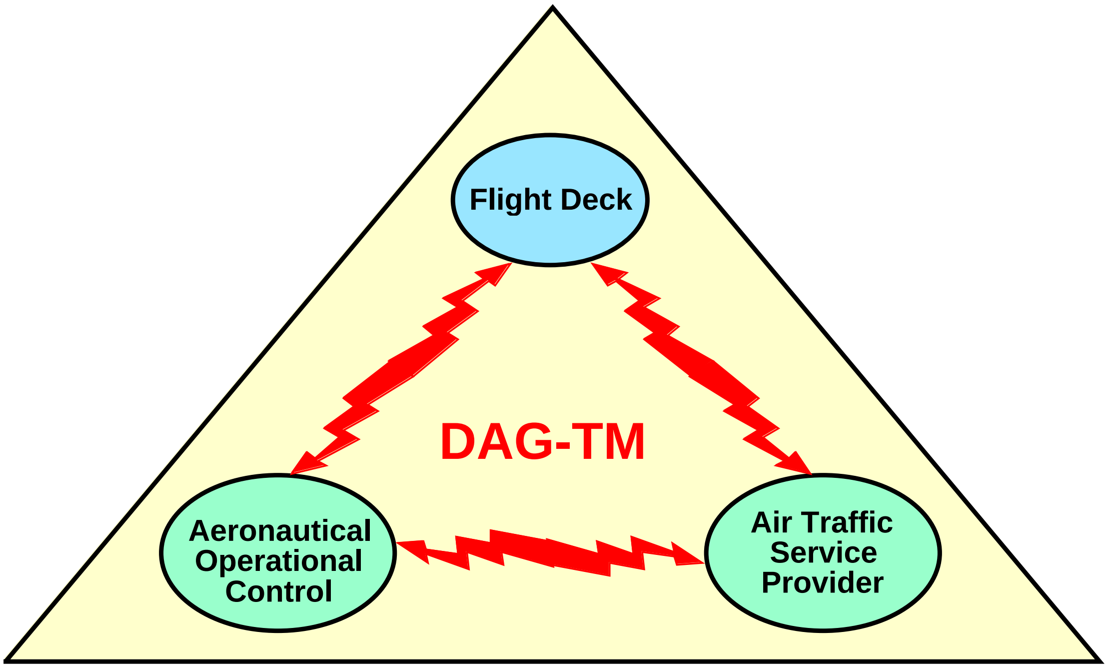
Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM)

Version 1.0



Advanced Air Transportation Technologies (AATT) Project
Aviation System Capacity (ASC) Program
National Aeronautics and Space Administration

September 30, 1999

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EXECUTIVE SUMMARY

The Distributed Air/Ground Traffic Management (DAG-TM) concept is a coherent set of conceptual elements that describe possible modes of operation within the outlines of the Free Flight concept defined by the RTCA Task Force 3 in Ref. 1. It may be viewed as one possible approach to the potential implementation of Free Flight, progressing along the path started by the Free Flight Phase 1 activities. This DAG-TM concept was developed by the Advanced Air Transportation Technologies (AATT) Project.

Background

The AATT Project is part of NASA's Aviation System Capacity (ASC) Program. AATT's objective is to improve the overall performance of the National Airspace System (NAS) as a whole. In order to meet this objective, AATT is developing decision support technologies and procedures to aid NAS stakeholders in the near-term, mid-term, and far-term. The vision of the AATT Project regarding far-term NAS operations is embodied in the DAG-TM concept definition presented in this document.

In order to develop this DAG-TM Concept Definition and a companion DAG-TM Research Plan (Ref. 2), the AATT Project created a DAG-TM Team, composed of personnel with expertise in various disciplines of Air Traffic Management.

DAG-TM Vision Statement

The fundamental characteristics of DAG-TM have been defined in the following vision statement developed by the DAG-TM Team.

> *"Distributed Air/Ground Traffic Management is a National Airspace System concept in which flight deck (FD) crews, air traffic service providers (ATSP) and aeronautical operational control (AOC) facilities use distributed decision-making to enable user preferences and increase system capacity, while meeting air traffic management requirements. DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing and Communication, Navigation, and Surveillance (CNS) / Air Traffic Management (ATM) technologies."*

Scope of DAG-TM Concept

DAG-TM is a proposed concept for gate-to-gate NAS operations beyond the year 2015. It will address dynamic NAS constraints such as bad weather, Special Use Airspace (SUA) and arrival metering/spacing. The goal of DAG-TM is to enhance user flexibility/efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the NAS.

The DAG-TM concept is intended to address all user classes (commercial carriers, general aviation, etc.) with an emphasis towards ensuring access to airspace resources for the entire user community. It covers all flight phases (Pre-Flight Planning, Departure, Cruise and Arrival) and operational domains in the NAS (Surface, Terminal Airspace and En route Airspace). Although other operational domains (e.g., European, oceanic, and under-developed airspace) are outside the scope of the current DAG-TM concept, research activities will give due consideration to global interoperability issues.

Formulation of DAG-TM Concept

The DAG-TM Concept was formulated as a coherent set of solutions to a series of key ATM problems (or inefficiencies) in the gate-to-gate operations of the current NAS. For each problem, one or more solutions were identified that could potentially solve the problem by utilizing distributed decision-making between the user (FD and/or AOC) and the ATSP. These solutions, known as concept elements (CEs), would potentially enable greater accommodation of user preferences and increased system capacity. A fundamental goal of the DAG-TM concept is the elimination of static restrictions, to the maximum extent possible. In this paradigm, users may plan and operate according to their preferences – as the rule rather than the exception – with deviations occurring only as dynamically necessary. Therefore, the DAG-TM concept elements were formulated to mitigate the extent and impact of dynamic NAS constraints, while maximizing the flexibility of airspace operations.

Outline of DAG-TM Concept Elements

Fig. E-1 presents an overview of the DAG-TM concept elements. A special concept element for universal information access/exchange covers all ATM operations from gate to gate. This concept element is presented first, numbered “CE 0” to indicate its over-arching nature. The other concept elements are numbered “CE 1” through “CE 14.” It is noted that CEs 1 – 14 each represent a solution to a problem/inefficiency in the operations of the current NAS. Their sequence corresponds to the progression of a typical flight. The CE titles include a label that indicates the applicable operational domain and flight phase (e.g., Terminal Departure). The label “Gate-to-Gate” applies to all operational domains and all flight phases.

CE	**Title**	
0	Gate-to-Gate:	Information Access/Exchange for Enhanced Decision Support
1	Pre-Flight Planning:	NAS-Constraint Considerations for Schedule/Flight Optimization
2	Surface Departure:	Intelligent Routing for Efficient Pushback Times and Taxi
3	Terminal Departure:	Free Maneuvering for User-Preferred Departures
4	Terminal Departure:	Trajectory Negotiation for User-Preferred Departures

5	En route: *(Departure, Cruise, Arrival)*	Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
6	En route: *(Departure, Cruise, Arrival)*	Trajectory Negotiation for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
7	En route: *(Departure, Cruise, Arrival)*	Collaboration for Mitigating Local TFM Constraints due to Weather, SUA and Complexity
8	En route / Terminal Arrival:	Collaboration for User-Preferred Arrival Metering
9	Terminal Arrival:	Free Maneuvering for Weather Avoidance
10	Terminal Arrival:	Trajectory Negotiation for Weather Avoidance
11	Terminal Arrival:	Self Spacing for Merging and In-Trail Separation
12	Terminal Arrival:	Trajectory Exchange for Merging and In-Trail Separation
13	Terminal Approach:	Airborne CD&R for Closely Spaced Approaches
14	Surface Arrival:	Intelligent Routing for Efficient Active-Runway Crossings and Taxi

Fig. E-1: Overview of Concept Elements

Technology Requirements for DAG-TM

The minimum equipage required to operate in a DAG-TM system will be the same as that required to operate in the current Air Traffic Control (ATC) system, in order to facilitate NAS access by all users. Users make business decisions on equipage level based on their cost/benefit assessments. Fully equipped users gain the maximum benefits due to the full range of options available to them for optimizing operations of individual aircraft and/or their entire fleet; these options include capabilities for flight autonomy, negotiation of user-preferred trajectories with the ATSP, and influencing ATSP decisions. Users who equip at an intermediate level gain significant benefits (over the current system) due to the options available to them for influencing ATSP decisions, including negotiation of user-preferred trajectories; however, they cannot conduct autonomous flight operations. This intermediate level of equipage also represents an intermediate point on the spectrum of NAS evolution towards DAG-TM. Even minimally equipped users may gain some benefits (compared to the current system) due to the improved overall efficiency of NAS operations and greater accommodation of user-preferences by the ATSP.

