NASA/TP–2011-217174

Autonomous Flight Rules

A Concept for Self-Separation in U.S. Domestic Airspace

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November 2011

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1. Introduction

As air traffic in the United States has increased through the years, the burden of assuring separation among all Instrument Flight Rules (IFR) aircraft in the National Airspace System (NAS) has steadily increased. In order to carry out this function in a safe and efficient manner, a complex Air Traffic Management (ATM) system has been established consisting of airspace design, rules and procedures, voice and data communications, primary and secondary surveillance radar equipment, controller displays, and controller support tools. All of this is managed by a dedicated controller workforce that remains responsible for the safety of IFR flights in respective control sectors. While this highly manual traffic separation service has maintained a sufficient level of safety in flight operations, the manner in which aircraft separation is assured limits capacity and constrains the operators' efficiency and flexibility in planning and flying business trajectories of their choice.

The restrictions common to IFR operations today have their roots in the earliest days of instrument navigation, when aircraft first ventured into the clouds (ref. 1). Without being able to see the ground to navigate or other aircraft to remain clear, operators had to rely on ground-based radio navigation aids and separation services, the latter provided through procedural separation and later also through radar-based separation. The human element of Air Traffic Control (ATC) inherently limited the number and traffic flow configuration of aircraft that could be safely managed. This gave rise to most of the IFR restrictions in place today, such as ground delay programs, congestion-based reroutes, speed and miles-in-trail restrictions, altitude level-offs in climb and descent, and use of structured routes and cardinal cruising altitudes. These restrictions, necessary for human controllers to meet their primary responsibility of separating aircraft, were derived from the limited technology available as air traffic services were formulated.

An alternative provision for separation assurance called "self-separation," now enabled by emerging technologies, allows the responsibility for separation to be distributed among ground and airborne elements. Evolved over many years of research and development (refs.2-10), self-separation places the responsibility for maintaining safe and legal distances from one aircraft to all other aircraft with the pilot, using on-board systems and procedures designed to support this function. While executing the self-separation function, such aircraft would be operating under a flight status proposed here called "Autonomous Flight Rules" (AFR). Through new policy and a significant update to the Federal Aviation Regulations (FAR), the equipment, training, and procedural requirements defined in support of AFR operations would be established so as to meet the stringent safety requirements of a primary separation system. Aircraft and pilots operating under AFR would maintain separation from all other aircraft in the airspace, including Visual Flight Rules (VFR) aircraft, IFR aircraft, and other AFR aircraft. AFR aircraft also would self-separate from terrain and obstacles, hazardous weather, and operationally restricted Special Use Airspace (SUA). They are thus removed from the ground-based ATM system's responsibility for the separation function whenever operating under the rules of this application. Normally, this application spans from the time the AFR aircraft are released by the Air Navigation Service Provider (ANSP) during departure until they are reinserted into the landing flow to a runway. The AFR aircraft cooperatively share their current trajectories and any changes with other aircraft and the ANSP, and they adjust their trajectories as needed to achieve the ANSP arrival plan for that aircraft.

Self-separation is technically enabled by the widespread use of the emerging cooperative airborne surveillance technology, Automatic Dependent Surveillance Broadcast (ADS-B). ADS-B will provide to AFR aircraft the position, altitude, and velocity vector (state vector) of other aircraft in the vicinity, as well as their target state if turning or changing altitude. Additional trajectory intent data will be provided by ADS-B and/or ground systems such as System Wide Information Management (SWIM). Backup airborne surveillance capability will be provided by a ground-based Traffic Information Service Broadcast (TIS-B) system and by the aircraft-to-aircraft Traffic Alert and Collision Avoidance System (TCAS). Both of these systems make use of the transponders in other aircraft for surveillance independent of the ADS-B positioning information. Weather information will be available from both on-board sensors and access to ground-based weather products provided either by an Aeronautical Operational Control (AOC) center or government and commercial weather services through air-ground data link. SUA status and other NAS information will also be available digitally to the automation onboard the AFR aircraft. In addition to cooperative airborne surveillance, self-separation is technically enabled by an "Airborne Separation Assistance System" (ASAS), a software automation system onboard the AFR aircraft. Integrated with the aircraft's navigation, surveillance, and display systems, the ASAS will model the traffic situation and perform conflict detection, resolution, and prevention functions. It will provide guidance to the AFR pilots to plan for and maintain separation from other aircraft, restricted airspace, and weather hazards. The ASAS will also assist the pilots in conforming to arrival and other operational constraints, such as a Required Time of Arrival (RTA), without compromising separation.

Benefits of AFR operations should accrue to both the aircraft operators and the ANSP. Under AFR, flight trajectories are under direct control of the aircraft operator, rather than the ANSP. Having assumed responsibility for separation for the aircraft, the operator may select flight trajectories that more closely match the business case optimum, producing both cost reductions and environmental benefits. In addition, because an AFR aircraft imposes minimal burden on the en route ground system for separation, the aircraft should be exempted from Traffic Flow Management (TFM) initiatives associated with en route congestion and can depart and arrive much closer to the operator's preferred schedule. Once airborne, the AFR pilot has the authority and maximum flexibility to alter the trajectory according to changing requirements. ANSP benefits should also accrue. AFR aircraft will not be managed by controllers, opening up additional ground system capacity for IFR aircraft and increasing the ANSP ability to more strategically manage NAS resources. AFR flights will be able to operate in the same airspace with IFR and VFR operations, thereby reducing the need for complex airspace structures or segregated operations far from the optimum business trajectories of AFR and IFR aircraft. The flexibility to conduct AFR operations side by side with IFR and VFR is expected to be an important element to the AFR investment decision by operators and acceptability by the ANSP. As IFR flights convert to AFR, controller workload will be reduced, and the absence of complex airspace structures for segregation will greatly simplify coordination and handoff procedures. With right-of-way given to the IFR aircraft by default, controllers will be able to focus their attention and services on the IFR population, while the AFR traffic will be required to give way to all IFR traffic.

The context of AFR can be either homogeneous operations (i.e., all AFR) or mixed operations (i.e., AFR, VFR, and IFR in shared airspace) in concert with the variety of concepts for the ANSP and ground-based operations described in Next Generation Air Transportation System

(NextGen) documentation (ref. 11). The AFR concept description herein emphasizes mixed operations and purposefully avoids specifying any particular concept for IFR operations to illustrate the flexibility of the AFR concept. Key differences and similarities between AFR, VFR, and IFR operations will be enumerated in various sections of this document when useful to describe the concept of AFR operations. The AFR domain described herein encompasses primarily the climb, en route, and initial descent phases of flight in US domestic airspace. It may terminate at the boundary of terminal airspace or, with ground automation, at an arrival merge point or metering fix. It may also smoothly integrate with and transition to Interval Management arrival operations.

The purpose of this paper is to define the concept of AFR in moderate detail. The concept is the culmination of more than a decade of research and development (refs. 9, 10). At the behest of the airspace user community, it could be implemented by the FAA, once the underlying enabling technologies and procedures have been sufficiently developed and then proven to regulators and certification specialists that they are capable of ensuring the safe, reliable, and efficient flow of aircraft. This document focuses its description on piloted AFR aircraft. Unmanned Aircraft System (UAS) vehicles, either remotely or autonomously piloted, would also be eligible for AFR operations. However, unique considerations for UAS vehicles to operate under AFR, although not expected to be significant, are beyond the scope of this document. Section 2 describes the context in which AFR operations are defined. Section 3 presents the objectives of AFR and its expected benefits. In Section 4, the Autonomous Flight Rules are described, including requirements for equipment, the flight crew, the airspace environment, conflict-free trajectories, coordination, and right-of-way. Section 5 describes procedures for nominal operations, including the perspectives of flight operations, the flight deck, and the ANSP. Sections 6 and 7 address airspace characteristics and system requirements, respectively. Section 8 discusses the impacts and contingencies of off-nominal conditions. Section 9 discusses the activities required for implementation at a high level, and the document is concluded in Section 10.

2. Context

AFR operations as described in this document would be performed in airspace currently designated as Class A, E and G. While operating in Class B, C or D terminal airspace, aircraft could retain their AFR designation and possibly perform certain procedures such as delegated separation, but they would communicate with the Tower or Terminal Radar Approach Control (TRACON) controller and comply with ANSP instructions, clearances and flow management constraints. Terminal AFR operations would be distinct from en route AFR operations and are not described in this document.

The physical operating environment for AFR operations includes the current NAS and all upgrades with NextGen Operational Improvements over the next 15 years. Near the end of this period, secondary radar surveillance should have been supplanted in most areas with ADS-B Out (i.e., airborne broadcast of surveillance data). The Global Positioning System (GPS) and its wide area and local augmentation services are expected to be the primary source of navigation and timing signals by all airspace users. Alternate means for aircraft positioning, navigation, and timing services may also be developed during this period, including possibly local and wide area multilateration to provide independent backup surveillance throughout the airspace. TIS-B should be available throughout the airspace, using the best available source of surveillance data. Communications should be transitioning from primarily Very High Frequency voice radio to digital data communications for both routine and flight critical functions, with voice available for backup. The ANSP would be providing traditional IFR services to IFR aircraft, and flight operational data, including weather data, is expected to be available to all flights through government or commercial services.

AFR may be used by any segment of the flying population, civil or military, commercial or private. AFR is designed so that the first equipped and approved operator may use the procedures in any of this described airspace. There is no requirement for a minimum percentage of the fleet to be equipped before AFR operations commence and benefits begin to accrue.

Aircraft not operating under AFR will be operating under either IFR or VFR. As NextGen emerges, a transition of IFR operations to a concept called Trajectory Based Operations (TBO) is expected to take place in which the detailed flight paths of IFR aircraft are negotiated with and approved by the ANSP and communicated to and flown by IFR aircraft with precision. Both separation and TFM services provided by the ANSP are being designed to use the more precise trajectory data in TBO to improve their efficiency. The AFR concept is consistent with TBO but should not require TBO to be in service. The VFR requirement to "see and avoid" all other aircraft when in Visual Meteorological Conditions (VMC) will be continued for all flights, regardless of the flight rules under which flights are operating.

3. Objectives and Anticipated Benefits

The objective of the AFR concept is to provide an alternative mode of aircraft trajectory-based operations that is safe, efficient, flexible, cost effective, and low risk for aircraft operators; that minimally subjects AFR aircraft to capacity-driven operational restrictions; and that coexists with existing modes of operation without causing disruption of such flights. Self-separation is not the objective of AFR operations; rather, it is the primary enabling capability. Self-separation enables the conduct of operator-managed trajectories in Instrument Meteorological Conditions (IMC) or in airspace currently reserved for IFR aircraft. The objective of the self-separation capability is to autonomously accomplish the ATM function of separation for AFR aircraft, thereby removing the burden and responsibility of this function from the ANSP. While AFR operations alone will not change the total number of flights in the airspace, the existence of the capability will provide a mechanism for significant expansion of en route airspace system capacity, which would benefit the ANSP and all airspace users. Specific benefits sought by the implementation of AFR operations are described in the following sections.

3.1. Improve Safety

The overall risk of mid-air collision is expected to be reduced by providing lower risk to individual flights through their use of self-separation equipment and procedures, and by reducing the number of aircraft within the ground-based separation management system. This risk reduction is enabled by automatic monitoring of the traffic situation on multiple airborne platforms (i.e., the redundancy provided by distribution, with the equipment on two or more AFR aircraft monitoring the same encounter) and by locating the entire control loop within the cockpit so that control loop time is reduced and vulnerability to air-ground communication failures is eliminated. As the ground ATM system becomes responsible for fewer aircraft, the service to those remaining aircraft would improve, and the risk of failures would also correspondingly decrease.

3.2. Improve Efficiency and Reduce Delay

While many IFR aircraft remain subject to that portion of ground delay programs that are related to congestion at terminal departure fixes and in en route airspace, AFR aircraft ready for departure would be more likely to receive an on-time departure clearance. The departure approval would be enabled by the AFR aircraft assuming the burden for separation responsibility from the ANSP shortly after departure and thus not contributing to the ANSP-related "congestion" that triggered the ground delay program. AFR aircraft might similarly be exempt from common miles in trail restrictions over IFR departure fixes.

While en route, AFR flights using self-separation equipment and procedures would be able to execute their business trajectories more efficiently because their operation would be independent of ANSP constraints driven by the quantity of ground-managed IFR aircraft, such as sector loading and balancing and the longer lead times needed to approve requests. The improved flight efficiency would be measurable as reduced block time and fuel burn, as well as improved on-time performance.

AFR operations would have greater throughput in regions of convective weather because individual weather rerouting decisions would be made per-aircraft, rather than the "playbook" decisions applied to large groups of aircraft that can significantly impede throughput. AFR consolidates decision-making for traffic separation and weather avoidance decision-making from two places (ANSP for traffic, flight deck for weather) to one (flight deck for both), thereby allowing more efficient use of the weather-impacted airspace and a greater number of viable routing and altitude options.

3.3. Increase Flexibility

Self-separation is designed to maximize the flexibility afforded to AFR flights by eliminating the requirements for ANSP pre-approval of trajectory changes and conformance to most static route and airspace constraints. AFR aircraft could therefore change their trajectory as frequently as conditions warrant, without imposing a burden on the ANSP or other aircraft. This added flexibility would also be a major contributor to flight efficiency, being advantageous not only in choosing an initial trajectory during flight planning, but also as changing conditions en route become apparent to the pilots. For airline and other flights involved in air transportation, these includes altered winds, turbulence, actual locations of severe weather, and changing company business objectives. Any of these dynamic factors translate to a different optimum flight profile – vertically, laterally, and speed toward destination. The increased flexibility should also be beneficial when weather delays are anticipated at the destination airport. Working with an ANSP TFM system, AFR operators would negotiate a scheduled time of arrival consistent with other traffic and the latest weather forecast, and they would negotiate a self-selected departure time to minimize the probability of en route holding or diversions and thus the excess fuel carried onboard for these purposes. Precision arrival-time capability of AFR aircraft enable the flexible en route operations to reliably transition to ANSP control at the arrival fix for the remaining arrival portion of the flight.

