and around controlled airspace and airports. Providing traffic separation and flow management services in airspace where density, tempo, or complexity increase can enable Digital Flight operations and facilitate integration with the ATM ecosystem. Connecting legacy ATM infrastructure and ensuring interoperability with xTM systems may require government investment in both physical systems and software.

The availability of such data is enabled by **Third Party Service Providers (3PSPs)**. The FAA has recognized the role of 3PSPs by adopting the eXtensible Traffic Management (xTM) concept, that it will rely on 3PSPs to expand existing and new services into new operational areas. Operators that want certainty that such services will enable operations will seek 3PSPs with independent validations or approvals, most likely from the regulator. Many operators may also decide to be service providers for some or all of their operations. The introduction of 3PSPs is an extension of the framework being developed for UTM Service Suppliers (USS) and Providers of Services for UAM (PSU). While not all services provided by 3PSPs will be considered safety-critical nor require connectivity to the legacy ANSP systems, some will and therefore, it is expected that some government investment will be need to enhance legacy systems.

A key feature of today's global communications infrastructure is the wide-spread use of **secure cloud-enabled processing and data storage services**. The scalability of Digital Flight is dependent on utilizing existing communications infrastructure and will most likely require the use of such capabilities as well, which may require investment in expanded infrastructure in some regions. Around the world, governments, militaries, and companies alike have demonstrated various architectures of secure cloud-based services that can deliver safety critical services and data in a timely way.

Many communication service providers already exist, and are utilized today, to provide services that are not considered safety-critical. UAS and other remotely piloted aircraft will rely on **C2 Link Communication Service Providers (C2CSPs)** to deliver safety-critical **Control and Non-Payload Communication (CNPC)**[8] data over one or multiple datalinks simultaneously. Since a C2 Link allows UAS to safely include ground-based systems in their operation, aircraft with a pilot onboard could utilize a C2 Link to enable Digital Flight operations. The development of C2 Links for UAS has largely followed the path taken to develop and deploy datalinks in Transport Category Aircraft, including performance-based considerations of availability, continuity, and integrity.

Primary and Secondary Surveillance Radar are used today by the FAA and global ANSPs to provide separation and traffic information services, but the data produced by these radars is either not easily disseminated to non-government entities or is not of sufficient quality or coverage to enable novel operational concepts. **Ground-based Surveillance Systems (GBSS)**[9] support Detect and Avoid (DAA) applications and could be provided by service providers to all airspace users to enable Digital Flight operations both in areas where ATC provides separation services today and outside of existing coverage areas.

Weather data in the NAS has historically been used for planning and strategic purposes with the onboard pilot being the collector and arbitrator of real-time atmospheric conditions. The collection and dissemination of **precise, timely, and localized weather/atmospheric data** can enable Digital Flight operations by turning large volumes of data into actionable information. In many use cases, air-ground datalinks could enable near-real-time sharing of in-situ atmospheric measurements. Services, such as Flight Information Service – Broadcast (FIS-B), could be enhanced with shared data to support tactical decision making.

The digital infrastructure to support digital flight will expand and evolve in a similar way to the internet, comprising of interconnected digital services to support aircraft operators, airspace managers, physical infrastructure providers, and air traffic control. It is important therefore that today's work to design and build digital services anticipates the future growth, capabilities, and needs of airspace users. Simulation will play a key role in validating safe operations at scale by allowing researchers and regulators to both create a big-picture view of future airspace and generate detailed data from the perspective of a myriad of stakeholders and reliable data to inform industry standards. Data from real operations can be incorporated into simulation models to improve fidelity and accuracy of results.

[8] See RTCA DO-377B

[9] See RTCA DO-381A

3.2 AIRCRAFT CAPABILITIES

The focal point of aviation will remain the aircraft flying through the sky, and the evolution to Digital Flight will require functions and capabilities onboard aircraft that leverage digital information available for timely action. A key theme through this report is increasing the level of automation of systems, especially systems onboard the aircraft that can support operations with or without a pilot onboard. While none of these new capabilities require new technology to be invented, they will represent significant advances for some use cases and a priority focus among stakeholders to pursue certification and operational approvals with the goal of enabling new operational concepts.

The onboard pilot's responsibility to "aviate" remains central to the safety of today's aviation operations, while at the same time autopilot technology has increased safety and reduced the workload of pilots, especially during critical phases of flight. **Advanced Aircraft Automation** that can be engaged through all phases of flight and does not rely on a human in-the-loop as a backup to system failure can enable Digital Flight by freeing the pilot to focus on higher-level aeronautical decision-making tasks. This combination will increase aviation safety by reducing and eliminating the most common causes of incidents and accidents today, including controlled flight into terrain (CFIT) and loss of control (LOC), as well as significantly reducing, if not eliminating, mid-air collisions, runway incursions, and other accidents related to inadequate situation awareness or inaccurate voice-based communication. This will also allow for precise **4D flight path and flight plan prediction and optimization**, which is necessary to efficiently share intent and interact with ATC managed airspace and airports.

In a similar way, modern Flight Management Systems (FMS) have simplified and enhanced a pilot's responsibility to "navigate" through all weather conditions. **Digital Flight Procedures**, which are the digital instantiation of a procedure to be followed and do not necessarily need to be human-readable, when codified and integrated with aircraft models into the modern FMS can ensure that every flight plan and flight path are free of terrain and obstacle hazards. Following IFR procedures guarantees this today, but onboard equipment and automated flight path management can also assure avoidance of dynamic hazards.