A core technology requirement for DAG-TM is the enabling of universal access/exchange of information between all NAS stakeholders. Users with full or intermediate equipage utilize a suite of AOC-based and/or FD-based Decision Support Tools (DSTs) to plan and execute their operations. They also use datalink capabilities to access and exchange information, including information on the positions and velocities (and possibly intent) of other aircraft on the vicinity.

Potential Benefits of DAG-TM

- Increased user efficiency/flexibility. DAG-TM offers users maximum opportunity to self-optimize their operations (both fleet-wide and flight-specific), within the dynamic constraints of the ATM system.
- Increased system capacity. Delegation of separation responsibility to appropriately equipped aircraft and ATSP-based DSTs could potentially reduce controller workload, thereby enabling the ATSP to handle more traffic.
- Increased system safety, due to a significant increase in situational awareness and distribution of workload.
- Distribution of the cost for NAS modernization between users and the ATSP.
- Decreased user dependence upon ATSP services and a ground-based infrastructure; this may also enhance global interoperability.

Relationship Between DAG-TM and Other Relevant Activities/Programs

In 1995, the RTCA Task Force 3 developed an implementation plan that represents a roadmap to NAS modernization. This led to various FAA and RTCA Concepts of Operation, ultimately resulting in the joint RTCA/FAA Concept of Operation for 2005. Additionally, in support of a 1997 AATT project milestone, AATT integrated the various concepts of operation into an overall AATT Concept of Operations which provided the vision for all AATT research. The DAG-TM Concept was formulated in the context of enhancing the various Concepts of Operation by adding a greater level of detail to the more “revolutionary” Free Flight applications outlined in the RTCA implementation plan (e.g., collaborative flow management and free maneuvering).

It is recognized there are a number of relevant activities (both within and outside of NASA) which directly relate to DAG-TM. It is critical that AATT-sponsored DAG-TM research leverage and build upon the results from these related activities, in order to maximize the limited research resources available. In addition, collaboration between NASA and the other organizations involved in these related activities is essential if DAG-TM is to be implemented. Some of these key relevant activities include:

- NAS Architecture v4.0
- Safeflight 21 Program
- CPDLC Program
- RTCA Activities
- European Activities (e.g., FREER, NEAN, NUP)
- Other NASA Programs (e.g., TAP, AvSP)

Conclusion

A concept definition for Distributed Air/Ground Traffic Management (DAG-TM) has been prepared by a multi-disciplinary team formed by the Advanced Air Transportation Technologies (AATT) project office. The DAG-TM concept, characterized by distributed decision-making between the flight deck, ATSP and AOC, is a NAS operations concept that increases user efficiency/flexibility and system capacity.

The DAG-TM Team recommends that this concept definition be evaluated as one potential extension of the various Free Flight implementation approaches currently under consideration.

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LIST OF FIGURES

ABBREVIATIONS

AATT	Advanced Air Transportation Technologies
ADL/DSSS	Aeronautical Data Link/Decision Support System Services
ADS-B	Automatic Dependent Surveillance – Broadcast
AOC	Aeronautical Operational Control
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
CD&R	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic Information
CE	Concept Element (of DAG-TM)
CNS	Communications, Navigation and Surveillance
CPDLC	Controller/Pilot Data Link Communications
CTA	Controlled Time of Arrival
DAG-TM	Distributed Air/Ground Traffic Management
DST	Decision Support Tool
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FCFS	First Come First Served
FD	Flight Deck
GPS	Global Positioning System
HUD	Head-Up Display
IFR	Instrument Flight Rules
IGS	Intelligent Ground System
IMC	Instrument Meteorological Conditions
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
R&D	Research and Development
RTA	Required Time of Arrival
SUA	Special Use Airspace
TFM	Traffic Flow Management
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

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1. INTRODUCTION TO DAG-TM

The Distributed Air/Ground Traffic Management (DAG-TM) concept is a coherent set of conceptual elements that describe possible modes of operation within the outlines of the Free Flight concept defined by the RTCA Task Force 3 in Ref. 1. It may be viewed as one possible approach to the potential implementation of Free Flight, progressing along the path started by the Free Flight Phase 1 activities. This DAG-TM concept was developed by the Advanced Air Transportation Technologies (AATT) Project.

1.1 Advanced Air Transportation Technologies Project

The National Aeronautics and Space Administration (NASA) Office of Aerospace Technologies has identified a technology objective stating:

> *"While maintaining safety, triple the aviation system throughput, in all weather conditions, within 10 years."*

To respond to this technology objective, NASA has created the Aviation System Capacity Program which has developed a roadmap describing how NASA will meet this objective (see *http://www.aero-space.nasa.gov/goals/fg/index4/goal4.htm* for details).

One step on this roadmap is the Advanced Air Transportation Technologies (AATT) Project. By the year 2004, AATT will have contributed to this technology objective by developing technologies that will increase flexibility, predictability and efficiency, thereby leading to increases in system capacity. AATT's objective is to improve the overall performance of the National Airspace System (NAS) as a whole. A stronger, more efficient, and less expensive aviation-transportation system will benefit the nation in two ways. First, the flying public and private sector will directly benefit from reduced transportation costs and increased schedule/connectivity. Second, the general public will indirectly benefit from the resulting economic growth (national productivity and gross national product) enabled by a more productive and efficient transportation system. The mechanism for improving the NAS as a whole is to improve the operations of both the system users (e.g., airlines, general aviation) and the Air Traffic Service Providers (ATSP).

In order to meet these objectives, AATT is developing decision support technologies and procedures to aid NAS stakeholders in the near-term, mid-term, and far-term. The vision of the AATT Project regarding far-term NAS operations is embodied in the DAG-TM concept definition presented in this document.

1.2 DAG-TM Activities under AATT

In order to develop this DAG-TM Concept Definition and a companion DAG-TM Research Plan (presented in Ref. 2), the AATT Project formed a DAG-TM Team, composed of personnel with expertise in the following disciplines:

- Aircraft systems and operations
- En route ATM systems and operations
- Terminal & surface ATM systems and operations
- Human factors
- Benefits and safety
- Advanced ATM communications.

From January through September of 1999, the DAG-TM Team conducted a series of five 3-day workshops and numerous weekly telecons to develop the DAG-TM concept and research plan, using a consensus-building process. Following AATT management and external reviews, DAG-TM research activities will be conducted at NASA Research Centers, contractor facilities and other organizations.

1.3 DAG-TM Vision Statement

The premise of the Distributed Air/Ground Traffic Management (DAG-TM) concept is that distributing real-time decision-making between users and Air Traffic Service Providers (ATSP) will maximize the users' flexibility to optimize their operations while increasing ATSP productivity, thereby increasing the efficiency and capacity of the system as a whole. The fundamental characteristics of DAG-TM have been defined in the following vision statement developed by the DAG-TM Team.

> *"Distributed Air/Ground Traffic Management is a National Airspace System concept in which flight deck (FD) crews, air traffic service providers (ATSP) and aeronautical operational control (AOC) facilities use distributed decision-making to enable user preferences and increase system capacity, while meeting air traffic management requirements. DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing and Communication, Navigation, and Surveillance (CNS) / Air Traffic Management (ATM) technologies."*

1.4 Scope of DAG-TM Concept

DAG-TM is a proposed concept for gate-to-gate NAS operations beyond the year 2015. It will address dynamic NAS constraints such as bad weather, Special Use Airspace (SUA) and arrival metering/spacing. The goal of DAG-TM is to enhance user flexibility/efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the NAS.

The DAG-TM concept is intended to address all user classes (commercial carriers, general aviation, etc.) with an emphasis towards ensuring access to airspace resources for the entire user community. It covers all flight phases (Pre-Flight Planning, Departure, Cruise and Arrival) and operational domains in the NAS (Surface, Terminal Airspace and

En route Airspace). Although other operational domains (e.g., European, oceanic, and under-developed airspace) are outside the scope of the current DAG-TM concept, research activities will give due consideration to global interoperability issues.

Certain issues, although important, are beyond the scope of DAG-TM activities conducted by the AATT Project; they include:

- FAA issues regarding implementation. DAG-TM activities will assume the NAS Architecture (currently version 4.0) as a baseline for FAA implementation plans; research on DAG-TM feasibility and benefits will provide the FAA and the user community with data to determine the appropriate NAS Architecture modifications to accommodate implementation of the DAG-TM concept.
- "Cultural" issues regarding the introduction of new technologies (DSTs), procedures and roles/responsibilities; e.g., operational training and pilot/controller acceptance.
- Business issues that influence user decision-making regarding operational priorities.
- Information security issues related to access and/or exchange of user-proprietary data.
- Issues relating to NAS benefits arising from a reduction in separation standards.