3.4. Lower Costs

AFR equipment costs to users are expected to be more than offset by operational cost savings from the increased flight efficiency and flexibility (refs. 12, 13). Furthermore, these benefits would be immediately available to operators upon commencement of AFR operations, a result of AFR being a per-aircraft application, i.e., the first aircraft to fly under AFR begins accruing benefits on its first flight with no minimum required participation by other aircraft. Aircraft fleet operators could select which aircraft types and routes would benefit the most from AFR and thereby reduce total investment costs across the fleet by not having to equip all aircraft and train all flight crews for AFR. The return-on-investment period of AFR capability is anticipated to be significantly reduced compared to operational improvements that depend on implementation of extensive ground-based infrastructure, a time-consuming process not under aircraft operator control. Once the planned surveillance systems are in place, there would be no need to coordinate the implementation timing of airborne equipment purchases with ground system operational readiness. Similarly, future upgrades to AFR capability could be put in service faster on a per-aircraft basis than upgrades to extensive ground-based infrastructure, thus accelerating the return-on-investment period.

Much of the equipment required for AFR operations is either in service or emerging independently of the AFR concept. Most airline aircraft are already equipped with Flight Management Systems (FMS), multi-function displays, and multi-function control and display units (MCDU), and these numbers are rapidly increasing. ADS-B Out-capable aircraft are also increasing rapidly in number, and the current rule requiring this capability by 2020 (ref. 14) will ensure eventual ubiquitous coverage of airborne surveillance in the most heavily traveled airspace. The marginal cost for ADS-B In, receipt of other's intent data from airborne or ground sources, and the flight-deck automation logic for self-separation are expected to be small compared to the operational savings. For many aircraft, ADS-B In equipment and processing capability will have already been installed to enable one or more of the many nearer-term ADS-B applications such as Interval Management (IM) (ref. 15) currently under development.

Ground system costs should also be positively affected by AFR. Performing separation from the ground requires iterative processing of n^2 traffic interactions, where "n" is the number of aircraft under ground control. In contrast, the distributed processing enabled by AFR increases linearly with increasing numbers of aircraft. Self-separation could therefore reduce complexity in communications and automation systems that robustly handle the n^2 problem, especially for an order of magnitude increase in traffic as might come from widespread use of UAS, and in local regions not well covered with ANSP communications. It does so by reducing the overall traffic growth that must be managed by ground systems. Since the ground system is experiencing frequent saturation today, AFR operations could prevent a further increase in operator and system costs associated with travel delays and recovery that would otherwise accrue as traffic demand from both manned and unmanned aircraft continues to grow in the future. Ground system costs may even decrease, as the number of aircraft remaining in the IFR system decreases.

3.5. Reduce Implementation Risk

AFR would provide the aforementioned benefits without dependence on government implementation of a system-wide, ground-based, automated separation infrastructure, while remaining compatible if and when such a system is implemented. Other than the required policy and regulatory changes to establish AFR and the provision of information from government sources (e.g., surveillance of non-broadcasting aircraft), the development and implementation schedule of AFR is determined by the operator community. Once the policy and regulatory changes are in place, the first aircraft equipped and authorized for AFR may initiate the procedure and gain immediate benefits without waiting for a sizable population to equip. These factors, which allow earlier yet gradual introduction of AFR operations into the airspace, could overcome the most challenging obstacle to achieving NextGen’s anticipated benefits: the transition period.

4. Autonomous Flight Rules

This document proposes the creation of a new set of operating regulations, referred to as Autonomous Flight Rules (AFR). AFR would exist alongside IFR and VFR as one of three available flight options for any appropriately trained and qualified operator with appropriately certified equipment. Proposing a new set of regulations, rather than integrating the proposed capabilities within IFR, is justified by fundamental differences in the methods and responsibilities for separation assurance. Keeping AFR and IFR clearly distinct allows continuity of service for the well-established IFR system, while giving regulators and operators flexibility in defining the new operations and how they will integrate. It allows the establishment of unique training, equipment, and certification requirements. Furthermore, it makes clear to operators that, by filing an AFR flight plan, they assume the responsibilities therein for that entire portion of the flight and will be governed by clearly delineated operating rules. Operators would retain the options of filing IFR or VFR flight plans if either option better suits their operation or the needs of the particular flight. IFR and VFR operating requirements would be unaffected by the existence of the AFR option.

The term "autonomous" can be defined as "not subject to control from outside" or "independent." Even though independent, an autonomous agent is still considered part of the community subject to rules and constraints. The term was chosen for AFR to elevate two fundamental principles of the proposed operation: the degree of *authority* the operator has over the trajectory of the aircraft, and the degree of *responsibility* the operator has to ensure safe operations in a traffic environment. These principles of independence create an important balance. The autonomous *authority* provides the operator the independence to define and change the trajectory without outside (i.e., ANSP) approval, as in VFR, with additional independence from VFR meteorological and airspace restrictions. The autonomous *responsibility* compels the operator to independently ensure (without relying on the ANSP as a ready fallback) that their trajectory does not breach established separation criteria from other traffic, a stronger safety requirement than VFR's "see and avoid." Thus, AFR represents not a "free for all" but rather a structured flight mode with balanced rules and procedures that, while highly flexible, methodically ensures separation safety with the utmost integrity.

There is a close analogy between AFR and VFR that is useful in describing and understanding AFR. Both place the responsibility for separation clearly on the pilot of the aircraft operating by those rules. Both relieve the ANSP from separation responsibility. Both require communications with, and participation in, terminal ANSP control services at those airports where they are provided. Just as VFR and IFR operations occur in shared airspace, AFR may also be performed in "mixed" operations, in which flights operating by different rules for maintaining separation can coexist safely in the same airspace.

The differences between VFR and AFR are as important as the similarities. VFR flight requires staying within certain prescribed weather minima; AFR does not. VFR operations are not permitted in Class A airspace, whereas AFR operations are. VFR operations are exempt from formal traffic management programs, while AFR flights do participate in them, with special rules. VFR flight does not require filing a flight plan. AFR requires an abbreviated plan to support TFM predictions and services, as well as search and rescue. VFR has no quantifiable minimum separation requirement in distance or time (i.e., separation standard). AFR uses quantified standards unless visual acquisition of VFR traffic is achieved.

Additional significant differences between VFR and AFR are evident from the ANSP perspective. VFR aircraft may impede a controller's flexibility in maneuvering IFR aircraft, since the VFR aircraft is only required to provide visual separation from all other aircraft. AFR aircraft maintain proper separation from IFR aircraft and yield right-of-way, and thus they are significantly less of an impediment. VFR flights often request radar traffic advisory services from controllers. AFRs will not, as there is no need to. En route VFR flights most often are not in communication with the ANSP. AFRs will be on frequency, should the need arise to communicate. Actions of VFR aircraft are unpredictable, whereas actions of AFR aircraft will be clearly communicated. In particular, any developing conflicts between AFR and IFR aircraft will be identified by the AFR aircraft early and its planned resolution communicated to the ANSP well in advance of any apprehension occurring in the controller about the developing situation.

The following subsections provide the requirements for each of the following operational features of AFR: minimum equipment; pilot qualification, training, and proficiency; applicable environment in which AFR operations may be conducted; the requirement to maintain conflict-free trajectories; the required mechanisms of coordination; and the application of right-of-way.

4.1. Minimum Equipment

Aircraft participating in AFR operations will contain the equipment required for flight under IFR plus:

- Primary and back-up cooperative airborne surveillance systems approved for AFR use
- ASAS processor and separation logic
- ASAS controls, displays, and aural alerting
- TCAS
- Controller Pilot Data Link Communications (CPDLC) capable of supporting AFR functions and ANSP interfacing

Requirements for these systems are described in Section 7.

4.2. Pilot Qualification, Training, and Proficiency

Individual pilots or flight crews operating under AFR must be trained and current in AFR procedures and have their certificates endorsed for such operations. The training requirements will be promulgated in FAR Part 61, 135 or 121 appropriate to the operations to be conducted. AFR operations will be permissible by single-pilot aircraft and flight-crewed aircraft. (For brevity, the remainder of this document will refer to flight-crewed aircraft.) Air carrier AFR training programs must be approved by the FAA safety oversight office's Principal Operations Inspector of each airline conducting such training. Following the training, the pilot's ability to safely operate under AFR will be confirmed by an appropriately rated check airman. It is expected that AFR proficiency will be maintained using standards similar to the IFR proficiency requirements that exist today.

4.3. Applicable Environment

4.3.1. Airspace

AFR operations are performed primarily in en route airspace. However, an AFR operator may fly in any class of airspace in the NAS currently designated as Class A, B, C, D, E or G. AFR capabilities may extend into terminal airspace, but their use will be limited in higher density areas. In Class B airspace, AFR operators, like VFR operators, must obtain and follow an ANSP clearance. AFR flights operating in Class C or D terminal airspace will participate in the ground-based traffic management services of that airspace. Although terminal airspace may not permit full AFR flexibility, delegated separation operations envisioned for NextGen may be facilitated by leveraging onboard AFR technologies.

AFR operations have no special ceiling or visibility requirements (i.e., IMC is normal) except that they must abide by procedural weather minima such as those on instrument approach procedures. They must also operate in VMC wherever the normal and backup sources of airborne surveillance are not available. AFR aircraft have no maximum altitude limit. Although adherence to cardinal altitudes and flight levels is not strictly necessary for the technical requirements of AFR aircraft, compliance would be recommended to maintain compatibility with existing operations. Compliance to hemispheric rules would not likely be required. For flights at lower altitudes, minimum altitudes employed by AFR aircraft are the same as VFR when operating in VMC, and must conform to the IFR minimum sector altitudes or published procedural altitudes when in IMC. This ensures both obstacle clearance and communications with the ANSP when approaching terminal airspace.

4.3.2. Mixed operations

AFR operations are designed to share the airspace with VFR operations and ANSP-controlled IFR operations without any segregation. By extension, they may also readily operate in airspace where ANSP services are limited or do not exist. AFR operations are intended to be compatible with a wide range of IFR operational concepts; from current and near-term “manual” air traffic control to midterm emergent TBO of NextGen to far-term visions of highly automated airspace. As will be discussed in more detail below, this integration is achieved by AFR aircraft yielding right-of-way to IFR aircraft.

4.4. Conflict Free Trajectories

An AFR aircraft must continuously maintain a conflict-free trajectory through the use of onboard ASAS separation functionality, i.e., conflict detection (CD), conflict resolution (CR), and conflict prevention (CP) functions as described in the subsections below. Detailed AFR regulations (not within the scope of this document) will define a minimum time horizon along the active trajectory (e.g., five minutes) required to be maintained conflict-free (based on declared intent of other aircraft, when available, or otherwise on state vectors). Beyond this time horizon, no such requirement will exist.

4.4.1. Conflict detection and resolution

The CD function of ASAS will continually monitor the ownship aircraft trajectory and traffic environment for potential future Loss of Separation (LOS), as defined by the applicable separation standard and some nominal look-ahead horizon (e.g., 10 minutes). The flight crew relies on the CD function and does not actively monitor for conflicts themselves. A CD-predicted LOS within an applicable time horizon will be declared a conflict and annunciated to the flight crew. This applicable time will be a function of the aircraft's priority in the conflict, or "right-of-way." Once notified of the conflict, the flight crew will follow defined procedures using the ASAS to resolve the conflict in a timely manner.

When a conflict is declared and annunciated to the flight crew, the CR function of ASAS will compute one or more alternative "resolution" trajectories that will not violate the applicable separation minima of any aircraft, if possible, within a defined time horizon (e.g., 20 minutes). Depending on time criticality, scenario complexity, and crew workload, the specific maneuver to resolve a conflict may be presented as the sole option by the ASAS, be chosen by the flight crew from among several computed acceptable options, or be designed by the flight crew using the ASAS to verify acceptability. In general, the flight crew selects the resolution that comes closest to maintaining the desired business trajectory. Resolutions may be "strategic" or "tactical." A strategic resolution is a fully specified "closed loop" reroute to the destination, normally executed through an FMS, and shall be the preferred option. A tactical resolution is an open ended (or "open loop") maneuver with a generally shorter time horizon, analogous to radar vectors, that does not specify from the outset the complete trajectory to the destination. A tactical resolution, if determined to be operationally necessary by the flight crew or by the ASAS, will require subsequent maneuver decisions for returning to the desired business trajectory. Strategic and tactical resolutions may be accomplished through maneuvering in the lateral plane, the vertical plane, through speed adjustment, or any combination of these.

4.4.2. Conflict prevention

While operating under AFR in Class A, E, or G airspace, the flight crew is authorized to change any aspect of the aircraft's trajectory (e.g., lateral path, altitude, speed) without requesting or receiving approval from the ANSP. However, any change to the current trajectory must be predetermined to be conflict-free to an applicable time horizon in order for the flight crew to be authorized to execute the change. This rule applies to strategic and tactical maneuvers. The flight crew uses the CP function of ASAS to probe desired trajectory changes for "provisional" conflicts (i.e., conflicts that would be created by executing the change). The flight crew is not authorized to execute trajectory changes having a provisional conflict within the applicable time horizon of the resolution mode (as determined by the predicted first point of LOS). If such a conflict is predicted, the flight crew may consider alternate trajectory changes, postpone and recheck the change at a later time, or remain on the current trajectory. Once a conflict-free trajectory change has been identified, the flight crew may execute the change without contacting the ANSP or receiving an acknowledgement. Two automatic transmissions of the new trajectory will be immediately initiated by aircraft systems: one broadcast over ADS-B containing near-term trajectory information and the other directed to the ANSP ground system over CPDLC containing more complete information on the trajectory if available.