As flight management extends to **Aircraft Management**, the ability to automatically respond to contingencies and emergencies can enable Digital Flight operations to quickly prevent unsafe conditions through automated contingency management. This is a key enabler to higher levels of automation that would be required for remote pilot or supervised operations. This could also be key to right-sizing training and qualification requirements for crew or passengers onboard aircraft operated with high levels of automation.

The concept of Conflict Management has always relied on an onboard pilot's ability to "see and avoid" other aircraft, even when flight visibility is limited. As a digital implementation of the human-centered "see and avoid" function, **Detect and Avoid (DAA) Systems** are an enabler of Digital Flight. DAA systems have been developed for UAS, to enable both Remain Well Clear and Collision Avoidance functions, while maintaining compatibility and interoperability with legacy systems and the "see and avoid" concept. Several modern transport-category aircraft are able to couple their **Airborne Collision Avoidance System (ACAS)** (i.e. TCAS II) to their autopilot in order to automatically perform collision avoidance maneuvers. The latest generation of ACAS (e.g. ACAS Xu and ACAS Xr) have been developed by the FAA to improve on legacy performance, increase functionality for new operations, and meet DAA standards. **Airborne DAA systems** have been tested onboard aircraft with a pilot onboard as a means to extend legacy

Collision Avoidance (e.g. TCAS II) capabilities and to improve traffic avoidance beyond "see and avoid". Automatically performing collision avoidance maneuvers onboard aircraft without relying on pilot input will improve real-world (i.e. beyond statistical simulations) safety, increase predictability, and enable new operations with reduced separation minima.

The ability to securely receive and process data originating offboard the aircraft will be a key enabler to Digital Flight. **Datalinks** will take many forms depending on the phase of flight, but the digital form means that these capabilities can be flexible and evolve over time as Air-to-Ground, Ground-to-Air, and Air-to-Air applications are developed. While regulatory segregation has historically been used to protect aviation use cases of RF spectrum, and this should not change for those legacy uses, new means of ensuring availability, continuity, and integrity should be explored for new uses of RF spectrum.

Besides today's most advanced IFR operations (e.g., CAT III ILS) aviation relies on natural human vision for navigation in critical operations close to terrain and obstacles. Digital sources of Navigation data, such as **alternate Position Navigation and Timing (APNT)** or **precision localization capabilities** (e.g., LIDAR), can enable Digital Flight operations by replacing or supplementing human vision in dynamic use cases. As these technologies improve, they could enable all weather operations independent of ground-based or space-based infrastructure.

3.3 SHARED TRAFFIC AWARENESS

In order to maintain safe separation distances, operators performing Digital Flight will maintain traffic awareness of aircraft participating in Digital Flight and those that are not, through independent and shared means. This shared awareness creates a common operating picture and leads to greater benefits as more users participate in it.

Detect and Avoid (DAA) systems[10] have been developed for UAS, to enable both Remain Well Clear and Collision Avoidance functions and could provide aircraft with or without a pilot onboard with extended traffic avoidance capability beyond today's "see and avoid" and ACAS capabilities. The ability to detect and track non-cooperative aircraft (i.e., those without approved electronic surveillance equipment) is key to a comprehensive DAA system that enables integration in the NAS. Coordination among ACAS/TCAS and DAA equipped aircraft increases safety and improves shared traffic awareness. The real-time intent sharing native to Digital Flight may enhance DAA systems by enabling coordination sooner in an encounter timeline.

The surveillance infrastructure that supports today's NAS is extensive and data sharing (from government to industry) through low latency terrestrial networks could enhance safety. As 3PSPs deploy additional **Primary Surveillance Sources** (e.g., radar) to augment existing surveillance coverage, two-way data sharing (from industry to government) back to the ANSP could enhance IFR operations, air traffic services, and airspace access. These new sensors are also critical to support Ground-based DAA systems, which may play a role in providing a comprehensive DAA capability all the way to the ground.

The secure sharing of position, velocity, and intent data between most or all aircraft sharing an airspace, a capability known as **V2V or A2X**[11], could enable more sophisticated operations than are possible with validated ADS-B alone. Most small UAS are prohibited from equipping with ADS-B due to spectrum concerns, so A2X provides a means to achieve surveillance for sUAS to support DAA capabilities. In addition to sUAS, AAM

[10] See RTCA DO-365C

[11] https://www.rtca.org/wp-content/uploads/2023/01/V2V-White-Paper-Final.pdf

and legacy aircraft could benefit from this capability, by for example designing it to support very dense and high-tempo operations, such as are envisioned to occur at a vertiplex. By enabling surveillance between all aircraft, both legacy and new entrants, a DAA system enabled by a V2V / A2X link can enable full integration and cooperative operations.

Since voice communication will remain a necessary means of communication, especially for VFR operators, natural language processing techniques, such as **Speech Recognition and Speech Generation** could provide a means of interaction between aircraft with higher levels of automation and legacy users.

3.4 COOPERATIVE PRACTICES

Digital Flight is envisioned to remain a flexible framework under which existing and new operations can evolve. Codifying cooperative practices outside of the regulatory system may allow for more rapid localized development within communities of interest and their associated airspace volumes. Cooperative practices can govern the behavior of Digital Flight operations to ensure a safe and harmonized use of the airspace.

As communities of interest form (e.g., UAM), a set of **Cooperative Operating Practices (COPs)** could enable more dense or complex operations to occur. This often occurs today for special events, such as airshows or fly-ins, where pre-coordination and dedicated voice communications facilitate safety. Likewise, certain geographic areas or airspace volumes could use COPs to enable diverse operations to take place, for example at a non-towered airport in Class G airspace.