2. EVOLUTION PATH TO DAG-TM

2.1 Issues, Concerns, and Opportunities in the National Airspace System

Many users of today's aviation system believe that the current, relatively centralized mode of air traffic control / management creates excessive constraints on their operations, resulting in operational inefficiencies. The U.S. air traffic control system has evolved considerably from its birth in the 1920's to today's system; a description may be found in Refs. 3 and 4. Today's system has evolved in response to the increase in traffic volume over the years. To deal with the increase in traffic volume, the Federal Aviation Administration (FAA) has employed several measures to prevent actual traffic levels from exceeding the human capabilities of the controllers who are responsible for the safe separation of traffic. These measures include airspace sectorization (to divide workload); airspace structure, procedures, and ATSP-preferred routes (to structure traffic flows and segregate aircraft); and flow restrictions (to prevent congestion from exceeding acceptable levels). The current system is considered to be technologically outdated and likely to bog down further as predicted traffic growth is realized. Without significant changes to the NAS, analysis indicates that predicted traffic growth will bring the system to gridlock by the year 2014 (Ref. 5). In fact, users are already experiencing significant losses due to inefficiencies. It has been estimated that scheduled air carriers alone lost $3.5 billion in direct operating costs due to delays in 1995 (Ref. 6). These delays and associated costs are noticeably greater today with the rapid growth of traffic in recent years. This has led to an effort within the aviation community to develop a more flexible system that increases capacity and allows the users to increase their operating efficiencies in ways that meet their own objectives. Users not only desire greater flexibility, but also less dependence on centralized air traffic control systems and infrastructure (to minimize their dependence on a government service and to maximize global interoperability). This loosely defined operational paradigm is commonly referred to as "Free Flight."

2.2 The Free Flight Concept

Free Flight has been defined (Ref. 1) as:

> *"... a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through Special Use Airspace (SUA), and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move toward free flight."*

The Free Flight paradigm recognizes that users of the aviation system each have their own unique objectives, and require the flexibility to achieve their objectives. The goal is to expand the domains of flight/fleet operations over which the users have the flexibility to self-optimize fleet throughput/connectivity, schedule integrity, and flight efficiency. The ultimate realization of free flight allows each flight to operate as if it were the only aircraft in the NAS. This allows users to optimize a single flight, or for scheduled fleet operators, allows users to manipulate their flights to optimize the fleet operations. ATSP-imposed restrictions would only occur as dynamically necessary, and only to the extent required for safety and system efficiency. Theoretically, the concept of Free Flight provides the users with the ultimate flexibility for self-optimization.

In contrast to Free Flight, today's system provides relatively little room for self-optimization. The users choose their schedule and routing, but even this is strongly influenced by the ATSP and other operators. Once the flight has been initiated, almost all decisions are made by the ATSP, often with little opportunity to accommodate user preferences. In order to address these issues regarding the current system, many organizations have initiated efforts towards NAS modernization.

2.3 Relationship Between DAG-TM and Other Relevant Activities/Programs

In 1995, the RTCA Task Force 3 developed an implementation plan that represents a roadmap to NAS modernization. This led to various FAA and RTCA Concepts of Operation, ultimately resulting in the joint RTCA/FAA Concept of Operation for 2005. Additionally, in support of a 1997 AATT project milestone, AATT integrated the various concepts of operation into an overall AATT Concept of Operations which provided the vision for all AATT research. The DAG-TM Concept was formulated in the context of enhancing the various Concepts of Operation by adding a greater level of detail to the more "revolutionary" Free Flight applications outlined in the RTCA implementation plan (e.g., collaborative flow management and free maneuvering).

Successful implementation of the DAG-TM concept will require an unprecedented level of distributed decision-making between the components of the ATSP-FD-AOC triad. This high level of distribution will also necessitate a high level of integration between airborne and ground-based systems and tools such as decision support automation, datalink applications, and CNS/ATM technologies.

It is recognized there are a number of relevant activities (both within and outside of NASA) which directly relate to DAG-TM. It is critical that AATT-sponsored DAG-TM research leverage and build upon the results from these related activities, in order to maximize the limited research resources available. In addition, collaboration between NASA and the other organizations involved in these related activities is essential if DAG-TM is to be implemented. Some of these key relevant activities are highlighted below; this description is not intended to be a comprehensive list of all relevant activities.

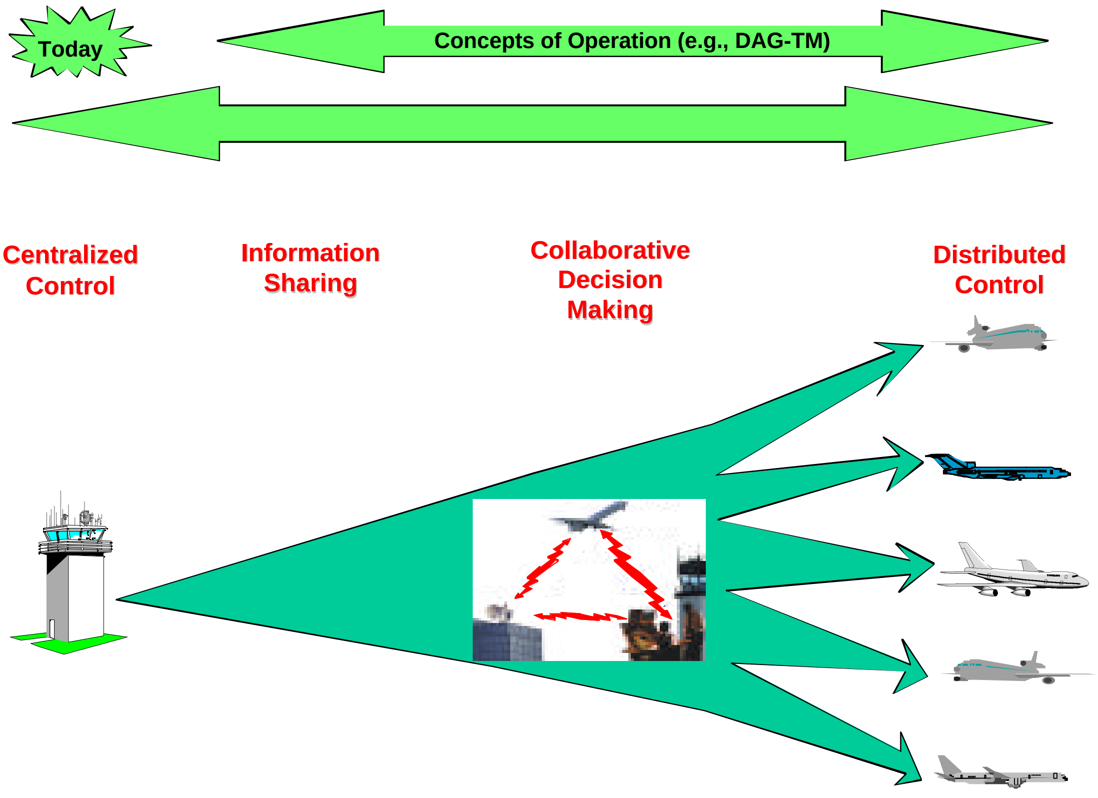
2.3.1 NAS Architecture v4.0

The NAS Architecture Version 4.0 plan (Ref. 7) describes the FAA's roadmap for the modernization of the NAS through the year 2015. Modernization includes the introduction of new CNS/ATM technologies/capabilities, ATSP decision support tools, and expanded information exchange to facilitate limited collaborative decision-making. DAG-TM will require many of the capabilities planned under NAS Architecture v4.0. It is recognized, however, that DAG-TM research may determine that additional capabilities and/or functionalities will be required for DAG-TM, above and beyond what is planned under NAS Architecture v4.0. These will be identified as part of the DAG-TM research activities.

Fig. 2-1 depicts the evolution of NAS modernization towards a DAG-TM system. While DAG-TM covers the entire spectrum of distributed decision-making, it is expected that the plans in NAS Architecture Version 4.0 will need to be expanded based on the findings of the DAG-TM research. Additionally, for DAG-TM to be realized, the users (flight decks and AOCs) will also need to increase their capabilities.

2.3.2 Safeflight 21 Program

Safeflight21 is performing an operational evaluation of Automatic Dependent Surveillance-Broadcast (ADS-B) technology. Datalink is considered to be one of the fundamental capabilities required by DAG-TM. Safeflight21 has already demonstrated enhanced pilot situational awareness of local traffic via the use of datalink and Cockpit Display of Traffic Information (CDTI) technology in the Ohio Valley demonstrations. DAG-TM research will consider this work.



2.3.3 CPDLC Program

The Controller-Pilot Datalink Communications (CPDLC) program is also relevant to DAG-TM. The capability for two-way datalink communications between the FD and ATSP is fundamental to DAG-TM operations. DAG-TM research will also consider this work.