4.4.3. Separation standards

In the transition to NextGen, it is anticipated that the "one size fits all" separation standard in use today for all en route IFR aircraft (i.e., five nautical miles and 1000 feet) will be replaced in the future with different standards that are functions of the surveillance information source and the performance-based operating capabilities of the aircraft involved. Accordingly, reduced separation standards would exist between AFR aircraft, which would have the best surveillance information and smallest control loop time. Such standards might be based on both physical distance and the Tau criterion, which defines a minimum time to the closest point of approach, to ensure the reduced standards remain outside the alerting parameters of TCAS. When in place, such reduced standards would reduce the conflict rate at a given traffic density. As more aircraft switch to AFR, prevalent use of smaller separation standards and the correspondingly reduced conflict rate would dramatically increase overall airspace capacity.

AFR aircraft, in separating from IFR aircraft, will apply a minimum separation standard equivalent to that used by the ANSP in separating IFR aircraft from each other plus likely an additional buffer in lateral and vertical dimensions (e.g., an additional two nautical miles and 1000 feet). The buffer will be sized to permit the ANSP to maneuver IFR aircraft with minimum regard to the presence of AFR aircraft, while also permitting sufficient time and maneuvering space for the AFR ASAS equipment and pilot response to preserve the minimum separation standard, even under conditions of unanticipated maneuvering by IFR aircraft. Effectively, AFR aircraft would generally remain a greater actual and predicted distance from IFR aircraft than is required between two IFR aircraft, thus minimizing the impact on strategic or tactical operations of the ANSP, a feasibility requirement of mixed AFR and conventional ANSP operations. In the future, as the ANSP implements automation tools for TBO, it may be possible to reduce or eliminate the buffers in favor of automated implicit maneuver coordination (discussed below).

Detailed AFR regulations will define these standards and buffers based on criteria necessary to achieve the target levels of safety. The most stringent separation standard that AFR aircraft will likely encounter will be for IFR aircraft when radar (provided via TIS-B) is the surveillance source, in which case the separation would be increased to account for the radar surveillance being less precise than ADS-B. For encounters with VFR aircraft, AFR aircraft will use quantified standards until visual acquisition of the traffic is achieved. The AFR flight crew may then maintain visual separation from these aircraft according to standard Visual Flight Rules.

4.5. Coordination

In the AFR concept, separation responsibility is distributed among the AFR aircraft in AFR/AFR conflicts, and it rests solely with the AFR aircraft in AFR/IFR conflicts. Safety in a system of distributed separation responsibility requires the concept of coordination. Coordination provides assurance that the aircrafts' separate decisions are mutually safe. Coordination may be *explicit*, where mutually safe decisions are communicated and agreed between aircraft, or *implicit*, where means other than communication and agreement are used to ensure mutually safe decisions are made. Other than for collision avoidance, where explicit coordination is used, the AFR concept employs implicit coordination to ensure mutually safe decisions are made for primary separation. Conceivably, explicit coordination could be applied for primary separation as well; however, this would produce costly and unnecessary communication requirements on AFR operations. Several mechanisms of implicit coordination in the AFR concept are described.

4.5.1. Coordination through intent sharing

The first mechanism of implicit coordination, which occurs regardless of detected conflicts, is the regular broadcast by AFR aircraft of trajectory intent information, i.e., the intended route of the aircraft. While not considered safety critical, sharing this information is intended to promote earlier detection of conflicts and more stability in the airspace through fewer trajectory changes.

This broadcast is communicated through one or more four-dimensional (4D) Trajectory Change Points (TCP) covering the near-term period (e.g., 25 minutes). The AFR aircraft also implicitly coordinates with ground systems by down-linking a more complete trajectory. Trajectory information from IFR aircraft (to the appropriate time horizon) is expected to be made available from future ground automation to the AFR aircraft (e.g., via SWIM). By sharing the intended near-term trajectory, AFR aircraft implicitly coordinate use of the airspace with other decision-makers and allow trajectory planning by all to minimize the need for trajectory changes.

Any change to an AFR aircraft's trajectory will be broadcast, where possible, before the aircraft initiates the turn, climb, or descent. When executed through the FMS, this procedure is accomplished by placing the initial TCP a short time ahead of the aircraft's current position (e.g., one to two minutes). When an AFR aircraft is operating in a tactical flight mode, the trajectory change is broadcast as an immediate target state message, indicating the new target heading or target altitude.

4.5.2. Coordination to avoid conflict creation when one aircraft maneuvers

The second mechanism of implicit coordination by AFR aircraft is the procedure of preventing the generation of new conflicts, out to a specified time horizon, when a trajectory change is made. This mechanism, comparing an intended flight path to the declared intent of other aircraft, provides for coordinated use of the airspace and is analogous to "looking both ways before crossing the street." By ensuring trajectory changes do not create conflict situations that may induce another aircraft to maneuver, operations of all aircraft are more efficient and stable.

4.5.3. Coordination to determine which aircraft should act first to resolve a conflict

The third mechanism of implicit coordination is the use of priority rules (a.k.a. right-of-way rules) which are invoked following the detection of a conflict for which adequate time exists to use priority rules (e.g., five or more minutes). The coordination is implicitly achieved because all aircraft will use a common predefined rule set to establish right-of-way. A high-level description of these rules is presented in Section 4.6, "Right of Way." The objective of applying priority rules is to reduce the occurrence of two aircraft maneuvering simultaneously to resolve the same conflict. In a conflict between two AFR aircraft, the flight crew of the lesser priority aircraft will be notified of the conflict first, thereby initiating the procedures onboard that aircraft alone for resolving the conflict. The flight crew of the higher priority aircraft will be notified of the conflict, if it still exists, after a short period (e.g., one to three minutes), at which point their CR procedures would be initiated. This approach of staggered alerting times has several benefits, including consolidating crew procedures, enabling the use of complex priority rule sets, and enhancing safety by automatically calling on the second aircraft's separation capability should some failure disrupt that of the first aircraft. If inadequate time remains for the use of priority rules (i.e., delaying the notification of one aircraft), then both flight crews are equally alerted so that they may both act to achieve separation. This ensures both aircraft do not inadvertently hold their course while expecting the other aircraft to maneuver. All resolutions are broadcast over ADS-B as trajectory intent information for other AFR aircraft and downlinked to the ANSP.

4.5.4. Coordination to ensure two conflicting aircraft have complementary maneuvers

The fourth mechanism of implicit coordination is the safety-critical use of maneuver coordination and is invoked when the predicted LOS is near in time (e.g., five minutes or less) and both aircraft may be considering maneuvers to provide separation. It is generally assumed that maneuver coordination is applied through the tactical CR logic, although application within the strategic CR logic is also possible and may provide efficiency benefits. Maneuver coordination is implicitly achieved by designing the CR logic onboard all aircraft to meet a defined set of criteria that is predetermined to ensure any maneuvers by both aircraft will be in complementary directions and not self-cancelling (i.e., additive to separation rather than subtractive). The specification and properties of such criteria are formally defined and understood today (ref. 16).

4.5.5. Coordination in mixed operations

In mixed operations of AFR and IFR aircraft, similar coordination mechanisms could be instituted between the two agents responsible for separation, the AFR flight crew and the ANSP. However, to enable the earliest implementation of the AFR concept, and to remain compatible with a full range of future, emerging IFR concepts, AFR aircraft will initially assume all responsibility for separation from IFR aircraft, thus minimizing significant coordination requirements and associated burdens on the ANSP in controlling IFR traffic. Basic ANSP-AFR coordination, if needed, will be available immediately using voice communication on the sector frequency. Over time, as the ANSP implements automation tools for controllers, certain automated coordination procedures are expected to be developed that may allow reductions in the extra separation buffers applied by AFR aircraft for AFR-IFR separation, as described in Section 4.4.3. In addition, adjusting AFR-IFR right-of-way to favor the better-equipped AFR aircraft can be considered.

In addition to yielding right-of-way to IFR aircraft, AFR aircraft will transmit their intended trajectory to the ANSP automation system, as well as any real-time changes to it. Thus, the ANSP will have access to the intended path of each AFR aircraft and, workload permitting, can provide traffic advisories to IFR or AFR aircraft in accordance with the FAA Air Traffic Control handbook para. 2-1-21 (ref. 17). In addition, since conflict prevention procedures of AFR aircraft do not distinguish between AFR and IFR traffic, AFR aircraft trajectory changes will ensure no conflicts with IFR are generated that would induce the ANSP to take action. AFR aircraft will resolve all conflicts with IFR aircraft, permitting the ANSP to maintain its separation focus primarily on the IFR traffic for which they are responsible. Although the ANSP is not responsible for AFR-IFR separation, the ANSP may also take action to resolve AFR-IFR conflicts by moving the IFR aircraft, if desired.

The primary mechanism the ANSP will use to coordinate with AFR aircraft is the sharing of IFR trajectory information. Specifically, a means will be established through future automation for making the active near-term trajectories of each IFR aircraft available to AFR aircraft. The provision would be either through uplink from an information network such as SWIM or through a future mandate to include trajectory data in all ADS-B Out broadcasts. The AFR concept assumes that the ANSP might need to alter the flight trajectory of an IFR aircraft under their control at any time for purposes of separation, to meet a TFM objective, to sequence or space aircraft, or for any other safety or efficiency reason. Because such maneuvers by IFR aircraft may not always be pre-announced in the trajectory intent messages, the AFR/IFR minimum separation targets in ASAS will include a buffer (as described in Section 4.4.3) to permit the AFR to safely react to such IFR maneuvers without a loss of separation. Only in an emergency resulting from total loss of AFR separation capability and threatening a loss of separation with an

IFR would the ANSP need to invoke the safety alert provisions of the FAA Air Traffic Control handbook para. 2-1-6 (ref. 17).

Through voice communication on the sector frequency, the ANSP will have the ability to coordinate with AFR pilots directly, should the need arise. Although ANSP sharing of IFR intent information and AFR responsibility for AFR-IFR separation should minimize the need for direct coordination, the option will exist to aid situation awareness and operational efficiency.

As the solely responsible party for their own traffic separation, AFR flights do not depend on the ANSP to serve as backup for separation while operating under AFR. The ANSP will bear no responsibility for monitoring AFR-AFR or AFR-IFR separation or for intervening, either by request or under its own volition, to provide separation in situations where the AFR flight crew is responsible. The ANSP has no intervention authority to cancel an aircraft's AFR status, just as they cannot compel a VFR flight to become IFR. Thus, an aircraft operator that files an AFR flight plan has accepted full responsibility for separation and must meet that responsibility under all normal operations. However, this does not preclude a controller from taking action with an IFR aircraft at any time. Contingency procedures for non-normal situations such as AFR equipment failure include the ability for the AFR operator to request an in-flight IFR clearance, just as an IFR-qualified VFR pilot in an IFR-equipped aircraft can do. Accommodation of such a request would occur, as today, workload permitting, upon which the flight would no longer be operating under AFR. Contingency procedures are addressed in greater detail in Section 8.

Coordination of active maneuvers among AFR aircraft, as described earlier, uses automated separation logic in both aircraft to ensure simultaneous maneuvers are complementary and not self-cancelling. Since the AFR concept is designed to be compatible with a range of IFR concepts, including current-day operations, maneuver coordination between AFR and IFR may not be possible until automation begins to play a more central role in ANSP separation decision-making. Once this occurs, safety will be enhanced if the ANSP separation automation tools are implemented using the same coordination criteria as ASAS separation automation.

4.5.6. Explicit coordination for collision avoidance

In the rare circumstance of failure of this multifaceted system of implicit coordination mechanisms, TCAS will be invoked as today to reduce collision risk. The AFR concept assumes TCAS or a replacement collision avoidance system is in place and is explicitly coordinated between aircraft, including IFR aircraft. The separation and collision avoidance systems are similar in many ways and should therefore be designed with compatibility in mind. By having both systems onboard, the issues associated with urgent transfer of control authority from the controller to the pilot (as in IFR) can be avoided. As a safety backup system to the onboard separation function, TCAS will be implemented with independent hardware and/or partitioned software to the extent needed to achieve the target level of safety for collision risk.

4.6. Right of Way

Right-of-way is employed in the AFR concept for several reasons: to reduce the occurrence of two aircraft simultaneously maneuvering to resolve the same conflict, to reduce the total number of trajectory changes occurring in the airspace, to establish some equity among aircraft that resolve conflicts, to support the integration of AFR in an ANSP-IFR environment with evolving capabilities, to help maintain the schedules of air carriers, and to give priority to emergency and other special-operations aircraft.

Right-of-way in the AFR concept is implemented through a set of “priority rules” shared and applied by all AFR aircraft. Applying the priority rules between any two aircraft in an encounter results in ranking one of the two aircraft as the “priority aircraft” (i.e., higher priority) and the other as the “burdened aircraft” (i.e., lower priority). Rankings of encounters of three or more aircraft are performed on a pair-wise basis (i.e., aircraft A vs. aircraft B, B vs. C, and C vs. A). Thus, an aircraft could be the priority aircraft in one encounter and simultaneously the burdened aircraft in another encounter. Conflict prevention rules apply in carrying out burdened-aircraft responsibilities, and thus a resolution of one conflict should resolve all existing conflicts for that aircraft.

In the AFR concept, the priority ranking determines the conflict notification timing for the flight crew and thus when the CR procedures are initiated. In general, the flight crew of the burdened aircraft is notified first, and the flight crew of the priority aircraft is notified after a short period if the conflict still exists. The flight crew bears no responsibility in determining the priority ranking because the rule set is explicitly defined and evaluated automatically within the ASAS of each AFR aircraft. This approach provides the advantage of allowing the use of complex rule sets that consider many factors beyond the relatively simple geometric factors in VFR and maritime encounters. It also reduces the potential for disparate interpretation between the two flight crews that may lead to hazardous situations where both crews believe they have priority in the encounter.