3.5 SEPARATION AUTOMATION

ICAO's Global ATM Operational Concept[12] describes three layers of Conflict Management; Strategic Conflict Management, Separation Provision, and Collision Avoidance. All three of these layers must be accounted for within the Digital Flight concept while maintaining interoperability with legacy systems.

Strategic conflict management is performed before an aircraft begins a flight and can continue after departure. Digital Flight facilitates new opportunities to design deconflicted airspace and routes, as well as coordinate and deconflict flight plans. These are some of the core functions of 3PSPs as part of a xTM environment, but may also be provided directly by Digital Flight operators.

A key benefit of Digital Flight is the capability for aircraft operators to choose and dynamically update their own optimized flight trajectories. This is enabled by their responsibility to provide separation provision relative to with other aircraft. **Separation Automation** is the set of tools available to pilots and operators under Digital Flight, building on recent work on Detect and Avoid (DAA) and ATC decision support tools. Expanding the concept of performance-based separation can increase efficiency in airspace where heterogenous operations are taking place. Since operations under Digital Flight will not impose a burden on VFR or IFR flight operations and the principle of there being a single separator between any pair of aircraft has to be maintained, interoperability with existing CNS/ATM capabilities and ATC procedures is critical. For example, quantitative DAA Well Clear (DWC) standards have been developed to ensure that DAA systems operating in the same airspace are being measured against the same metric in design, development, and certification.

[12] ICAO DOC 9854

Digital Flight also enhances overall operational safety by providing a **Collision Avoidance** capability that activates if separation criteria are not maintained. Automation of TCAS Resolution Advisories has already been implemented on many modern commercial aircraft, which improves response times and adherence to the collision avoidance maneuver. Next generation Airborne Collision Avoidance Systems (ACAS) are being deployed now to enhance safety and provide protection during new operations, such as closely spaced approaches. ACAS X variants are also key components of some airborne DAA systems. Enabling ACAS is a key requirement for V2V/A2X links, which would include two-way coordination techniques and could share enough information to enable performance-based separation standards.

4 ACTIONS AND RECOMMENDATIONS

The Forum on Digital Flight intends to issue a Call to Action: while this report represents a vision, no single group can implement it in today's complex aviation ecosystem. The entire aviation ecosystem must work together, recognizing that everyone stands to benefit from such action. This section outlines several actions that can be taken in the near term and in the long term to achieve the vision of Digital Flight. This builds upon the actions specified in other recent industry documents[13].

4.1 DEFINE DIGITAL FLIGHT – A NEW OPERATING MODE TO HARMONIZE EMERGING CONCEPTS

As both the U.S. ANSP and Aviation Regulator, the FAA must play an indispensable role implementing Digital Flight. Recognizing that the FAA has articulated a vision through the **Info Centric NAS**, the Forum asks that the FAA explicitly incorporate Digital Flight into that vision. This can lead to an alignment of FAA resources and a recognition that operations that are aligned with Digital Flight have an inherent public benefit.

As the primary source of exploratory aviation research, NASA also plays a critical role as the initiator of the Digital Flight concept and as an organization that can lead research efforts to advance it. Recognizing that NASA's **Sky for All Vision** represents the agency's primary vehicle for articulating its future roadmap, the Forum asks that NASA expand the role of Digital Flight in bringing about the Sky for All vision, thereby expanding the potential R&D effort.

Cooperation between all stakeholders in the aviation ecosystem will be important, and especially to support secure data sharing among participants, there must be **strong cooperation and collaboration between government and industry** that includes academia and the various research institutions that support aviation.

A key challenge in developing Digital Flight will be **defining Cooperative Operating Practices** that supports all users but with enough flexibility to ensure that they can evolve as technology evolves. The integration of new entrants may provide the timeliest means to implement these concepts, but it must be done through a strategic framework so that "quick wins" don't block a long term inclusive vision. Airspace that can serve as a proving ground without disrupting legacy operations will facilitate experimentation.

Considering that 3PSPs exist today (e.g., space-based ADS-B), supporting their growth in a way that allows for new functions to be supported and new operations to be enabled will help not only create the marketplace but also define the roadmap for further development. The deployment of USS in BVLOS operations could provide a starting point to build on, but it is important that the safety-critical aspect of the services provided by 3PSPs be maintained.

Several enablers discussed in this report are already implemented in published standards although there benefit to a new operating mode was not articulated, therefore, **Standards Development Organizations (SDOs)** will play a key role in evolving and developing standards as concepts and technologies mature toward the Digital Flight vision. The success of SDOs relies on active participation from stakeholders across the aviation ecosystem; developers, operators, regulators, researchers, and users.

[13] https://www.auvsi.org/sites/default/files/Blueprint-for-Autonomy-Building-Blocks-for-Our-Collective-Future.pdf

4.2 ENABLE DIGITAL FLIGHT ALIGNED OPERATIONS

Recognizing that Digital Flight will take some time to come into full maturity, it is imperative that the long term vision inform near-term approvals of Dight Flight aligned operations, which will include implementations of functions, capabilities, and operations. By **viewing near-term operational innovations on a path to Digital Flight**, the whole community can understand the benefits that are being gained as aircraft continue to operate under VFR and IFR. The waiver and exemption process already provides a viable means for the FAA to approve operations that maintain an acceptable level of safety while being in the public interest. The introduction of Digital Flight is clearly in the public's interest. Forums where industry, researchers, regulators, and stakeholders can come together to agree on rationale transitions and evolutions will greatly facilitate making Digital Flight a reality; **government stakeholders must participate** to make these forums productive.