2.3.4 RTCA Activities

Relevant activities within the RTCA include the Aeronautical Data Link Advisory Special Committee (SC-194) work on flight operations and ATM integration (WG-2). Specifically, WG-2's work with respect to Aeronautical Data Link/Decision Support System Services (ADL/DSSS) which has evolved from the work (Ref. 8) of the FAA/Industry group on FMS-ATM Next Generation (FANG) is highly relevant to DAG-TM. In addition, work in the ADS-B Special Committee (SC-186/ WG-1 and WG-4) with respect to conflict detection and resolution is also highly relevant.

2.3.5 European Programs

Many activities in Europe are highly relevant to DAG-TM, including CD&R work by NLR and Eurocontrol (FREER), and ADS-B work via the North European ADS-B Network (NEAN) as well as the Network Update Program (NUP).

2.3.6 Other NASA Programs

Research relevant to DAG-TM from other NASA programs such as the Terminal Area Productivity (TAP) and the Aviation Safety Program (AvSP) will be also be considered by DAG-TM research.

2.4 Technology Requirements for DAG-TM

It is believed that DAG-TM can be realized with current technology capabilities (as opposed to requiring breakthrough technology innovations), although they may require further refinement and maturation. The innovation required for realization of DAG-TM will be the development and integration of human-centered technologies/procedures to enable distributed decision-making between users and ATSP. Results of DAG-TM research activities will include the requirements for human factors/procedures, functional capabilities and integration of user/ATM decision support technology. These requirements, along with supporting cost/benefit analyses, will generate a clear target for an evolutionary modernization of the NAS and user systems towards DAG-TM operations.

A core technology requirement for DAG-TM is the enabling of universal access/exchange of information between all NAS stakeholders, i.e., the ATSP and the users. The term "user" refers to the Aeronautical Operational Control (AOC) facility and/or the Flight Deck (FD) crew. The access and exchange of information is facilitated by datalink with broadcast and addressing capabilities.

The minimum equipage required to operate in a DAG-TM system will be the same as that required to operate in the current ATC system, in order to facilitate NAS access by all users. Users make business decisions on equipage level based on their cost/benefit assessments. Fully equipped users gain the maximum benefits due to the full range of options available to them for optimizing operations of individual aircraft and/or their entire fleet; these options include capabilities for flight autonomy, negotiation of user-preferred trajectories with the ATSP, and influencing ATSP decisions. Users who equip at an intermediate level gain significant benefits (over the current system) due to the options available to them for influencing ATSP decisions, including negotiation of user-preferred trajectories; however, they cannot conduct autonomous flight operations. This intermediate level of equipage also represents an intermediate point on the spectrum of NAS evolution towards DAG-TM. Even minimally equipped users may gain some benefits (compared to the current system) due to the improved overall efficiency of NAS operations and greater accommodation of user-preferences by the ATSP.

Users with full or intermediate equipage utilize a suite of AOC-based and/or FD-based Decision Support Tools (DSTs) to plan and execute their operations. They also use datalink capabilities to access and exchange information, including information on positions and velocities (and possibly intent) of other aircraft on the vicinity. This information on local traffic would be available directly by continuous broadcasts from aircraft with full or intermediate equipage, and indirectly by ATSP broadcasts of ground-based surveillance data and flight plans for minimally equipped aircraft.

3. POTENTIAL BENEFITS OF DAG-TM

3.1 Overview of DAG-TM Benefits

Distributed Air/Ground Traffic Management is a revolutionary paradigm for flight operations in which the flight deck crew, and if applicable, the AOC participate with the ATSP in dynamic decision-making regarding their operations within the NAS. This includes the sharing of real-time information between the aircraft and the ground (both AOC and ATSP), collaborative decision-making between the users (AOC and/or flight deck) and the ATSP, and in some cases, autonomy for the aircraft to free-maneuver. DAG-TM brings the user into the decision-making process, starting with preflight planning and continuing throughout all phases of flight; this process offers the potential for VFR-like operational flexibility for IFR operations.

The primary benefit of DAG-TM is that it gives users maximum opportunity to self-optimize their operations within the dynamic constraints of the ATM system. The most obvious user benefit is a reduction in the per-flight direct operating cost that every user operating under IFR can obtain through real-time optimization of their flight trajectory. It is not clear, however, whether the distribution of control will actually provide more benefit than improving the capabilities and information exchange in a centralized mode of control. This is a research issue that has not yet been resolved. However, AATT has considered multiple issues for determining the focus towards distributed control. Perhaps the first consideration is the goal of offering the largest possible benefit to all users of the NAS; this is different from optimizing the performance of the NAS. Determining the globally optimized performance of the NAS may lead to an unequal distribution of benefits to the various users of the NAS. Therefore, AATT has focused on a more equitable approach that considers the distribution of stakeholder benefits. The distributed approach will provide the largest benefits to the users while indirectly providing the necessary improvements in the NAS to benefit the ATSP. A second consideration, which is in alignment with NASA's number-one value, is the potential improvement in system safety. From a high-level perspective, the distributed control concept provides a significant increase in situational awareness and a distribution of the workload. Both of these will be required to deal with predicted traffic demand increases in the future. These improvements will be driven by the desire of every user to maximize their benefits-to-cost ratio. It is hypothesized that the optimal benefit-to-cost will be achieved by the aircraft and AOCs equipped for fully distributed control. The technologies required on board an aircraft to support the fullest distribution will allow these appropriately equipped aircraft to contribute to separation assurance as traffic growth continues. This effectively increases the resources available for separation safety.

A second benefit is the increase in capacity. In centralized control, the volume of traffic will be limited partly by the ability of the ATSP to safely manage the traffic. With distributed control, research may determine that self-separating aircraft can off-load the ATSP to some extent. Therefore their attentions can perhaps be focused primarily on those aircraft that are not equipped for self-separation. This may allow more aircraft to operate within the airspace for the same number of ATSP personnel.

A third benefit is the distribution of the cost for NAS modernization. In the centralized system, the cost for modernization rests largely with the ATSP. In the distributed system, the cost is shared by the users to a greater extent. This is likely to lead to an acceleration in the realization of benefits to all NAS stakeholders.

A fourth benefit is the decreased user dependence upon the ATSP and a ground-based infrastructure. This may also enhance global interoperability.

3.2 Benefits of Air-Carrier Fleet-Wide Optimization

While the benefits described above make a case for maximizing equipage to allow individual flights to obtain benefits, there is actually one layer of control which constrains the flexibility of the flight deck but substantially increases user benefits. This is represented by the Aeronautical Operational Control (AOC) facilities that provide flight scheduling and planning services for their aircraft. Each air carrier fleet represents a sub-system that operates within the overall National Airspace System. DAG-TM maximizes the opportunity for these sub-systems to self-optimize. This provides perhaps the strongest mechanism for improving the performance of the entire NAS.

Air carriers (both scheduled airline and cargo operations) have very time-consequential objectives. In general, operators need to get their aircraft to their destinations on time for connectivity. In the case of scheduled airlines, the schedule is their primary performance metric (vital to connectivity of crews, equipment, and resources). In addition, air carriers desire predictability in their flight operations in order to minimize excess buffers in their schedule (leading to maximum productive use of capital resources). However the NAS is a very dynamic environment that poses significant challenges to meeting these objectives. DAG-TM provides the flexibility to these operators to respond in real-time to changes in the NAS in ways that optimize their own objectives. This is enabled through real-time sharing of information between the ATSP and AOCs. The operators may then utilize this information to modify and optimize their operations within the dynamic constraints of the ATM system.

The major cargo and scheduled airline operators use a hub-and-spoke system. This enables a large increase in the efficiency of their operations. In the hub-and-spoke system, flights are scheduled such that aircraft arrive from scattered spoke airports to a central hub airport in closely-timed banks. The passengers and crew may then transfer to connecting flights which then transport them to other spoke destinations. While this hub-and-spoke system introduces its own challenges into the dynamics of the NAS, it also provides a significant opportunity to air carriers under DAG-TM.

In today's operations, when dynamic conditions cause delays to flights, airlines often do not know about these delays until, at best, the aircraft are close to their destination airports. This allows them very little flexibility to adapt to these constraints. In DAG-TM, the AOC will have updated information on each flight from the moment the flight plan is filed through when the flight arrives at the gate. This will allow them the ability to see real-time changes to the estimated arrival time (ETA). AOCs will now have the opportunity to modify the desired arrival times of their fleet of aircraft to optimize their operations. These new arrival times can then be transmitted to their aircraft in mid-flight, thereby allowing the aircraft, utilizing DAG-TM technologies, to replan their trajectory in real-time to meet the new arrival target. This represents a capability to allow the AOC to get their most important flights in first. It is likely that this will increase the connectivity of passengers, cargo, flight crews and aircraft, thereby reducing the downstream propagation of delay.