4.6.1. Factors in determining priority

Detailed AFR regulations will establish the precise definition of the priority rules, but multiple factors are expected to play a role in the ultimate determination of priority. In order of relative precedence, these factors include emergency status, flight rules, arrival constraints, and encounter geometry. If other priority considerations such as "Best Equipped Best Served" are implemented, it could cause the priorities listed below to be re-visited.

Emergency status

Any aircraft in emergency status (or otherwise designated as a special operation) will have priority over an aircraft not in emergency status.

Flight rule status

In encounters between AFR and IFR aircraft, the IFR aircraft will have priority over an AFR aircraft, except where the Emergency Status rule applies. This is done so that there is no burden on the ANSP to provide right-of-way to an AFR aircraft by altering the path of an IFR aircraft they are controlling. AFR aircraft will be displayed to controllers with their flight rule status in the aircraft data tag. A controller may, as an additional duty, time permitting, issue a traffic advisory to an IFR or AFR aircraft in the same manner as he would point out a proximate VFR or other IFR aircraft.

This right-of-way rule is considered critical to enabling mixed AFR-IFR operations in environments where controllers are not supported by automation tools for conflict management.

As automation tools are introduced, rebalancing of right-of-way in favor of the better-equipped AFR aircraft can be considered. Meanwhile, the ANSP is not prohibited from maneuvering the IFR aircraft should it be desired.

AFR-VFR encounters will be governed by standard Visual Flight Rules, as are IFR-VFR encounters. As always, each pilot must see and avoid all other aircraft in VMC.

Arrival constraint

An AFR aircraft with a near-term arrival constraint may be given priority over an AFR aircraft without a near-term arrival constraint, except where the previously mentioned rules take precedence. Examples of arrival constraints are a Required Time of Arrival (RTA) at the arrival metering fix and an IM clearance for airborne spacing to the runway (which may commence in en route airspace).

Research has not yet suggested the need for this rule, the time horizon over which it would apply, or the source of the required information. The rule is included here as a conceptual placeholder.

Encounter geometry

In encounters between two AFR aircraft where priority has not been determined by the preceding rules, the geometry of the encounter will be used to determine priority. The VFR rule set governing right-of-way in various geometric encounters should be the starting point for the corresponding AFR rule set, the objective being to maintain compatibility with visual separation rules that would be applied by all aircraft in visual conditions. More importantly, however, this rule set should be comprehensive in its coverage of encounter geometries, including vertical segments of the trajectories of the subject and traffic aircraft. Current VFR rules are not explicit enough to serve as a complete model. The rule set must cover all possible geometries and have no gaps or singularities. Departure from the VFR example may be necessary to accomplish this requirement.

4.6.2. Additional requirements for priority determination

The right-of-way rule set and its implementation should have the following additional characteristics and properties.

Restricted to data available from surveillance sources

Information on traffic aircraft for priority determination will be limited to that which is available over ADS-B or TIS-B. The rule set must work within this restriction. If additional information is determined to be necessary, this may require modification to the ADS-B minimum required message set, TIS-B content to be enhanced, or an alternative uplink by the ANSP of the required information.

Asymmetric and coordinated

The rule set should produce a rank ordering and generally avoid declaring a tie, i.e., equal priority. Ideally, applying the rule set from either aircraft should produce the same ranking result. However, a conservative implementation may allow for equal priority in boundary cases (i.e., where uncertainty effects prevail), provided that both aircraft consider themselves the burdened aircraft. To be avoided are situations in which both aircraft assume they have the right-of-way.

Stable in the presence of uncertainty

Where the inputs to the rule set may fluctuate due to measurement uncertainties or environmental variations, the output should be reasonably stable, i.e., the ranking should not continually flip. In addition, the rule set should use the most stable information available as input and minimize reliance on predictions subject to significant errors or uncertainties.

5. Procedure Description

5.1. Flight Operations Procedures

AFR may be conducted by any civil or military aircraft in the NAS. This section outlines AFR-related procedures envisioned for fleet operators that have operational support from their own ground-based facilities. Procedures envisioned for non-fleet operators are addressed at the end of this section.

5.1.1. AFR Fleet Management

AFR equipment installations would be prioritized by fleet type, starting with the fleet that could derive the greatest benefit from AFR procedures. From a maintenance standpoint, the individual tail numbers of aircraft are already tracked to ensure the proper inspections are performed and spares are on hand. In any fleet at any time, there are wide differences among the aircraft as modifications and upgrades to many systems are installed during the regular maintenance downtime schedule. Retrofitting an aircraft with AFR capability would be worked into this schedule.

Aircraft fleet routing at airlines is planned in a strategic sense typically a month in advance of the schedule being flown to accommodate both anticipated loads and scheduled maintenance visits. On the day of operation, equipment substitutions (if needed) are made in the same aircraft type, if available. The aircraft routers would schedule the AFR aircraft on the routes that would provide the greatest return on investment. These would generally be the routes most constrained under IFR, i.e., in regions with the higher traffic densities.

For any given city pair, an AFR aircraft may have a somewhat lower flight time and fuel burn than the same type of aircraft operating under IFR. This time difference may be most apparent on shorter flights where the IFR penalties are greater. Keeping AFR aircraft only on particular routes may prove difficult and/or inefficient to integrate within existing route schedules while their numbers are few among the airline's fleet. Therefore, it is likely that airline schedules will change in a way that maximizes the AFR flight time benefit only after a substantial portion of any single fleet type is equipped. At lower AFR equipage levels, shorter fleet-wide flight times and improved on-time performance may still result, although not to their maximum extent.

5.1.2. AFR Flight Planning

All of the current procedures and requirements for safety and operational integrity of the fleet operator would be used in planning AFR flights, just as they are for IFR flights. The biggest difference in planning an AFR flight would be in the available choices for the flight trajectory.

The operator’s business needs are the basis of the flight plan. Finding the least-cost flight trajectory that meets the constraints of safety and security is the job of flight-planning software at nearly all major carriers today, and the sophistication of these systems will increase dramatically as restrictions to operation in the airspace are removed by operating under AFR. 4D flight planning is designed to optimize the earnings contribution of each individual flight in an airline’s schedule. Earnings contribution is the revenue generated by the flight minus the cost of operating it. While passenger revenue is well determined just before departure time, cargo revenue often is not, being subject to the load-carrying capability of the aircraft. If an AFR aircraft is assigned to the flight, additional payload may be carried, as the fuel load will reflect a lower "burn out" along the trajectory and may also have lower required reserves. Making passenger connections, especially to flights that only operate once daily or less, has both revenue and cost implications. Spilling a passenger to a competitor's flight means lost revenue. Putting passengers up for the night and feeding them adds to cost. All of these factors are considered simultaneously when planning the flight trajectory, including aircraft speed along the chosen vertical and lateral path. AFR capability should enable greater optimization of flight operations with respect to achieving a fleet operator's business and customer service objectives.

There is not yet one "best" implementation of such a flight-planning system and the degree to which a particular airline has been able to optimize this function is a major competitive discriminator. Adding AFR aircraft to the mix provides even more opportunity for flight-planning sophistication. Removing restrictions to the flight can simplify some aspects of the planning process but since many flight-planning systems have the current ANSP constraints built into them, removing those constraints will lead to more flexible trajectory optimization algorithms. The flight-planning system will take into account the added flexibility of AFR operations, as well as the availability of AFR aircraft in the fleet, in solving this complex optimization problem.

5.1.3. En route replanning and flight deck coordination

The flight plan created prior to departure is the basis for the final fuel load and the planned payload at departure. Once underway, many of the parameters used in the original plan change, including things of interest only to the operator. Therefore, the 4D flight planning system continues to run new plans (called forward flight plans) periodically from an airborne aircraft's current location to its destination, using the altered input parameters. These plans may result in changes to the lateral path flown, the vertical flight profiles used, and airspeed flown along track, any of which may or may not change the Estimated Time of Arrival (ETA) at the destination. The ability to fly AFR would maximize the ability to exercise this flexibility because ANSP approval for changes is not required and therefore the type, scope, and frequency of changes are not limited.

Ad hoc changes to the original plan may originate either with the dispatch function or in the cockpit, but all such changes are vetted by the flight crew prior to execution. In performing forward flight planning, not only the expected external influences are considered, such as SUA status, actual and updated forecast winds, turbulence, and the actual existence and location of thunderstorm cells, but also the internal factors such as measured fuel compared to planned fuel at waypoints, status of other flights to which connections are to be made, and actual gross weight which determines altitude capability and other performance parameters. Additional requirements related to the condition of passengers on board, though less frequent, create other common perturbations to the original plan. The flexibility of AFR to immediately accommodate these changes, as well as things only visible to the flight crew, makes it cost effective for operators to invest in the development of sophisticated "contribution optimization" algorithms in their flight-planning systems.

5.1.4. Flight restrictions monitoring and preemptive decision-making

The airline flight dispatch function keeps track of SUA status and congestion at the airports and in the airspace. This information can be immediately used by AFR aircraft to alter their trajectories and avoid unnecessary maneuvering and inefficiency while flying through these areas. There is no need for them to pre-coordinate such decisions with the ANSP before taking action. Similar efficiencies result when SUA is opened up to civil flights, the acceptance rate of an airport changes unexpectedly, or convective weather fails to materialize or shows up where not expected. The AFR flight crew can immediately make a route, altitude, or speed change and then request an updated flight plan from flight dispatch to reflect the new reality the remainder of the way to destination.

5.1.5. ANSP coordination for arrival scheduling

An AFR flight that is planned to a capacity-constrained airport will provide to the ANSP the ETA at that airport prior to its push-back from the departure gate, followed by regular en route updates. This information is used by the ANSP in any traffic management initiative to be imposed on all flights to balance capacity and demand. "Best Equipped Best Served" may qualify AFR flights for priority in the altered arrival schedule. Any required alteration to the ETA would be issued by the ANSP as an RTA and sent to both the dispatch function and the flight crew. To comply with a delayed arrival time, the operator may elect to delay the AFR flight at the gate, on the ground away from the gate, or in the air.

Once in the air, changes to the arrival schedule will be used by the dispatcher in forward flight planning and executed by the flight crew to take advantage of available airport capacity as a part of the dynamic optimization of all the fleet operator’s flights.

5.1.6. Procedures for Non-Fleet Operators

Many General Aviation (GA) operators do not have their own ground support facilities for information gathering, flight planning, and en route flight plan updating. Rather, they rely on either government or private services for these needs. For non-fleet operators, AFR flight planning is conducted similar to IFR flight planning for flights to other airports, or similar to VFR flight planning for local flights where the origin and destination are the same airport (e.g., flight training). Takeoff, approach, and landing clearances would be requested from the appropriate ANSP facility, where these airport services are provided, and the departure and arrival would be performed in accordance with the issued clearance. While en route, information is expected to be available through authorized aircraft access to the SWIM database of current airport and NAS information, including weather data.

5.1.7. Flight Plan Filing

All AFR flights would file AFR flight plans with the ANSP. For flights to distant airports, the AFR flight plan would indicate the initially planned trajectory (route, speed, and altitude) to support ANSP awareness of aggregate AFR operations in the airspace as well as search and rescue requirements. The filed route would include at least one waypoint for each crossing of an Air Route Traffic Control Center boundary. For flights conducted entirely within a single Center, a route specification would not be required, and the ANSP would assume a direct route between airports. For local flights, the route may simply indicate “AFR local.”

The ground automation would assign a transponder code so that the AFR status of the flight would be known to the ANSP and to other aircraft throughout the flight. Where IFR handling is specifically desired at the origin or destination airports, the option would exist to file a composite flight plan that specifies AFR for the en route segment and IFR for the departure and/or arrival segments. Similar to VFR-IFR composite flight plans, the AFR-IFR composite flight plan would specify the AFR-to-IFR transition fix and ETA. With this information, the ANSP would have an IFR clearance ready for the aircraft upon its reaching the arrival transition fix, and the remainder of the flight would be planned and conducted as an IFR flight. Some terminal airspace with complex operations (e.g., Class B) may require such composite flight plans under certain conditions, e.g., when IMC is forecasted.

5.2. Flight Deck Procedures

The procedures used by flight crews operating under AFR are considerably more proactive than under IFR because so much more freedom of action is available to them. The flight crew will be continually involved in assessing changing conditions both on and off the aircraft and participating in the determination of the future flight path to maintain safety from all hazards and to optimize their own flight's performance in the business sense.

5.2.1. Transitioning from IFR to AFR

Wherever the ANSP provides an airport control service, AFR aircraft are required to participate in that service and conform to any ANSP-issued clearances, the same as any other VFR or IFR aircraft. AFR aircraft on the airport surface operate under ANSP Ground Control and will comply with ground control instructions. The ANSP will also provide the takeoff clearance to AFR flights as it does to all others, usually with an initial heading and altitude or departure procedure, including noise abatement procedures. For AFR departures from airports within Class B or C airspace, the flight may initially operate as an IFR departure. After takeoff, a handoff will be made from tower to departure control. When the aircraft is initially clear of other traffic, the ANSP may clear the aircraft to “proceed under AFR”. Taking off from an airport in Class D airspace will only involve the tower for the taxi and takeoff clearance. At non-towered airports in Class E and G airspace, the AFR flight will use surface applications of ADS-B from the beginning of taxi and self-separation capabilities starting at takeoff.

While operating under IFR, the flight crew may be permitted to operate the ASAS equipment from the beginning of taxi throughout the takeoff and departure. However, ASAS use will be restricted to other approved ADS-B applications separate from AFR, such as surface alerting or departure IM procedures.

When the flight crew is informed to "proceed under AFR", the clearance is acknowledged, and the flight guidance is engaged to the business trajectory that is loaded in the navigation system, commencing AFR operations and continual flight optimization.