A straightforward first step is to leverage **existing technologies in new ways to enable new operations** and also provide operational validation data toward Digital Flight. For example, equipping an IFR-qualified aircraft with an IFR-qualified pilot onboard with a DAA system could enable limited operations through IMC under VFR. Another example is the use of simple radar reflectors in addition to runway lights to enable runway verification and localization by automated aircraft.

A second logical step is to expand currently deployed infrastructure and equipment to more users through further investment that increases the use of digital capabilities. For example, **Data Communications can be favored over Voice** in more areas for more operators. If operators are able to clearly derive benefit from investments in new equipment or capabilities, that will encourage additional investment. A small first example would be the expansion of pre-departure clearances to use mobile commercial cellular networks would have a large positive impact on IFR operations at non-towered airports.

The near-ubiquitous use of Electronic Flight Bags (EFBs) has greatly expanded the scope of information services in today's NAS, but there remains a gap to **allow safety-critical 3PSPs** that can be approved independent of a particular operator. The approval of C2CSPs may offer the first opportunity to exercise this new framework.

The U.S. Government controls significant volumes of Special Use Airspace (SUA) that is used in a very limited way for commercial research and development activities today. The Government should work to **make this national resource more accessible** for industry and academia testing and experimentation. While R&D activities must be performed in a safe and responsible manner, the use of SUA, especially Restricted Airspace, provides a valuable opportunity to test new aviation technology and advance national interests. For example, terminal area and airport operations under Digital Flight could be fully tested by companies in Restricted Airspace without impacting civilian airspace users.

4.3 DEVELOP NEW SYSTEMS

While new inventions are not needed, new systems must be developed to realize the vision of Digital Flight and many have already been identified. These, presented here in no particular order, can inform R&D roadmaps and investment. Consensus-based standards should be developed, at least, when interoperability is required between equipment, and active participation of the FAA can make acceptance and operational approval more likely.

It is worth mentioning here at this report has pointed to many existing technologies and capabilities that have been developed recently that can be repurposed or reimagined as enablers for Digital Flight. It is critical, for example, that the FAA finish its work on ACAS

Xr and facilitate the deployment of other variants of ACAS X, as near-term means of compliance with Detect and Avoid requirements. Several ADS-B IN applications, for example, Flight Interval Management and CDTI Assisted Visual Separation, can be leveraged to facilitate digital flight aligned operations today.

A secure means of exchanging position, velocity, and intent data between aircraft and from aircraft to other data nodes, known as **V2V or A2X**, will require investment on the order of what was required for the community to develop ADS-B. With the lessons learned from ADS-B deployment, however, the cost and timeline can be significantly reduced.

The vast majority of airports remain dependent on visual operations to maintain efficiency, therefore technologies to support **Automated Surface Operations** are key to increasing safety and efficiency through all weather conditions. Automated navigation, obstacle detection, and obstacle avoidance remain capabilities that have to be developed and standardized. Improvements to airport infrastructure could also greatly enhance operations, especially at non-towered airports. In addition to surface surveillance, surveillance of the airspace around airports from the ground is critical to support take-off, landing, and operations in the vicinity of an airport (e.g. traffic pattern).

The deployment of new ground-based primary surveillance systems to support DAA systems provides an opportunity to develop an **Enhanced Traffic Awareness** function, potentially leveraging existing TIS-B system components, that could be used by today's users of the NAS to improve traffic awareness and enable collision avoidance. This feature of the FAA's ADS-B network would also naturally facilitate two-way data sharing between industry and government.

The FAA is developing a AI/ML certification roadmap and while these tools are not critical for Digital Flight, it is worth noting that investment will be required to develop novel **Techniques and Methods** that designers can leverage. Developments in aviation that support high assurance applications could positively impact other domains and society at large.

For Digital Flight to not impact today's VFR operations, voice communication will remain a critical capability, therefore the development of **Standard Aviation Speech Recognition and Generation** capabilities will be an enabler and could also provide positive benefit to all aviation users. At the same time, moving away from over-the-air voice communication, either through ground-to-ground Voice Over IP (VOIP) capabilities or through data communications can be expanded.

The use of GPS (and GNSS more broadly) will remain a key component of aircraft operations. However, because of the known issues with security and performance, a **scalable PNT alternative to GPS** can enable highly automated operations and provide an additional level of robustness for all aviation users through all phases of flight. Onboard localization and navigation technologies (e.g., cameras) could also be used to verify existing landing locations and select an obstacle free landing location in case of an emergency.

4.4 CODIFY NEW PROCEDURES

Moving more functionality to systems and equipment requires that procedures that rely on human interpretation or judgement today must be codified in a manner that can be implemented digitally.

Today, instrument procedures are codified in a way that is readable by humans when printed on paper, but **Digital Procedures** could enable more complex or more constrained operations with or without a pilot onboard the aircraft. By taking advantage of new and legacy technology (e.g., terrain avoidance systems), procedures that have historically relied on natural human vision could be codified and executed through advanced flight management systems. More information can be encoded digitally so that operations that would have historically relied on visual procedures or a visual segment can be flown in all visibility conditions.

Under IFR today, **Separation Standards** are typically 3nmi or 5nmi horizontally but new operations, such as Closely Spaced Parallel Approaches using Precision Runway Monitoring, and the introduction of new capabilities, such as RNP, are allowing for more tailored pair-wise standards to be implemented. This is especially important when airspace is being shared among aircraft with diverse performance characteristics. The introduction of intent sharing and cooperative operating practices can facilitate further refinements.