The reduction of delay propagation is a very powerful benefit mechanism. Considering the number of flights operating under the hub-and-spoke system, the performance of the entire NAS may be improved significantly. Although the integration of this benefit mechanism with various other benefit mechanisms is complex, this could contribute to meeting key objectives of the AATT project.

By reducing the downstream impact of delays in the system, the predictability of flights meeting their departure and arrival times is increased. When flights can repeatably meet their scheduled arrival times, the buffer added by airlines to their flight schedules (to compensate for variations in flight times) can be reduced. With the buffer reduced, the scheduled flight times between airports are reduced. Ultimately this will allow the airline resources to be scheduled to fill the excess periods that represent the sum of the removed buffer times. This means more flights (i.e., more capacity) and more revenue. If efficiency is measured in terms of profit, DAG-TM addresses both the reduction of operating costs and the increase of revenue. Both sides of the profit equation benefit. DAG-TM research will be conducted to confirm that these improved benefits outweigh the costs to equip the aircraft and the AOCs.

3.3 Air Traffic Service Provider (ATSP) Perspective

From the perspective of the ATSP, DAG-TM technologies/procedures will not only enable them to more efficiently manage all aircraft regardless of user equipage, but will also enable the ATSP to handle more aircraft at a time without an increase in workload. This will be accomplished through the following technologies and capabilities:

- Information exchange with the users, such as:
  - User preferences (aircraft and fleet)
  - Aircraft states and trajectory intent
- Predictive capabilities to forecast the potential need for future constraint applications, thereby facilitating user actions to reduce the severity of the constraints
- Improved predictability of aircraft trajectory maintenance, thereby allowing reduced excess spacing buffers
- Procedures and tools that allow user-ATSP collaboration to meet ATSP requirements while maximizing user benefit
- Advisory decision support tools to more effectively sequence and control aircraft

- Enhanced multi-sector and multi-facility interaction
- Advanced CNS capabilities.

3.4 Flight Deck (FD) Perspective

Every aircraft in the NAS will obtain some benefits regardless of their equipage level, with the level of benefits increasing as the level of equipage increases. While levels of equipage will vary among aircraft, the following technologies and capabilities will offer maximum benefits to the fully equipped flight deck:

- Information exchange with the ATSP and the AOC, such as:
    - Weather information access and displays
    - Winds aloft updates
    - SUA status
    - Traffic complexity parameters
    - Constraint information
- Tactical trajectory replanning for efficient conflict avoidance
- Strategic trajectory replanning to minimize constraints and eliminate conflicts while meeting up-to-date arrival times
- Procedures and tools that allow user-ATSP collaboration to meet ATSP requirements while maximizing user benefit
- Enhanced situational awareness through display of traffic, weather, and SUA information
- Advanced CNS capabilities
- Taxi navigation information and displays

3.5 Aeronautical Operational Control (AOC) Perspective

In the tactical mode, the AOC will have access to real-time information on the status of the NAS, and the ability to dynamically adapt their operations to changes in the NAS. In the strategic mode, the AOC will be able to provide preferences and priorities to the ATSP and to the aircraft in their fleet, presenting an opportunity to dynamically influence the status of the NAS. This will be accomplished through the following technologies and capabilities:

- Information exchange with the ATSP and FD, such as
    - Weather information
    - Traffic displays and data
    - Traffic complexity parameters
    - SUA status
    - Desired arrival times

- Advanced communications capabilities

4. DESCRIPTION OF DAG-TM CONCEPT

4.1 Formulation of DAG-TM Concept

The DAG-TM Concept was formulated as a coherent set of solutions to a series of key ATM problems (or inefficiencies) in the gate-to-gate operations of the current NAS. For each problem, one or more solutions were identified that could potentially solve the problem by utilizing distributed decision-making between the user (FD and/or AOC) and the ATSP. These solutions, known as concept elements (CEs), would potentially enable greater accommodation of user preferences and increased system capacity. A fundamental goal of the DAG-TM concept is the elimination of static restrictions, to the maximum extent possible. In this paradigm, users may plan and operate according to their preferences – as the rule rather than the exception – with deviations occurring only as dynamically necessary. Therefore, the DAG-TM concept elements were formulated to mitigate the extent and impact of dynamic NAS constraints, while maximizing the flexibility of airspace operations.

The DAG-TM Team first determined a comprehensive (albeit not exhaustive) list of problems/inefficiencies in the current ATM system, guided by a three-dimensional matrix that covered the entire regime of NAS operations. The first dimension spans the operational domains of Surface, Terminal Airspace and En route Airspace.* The second dimension spans the flight phases of Pre-Flight Planning, Departure, Cruise and Arrival. The third dimension spans the dynamic NAS constraints of Separation (traffic), Airspace (bad weather, SUA, congestion), and Transition (arrival metering/spacing); see Fig. 4-1. It is noted that many cells of the matrix cannot be populated; e.g., all cells involving the operational domain of Surface and the flight phase of Cruise. Numerous problems/inefficiencies in the operations of the current ATM system were identified, cataloged, and finally consolidated into a set of 10 key problems. These problems will be described later in Section 4.3.

Next, the DAG-TM Team identified one or more solutions to each of the 10 key ATM problems. It is noted that there are many potential ways to solve these problems, including technological and procedural changes that enhance the current ATM system without significantly changing its paradigm of operations (this approach has already been used to develop many of the innovative ATM DSTs and supporting technologies that are now coming online). However, in order to qualify as a DAG-TM concept element, the solution had to include a significant level of distributed decision-making between the user (FD and/or AOC) and the ATSP; this criterion for inclusion in the DAG-TM concept is, for lack of a better term, informally referred to by the team as "DAGgishness." Using this approach, 14 concept elements were obtained as solutions to the 10 key ATM problems (four of the problems had two solutions). A common thread running through these concept elements was the requirement for information access/exchange. Therefore, gate-to-gate information access/exchange was considered to be a special concept element,

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* Although oceanic and under-developed airspace were not explicitly included, DAG-TM activities will give due consideration to global interoperability issues.

in recognition of its pervasive nature. The resulting set of 15 concept elements establishes the framework of the DAG-TM Concept.

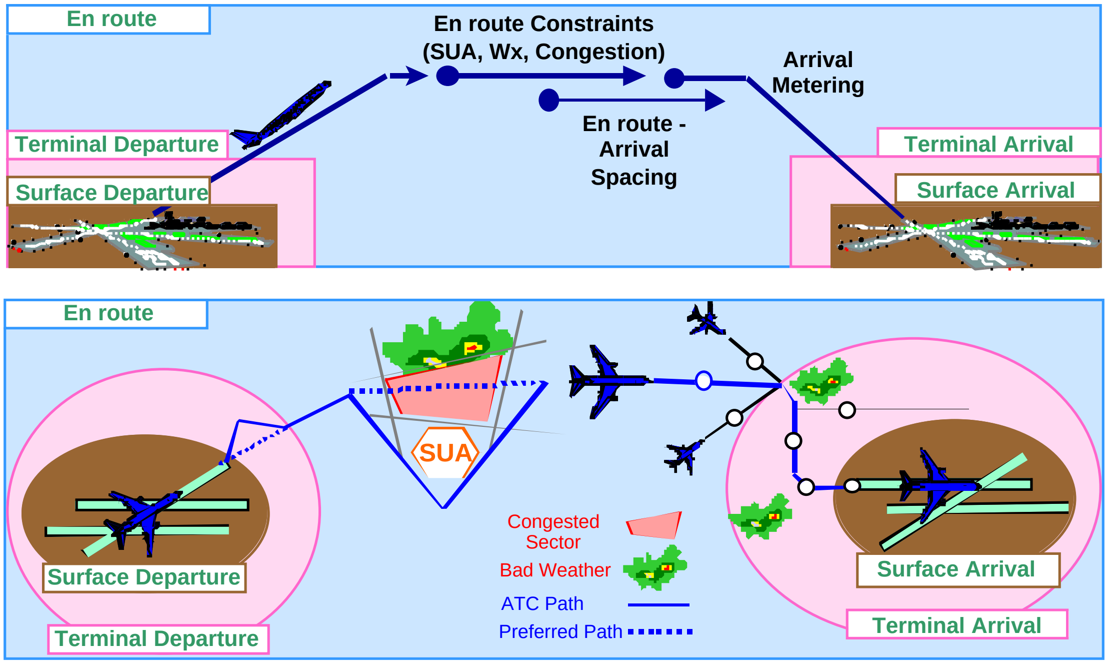


Fig. 4-1: Representation of NAS Constraints

4.2 Outline of DAG-TM Concept Elements

Fig. 4-2 presents an overview of the 15 DAG-TM concept elements. As stated earlier, a special concept element for universal information access/exchange covers all ATM operations from gate to gate. This concept element is presented first, numbered “CE 0” to indicate its over-arching nature. The other concept elements are numbered “CE 1” through “CE 14.” It is noted that CEs 1 – 14 each represent a solution to a problem/inefficiency in the operations of the current NAS. Their sequence corresponds to the progression of a typical flight. The CE titles include a label that indicates the applicable operational domain and flight phase (e.g., Terminal Departure). The label “Gate-to-Gate” applies to all operational domains and all flight phases. Fig. 4-3 shows the relationship between CEs in the operational domain of En route Airspace.