5.2.2. En Route operations

AFR operations will typically commence while the aircraft is climbing to its initial cruise altitude. Once released by the ANSP, the climb profile will not be subject to institutionalized altitude level-off restrictions prior to reaching the cruise altitude. The procedures during climb and cruise are the same; the flight crew monitors the progress along the business trajectory and performs other normal piloting tasks. Although positions of nearby traffic will be shown on a display, the flight crew is not required to monitor the display or to scan for potential conflicts. The CD function is performed entirely by the ASAS automation, and the flight crew will be notified if a conflict is detected that requires a pilot response. In such events, the pilot will be provided with flight guidance to maintain separation, which must be followed, just as an ATC clearance for IFR aircraft.

While en route, the flight crew maintains a listening watch on the voice frequency for the ANSP sector being traversed, that frequency being continuously updated during the flight. The voice frequency is guarded for potential use in emergency situations, enabling communications with the ANSP or other nearby flights. Normal operations will generally not require voice communication with the ANSP, including transfer of communication, which is expected to be transitioned to CPDLC in the coming years. Voice communications will also provide the option for the ANSP to coordinate directly with the AFR pilot to aid situation awareness and operational efficiency, although such coordination is expected to be infrequent.

The majority of the flight will generally be conducted in a strategic autoflight mode, with the autoflight system coupled to the FMS (if available) or by a pilot following the flight director that conforms to the desired business trajectory. The flight crew also has the option to fly in tactical flight modes if the conditions dictate, such as when navigating in and around convective weather. The near-term portion of the active trajectory is automatically and repeatedly broadcast over ADS-B without pilot involvement, thereby promoting shared awareness of the aircraft's intended path. When on an active FMS route, a more complete trajectory is also maintained current with the ANSP through automated CPDLC downlink. The ETA at the destination will be continually updated as conditions change en route for use in ANSP traffic management algorithms.

The flight crew monitors the conditions of the flight (e.g., weather, turbulence, and fuel state) and periodically reassesses the conditions to ensure the business trajectory remains optimal. If the flight has been assigned an RTA by the ANSP, the flight crew monitors progress towards the RTA waypoint. RTA assignments will have either a standard or specified tolerance, and onboard systems will aid the flight crew in monitoring conformance. The flight crew will adjust the trajectory as needed to maintain conformance, or if unable to meet the assigned time, they will contact the ANSP and coordinate a revised assignment.

5.2.3. Conflict management

During AFR flight, the onboard ASAS automatically and continually probes the active trajectory for conflicts with other aircraft trajectories, using surveillance and trajectory information received automatically from the other aircraft or ground systems. From the flight crew perspective, this process occurs in the background and the flight crew will only be notified if a conflict is detected and a pilot response is required. Depending on its design, the ASAS may provide manual tools that the flight crew could use to monitor traffic encounters on the traffic display. However, only active conflicts indicated by the ASAS alert system would require the flight crew to respond with a trajectory change. Preemptive and speculative adjustments of the trajectory by the flight crew to avert potential conflicts would generally be counterproductive and are discouraged, although not prohibited. Any such pilot-initiated adjustments would have to follow procedures for conflict prevention, described next in Section 5.2.4.

The ASAS will notify the flight crew of an actionable conflict by both visual and aural indications. If a multi-level alert system is used, the visual and aural indications will reflect the urgency for flight crew response. Although detailed procedures will be somewhat dependent on a particular ASAS design, the general flight crew procedure for non-urgent conflicts would begin with acquiring awareness of the particular conflict situation indicated by ASAS, including the conflicting aircraft's relative position, altitude, direction of flight, and location of the predicted LOS. Although developing this awareness is not required to resolve the conflict, it would be considered good safety practice, similar to a controller pointing out traffic under VFR Flight Following. For urgent conflicts, this step could be skipped. In most implementations, an ASAS conflict alert is the flight crew's indication that a trajectory change will be required. The flight crew will not be required to decide whether a resolution maneuver is needed, as this would inhibit the built-in coordination mechanisms described in Section 4.5.

To resolve an indicated conflict, the flight crew must use the ASAS to determine the maneuver, as it is the only mechanism for ensuring that the trajectory change will resolve the conflict and not create new conflicts. The ASAS CR function may compute several acceptable trajectory-change solutions for pilot selection, but it will always provide at least one solution (a likely certification requirement). In all but the rarest situations, the solutions provided by ASAS will be conflict-free all the way to the chosen time horizon. (Rare situations in which no conflict-free maneuvers exist, which can also occur today, would still result in ASAS-generated maneuvers that prevent LOS, if possible, or minimize the hazard, if a LOS is inevitable.) In typical installations, the CR solutions will be displayed on the Navigation Display (ND), Primary Flight Display (PFD), other dedicated display, and/or the MCDU. The CR solutions may be strategic (i.e., executable as a modified FMS route or altitude) or tactical (i.e., executed by direct pilot control of the autoflight settings or manual flight controls). In general, tactical resolutions will be used when the time-to-LOS is within a few minutes, because they can typically be executed more quickly.

The flight crew must make a trajectory change that is consistent with ASAS guidance. In most situations, the flight crew will simply execute one of the supplied maneuver options. In some situations, the pilot could modify the maneuver to suit crew preferences, for instance to climb 2000 feet rather than the 1000 feet indicated by the ASAS CR. However, such modifications must conform to the conflict prevention procedures discussed next in Section 5.2.4. Since information on convective weather and SUA (i.e., area hazards) will likely be available in digital form on the flight deck, most ASAS installations will typically ingest and take this information into account when producing CR guidance. ASAS will be designed to keep the aircraft separated from both traffic and airspace hazards and will apply appropriate priorities between them. Generally, area hazard definitions will include sufficient safety buffers to allow temporary latitude in resolving traffic conflicts in the vicinity of the area hazard. As today, the flight crew will use experience and judgment to complement policy when determining safe distances from weather hazards.

Most conflict resolutions will be of the strategic type, meaning the maneuver is fully executed through one update of the FMS active route. In such situations, no further flight crew action is required. The flight crew may choose to monitor the closest point of approach of the previously conflicting aircraft, although it is not required. If the flight crew switched to a tactical flight mode, for instance in response to a tactical CR, they may continue indefinitely in the tactical flight mode or, preferably, return to the lower-workload strategic mode following appropriate CP procedures.

5.2.4. Conflict prevention

While en route, AFR flight crews may have reason to modify the aircraft's trajectory for purposes other than to resolve a conflict. The change may be a complete re-plan of the business trajectory in response to, for example, an updated wind forecast or changed arrival priority. It could be a re-optimization of the cruise altitude for improved ride quality or fuel efficiency. Or it could be a temporary deviation to navigate around a weather cell. Whatever the reason for the change, the flight crew must follow conflict prevention procedures to ensure the trajectory change does not create a conflict.

The universal CP procedure for verifying acceptability of a specific desired change is to enter the intended maneuver into the ASAS so that it can probe the maneuver for conflicts. The specific method for entering the maneuver will be dependent on the particular ASAS design and installation. The ASAS CP function will accommodate both strategic and tactical provisional trajectories. For most integrated avionics installations, the flight crew will be able to preselect the maneuver in the autoflight system. Provisional strategic maneuvers will generally be entered by creating an FMS "mod" route. Provisional tactical maneuvers will generally be entered through flight control presets. Prior to execution of either type, ASAS will probe the maneuver. If no provisional conflict is indicated, the flight crew may execute the maneuver.

Other CP functionality may include an "at a glance" display of conflicted maneuvers (or alternatively, conflict-free maneuvers). Using this capability, the flight crew could see, for example, that tactical turns to the left are available but turns to the right are not. This information could aid in situation awareness and advance maneuver planning, but the procedure above will still be required prior to any specific maneuver.

5.2.5. Transitioning from AFR to IFR

If the destination airport has ANSP-provided terminal services, AFR flights must participate in those services. If the ANSP terminal automation provides a metering list used by controllers, the AFR aircraft will provide an ETA at the metering fix in order to facilitate the merge with other traffic at the arrival airport. If the ETA must be adjusted to meet flow management constraints, such adjustment will take the form of an RTA issued to the AFR flight. At airports where automated arrival fix metering for all flights is not implemented, AFR flights will arrive at the terminal airspace boundary at a separate designated fix, when justified by traffic volume, to pick up their ATC instruction (usually a heading and an altitude) and will follow radar vector procedures to the final approach course, the same as IFR flights. Alternatively, the flight crew may pick up an actual IFR clearance upon entering terminal airspace and proceed under IFR. AFR aircraft arriving at airports within Class C or D airspace in VMC must follow the same requirements as VFR arrivals for contacting the tower. When the weather is IMC, ANSP approval must be received before entering the airspace. The AFR flight plan filed before flight will be on file at the destination airport, and thus the ANSP will be expecting the flight's arrival, have a flight strip on it, and have an IFR clearance ready for issuance at the specified transition fix. Flights by AFR aircraft to and from uncontrolled airports located within Class E or G airspace may be made without any contact with the ANSP in VMC. Use of AFR procedures at these airports in IMC requires TIS-B coverage or the ADS-B Out requirement for all aircraft operating at the airport in IMC.

The specific procedures used by an AFR flight arriving at the terminal boundary depend on the state of implementation of NextGen automation for the time period in question. Three subsequent time periods are illustrated here, by way of example.

Current – In today's system, the flight crew of the AFR flight calls the TRACON prior to entering the terminal area, whose lateral and vertical boundaries are shown on the map display. The approach controller responds, verifies identity, and declares "radar contact." From that point on, the AFR flight is treated like an IFR aircraft, including issuance of clearances for charted procedures, vectoring, and speed control all the way to the runway. At high-traffic airports, dual fixes at the arrival corner posts will provide for initial separation of AFR and IFR flights during the transition to terminal IFR procedures. The AFR flights would proceed inbound from their arrival fix at an ANSP-assigned altitude and on a heading parallel to the traffic crossing the IFR fix. Subsequent radar vectors would be used to merge the AFR and IFR aircraft to the appropriate final approach course. It is important to note that the existence of AFR will not, in itself, cause any change in the total volume of traffic. AFR flights would otherwise have been IFR or VFR flights already using the airport, and the total traffic handled will not change.

Midterm – In the mid-term, data communications will be in use domestically, and the re-establishment of ANSP control will take place through that medium. Optimum Profile Descents (OPD) may be in use at the airport along with IM operations. Both of these procedures are coordinated through the ground-based ANSP so the transition from AFR to IFR may take place near the Top of Descent with the issuance of a clearance to perform the OPD and IM, along with an RTA (if required) and the landing sequence in the form of the identity of the aircraft to follow. There will be a mix of capabilities in this time frame, and the ANSP will be using vectoring and speed control to assist the merge for some aircraft and to maintain their proper spacing on final.

Far term – In the far term, the merge for each runway will be performed using a time rather than distance interval until short final where aircraft using the same runway will interleave for landing. The ANSP automation will still assign the landing sequence in response to the ETAs given by all incoming aircraft, but AFR flights will be able to maintain AFR status all the way to the runway. Their OPD will be ad hoc, conforming to their business trajectory while separation responsibility is continued. The IM function will be performed as a timing tool, perhaps to follow an aircraft approaching the runway from the opposite direction. Spacing on short final is also an airborne function performed without ANSP assistance. There will always be a mix of airborne capabilities in the airspace, but manual control by the ANSP should be the exception.

5.3. ANSP Procedures

During the transition to NextGen, the ANSP procedures used by human controllers will evolve as additional decision support tools are implemented in the ATC facilities. Many of the procedures used to control IFR and VFR aircraft in various portions of the airspace will change with the introduction of TBO and ANSP data communications. However, by design, almost no new procedures are required to accommodate AFR flights in the en route airspace.

5.3.1. Releasing flights to AFR

AFR flights are identified to the ANSP as such in the initial flight plan and on the flight strips used by airport and terminal area controllers. These flights are treated like any other IFR departure until after takeoff, when the departure controller hands off separation responsibility to the flight crew. This handoff occurs when the AFR flight is not in a current or imminent conflict situation with any other IFR flight. The phraseology might be, "Transcon 123, radar service is terminated, proceed under AFR". The ANSP must receive pilot acknowledgement for the handoff to be complete.

5.3.2. Managing IFR flights in mixed IFR/AFR airspace

Normal control of en route IFR flights continues with minimum regard given to the presence of AFR flights. Any exceptions are considered non-normal operations and are discussed in Section 8. The ANSP has no separation or trajectory management responsibility for AFR flights from the time they are released to AFR until re-established on an IFR clearance, normally in the vicinity of the destination terminal airspace. AFR flights will still be displayed on the controller's display but, at the controller's discretion, may have reduced or suppressed data tags, similar to VFR flights in certain airspace. ASAS separation logic is designed to detect and resolve conflicts between AFR aircraft and ANSP-managed IFR aircraft in a timely fashion to preclude controller concern about whether the AFR flight is going to resolve the conflict or how it will be resolved. A concerned controller may always take action by maneuvering the IFR aircraft. Normal ANSP procedures of not creating a known hazard apply. In addition, contacting AFR pilots on the voice frequency is available to aid situation awareness and operational efficiency. In normal operations, voice communication between en route controllers and AFR pilots should not be frequently required.

5.3.3. TFM and AFR

Traffic management initiatives will be coordinated with both the operator’s flight operations center (if applicable) and the aircraft involved. If necessary, flight dispatch would reissue flight plans taking the traffic management constraints into account. Two common constraints that may be imposed on AFR operations are an RTA at a geographic point or, alternatively, an IM clearance to perform airborne spacing on a lead aircraft in the arrival flow.