Interactions between VFR and IFR aircraft can be complex and while significant guidance exists to help pilots safely handle these interactions, they tend to be highly dependent on human judgement. Procedures for interactions between aircraft performing Digital Flight operations and aircraft operating under legacy flight rules must be codified. This includes the transition between Digital Flight and operations under existing VFR or IFR, which will be necessary at airports dominated by IFR traffic or in airspace where the services or capabilities needed for Digital Flight are not available.

4.5 CODIFY NEW RULES

Ultimately, for Digital Flight to deliver its full promise to all users of the airspace, a new set of Flight Rules will be needed. It is the prerogative of Civilian Aviation Authorities, such as the FAA, and the International Civil Aviation Organization (ICAO) to develop such fundamental aspects of aviation. However, just as the development of IFR started with a clear operational need expressed by the aviation industry, so too, the motivation for the creation of Digital Flight Rules can start by **the whole community coming together to call for change**. Significant resources will need to be allocated; this allocation will need to be justified by clear safety and economic benefits.

A new set of Flight Rules could be developed at a high level, with technical prescription only where required for interoperability. Today's rules are often codified in this manner, with the operating rule being very generic, and more detail coming in the form of guidance material and standards. By leveraging standards, developed through a rigorous data-driven process and supported by the regulator, the aviation industry has been able to deploy many new technologies over the past several decades leading to improved safety and gains in operational efficiency.

If a new set of flight rules becomes the goal of the international aviation community, supported by all stakeholders, then incremental but intentional progress towards that goal can be viewed as a benefit to the entire globe, not just the companies at the forefront of advanced technology.

5 TIMELINES

Developing new technology and deploying it into the National Airspace System can be a difficult and time-consuming process; this is often because safety is the guiding principle that must be upheld in aviation. Without compromising the safety or the efficiency of existing airspace users, the concept of Digital Flight as an operating mode is powerful. It facilitates systematic advancements in certain parts of the community that lead to benefits in all parts of the community. As discussed in this report, many enabling components that are considered part of Digital Flight are already going through certification or approval processes. Those projects can be advanced in the short term.

Bringing the full vision of Digital Flight to reality will require a globally-connected national effort motivated by the goal of safely bringing the benefits of flight to more people in more places. The community cannot proceed with a "business as usual" mentality but must come together with a shared goal. Perhaps even more exciting than the benefits to operational use cases that can be identified today, is the potential for Digital Flight to unlock aviation applications that have not yet been envisioned. Increased data flow, increased autonomy, increased operational flexibility, and a more robust safety landscape are powerful enablers. Investing in Digital Flight could have benefits far into the future that are beyond the scope of what is under development today.

Many aspects of Digital Flight can be implemented today without changes to regulations. In the long term, however, rulemaking will be required. While rulemaking can be a time-consuming process, by explicitly advocating for Digital Flight aligned operations, the aviation community can build the experience and evidence that it needs to justify new regulations.

5.1 DFR AS A NATIONAL PRIORITY FOR THE UNITED STATES

The United States holds all the necessary elements to develop and deploy Digital Flight, in the U.S. NAS and around the world. This is an opportunity to accelerate domestic economic activity, bring the benefits of flight to more people in more places, and advance global leadership in aviation. These technical and operational advances are already being explored in other countries. Without a clear statement of priority and policy objectives, the U.S. is at risk of falling behind in what will become the next chapter in aviation. This is a **Call to Action**; a new operating mode, which we call Digital Flight, should be a national priority.

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APPENDIX A REFENCES AND ADDITIONAL INFORMATION

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3. FAA Info-Centric NAS https://www.faa.gov/about/office_org/headquarters_offices/ang/icn
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APPENDIX B OPERATIONAL USE CASES FOR DIGITAL FLIGHT

This section looks briefly at a variety of operational visions for how Digital Flight could benefit existing and emerging concepts of operations. To do this, scalability, economy, interoperability, predictability, and flexibility must all be balanced. The existing flight rules - visual flight rules (VFR) and instrument flight rules (IFR) - can accommodate many initial applications of digital operational technology. As computers find their way more and more into aviation operations, both VFR and IFR are being stretched to accommodate a more digital version of aviation operations. As the list of flight critical functions for which on- and off-board systems are responsible is only poised to increase over time, so too will the demand for digital flight operations.

B.1 Commercial Airlines

The primary way in which the vast majority of the general public interacts with aviation is through the commercial airline industry. Commercial Airlines are a vital part of the economy, fly under instrument flight rules (IFR) today, and are held to the highest level of safety within the FAA's safety continuum. Even with their highly trained pilots and the controllers that support them, commercial airline operations would realize a safety benefit from Digital Flight.

Most prominently, digital communications between pilots and air traffic controllers through all phases of flight could see a significant benefit through increased accuracy, reduced pilot workload, and the decluttering of voice communication frequencies. Simply moving basic taxi and flight planning information exchange to digital communications already benefit both commercial airline pilots and the air traffic controllers with whom they interact. More advanced tools for spacing and sequencing in terminal environments will improve predictability and on-time performance.

Digital Flight capabilities would also allow expansion of computer- and equipage-aided traffic awareness and deconfliction. While currently separation service is provided for commercial airline IFR operations by air traffic control, Digital Flight could provide a robust backup to this system. Denser flight operations, for example maintaining visual arrival rates during periods of IMC, could also be enabled through aircraft-to-aircraft communication and by providing ground-based traffic and weather information directly to the flightdeck. In many ways, Digital Flight would be an evolution of capabilities already employed in commercial airline operations; making these capabilities more widespread and robust would have a positive impact on safety and operational efficiency.