CE	Title	
0	Gate-to-Gate:	Information Access/Exchange for Enhanced Decision Support
1	Pre-Flight Planning:	NAS-Constraint Considerations for Schedule/Flight Optimization

2	Surface Departure:	Intelligent Routing for Efficient Pushback Times and Taxi
3	Terminal Departure:	Free Maneuvering for User-Preferred Departures
4	Terminal Departure:	Trajectory Negotiation for User-Preferred Departures
5	En route: *(Departure, Cruise, Arrival)*	Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
6	En route: *(Departure, Cruise, Arrival)*	Trajectory Negotiation for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
7	En route: *(Departure, Cruise, Arrival)*	Collaboration for Mitigating Local TFM Constraints due to Weather, SUA and Complexity
8	En route / Terminal Arrival:	Collaboration for User-Preferred Arrival Metering
9	Terminal Arrival:	Free Maneuvering for Weather Avoidance
10	Terminal Arrival:	Trajectory Negotiation for Weather Avoidance
11	Terminal Arrival:	Self Spacing for Merging and In-Trail Separation
12	Terminal Arrival:	Trajectory Exchange for Merging and In-Trail Separation
13	Terminal Approach:	Airborne CD&R for Closely Spaced Approaches
14	Surface Arrival:	Intelligent Routing for Efficient Active-Runway Crossings and Taxi

Fig. 4-2: Overview of Concept Elements

In Fig. 4-2, concept elements that are separated by a gray (instead of black) horizontal line are “parallel” concept elements; they are CEs 3/4, 5/6, 9/10 and 11/12. Parallel concept elements occur in those cases where the DAG-TM Team identified two solutions to the same problem. In all parallel concept elements, there is one solution with a flight deck focus (greater distribution of decision-making to the flight crew), and another solution with an ATSP focus. As an example, for the en route problem of non-preferred deviations for separation assurance, one approach/solution is to delegate separation responsibility to the flight deck and enable free maneuvering (CE 5a); the other approach/solution is trajectory negotiation between the user and ATSP for user-preferred deviations, with the ATSP retaining separation responsibility (CE 6a). Although these parallel solutions may appear to be competitive, they are simply alternative modes of solving the same problem. Either mode may be the preferred solution, depending on variables such as airspace complexity and user equipage. Consider again the problem of non-preferred deviations for separation assurance. The free maneuvering solution may be advantageous only in some regions of airspace, due to factors such as congestion. Alternatively, a user may make a business decision to equip their aircraft at an intermediate level that enables only trajectory negotiation, rather than a full level of equipage that enables both trajectory negotiation and free maneuvering. Therefore, parallel concept elements may be regarded as complementary solutions to the same problem.

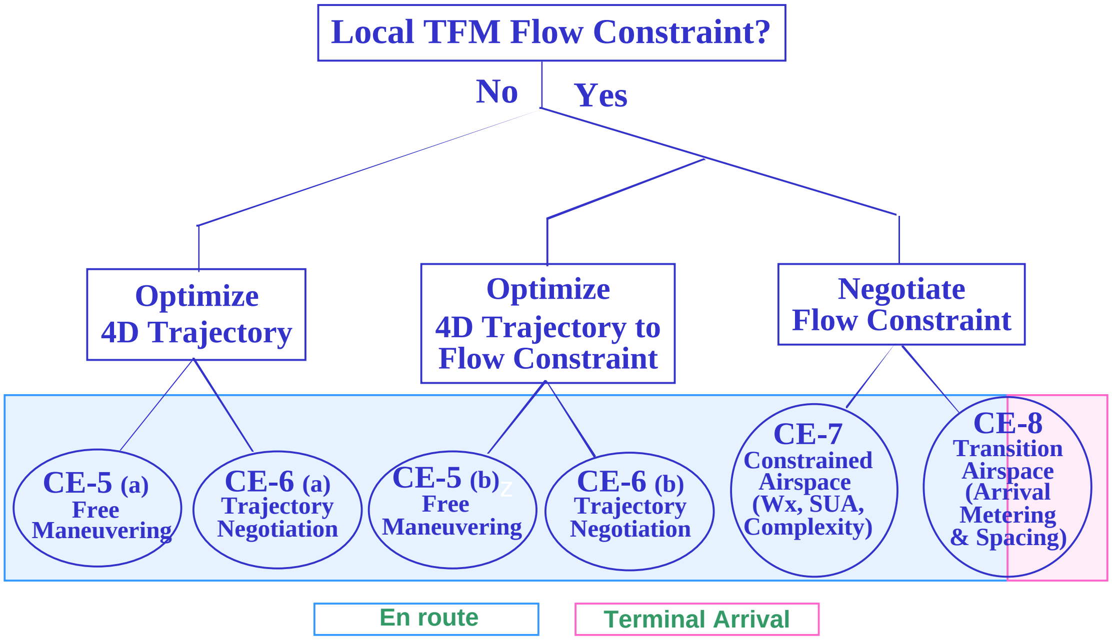


Fig. 4-3: Relationship between En route Concept Elements

4.3 Detailed Descriptions of Concept Elements

This section presents detailed descriptions of each concept element, using a uniform format. First, a problem/inefficiency in the current operational ATC system is presented. Next, a solution to the problem is presented, within the framework of the DAG-TM paradigm. Finally, a list of potential benefits is presented along with their associated benefit mechanisms.

The concept elements call for a variety of DSTs to be used by ATSP and/or FD and/or AOC personnel. In all cases, DST equipment will be designed, and accompanying procedures established, in a manner that will maintain workloads at a comfortable level for all parties, while ensuring that the decision-making process is timely and intuitive. By timely it is meant that the equipment and procedures allow sufficient time for the human decision-makers to evaluate the situation and determine solutions, while keeping system delays and response times to a minimum. By intuitive it is meant that it is easy for the human operators to understand the relationships between their inputs and the resulting outputs of the DSTs.

4.3.0 Gate-to-Gate: Information Access/Exchange for Enhanced Decision Support

4.3.0.1 Problem

Inefficiencies across NAS operations, due to the lack of timely and accurate NAS state information available to stakeholders (FD, AOC, ATSP).

The efficiency of current NAS operations is limited by the information available for flight planning (by users) and traffic management (by ATSP).

4.3.0.2 Solution

Provide capabilities to all stakeholders (FD, AOC, ATSP) for convenient access/exchange of timely and accurate information.

This information includes (but is not limited to) the following:

- Current and predicted NAS constraint information (delays, flow initiatives, SUA status) will allow users to advantageously plan/re-plan trajectories according to their preferences, within the dynamic constraints of the NAS.

- 4D weather information (winds, temperature, turbulence, storm cells, icing, etc), combined with analysis of trajectory predictions to determine the flights that are possibly affected, will allow users (FD / AOC) to more effectively plan and re-plan various flight operations.

- Real-time pilot reports (pireps) from aircraft maneuvering near weather-impacted areas (e.g., extent of turbulence, cloud tops, icing/temperature) will provide the ATSP and users (FD and/or AOC) with information to validate forecasts and improve the predictions about the impact of inclement weather on individual flights and airspace.

- Updated FD information on intent will improve ATSP analysis of predicted traffic demand for capacity-constrained sectors, and will therefore reduce overly conservative use of traffic management constraints. Accurate user-provided updates on estimated departure time for satellite/spoke airports that feed high-density hub airports will improve the arrival-demand predictions used by the ATSP for arrival metering. This will reduce excess metering, due to uncertainty in arrival demand, and result in more equitable metering delays for both airborne and satellite departure flights that are within the metering horizon.

- User-ATSP exchange of state and intent data will improve the accuracy of, and consistency between, FMS and ground-based trajectory predictions. This will enhance the performance and compatibility of airborne and ground-based decision support tools. Downlink of aircraft state, intent, and atmospheric state will enhance ground-based predictions of both trajectories and winds/temperature aloft. Uplink of the latest winds aloft and trajectory constraints (e.g., dynamic crossing restrictions and terminal area routes/speeds) will enhance FMS trajectory planning. Performance enhancements will reduce the rate of conflict false alarms and missed alerts and reduce corrective interruptions for conflict resolution and flow-rate conformance (e.g., metering).