The RTA could be assigned to meet a TFM objective at a busy destination airport to limit the arrival rate. It might also be used to facilitate an AFR flight's resumption of ANSP-managed control (either transition to IFR or issuance of ATC vectors) at a terminal airspace entry point. When an RTA exists, it is included as a constraint in the AFR aircraft’s strategic CR function of the ASAS. In these instances, separation is maintained while still complying with the active RTA. If for any operational reason it becomes unsafe, impractical, or impossible to meet an RTA, the cockpit automation systems (FMS and/or ASAS) advise the flight crew of this, along with a new time window that can be met. This time window would be sent to the ANSP as the opening request in a computer negotiation for a revised RTA. The revised RTA from the ANSP would be acknowledged and met by the AFR flight.

IM procedures would typically be used as a TFM initiative to maximize arrival throughput. IM uses airborne spacing capability to achieve precise intervals between aircraft at the merge point or runway. Because the procedure may start prior to the aircraft’s Top of Descent, integrating the AFR and IM concepts will need to be considered. Integration of these concepts is considered feasible, but further research is required to develop a detailed description.

When traffic management initiatives are not in effect, the ANSP would use the aircraft's ETA at the transfer point for arrival planning. The ETA would automatically be provided from the FMS by data link or advised by the flight crew by voice, and it would not constitute a constraint on the business trajectory. If an RTA or IM procedure is required for congestion or merging with other traffic, the ground scheduler would use the ETA to optimize the arrival sequence and minimize delay.

5.3.4. Transitioning from AFR to IFR

If the destination airport has ANSP-provided airport services, AFR flights must check in with the ANSP and receive a clearance prior to entering Class B, C, or D airspace. The procedural nature of this transfer of control depends on the degree of implementation of NextGen capabilities. If the ANSP terminal automation provides a metering list used by controllers, the AFR aircraft will provide an ETA at the metering fix in order to facilitate the sequencing of traffic at the arrival airport. In the near term, the ETA would be sent by voice transmission to a controller. If the ETA must be adjusted to meet flow management constraints, such adjustment will likely take the form of an RTA issued by the controller to the AFR flight. In the midterm, this merge time negotiation will be performed using data communications, and RTA or IM procedures may be used. In the far term, the ETA transfer should be an automated airborne to ground system communication, and extensive use of RTA and IM procedures should be the norm. AFR aircraft arriving at airports within Class C or D airspace must follow the same requirements as VFR arrivals for contacting the TRACON and tower and for complying with any issued clearances. Flights by AFR aircraft to and from uncontrolled airports located within Class E or G airspace may be made without any contact with the ANSP in VMC. Use of AFR procedures for these airports in IMC requires TIS-B coverage or the ADS-B Out requirement for all aircraft using the airport in IMC.

6. Airspace Characteristics

The airspace structure of the NAS need not be altered for the introduction of AFR operations. The existing airspace classification scheme, in which the U.S. employs Classes A, B, C, D, E and G, could continue, with AFR operations being permitted in A, E and G airspace without participation in the ground-based ANSP separation function. Operations in terminal airspace classified as B, C, or D would require participation in the ANSP ATM system through compliance with any issued ANSP clearances. Separation responsibility may be delegated to the flight crew by the ANSP within terminal airspace as described in NextGen documentation, but absent such delegation, the responsibility rests with the ANSP for both AFR-AFR and AFR-IFR interactions. AFR capabilities could act as a backup safety system for all encounters, including those with VFR traffic.

6.1. Airspace and Route Structures

AFR operations are conducted independently of airspace structure, except for the terminal airspace boundaries governing transition to and from ANSP-managed operations. ANSP facility airspace boundaries and inter-facility control sector boundaries may be retained or modified without impact on AFR flight, as they pose no restriction on AFR trajectories. Where more flights elect to fly under AFR and the quantity of IFR aircraft in the airspace decreases, the opportunities for sector combination and facility consolidation may increase. Terminal facilities would likely be mostly unchanged, as they continue to provide airport access to the mix of aircraft capabilities.

AFR operations will typically be flown using Area Navigation (RNAV) equipment and will not require any route structure for either navigation or separation. The flights are "trajectory-based", meaning that a path through space, defined in three dimensions and with planned speeds along track, is created in the flight planning system, entered into the aircraft FMS, and executed by the pilot and/or autopilot. This 4D trajectory is planned for business and safety considerations, is flight-specific, and is not charted.

Route and airway information may continue to be published for use by traditional IFR flights but would not typically be used in the description of AFR flight trajectories. Published terminal routes, IFR departure and noise abatement procedures, and instrument approach procedures do not require modification for the accommodation of AFR flights. Such flights may or may not use them, as permitted by the ANSP clearance. It is expected that more use will be made of RNAV-based terminal procedures in the future for IFR aircraft, and these also may or may not be used by AFR flights. For safety, minimum obstacle clearance altitudes will be observed by AFR aircraft while operating in IMC.

6.2. Navigation and Surveillance Services

AFR operations will use the prevailing navigation services available without imposing any special requirements. GPS services will likely be available throughout the subject operating region, with predictable performance and availability. Ground Based Augmentation Systems will also likely be ubiquitous in this airspace, although the extra precision is not a requirement for AFR. Airborne inertial systems will provide both attitude information and a coasting capability for navigation in areas and at times of GPS outage. Backup en route navigation for longer periods may be available through independent systems such as Loran, Distance Measuring Equipment, or a data link-dependent service like multilateration positioning, sent to the aircraft for use in navigation.

The primary form of surveillance for both the ANSP and AFR aircraft operators will be ADS-B, supplying position and velocity information directly from the traffic aircraft. Backup surveillance on the ground will be through a combination of retained primary/secondary radars and transponder-based multilateration. The primary radar coverage will likely be only that needed for military and national security requirements. The backup airborne surveillance source will be the TIS-B service from the ground, which supplies aircraft with the best information available to the ground service provider. To be a viable backup for ADS-B surveillance used in AFR operations, TIS-B performance may have to be improved over the current radar-based service. For collision avoidance, it is assumed that TCAS, which has its own means for surveillance, will be retained and likely enhanced.

6.3. Air/Ground Communications

As long as traditional IFR services are provided in a given airspace, the air/ground voice frequency in use for that service will be monitored in the cockpits of AFR flights. Increasingly, air/ground communications with AFR flights will be data communications. Aeronautical information services on the status of weather, airports and SUA will be requested and received over existing or new data links. In the midterm, ETAs, RTAs, and other traffic management initiative information will be transmitted and negotiated through CPDLC. Trajectory information on IFR flights will also be made available to AFR aircraft through data link. In the far term, all communications between AFR aircraft and ground services are expected to be airborne automation to ground automation, through CPDLC or other prescribed data communication systems. Voice communication will remain as a mechanism for coordination and emergency communications.

6.4. Air-to-Air Communications

Trajectory information used on AFR flights in the ASAS separation functions will be broadcast as part of the ADS-B message. When such intent information is not available, the ADS-B message will still contain the state vector for use by the separation algorithms. As all of this information is broadcast, the AFR concept has no requirement for addressed air-to-air data communications other than that already in place for TCAS.

Air-to-air voice communications are not required for AFR flight. In rare abnormal or emergency situations, it may be useful, but not required, to have this capability, and the IFR ANSP frequency might be used during the initial time period when AFRs are guarding that channel. In the future, a single dedicated channel may be provided for emergency voice guard, as is done over oceans today.

6.5. Shared Airspace for Mixed Operations

AFR operations are designed to be immediately available to the first aircraft equipped and authorized to perform them. Thus the occurrence of AFR, IFR, and VFR operators flying simultaneously in shared airspace will be both commonplace and safe. AFR will begin as far less than one percent of the operations in the airspace but could potentially grow to encompass most operations within a few decades. Most of the VFR operations flown by sophisticated aircraft today may become AFR in the future, given the weather-independent flexibility provided by AFR and reductions in equipment costs through economy of scale. It is expected that VFR will continue at low altitudes and for recreational and special uses indefinitely.

6.6. Special Use Airspace and Weather Hazard Avoidance

The existing classifications of SUA require no modification for AFR flight. The restrictions to civil operations imposed by these restricted areas are the same regardless of the operating flight rules. In the future, when access to restricted airspace becomes more dynamic, it is expected that active and inactive status information will be available directly to all operators through the SWIM system. If an SUA changes status, the flight crew will receive the update and can replan their trajectory en route. Alternatively, a reroute can be coordinated through a flight operations service. Temporary flight restrictions issued with short notice can be communicated to AFR aircraft by the ANSP through CPDLC or voice communications. The flight crew can then immediately replan to avoid the restricted airspace.

AFR flights will not require en route hazardous weather re-routing services by the ANSP. The responsibility for avoiding areas of hazardous weather will remain with the flight crew, supported by an AOC or flight operations service when available. It is assumed that the NextGen concept of the 4D Weather Cube (ref. 11) will be available in the midterm to supply weather hazard information to supplement onboard detection and warning systems for convective activity, wind shear, airframe icing, and clear air turbulence. Weather tolerance limits will be specific to the operation and approved as part of the operations specifications for airlines. AFR aircraft will have the flexibility to determine their optimal route through or around the weather, according to their individual business objectives and risk tolerance. As most aircraft in this environment may be operating in a tactical mode, the ASAS must be robust enough to ensure safety with little or no intent information available beyond the state vector and target states.

7. System Requirements

This section discusses the expected high-level system and technical requirements to enable AFR operations. Requirements are presented for the AFR aircraft and the ANSP.

7.1. Aircraft Requirements

To file and fly under AFR, the aircraft must be properly equipped for IFR flight through all airspace classifications along its filed flight-plan route. In addition, the following AFR-related equipment must be installed and functional at the time of departure to support AFR flight.

7.1.1. ADS-B Out and In

ADS-B Out and In are required of all AFR aircraft to support the cooperative surveillance environment.

The ADS-B Out system will consist of positioning navigational equipment, such as GPS, a processor capable of composing ADS-B messages, and data communications equipment capable of broadcasting the messages at the specified intervals on either the Universal Access Transceiver (UAT) or Mode S frequencies. The content, format, broadcast intervals, and transmission range of the ADS-B Out messages will be the subject of detailed aviation system and operational performance specifications applicable to AFR operations. These specifications are beyond the scope of this document, and will likely require updates or revisions to the current ADS-B Minimum Aviation System Performance Standards (MASPS) and Minimum Operational Performance Standards (MOPS) (refs. 18-20) to support AFR operations. ADS-B Out information to support AFR operations is expected to include:

Minimum content
Aircraft identity and operational status (e.g., AFR/IFR, navigation accuracy)
State vector (e.g., position, velocity, altitude, vertical rate)

Additional content, possibly required
Target state (e.g., target or maintained altitude, target or maintained heading/track)
Trajectory changes (e.g., 4D positions of any TCPs out to a specified time horizon)
Trajectory constraints (e.g., RTA at a specified fix)

ADS-B In serves as the primary surveillance source for AFR operations. The ADS-B In system will consist of equipment capable of receiving ADS-B messages from other aircraft on either the UAT or Mode S frequencies (assuming a rebroadcast service is provided by the ANSP) and providing the information to a flight crew display and to an ASAS processing system containing approved separation logic.

7.1.2. TIS-B

The TIS-B receiver serves both as the backup surveillance source for the ADS-B In system and a primary surveillance source for non-broadcasting traffic aircraft. The TIS-B receiving equipment must be capable of decoding the TIS-B messages and providing the information to the flight crew display and to the ASAS processing system containing approved separation logic.

For AFR operations solely in non-ANSP-managed airspace or airspace outside of TIS-B coverage, an operating TIS-B receiver may not be required. However, a redundant ADS-B In receiver may be necessary to fulfill the backup surveillance source requirement. Otherwise, AFR aircraft must revert to VFR and operate in VMC whenever both the primary and backup sources of airborne surveillance are not available.

7.1.3. ASAS Processor and Separation Logic

A processor certified for the primary separation function is required and must be completely independent of TCAS. The processor would be integrated with the aircraft avionics system so that it can receive and send information pertinent to the separation function. Inputs to this processor would come from the ADS-B receiver, TIS-B receiver, the navigation system or FMS, autoflight settings, and flight crew interfaces.

The separation logic in the ASAS processor must include the functions of own-ship trajectory prediction, traffic aircraft trajectory prediction (or reconstruction), conflict detection, conflict resolution, and conflict prevention. Mechanisms must be in place to apply appropriate separation standards, time horizons, right-of-way rules, and maneuver coordination. Additional factors that the separation logic should consider (but may demote in criticality when needed to preserve traffic separation) include area hazards such as convective weather and SUA, and ANSP-supplied trajectory constraints such as an RTA or other crossing restrictions.

The separation logic may include a strategic mode but must include at least a tactical mode. The strategic separation mode provides certain advantages in AFR operations that may be required in some airspace. If it is required anywhere, it will likely be in Class A airspace where IFR Trajectory-Based Operations are expected to be prevalent. Alternatively, it might be required for a certain class of flight operations, such as those conducted under FAR Part 121. The strategic separation logic may not be required for some operators, such as GA operators, who may not have the necessary navigation equipment (e.g., FMS) or other avionics systems to support it. Certain airspace access restrictions may apply to AFR aircraft without the strategic mode capability.

The tactical separation logic will be required for AFR in all airspace as a safety backup to the strategic system (for those carrying it) or for primary separation (for those not). This tactical separation mode may be capable of using trajectory intent information when it is available, but will always be capable of using state-based information transmitted for all AFR and IFR flights. The tactical system may require a higher level of certification than the strategic system, given its safety-critical role.

The design and features of ASAS avionics systems for AFR operations may vary between aircraft and can evolve and be improved via periodic upgrades. Certain functions, however, may be required to meet common standards to ensure implicit coordination mechanisms described in Section 4.5 are effective. Primary examples include the functions that support the application of right-of-way rules and maneuver coordination.