B.2 General Aviation (GA)

General Aviation (GA) includes a wide range of missions using existing airports and aircraft and operating in both visual and instrument meteorological conditions (VMC and IMC) and flight rules (VFR and IFR) and utilize both controlled and uncontrolled airports and airspace. Many GA flights are conducted by individuals flying individually owned aircraft for their own personal enjoyment or business. There is a significant opportunity for digital flight capabilities to reduce the accident rate for GA aircraft while simultaneously making personal aviation both safer and less stressful for the recreational pilot.

Digital flight could help GA pilots fly at elevated levels of safety by facilitating the automation of many communication and navigation tasks. Digital communications could automate and significantly reduce the error of most of the VHF voice transmissions that are used for routine GA communication. This would help alleviate channel congestion, improve communication accuracy, reduce pilot workload (especially critical in single pilot terminal area operations), and eventually create opportunities to reallocate some voice spectrum for additional digital services. Digital communication would be helpful across all of the communications currently essential to GA operations, and could be supplemented further through standard aviation speech recognition.

Navigation is already an area where, thanks to GPS and other technologies, GA pilots can rely on systems to support them during flight. However, GPS-based navigation systems are vulnerable to outages and having a digital flight backup would improve safety and the robustness of the GA system. It could also allow for more efficient and safer operations in congested airspace. Having a wide-area Position Navigation and Timing (PNT) alternative to GPS is a significant benefit to GA of digital flight. Additional positioning aids in terminal areas that could be used by assistive automation (e.g., autoland capabilities) would also have a positive impact on safety.

The integration of Digital Flight into GA operations will facilitate automation that reduces pilot workload and errors, enhances aeronautical decision making, and ultimately leads to a significant improvement in GA's safety record.

B.3 Urban Air Mobility (UAM)

As outlined in the FAA UAM ConOps v.2.0, Urban Air Mobility (UAM) enables highly automated, cooperative, passenger or cargo-carrying air transportation services in and around urban areas with advanced technologies, including electric aircraft, or electric vertical takeoff and landing (eVTOL) aircraft, in both controlled and uncontrolled airspace. As a subset of advanced air mobility (AAM), UAM focuses on operations moving people and cargo in metropolitan and urban areas. While there are a wide variety of aircraft under development, UAM vehicles will typically operate between 1500 and 3500 ft AGL, with an operational ceiling of 10,000 ft AGL. Typical range is between 20 and 50 miles (32 km and 80 km), with speeds up to 150 mph (240 km/h).

Different entrants into the UAM space also have different concepts of operation when it comes to the extent of automation in use and the rolls of humans, systems, air traffic management, and other third party service providers. While autonomous uncrewed UAM operations stand to benefit the most from Digital Flight Rules, and will clearly be an early adopter, even UAM operations with an onboard pilot will benefit from the efficiency and interoperability of DFR.

At entry into service, in the absence of Digital Flight, UAM operations will be capable of complying with existing instrument flight rules (IFR) and will interact with existing air traffic management services in much the same way as existing GA traffic. As the ecosystem continues to evolve towards the adoption of Digital Flight, operations will evolve and more autonomous operational capabilities will be able to be employed, including m:N operations. One of the main ways in which Digital Flight could benefit UAM operations, specifically early operations, is that of digital flight routes.

Specifying digital flight routes simplifies airspace management and allows higher density operations without increasing the workload for existing air traffic controllers. Routes can be reconfigured to optimize fleet behavior and tailored to the capabilities of the UAM vehicles using it. If needed, the vehicles' path can be rerouted through different/new routes created on demand.

B.4 Small Package Delivery and other sUAS Applications

Small uncrewed aircraft systems (sUAS) are currently being used to deliver packages, perform infrastructure inspections, put on complex performances, and conduct a wide range of other commercial and personal operations. As with other uncrewed operations, there is a spectrum of autonomy in play in their operations and a desire to expand operations that can be conducted beyond the visual line of sight (BVLOS) of the pilot/operator.

Significant work has already been done on unmanned aircraft traffic management systems (UTM) and other ways in which low altitude UAS can be operated outside of the existing air traffic control system. While the workload associated with integrating UAS into existing ATC procedures is prohibitive, thus inspiring the creation of segregated airspace and third party service providers to support UTM as a separate system from the rest of the airspace management, Digital Flight has the potential to reintegrate sUAS operations into existing airspace management without controller workload increases. This would increase the effective situation awareness of all airspace users, provide greater operational flexibility, reduce or eliminate the need for segregation, and simultaneously increase safety by reducing (or even eliminating) the potential for sUAS collisions with other aircraft.

The aircraft-to-anything (A2X) communication facilitated by Digital Flight would enable sUAS to proactively deconflict from each other and from other aircraft while staying in contact with their ground stations for flight path management and other communications. This would supplement on-board detect and avoid (DAA) systems and enable expanding BVLOS operations. Additionally, the enhanced PNT supporting Digital Flight provides robustness to sUAS navigation in areas where GPS is not reliable, including urban canyons and other areas in which delivery and inspection operations are highly desirable.

B.5 Regional Air Mobility (RAM)

A subset of AAM along with UAM, Regional Air Mobility (RAM) operations cover a range of operations using fixed-wing aircraft operating between smaller airports or between small and large airports. These operations satisfy a need to transport passengers and cargo into local communities utilizing existing, but under-utilized facilities and infrastructure.

RAM vehicles include both retrofits to existing airframes, such as the Cessna 208 Caravan, or purpose-built vehicles. Initial operations are expected to include both pilot-on-board and remotely operated configurations with an evolution towards remotely-supervised to fully autonomous operation of one to multiple vehicles simultaneously. Operations will generally be conducted under Part 135 as on-demand operations.