4.3.0.3 Potential Benefits

- Increased overall efficiency of NAS operations and increased productivity of all stakeholders (FD, AOC, ATSP), due to improved quality, timeliness and accessibility of NAS information. Examples include:
  - » Improved definition of user preferences
  - » Reduction in flow constraints and more equitable distribution of flight deviations for flow constraints
  - Improved flight efficiency and reduction in ATSP workload, due to:
    - » Decreased flight deviations due conflict probe false-alarm/missed-alert rates
    - » Better planning and implementation of flow-rate conformance

4.3.1 Pre-Flight Planning: NAS-Constraint Considerations for Schedule/Flight Optimization

4.3.1.1 Problem

Inadequate accommodation of user preferences for schedule/flight planning, due to static and dynamic NAS constraints such as SUA status, bad weather and traffic management.

In the current ATM system, users have limited knowledge of NAS constraints when they conduct pre-flight planning. Consequently, their proposed flight plans often violate NAS constraints. In such cases, the ATSP has to modify the proposed flight plans to conform with NAS constraints; these flight plan modifications may not be user-preferred.

4.3.1.2 Solution

Using information on current and predicted NAS constraints, users collaborate with the ATSP during pre-flight planning to determine "optimal" (user-preferred) schedules and trajectory plans that satisfy current and predicted NAS constraints.

ATSP provides AOC with information on current and predicted states of the NAS, including information on bad weather, SUA status, airport/airspace delays and flow constraints. Using this information, the AOC optimizes fleet-wide schedules and trajectory plans, according to its business objectives. After verification that these trajectory plans do not violate any of the NAS constraints, the planned trajectories are approved by the ATSP. If a trajectory is denied, specific constraint violation information is provided by the ATSP to the AOC.

This represents a new flight planning paradigm that requires new flight planning algorithms, displays, and capabilities, real-time comprehensive data exchange between ATSP and AOC, centralized and consistent dissemination of NAS constraint data, and procedures governing the linking and coordination of all candidate and approved flight plans of system users.

4.3.1.3 Potential Benefits

- Increased flexibility and user efficiency (schedule, fuel, flight time), due to user-preferred pre-flight planning.

4.3.2 Surface Departure: Intelligent Routing for Efficient Pushback Times and Taxi

4.3.2.1 Problem

Inefficient taxi operations due to departure runway queues, verbal clearances, and radio frequency congestion.

In current day operations, studies have shown that surface operations are inefficient and prone to high workload levels, radio frequency congestion, and communication errors. Also, the requirement for pilots to write down the clearance and read it back to ATSP for verification unnecessarily increases workload for both pilots and controllers and reduces the efficiency of the entire system.

An additional source of taxi delays is the long departure queues that can develop when aircraft push back from the gate and "get in line" for departure. Individual aircraft push back near their scheduled departure time, then taxi to the departure queue which may be as large as 20 aircraft during departure pushes. Sitting in a slow-moving departure queue (as opposed to staying at the gate or another area on ground power) wastes fuel and increases emissions.

4.3.2.2 Solution

ATSP uses an Intelligent Ground System (IGS) to determine pushback time, based on an estimated departure time transmitted (via datalink) by the user/ramp.

The IGS coordinates aircraft pushback requests, and determines a pushback time that minimizes departure queues at the runways while balancing runway assignments and intersection/runway crossings. The proposed pushback time is displayed to the ATSP via an interface that allows controllers to interact with the IGS and enter any additional constraints known to them. ATSP transmits (via datalink) this pushback time to the FD, ramp, tower, TRACON and supporting positions. After pushback at the specified time, the aircraft begins taxiing toward the departure queue on a cleared datalinked route. Through the optimization of pushback timing, the departure runway queue can be minimized.

4.3.2.3 Potential Benefits

- Reduced departure delay and taxi time, and due to efficient pushback time.

- Reduced fuel consumption and emissions, due to decreased engine operation time on the ground (resulting from efficient pushback time).

- Increased taxi efficiency, due to datalink capabilities which may decrease or eliminate the need to stop while receiving a taxi clearance.

- Reduced workload, due to decreased verbal communication, frequency congestion, and opportunities for communication errors.

4.3.3 Terminal Departure: Free Maneuvering for User-Preferred Departures

4.3.3.1 Problem

Inefficient departure routing due to static restrictions for separation conformance.

In terminal areas with low traffic density, aircraft are often cleared for immediate climb and on-course heading soon after initial contact with departure control. However, during conditions of moderate or high traffic density, controllers ensure traffic separation by instructing aircraft to follow published departure routes, thereby reducing the workload of monitoring for conflicts and vectoring aircraft for conflict resolution. These standard departure routes are designed for managing high traffic-density levels and do not necessarily provide efficient and expeditious routing consistent with the intended en route course of all aircraft.

4.3.3.2 Solution (Flight Deck focus)

Appropriately equipped aircraft are given authority to select departure path and climb profile in real time, along with the responsibility to ensure separation from local traffic.

During terminal-area operations, appropriately equipped aircraft are given the authority to use FD-based trajectory planning DSTs to autonomously select and implement a preferred departure path and climb profile. Pre-departure clearance to operate in this mode is given by the ATSP, based on an assessment of acceptable levels of terminal-area constraints. While operating in autonomous departure mode, the flight crew is responsible for ensuring separation from local traffic. The flight crew performs this task with the aid of a CDTI with CD&R capability, linked to a trajectory-planning capability. Aircraft intent information is automatically broadcast via datalink to assist other equipped aircraft and ATSP in conflict detection. The ATSP monitors all operations in the terminal area and continues to provide normal departure-clearance services to aircraft not equipped for free maneuvering. For cases where the flight crew attempts, and fails, to resolve a conflict, automated systems or the ATSP will provide a required resolution.

4.3.3.3 Potential Benefits

- Increased departure efficiency, due to user's ability to select their own departure trajectories.

- Reduced controller workload due to reduced voice communications, particularly in regions of high frequency congestion.

4.3.4 Terminal Departure: Trajectory Negotiation for User-Preferred Departures

4.3.4.1 Problem

Same as 4.3.3.1, but repeated below for completeness.

Inefficient departure routing due to static restrictions for separation conformance.

In terminal areas with low traffic density, aircraft are often cleared for immediate climb and on-course heading soon after initial contact with departure control. However, during conditions of moderate or high traffic density, controllers ensure traffic separation by instructing aircraft to follow published departure routes, thereby reducing the workload of monitoring for conflicts and vectoring aircraft for conflict resolution. These standard departure routes are designed for managing high traffic-density levels and do not necessarily provide efficient and expeditious routing consistent with the intended en route course of all aircraft.

4.3.4.2 Solution (ATSP focus)

User and ATSP collaboratively plan a user-preferred departure trajectory.

The user (AOC and/or FD) selects the key parameters of their user-preferred departure trajectory (desired routes, fixes and speeds), and transmits them to the ATSP via datalink. Using a departure planning DST, the ATSP computes a nominal conflict-free departure trajectory that accommodate user preferences; this trajectory is then uplinked to the FD for execution. ATSP monitors the execution of the nominal trajectory for conflicts and transmits trajectory deviations as necessary for conflict avoidance.

4.3.4.3 Potential Benefits

- Increased departure efficiency, due to user's ability to influence their departure trajectories.

4.3.5 En route: Free Maneuvering for User-preferred Separation Assurance and Local TFM Conformance

It is noted that this concept element applies to all flight phases (Departure, Cruise and Arrival) in the operational domain of En route Airspace.

4.3.5.1 Problem

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current ATC system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers for conflict detection and resolution (CD&R). Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary "resolution" of false alarms (i.e., predicted "conflicts" that would not have materialized had the aircraft continued along their original trajectories). In those cases where a potential conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and displays), and also to a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user's (FD or AOC) trajectory preferences for conformance with local traffic flow management (TFM) constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (FD or AOC) is required to submit their request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing) can result in the FD or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and FD can adversely impact voice-communication channels and increase ATSP and FD workload.

4.3.5.2 Solution (Flight Deck focus)

(a, b) Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local traffic flow management (TFM) constraints.

While in the en route operational domain, appropriately equipped aircraft are given the authority, capability and procedures needed to execute user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew take on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. The trajectory change should also conform to any active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing). User-preferred trajectory modification may be generated by the FD with AOC input if appropriate, or generated entirely by the AOC and transmitted to the FD via datalink. The FD broadcasts its modified flight plan via datalink (includes notification of ATSP) immediately after initiation of a trajectory modification; in most situations, this task is handled by on-board automation.