7.1.4. ASAS controls, displays, and aural alerting

The ASAS must provide the flight crew with controls, display of information, and aural alerts as necessary to maintain adequate awareness and perform the procedures of self-separation. Controls enable the pilot to inform the ASAS of desired trajectory changes and to interact with the display of traffic and conflict information. ASAS information may be integrated into forward field-of-view displays, Electronic Flight Bag (EFB) displays, or FMS interfaces, as appropriate to the criticality of the information. They must communicate the existence of conflicts, the associated urgency level, and the maneuver guidance for conflict resolution. They must also indicate whether provisional trajectory changes are conflicted. The FMS or EFB may be used as a crew input device for the ASAS. Aural alerts shall be used to draw flight crew attention to conflicts and shall be independent of the TCAS aural alerting system. Some installations may require integration with existing flight-deck alerting systems, such as the Engine Indications and Crew Alerting System.

7.1.5. TCAS

An approved TCAS II (or later) system is required. The TCAS surveillance, processing, and aural alerting systems must be completely independent of the ASAS and ideally be powered by a separate electrical bus, if available. TCAS may share traffic and resolution advisory display space on the same multi-function interfaces used for displaying ASAS information.

7.1.6. Data Communications

The AFR requirement for addressed air/ground data communications (e.g., CPDLC) is dependent on the ANSP requirements for that airspace, which will likely evolve over time and may vary by the type of aircraft (e.g., some GA aircraft may be exempt). Data communication equipment, if required, must be capable of automatically transmitting trajectory information to the ANSP including changes and pertinent ETAs. Additional capability that may facilitate AFR operations includes the receipt of ANSP messages regarding arrival constraints, TFM initiatives, weather and SUA hazards, voice frequency changes, and airport conditions for arrival planning. CPDLC will be appropriate for some of these functions, and an alternate data link may be necessary for others, such as the receipt of SWIM uplinks.

7.2. ANSP Requirements

In order to accommodate AFR within airspace containing IFR aircraft, the ANSP may be required to have or provide the following systems, capabilities, or services.

7.2.1. Alternate surveillance broadcast

To support AFR (and other ADS-B In applications), the ANSP shall provide an alternate ground-based surveillance source and broadcast system (TIS-B). The alternate source may be radar, multilateration, or some other surveillance mechanism, but it should provide the most accurate and reliable surveillance data available. Broadcast stations should provide coverage of all en route and terminal airspace in which IFR aircraft operate. Ideally, the information content would mimic the information contained in ADS-B Out messages, but should at least provide basic identification, position, altitude, and velocity vector information.

TIS-B coverage should be made available in all Class A, B, C, D, and E airspace. This could be accomplished by installing TIS-B transmitters at all ADS-B ground stations. TIS-B filtering of aircraft by quadrant and traffic proximity, as currently instantiated, must be discontinued to eliminate gaps in service.

As an additional co-located service, the ANSP shall provide rebroadcasting of ADS-B messages, enabling mixed operations of UAT and Mode S aircraft. It may also be advantageous to use this system to extend the reception range of ADS-B.

7.2.2. Trajectory intent information for IFR aircraft

For safety and the support of efficient mixed operations, the ANSP may be required to provide to AFR aircraft an alternate source of near-term IFR aircraft trajectory intent information for those IFR aircraft unable or not mandated to broadcast this information. The information would range from the next TCP up to the most recently cleared trajectory for the IFR aircraft extending to a specified horizon (e.g., 25 minutes). Possible mechanisms for providing this information are uplink from the NextGen SWIM system, either a general broadcast or by response to an AFR downlinked request, or uplink directly from ANSP trajectory automation via automated CPDLC. If the standards for ADS-B are updated in the future, the addition of trajectory information broadcast from the IFR aircraft auto-flight system would be the best way to obtain this information.

7.2.3. Controller display of AFR aircraft and support for safety services

The display of AFR aircraft to controllers will likely be similar to the display of VFR aircraft, i.e., at their discretion, a reduced data block and (possibly) unique symbology. Information displayed in the data block would likely include the call sign, altitude, and AFR status. The controller would be able to display the trajectory intent of the aircraft, if so desired.

The controller will likely require support for traffic advisories and safety alerts. The level of support will depend on the IFR operations underway in the airspace (i.e., current day operations vs. future TBO) and the ANSP automated decision support tools available.

ANSP sector capacity tools, such as today's Monitor Alert Parameter, will need to be adjusted to remove the AFR traffic from the IFR traffic population in the sector.

7.2.4. Data communications

Data communications capability should be provided to send automatic messages for frequency changes, enabling the AFR flight crew to keep a listening watch on the sector frequency. Data communication may also be useful for transmitting other information such as arrival constraints and clearances for the AFR aircraft to expect upon reaching terminal airspace. If the ANSP requires real-time trajectory change and ETA information from AFR aircraft, it will need to provide the data link to automatically receive and process this information.

8. Non-Normal Operations

This section sets forth a qualitative discussion of failures, both mechanical and human, and the contingency procedures that may be used by AFR aircraft in the event of such failures. For each type of failure, the qualitative impact of the failures is presented, followed by contingency actions that could be taken to mitigate the risk of loss of separation or mid-air collision. This high-level presentation is commensurate with this document's objective of presenting an overall description of the AFR concept. It is not intended to be a detailed enumeration of crew procedures or system requirements, nor is it an actual safety risk analysis associated with the various probabilities of such failures or the total system risk from implementing AFR. The information presented is intended to support such a risk analysis, when it is made.

8.1. Surveillance Failures

8.1.1. Impact

If the trajectories of an AFR aircraft (i.e., the subject aircraft) and a traffic aircraft (i.e., the reference aircraft) are in conflict, but a surveillance subsystem failure prevents the detection of the conflict, safety will be impaired to a degree directly related to the specific surveillance impairment. The surveillance layers to be considered are ADS-B Out (primary source), TIS-B (backup source), ADS-B rebroadcasting (ADS-R), ADS-B In, TCAS, and visual sighting.

ADS-B is a highly distributed surveillance system that is not generally vulnerable to single-point failures (other than the reception system on the subject aircraft, as discussed below). ADS-B Out surveillance will be impaired if there is a navigation failure deteriorating the positioning accuracy of the reference aircraft. It will also be impaired if a reference aircraft avionics unit does not create and broadcast the ADS-B Out message as designed. Any of these failures affect surveillance of the single reference aircraft and would create a small reduction in system safety.

TIS-B surveillance does not depend on the navigation systems in either the reference or subject aircraft, since positions of aircraft are derived from ground-based primary and secondary radar or from multilateration. TIS-B is heavily reliant on the Mode A/C or Mode S transponders in aircraft to remotely determine its position information. A failure of an onboard transponder would cause a limited TIS-B failure affecting surveillance of only that single reference aircraft. TIS-B surveillance could fail more extensively, affecting surveillance of all covered aircraft, if the radar system and multilateration fail, or the ground processing of the position data into TIS-B messages shut down, or the broadcast data link system failed. TIS-B ground transmitters will have some overlapping coverage, so a single site failure might leave a hole in surveillance coverage, but not total lost coverage. In airspace where ADS-B Out will be required for primary surveillance, the system safety reduction from failures of the backup TIS-B system will be small.

Failure of ADS-R would share impact characteristics with a TIS-B station failure, since they will typically use common ground equipment. The failure would impede reception of all UAT aircraft by Mode S aircraft, and vice versa.

A failure of ADS-B In on the subject aircraft would be more serious than the aforementioned failures. If the failure is specific to the receipt or processing of ADS-B data, the use of TIS-B as the alternate surveillance source may be used for all traffic aircraft. Failure of the 1030 MHz receiver would prevent reception of ADS-B, TIS-B, and ADS-R messages. The inability of a subject aircraft to receive these services would place its ability to continue under AFR in serious jeopardy, as nominal surveillance of all traffic would be lost. The impact on safety would be dependent on the operating modes of the traffic aircraft. For encounters with reference aircraft that are AFR, the reduction in safety is mitigated by the improbability of simultaneous ADS-B In failures on both aircraft. For encounters with IFR reference aircraft, the impact on safety depends on whether the ANSP is informed of the AFR aircraft's onboard surveillance failure and the time and degrees of freedom available to take action.

TCAS has a separate antenna, receiver, and processor from the ADS-B, TIS-B, and ASAS systems. As long as the transponders on all proximate reference aircraft are operable, this back up surveillance system will provide collision protection, but it will not prevent a loss of nominal separation. As is the case for IFR aircraft today, failure of TCAS would deprive an AFR aircraft of the backup system for the nominal separation assurance system.

The use of visual "see and avoid" procedures is the final safety net, but can be thwarted by flight in IMC. It is also limited by reduced visibility and the limited areas visible around the aircraft through the cockpit windows.

8.1.2. Contingency actions

A GPS outage or degradation of service would be reflected in the navigation figure of merit, which is communicated in the ADS-B message and available for use by receiving aircraft. The applied separation values and look-ahead times would be adjusted as appropriate for the reduced navigational performance reflected in the surveillance message. Because of measures being taken to make the GPS service more robust, widespread outages of GPS service should be very rare in the future, as well as more predictable. Inertial reference systems would provide a suitable temporary alternative, if needed.

The loss of ADS-B Out information from a single reference aircraft would mean that the subject aircraft's ASAS separation functions (i.e., CD, CR, and CP) would use TIS-B for that aircraft instead. Therefore, with TIS-B available as backup, losing ADS-B Out on a single aircraft would have negligible impact on safety or efficiency. The lower precision of TIS-B surveillance data will mean that larger target separation values and possibly slightly longer look-ahead times would be used in the ASAS separation logic. In most aircraft, dual receivers would be available, making the loss of all ADS-B and TIS-B surveillance based upon on-board receiver failure a very remote possibility. If both sources of surveillance information from a single reference aircraft were lost, a determination would be made, using the most recent surveillance data, of the likelihood of a conflict with that aircraft. If the possibility exists, action will be taken to adjust the trajectory to a non-conflicting course and altitude using a wide separation margin (e.g., three times the normal standard).

Total loss of both ADS-B In and TIS-B during AFR flight would require one of two contingency actions. The flight could leave Class A airspace, seek VMC, and continue under VFR until a point of landing. Alternatively, the flight could request an IFR clearance. Since this is an aircraft hardware failure and not a system failure, this particular failure mode would occur rarely and for only a single subject aircraft, making reversion to IFR flight generally feasible for the ground system.

In locations where no ground system is be available to provide en route IFR separation service, and where switching to VFR is not feasible, a total loss of airborne surveillance would prompt the selection of a specially assigned transponder code, such as 7777, that would indicate this failure to other aircraft. This procedure is similar to the more general declaration of emergency, which already gives such aircraft right-of-way over all other flights. In this case, the ASAS separation logic on other aircraft (and in the ANSP) would recognize the code and automatically treat any conflict with this aircraft by giving it the right-of-way. The TFM function and other voice and data communications would be unaffected by this failure, so the flight could potentially proceed along its current business trajectory to the destination if not too distant, or a decision to divert could be made.

A TCAS failure on an AFR aircraft, when normal ADS-B and TIS-B surveillance is available, would only require that the unit be fixed at the first point of landing. As is done today, the flight could continue to its intended destination or divert to a location where the maintenance could more easily be performed.

8.2. ASAS Processing Failures

8.2.1. Impact

A failure of the ASAS logic processor would deprive the flight crew of automatic detection of conflicts and the provision of guidance to resolve those conflicts. The flight crew would be left with the task of analyzing the traffic situation visually on the display and determining mentally the trajectory to fly so as not to encroach upon any nominal protected airspace. Pilot workload may preclude the possibility of this procedure.

When ASAS separation logic is executed in strategic and tactical modes, losing one might not mean losing the other, depending on the failure site and the avionics architecture. Of the two, losing the tactical mode would be more serious. Whereas the strategic mode is focused more on longer time horizons and efficiency, the tactical mode is focused primarily on safety. It would contain the logic for maneuver coordination and be more responsive for short-notice separation assurance.

In the strategic separation mode, the FMS may be used to host the resolution trajectory, amongst other functions. Where this is the case, loss of the FMS computer would make the strategic mode unavailable. Other implementations place this function outside the FMS, for instance, on an EFB display. In this case, only the FMS-coupled autopilot mode for carrying out the strategic resolution would be lost.

Ancillary avionics control boxes that serve as part of the human/computer interface could also fail, making use of the ASAS separation functions more difficult for the flight crew. The impact of a failure on crew workload would be a function of the availability of redundant software control of the physical control functions.

8.2.2. Contingency actions

Assuming the ASAS system is designed to a high assurance level, the chance of a processing failure is very unlikely. Most commercial aircraft would likely have a redundant ASAS architecture, and switching to the operational ASAS processor would be automatic, providing near-continuous service with full functionality. An avionics processing failure rendering some or all of the separation logic inoperative would be handled in a manner depending on what remains functional. If only the strategic functions failed, the flight could continue using the tactical guidance. If the tactical portion failed but the traffic display was complete and the strategic functions still available, the flight could continue to destination if the display were continuously monitored by at least one flight crewmember for the remainder of that flight. The crew would activate the separation boundary feature on the display (showing the minimum permissible separation) around all proximate aircraft and manually avoid all for which no strategic resolution assistance was available. As an alternative to this degraded mode, the flight crew could request an IFR clearance if the service is available in the airspace.

In smaller aircraft without dual equipage of the ASAS avionics, loss of either surveillance or separation processing would be treated like a total communications failure under IFR, with the addition of selecting 7777 on the transponder. The procedure would be to seek VMC, proceed under VFR, and land as soon as practicable. Alternately, an IFR clearance can be requested.

Loss of an FMS in most airline aircraft with dual FMS equipment means relying on the remaining operational FMS for the balance of the flight. The ASAS would be unaffected, as it will be designed to work through either the installed FMS or a dedicated processor. On aircraft with only one FMS, its loss might be equivalent to losing the strategic mode of ASAS. The flight could continue to the destination under AFR using tactical guidance alone.