A typical cargo mission would involve transporting goods from a major distribution airport to a small community airport a few hundred miles away thus augmenting or replacing truck transportation. Reliable and predictable operations in most weather conditions is critical to a successful business model. Ensuring timely delivery to customers and maintaining availability of the RAM network enables reliance on this transportation mode. As these operations will tend to be frequent, controlling cost efficiencies such as fuel/energy consumption, pilot utilization, and deadheading flights are important operational considerations.

In an operating environment without Digital Flight, RAM flights are conducted in much the same way as existing piloted operations; even for highly autonomous operations the remote pilot ensures that existing airspace integration procedures are followed, flight plans are files and approved, and communications happen seamlessly with ATC and other airspace users.

As Digital Flight capabilities are advanced, many of the benefits discussed for GA and UAM are also applicable to RAM.

While uncrewed RAM operations can be conducted without Digital Flight, this new operating mode would provide significant benefits for RAM, particularly for operations at scale and utilizing a greater extent of automation. Under a Digital Flight operation, the remote pilot, managing one to multiple aircraft via a Control Station, would file their flight plan and coordinate takeoff with the relevant ATC tower. Once airborne, the pilot would make use of available automation, including traffic information about other flights which might include vehicle-to-vehicle data exchange, to maintain situational awareness, provide separation, and navigate along the planned route. As needed, the pilot would adjust the planned flight route and communicate with Air Traffic Control and other nearby aircraft. This would allow the pilot to plan updates that prioritize their business model such as minimizing flight time to maintain their operator's network schedule. The ability to operate in the same manner regardless of visibility provides predictability and consistency to the operator, which allows for more accurate predictions of energy usage, pilot utilization, and maintenance intervals providing the ability to minimize operating costs.

B.6 High Altitude Platform Systems (HAPS)

Higher airspace operations represent a new frontier for aviation which will provide significant societal benefits. High Altitude Platform Systems (HAPS), sometimes referred to as High Altitude Pseudo Satellites (HAPS) in the past, will be the airborne infrastructure that delivers connectivity to millions of people without internet access, that assists search and rescue efforts, monitors our planet's emissions and pollution, supports the fight against wildfires, and provides many more valuable services. HAPS transit through controlled airspace by relatively traditional methods consistent with their capabilities (e.g., lighter than air or fixed wing). The short duration of the transition (hours) compared to the time spent at altitude (months/years) significantly reduces the frequency and impact of controlled airspace transition.

Once at altitude, most HAPS remain aloft for months at a time and perform one or multiple missions. Platforms may be (dynamically) re-arranged to optimize for a common goal (e.g., maintain connectivity, photograph a large area, search for missing persons). This fleet-wide orchestration will have important consequences relative to digital flight in that communication with fleet orchestration systems may be preferred for strategic deconfliction, rather than communication with individual platforms.

Digital Flight would benefit non-transiting HAPS operations by facilitating platform and ground autonomy with only strategic and "exception-centric" supervisory management from a remote operator. A2X communications supports cooperative airspace management at altitude, navigation, and data transmissions for functions such as health monitoring, power and network management, and dynamic dispatching.

Cooperative airspace management at altitude is perhaps the most unique application of Digital Flight for the HAPS use case. High Altitude operations will be composed of a very heterogenous mix of craft, both lighter-than-air (LTA) and heavier-than-air (HTA) with a wide ranging, and time-dependent set of performance capabilities and speeds, as well as supersonics in a more distant future.

HAPS Operations will have an irregular distribution with concentrations over countries where these vehicles supply vital services. The ebb and flow of these operations will create a dynamic density that will influence how airspace is organized and managed. Thus, new paradigms for both vehicle management and flight rules are needed. The stratosphere provides a low-density, comparably low risk environment, and a critical opportunity for the aviation community to develop Digital Flight.

B.7 Aerial Work

Aerial work describes a wide variety of flight operations that do not involve transporting passengers or goods from location to location. Actives include aerial spraying, surveying and inspection, for commercial purposes, and a variety of public safety missions. The flight paths required for these activities are typically more complex than for air transportation, involving frequent turns and a variety of patterns that cannot be defined using published transit waypoints. Often, the aircraft will remain in one area for an extended period of time, and the exact position of the aircraft at a given time in the future within that area is not easy to predict. Consequently, aerial work operations are typically conducted under Visual Flight Rules (VFR), with the pilot or local remote pilot performing visual self-separation and following the right of way rules of the air.

Conceptually, aerial work operations could be conducted with an IFR flight plan, but that would require either defining multiple bespoke waypoints for each operation, or blocking out a volume of airspace, defined by a geographic area and flight level boundaries, for exclusive use during the operation. These concepts would require changes to current IFR flight plan formats and processes, and so aerial work operations in Class A airspace or by UAS operating BVLOS in controlled airspace, or through Instrument Meteorological Conditions (IMC) are not routinely possible.

With Digital Flight, different aerial work operations may be conducted over the full range of altitudes and potentially in all classes of airspace. For example, aerial spraying is typically performed at low altitude (Class G airspace) in remote/rural areas. Similarly, localized inspections conducted with drones are typically performed below 400 ft AGL and away from densely populated areas. When used for inspecting commercial transport aircraft with drones, these operations could be conducted in parking and maintenance areas of airfields within terminal area airspace (Classes B-E). Inspections of linear infrastructure, including railroads, pipelines, powerlines and canals/waterways, may be conducted at low to medium altitude (in Class G or E airspace) and over short or long ranges, depending on the type of aircraft used and the detection range of the sensors employed. Topographical, land or mapping surveys using lidar or photogrammetry are currently conducted at medium altitudes (Class E airspace) and could potentially be conducted at higher altitudes (Class A or Class E above A) for wide area / pseudo-satellite imaging.

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APPENDIX C INTEGRATING DFR INTO ICAO ANNEX 2 AND 14 CFR PART 91

Annex 2 of the ICAO Chicago Convention provides Rules of Air that are followed around the world and codified at a national level, for example in 14 CFR Part 91 in the U.S. A global harmonized implementation of Digital Flight Rules could be implemented through updates to ICAO Annex 2 and potentially other Annexes. This would eventually flow to the U.S. for implementation in 14 CFR. There is a potential path where the U.S. proactively updates Part 91, while showing how it complies with or maintains compatibility with Annex 2. This Appendix outlines potential changes to Part 91 and the section of Annex 2 that it is linked with.

C.1 Responsibility for Compliance

The Pilot In Command (PIC), or Remote PIC as modified by ICAO, is generally understood to be an individual even though the word “person” is used, which has a more broad definition throughout 14 CFR. Tracing responsibility and authority of a flight operation will always be critically important to aviation regulators and the public, and that will remain true with the introduction of DFR. A broader interpretation or definition of PIC and RPIC could expand the responsibility beyond a single individual and to an organization in order to more accurately reflect the operational reality.

This expansion of responsibility for flight operations could also extend to preflight actions. Safety-critical 3PSPs and high integrity data sharing will increase the reliance of the operator, and therefore PIC, on external actors who may be approved independently.

14 CFR §91.3 traces to Annex 2 Ch. 2.3.1.. 14 CFR §103 traces to Annex 2 Ch. 2.3.2..

C.2 Protection of Persons and Property

The inclusion of terrain and obstacle awareness capabilities under DFR could result in a more performance-based minimum altitude requirement that ensure that a safe landing can be made without prescribing heights for different environments.

14 CFR §91.119 traces to Annex 2 Ch. 3.1.

C.3 Avoidance of Collisions

Following the three layers of Conflict Management described by ICAO, DFR could codify performance-based traffic awareness and avoidance requirements while ensuring interoperability with legacy CNS/ATM systems. ICAO Annex 2 has been updated to incorporate DAA systems, which forms the basis for facilitating systems fulfilling the requirement to “see and avoid” other airspace users.

14 CFR §91.111 traces to Annex 2 Ch. 3.2.1. 14 CFR §91.113 traces to Annex 2 §3.2.2.

Operations in proximity to other aircraft are necessary (e.g. traffic pattern) and can be made safer under DFR with impacting the efficiency of legacy airspace users. Changes to the requirements for operating in controlled airspace will be required to integrate DFR, especially around aerodromes.

14 CFR §91.126, 127, 129, 130, and 131 trace to Annex 2 Ch. 3.2.5.

C.4 Flight Plans

The data sharing requirements of DFR could require more rich flight plan and intent data to be shared between operators and service providers. A DFR flight plan could contain at least the information contained in legacy IFR and VFR flight plans, but additional data, potentially aligned with cooperative operating practices, will be needed.

14 CFR §91.153 and §91.169 trace to Annex 2 Ch. 3.3.

C.5 Air Traffic Control Services

The use of 3PSPs to provide safety-critical services and to interface with ATM through the xTM concept will require changes to rules surrounding ATC services. Performance-based regulations can enable innovation among service providers while maintain key safety and interoperability requirements.

14 CFR §91.123 traces to Annex 2 Ch. 3.6.

C.6 Aircraft Equipment

The precision and predictability required by Digital Flight will most likely result in more equipment and capabilities onboard aircraft, but regulations that define a performance outcome, rather than prescribe components, will result in evolution and innovation.

14 CFR §91 Subpart C traces to Annex 2 5.1.1.

C.7 ATC Clearance and Air Traffic Services

Interoperability with ATC will necessitate some form of coordination or information sharing with aircraft under DFR. 3PSPs could be the interface between aircraft operators and ATC, or the flow of information could be one-way.

14 CFR §91.173 traces to Annex 2 Ch. 3.6.1.

C.8 Communications

Whereas, historically, voice communication has been the assumed default in aviation, it will be uncommon under DFR. Therefore, communication requirements should be modified to be broader and enable all forms of communication, depending on the capabilities of the two parties involved.

14 CFR §91.183 traces to Annex 2 Ch. 4.9. 14 CFR §91.185 traces to Annex 2 Ch. 5.3.2.

C.9 Fuel Requirements

The precise flight planning and flight path management required under DFR necessitates precise energy capacity and energy consumption estimates onboard the aircraft. This opens the possibility for energy reserve requirements tailored to the operation and the operational mitigations specific to an operator.

14 CFR §91.151 and §91.167 do not directly trace to Annex 2.

APPENDIX D ITEMS CLOSELY ALIGNED TO DIGITAL FLIGHT

Over the course of developing this report, many topics were discussed that are often considered as part of future looking aviation considerations, but are actually separate from the concept of Digital Flight. They are briefly listed here so that the reader can consider other sources:

- The concepts of “Automation”, “Autonomy”, “Artificial Intelligence”, and “Machine Learning” are often intermingled or confused. While Digital Flight depends on the automation of more functions onboard the aircraft and will enable operations of aircraft with higher levels of automation, the issues should not be conflated.
- The use of radio frequency spectrum, especially the distinction between the use of protected and license spectrum in aviation, is certainly a concern for any new equipment, should be considered one consideration among many as new systems are developed.

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