The design of the ASAS avionics interface might consider making flight crew control of the functions available through both physical knobs and buttons and through point-and-click software logic. With this redundancy, a failure of either mode would not impair use of the functions.

8.3. Display and Alerting Failures

8.3.1. Impact

In glass cockpit aircraft with navigation and primary flight displays, the visual displays associated with the ASAS separation functions may share the ND, some parts of the PFD, and the MCDU display screen. A failure of the ND would affect not just the ability to see the traffic situation and the strategic conflict resolutions, but also the relationship of the aircraft to the basic route guidance coming from the FMS. While the tactical separation mode could still be used, loss of the ND represents a serious impairment to the AFR capability.

Loss of the PFD would be more serious because of the loss of tactical resolution guidance as well as basic attitude, altitude and speed awareness. A redundant location for the basic flight information is already required by regulation, and the same may hold true for tactical separation maneuver information.

Aural alerting would be a part of the ASAS equipment design, used at a minimum to call the crew's attention to a conflict that needed to be expeditiously resolved. The aural alerting system could also be used as a redundant source of guidance for tactical resolution maneuvers, in a manner similar to that implemented in TCAS. In order to preserve true back up status, different aural systems should be used for ASAS and TCAS. Then, a failure of the ASAS aural system would not be as serious a loss.

8.3.2. Contingency actions

The display systems for primary flight and navigation information are generally multi-function displays that are capable of accepting any function on any display. Thus, if there are three or more such displays in the cockpit, a loss of one of them would not impair the functions they serve, including the display of ASAS separation function information. Loss of a second display such that the ND and PFD could not be viewed together would require that all tactical resolution guidance be shown on the remaining PFD. Under this scenario, the flight could continue to destination in a tactical mode, degraded from the nominal state but still safe in terms of separation. Alternatively, the flight crew could request an IFR clearance.

The loss of the aural alerting function of ASAS would require that at least one of the flight crew members visually monitor the displays for the balance of the flight. No further flight of that aircraft would be permitted under AFR until the aural alerting system was fixed. The ASAS aural alerting system must be completely separate from the TCAS aural alerting system so that TCAS can remain an independent safety backup.

8.4. Air / Ground Communication Failures

8.4.1. Impact

Both voice and data communications are expected to be used in the subject environment and they serve to back up each other in the event of failure of one. Voice failures in particular would have far less impact than they do today since voice communication is not a normal part of AFR operations. The loss of data communications would deny the full path trajectory information from being sent to the ANSP and the receipt of near-term intent on IFR flights. Neither of these losses impacts the safety of AFR operations because they improve efficiency rather than safety. Terminal and airport operations performed using traditional IFR techniques would be impacted the most by communications failures in the same manner as today.

8.4.2. Contingency actions

Redundant communication equipment is expected to be required both for voice and data communications. As these will be required by NextGen operations exclusive of AFR, the requirement is not an additional burden to AFR. Lost communication procedures call for the pilot to proceed according to the last clearance received and to begin the approach at the ETA for the destination airport. An AFR flight with lost voice communication would be able to proceed normally using data communications, and vice versa. In the extremely rare event that all voice and all data communications were lost, the existing lost communication procedures in the regulations would apply. The remaining presence of ASAS in addition to TCAS would provide even greater safety during communications failures than the same failures under IFR without ASAS.

8.5. Human Failures

8.5.1. Impact

In automatic control systems, human failures are difficult to predict and protect against. In AFR, means do exist to overcome most human failures. AFR is considerably less vulnerable to the catastrophic effects of human failure than the current ATM system because of the one-to-one relationships between AFR flight crews and their aircraft as opposed to the one-to-many between controllers and aircraft.. A single controller may be responsible for the separation of a dozen or more aircraft, while an AFR flight crew (and often two flight crews) is only responsible for one. In any given separation encounter, two flight crews, one on each aircraft, can detect and resolve the same conflict. Instead of one person being responsible for all potential conflicts among twelve or more aircraft, two to four people are each responsible for just one potential conflict.

One human failure mode in an AFR aircraft is delayed reaction, resulting in a later application of trajectory modification than is modeled in the ASAS separation logic. This pilot delay can render an implemented CR trajectory ineffective at maintaining the desired separation. The system can compensate by continually monitoring the progress of the implemented solution and presenting an alternate trajectory should the modeled resolution no longer be sufficient because of late reaction by the pilot or any other cause altering the encounter.

A more serious human failing is missing and not responding at all to the resolution guidance, in any of its iterations prior to loss of separation. Such a human failing is tantamount to a system failure or shutdown, and it must be accounted for in system design. Aural alerting will help to reduce the likelihood of this occurring. Additionally, having self-separation capability on both aircraft in the encounter provides an effective back up to this failure. In the event of this occurrence in conflicts with IFR aircraft, the ANSP will be provided automation support to issue safety alerts to the pilots of either or both aircraft. However, responsibility for action remains with the AFR pilot.

Another human failure is acting contrary to the guidance provided. This could possibly be more serious than taking no action, if it resulted in further reducing the projected separation. It is presumed that this failure would be the result of an error by the flight crew, not a deliberate attempt to create a collision. The ASAS separation logic would continue to provide corrective guidance to maintain separation or safely regain it if lost. This guidance may use any maneuver dimension (or a combination) and will also occur on both aircraft in the conflict, thus mitigating the hazard.

8.5.2. Contingency actions

The human failure to cause the airplane to follow a new trajectory in a timely fashion is handled by continuing computations and guidance from the ASAS separation logic, commanding ever increasing deviations from the original trajectory as needed to accomplish the separation objective in the remaining time. Increased turn and climb rates, larger heading changes, and the use of the alternate resolution dimension, if only one was used initially, would be used. Increasingly urgent aural messages would also be used to make the crew aware of an unresolved situation. These would generally be sufficient to reengage the crew to initiate the necessary maneuvers in time to prevent a separation loss.

Failure to follow ASAS guidance following a conflict alert is comparable to ignoring a controller’s instruction and carries the same seriousness. If a separation loss does occur, the ASAS would continue to provide guidance to safely reestablish the required separation. TCAS would also continue to operate as an independent system and may alert both aircraft to a potential near collision and provide both with coordinated avoidance maneuvers. If in VMC, the pilots might also see and avoid each other.

9. Required Activities for Implementation

Throughout this document, references have been made to additional standards, procedures, rules, and training that will be needed but are beyond the scope of this document. This section addresses those needed activities by government and industry participants for the development, approval, and implementation of the AFR capability.

9.1. Standards

Standards-setting activities supporting AFR should be undertaken by FAA advisory committees such as RTCA, including updating the ADS-B MASPS and MOPS (refs. 18-20) to meet AFR requirements, possibly generating MASPS specifically for AFR, and generating MOPS for ASAS equipment to be certified for AFR use. These should be specific enough to enable interoperability among various manufacturers' equipment through use of common rule sets, for both high- and low-end avionics. These standards, when completed, would be used by FAA in the rule-making and approval processes.

9.2. Research studies

Research studies to verify assumptions, design decisions, and expected behaviors mentioned in the document should be continued by NASA, FAA, and their contractors. Industry participants should be included in these research activities. Examples include a study to verify the values chosen for separation buffers outside the IFR separation minima and appropriate separation values for AFR/AFR conflicts. Human-in-the-loop simulations should be followed by flight testing the designs and behaviors for concept verification.

9.3. Safety analysis

A system safety analysis should be performed using the values for design parameters chosen for the MASPS and MOPS, with iteration as necessary to ensure safe values are used in the final avionics and automation designs. The safety analyses will also support rule-making, system and procedures approvals, and the determination of liability accommodations. TCAS approvals might serve as models in this activity.

9.4. Ground infrastructure

Upgrades will be needed to the existing ground services, TIS-B and ADS-R, to ensure the back-up surveillance and navigation functions meet the required parametric values found in the safety analysis.

9.5. Policies

FAA rule-making should commence for the modification and creation of operating and training regulations for AFR, mostly in FAR Parts 61, 91, 135, and 121, and others as necessary.

9.6. Training and education

Initial and re-current training programs will be needed for pilots and familiarization training for controllers to use and recognize the use of AFR procedures. General education of the flying population to the new rules would accompany this activity.

10. Conclusion

This document proposes the creation of a new set of official operating regulations, referred to as Autonomous Flight Rules (AFR). AFR is a flight operating concept designed to improve access and flexibility in airspace use while not increasing and possibly decreasing the burden on ANSP services. The objective of the AFR concept is to provide an alternative mode of aircraft trajectory-based operations that is safe, efficient, flexible, cost effective, and low risk for aircraft operators; that minimally subjects AFR aircraft to capacity-driven operational restrictions; and that coexists with existing modes of operation without causing disruption of such flights. The AFR concept extends the NextGen vision for self-separation to mixed operations in all classes of airspace. It is anticipated that AFR operations will provide a mechanism for significant expansion of en route airspace system capacity, which would benefit the ANSP and all airspace users.

By leveraging the technologies of GPS, ADS-B, and flight-deck automation software with separation functions, aircraft operating under AFR keep track of all other aircraft in the local airspace and take responsibility for maintaining safe separation from these aircraft, as well as SUA and all other flight hazards. AFR provides the operating rules and procedures to enable sufficient coordination with others so that all maneuvers are safe and conflicts are handled in a timely and orderly manner. The burden of separation of AFR aircraft is removed from the ANSP by always giving right-of-way to IFR aircraft. In addition, AFR aircraft will maintain a sufficient distance from IFR aircraft such that few if any constraints are placed on a controller's freedom of action with IFR aircraft under his control as a result of AFR aircraft present in the airspace.

Arrival and departure operations are integrated by operating AFR aircraft similar to IFR flights during takeoff, approach, and landing. AFR flights participate in TFM initiatives at capacity-constrained airports, providing initial and updated ETAs for use in the TFM program, and meeting RTA constraints at the terminal airspace boundary when required. AFR flights need not be included in en route TFM initiatives, as they shoulder their own separation responsibility and will remain sufficiently clear of IFR aircraft, not constraining ANSP management of any IFR aircraft.

The safety requirements for this new form of primary separation are expected to be met through independent means of backup surveillance and redundancy in systems, a layered approach to separation assurance and collision avoidance, and continued human involvement in the review of computer-generated flight guidance information. It is expected that the AFR concept may substantially improve the level of safety of NAS operations overall due to the greater number of systems and people involved in ensuring separation under all circumstances, compared to current operations. Having the entire control loop resident in the aircraft also removes exposure to communications failures on separation safety.

The potential benefits of using AFR as an additional Operational Improvement in the NextGen environment are expected to be substantial to both airspace users and service providers. Greater use of the available airspace, reduced flight delays, greater flight efficiency and operational flexibility, reduced burden on ANSP resources, and a gradual yet robust transition to a modernized air transportation system all underscore the importance of moving ahead with the identified activities to enable this operating concept.

Acronym List

4D	4 Dimensional (3 dimensional position plus time)
ADS-B	Automatic Dependent Surveillance Broadcast
ADS-B In	Receiving ADS-B Messages
ADS-B Out	Broadcasting ADS-B Messages
ADS-R	Rebroadcasting ADS-B Messages
AFR	Autonomous Flight Rules
ANSP	Air Navigation Service Provider
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATM	Air Traffic Management
CD	Conflict Detection
CP	Conflict Prevention
CPDLC	Controller Pilot Data Link Communications
CR	Conflict Resolution
EFB	Electronic Flight Bag
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FMS	Flight Management System
GA	General Aviation
GPS	Global Positioning System
IFR	Instrument Flight Rules
IM	Interval Management
IMC	Instrument Meteorological Conditions
LOS	Loss of Separation
MASPS	Minimum Aviation System Performance Standards
MCDU	Multifunction Control and Display Unit
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
ND	Navigation Display
NextGen	Next Generation Air Transportation System
OPD	Optimized Profile Descent
PFD	Primary Flight Display
RNAV	Area Navigation
RTA	Required Time of Arrival
SUA	Special Use Airspace
SWIM	System Wide Information Management
TBO	Trajectory Based Operations
TCAS	Traffic Alert and Collision Avoidance System
TCP	Trajectory Change Point
TFM	Traffic Flow Management
TIS-B	Traffic Information Service Broadcast
TRACON	Terminal Radar Approach Control Facility
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* 01- 11 - 2011	**2. REPORT TYPE** Technical Publication	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE Autonomous Flight Rules - A Concept for Self-Separation in U. S. Domestic Airspace	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Wing, David J.; Cotton, William B.	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 411931.02.51.07.01
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199	**8. PERFORMING ORGANIZATION REPORT NUMBER** L-20058
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	**10. SPONSOR/MONITOR'S ACRONYM(S)** NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/TP-2011-217174

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified Unlimited
Subject Category 03
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Autonomous Flight Rules (AFR) are proposed as a new set of operating regulations in which aircraft navigate on tracks of their choice while self-separating from traffic and weather. AFR would exist alongside Instrument and Visual Flight Rules (IFR and VFR) as one of three available flight options for any appropriately trained and qualified operator with the necessary certified equipment. Historically, ground-based separation services evolved by necessity as aircraft began operating in the clouds and were unable to see each other. Today, technologies for global navigation, airborne surveillance, and onboard computing enable the functions of traffic conflict management to be fully integrated with navigation procedures onboard the aircraft. By self-separating, aircraft can operate with more flexibility and fewer restrictions than are required when using ground-based separation. The AFR concept is described in detail and provides practical means by which self-separating aircraft could share the same airspace as IFR and VFR aircraft without disrupting the ongoing processes of Air Traffic Control.

15. SUBJECT TERMS

Autonomous Flight Rules; AFR; self-separation; mixed operations; air traffic management; separation assurance

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER ***(Include area code)***
U	U	U	UU	51	(443) 757-5802