The ATSP monitors separation conformance for free maneuvering aircraft, and provides separation assurance for lesser-equipped aircraft, using CD&R DSTs. ATSP may act on behalf of lesser-equipped aircraft when they are in potential conflict with free maneuvering aircraft. For cases where the flight crew attempts, and fails, to resolve a conflict, automated systems or the ATSP will provide a required resolution. Procedures and flight rules are established that provide incentive for aircraft to equip for self separation, such as, perhaps, priority status in conflicts with lesser-equipped aircraft.

4.3.5.3 Potential Benefits

- Reduction in excessive and non-preferred deviations for separation assurance and local TFM conformance, due to the ability of the flight crew (of appropriately equipped aircraft) to self-separate and maintain local TFM conformance according to their preferences.

- Increased safety in separation assurance for all aircraft, due to CNS redundancy (FD as primary and ATC as backup) and increased situational awareness on the FD of appropriately equipped aircraft.

- Reduced ATSP workload for separation assurance and local TFM conformance, plus reduced flight crew workload for communications, due to distribution of responsibility for separation assurance and local TFM conformance between the ATSP and appropriately equipped FDs.

4.3.6 En route: Trajectory Negotiation for User-preferred Separation Assurance and Local TFM Conformance

It is noted that this concept element applies to all flight phases (Departure, Cruise and Arrival) in the operational domain of En route Airspace.

4.3.6.1 Problem

Same as 4.3.5.1, but repeated below for completeness.

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current ATC system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers for conflict detection and resolution (CD&R). Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary "resolution" of false alarms (i.e., predicted "conflicts" that would not have materialized had the aircraft continued along their original trajectories). In those cases where a potential conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and displays), and also to a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user's (FD or AOC) trajectory preferences for conformance with local traffic flow management (TFM) constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (FD or AOC) is required to submit their request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing) can result in the FD or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and FD can adversely impact voice-communication channels and increase ATSP and FD workload.

4.3.6.2 Solution (ATSP focus)

(a) Reduce unnecessary and/or excessive ATSP-issued route deviations for traffic separation by enhancing ATSP trajectory prediction capability through user-supplied data on key flight parameters.

The user (FD and/or AOC) will provide information via datalink on key parameters such as aircraft weight, trajectory intent (route, altitude, speed profile), local winds/temperature aloft, and navigational performance. The provision of this information will not adversely affect FD and/or AOC workload, and will probably be automated. An ATSP-based DST will use this data to improve its trajectory predictions, resulting in improved CD&R performance. This improvement will: (1) Reduce the number of unnecessary conflict resolution maneuvers by decreasing the conflict prediction false-alarm rate; and, (2) Reduce the extent of excessive trajectory deviations for conflict resolution by decreasing the uncertainty in future positions of the aircraft.

Appropriately equipped users will be able to submit their preferences for resolving conflicts. These preferences may include (but are not limited to): a specified 4D trajectory; a specified route, and/or altitude and/or speed profile; or, preferred degree(s)-of-freedom (route, altitude, speed) for conflict resolution. The trajectory negotiation process may involve single-flight collaboration between the ATSP and an individual user, or multiple-flight collaborations between the ATSP and multiple users for determining a balanced set of deviations among a “gaggle” (group) of flights. Following the selection of a conflict-resolution plan, the ATSP then transmits (via datalink) the conflict-free trajectory solutions to the appropriately-equipped aircraft for execution (thereby further reducing trajectory uncertainty and subsequent conflict false-alarm and missed-detection rates). It is emphasized that the ATSP retains full responsibility for separation assurance.

(b) Facilitate trajectory change requests for en route aircraft by providing the user (FD and/or AOC) the capability to formulate a conflict-free user-preferred trajectory that conforms to any active local-TFM constraints.

By making use of information on local traffic and TFM constraints, the user is able to formulate intelligent trajectory change requests that are likely to be acceptable to the ATSP and therefore less workload-intensive for the ATSP to evaluate and coordinate. Using datalink, the AOC transmits relevant information on airline preferences/constraints to the FD. The flight crew use a FD-based trajectory planning DST to compute a conflict-free user-preferred trajectory that conforms to any active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing). The FD transmits the desired trajectory to the ATSP via datalink. The ATSP uses their DST to review the request, and in most cases, finds the request acceptable and issues a clearance for the new trajectory. If the request is not acceptable, the ATSP denies the request and may use their DST to formulate an alternative clearance or provide additional information on ATSP requirements/constraints. It is emphasized that the ATSP retains full responsibility for separation assurance.

4.3.6.3 Potential Benefits

- Reduction in excessive deviations for separation assurance, due to improved CD&R capabilities of ATSP-based DSTs, enabled by user-supplied data on key flight parameters.

- Reduction in non-preferred deviations for separation assurance, due to user-ATSP collaboration for conflict resolution maneuvers.

- Increased ATSP accommodation of user requests for trajectory changes, due to the user’s ability to intelligently formulate trajectory change requests that conform to local traffic and TFM constraints.

- Reduced ATSP workload, due to improved CD&R capabilities (enabled by user-supplied data) for separation assurance, and intelligent user requests for trajectory changes that conform to local traffic and TFM constraints

4.3.7 En route: Collaboration for Mitigating Local TFM Constraints due to Weather, SUA, and Complexity Constraints

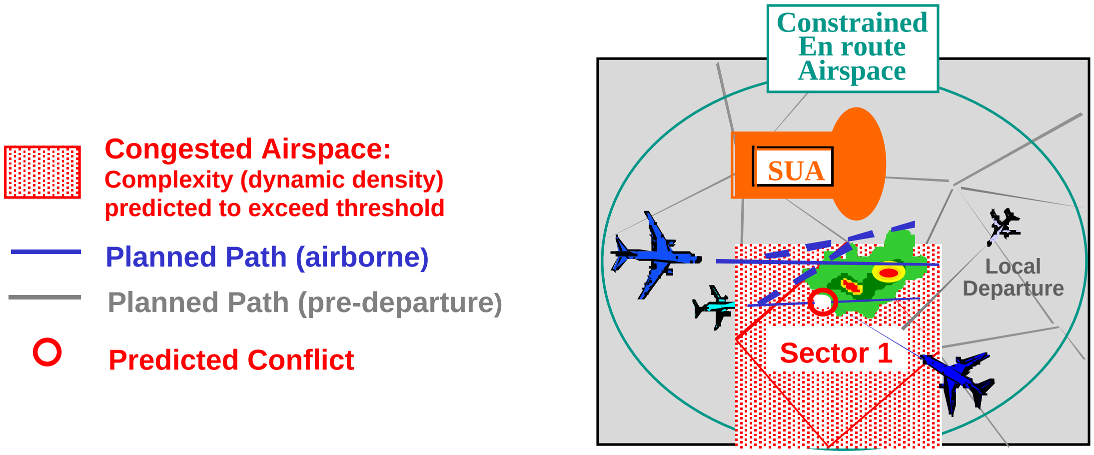
It is noted that this concept element applies to all flight phases (Departure, Cruise and Arrival) in the operational domain of En route Airspace.

4.3.7.1 Problem

Deviations resulting from local traffic flow management (TFM) constraints are often excessive and not preferred by users, due to inefficient use of en route airspace in the presence of bad weather, SUA and complexity.

Currently, ATSP imposes constraints on users when NAS operations are predicted to be restricted in certain regions of en route airspace due to bad weather, SUA and airspace congestion/complexity. These constraints may take the form of speed changes, altitude changes, or path changes, all of which represent a deviation from the preferred trajectory planned by the user. In some instances, these NAS operational constraints may affect aircraft long before they are near the affected region of airspace.

In many cases, the deviations issued by the ATSP are different from what would be preferred by the user (both FD and AOC). There may be multiple ways in which the constraint can be satisfied, and the deviations imposed by the ATSP may not be the most efficient (or desired) in terms of meeting the users' business objectives. Examples may include: the choice of flights to be deviated, the direction of the deviation, the type of deviation (route, altitude, speed), route deviations around airspace/weather through which the user might be willing to fly, or route deviations that involve flying through airspace/weather that the user would prefer not to penetrate.



Air Route Traffic Control Center (ARTCC)

Fig. 4-4: Problems in Constrained En Route Airspace

4.3.7.2 Solution

A system-wide collaboration between ATSP and multiple users (FDs and/or AOCs), with the objective of eliminating or mitigating the impact of predicted NAS operational constraints due to bad weather, SUA and complexity.

The users are represented by the FD and/or AOC, depending on the situation and source of the user's preference. Consider a scenario in which the ATSP predicts that a traffic management constraint will have to be imposed in en route airspace. A system-wide approach is used in which the ATSP collaborates with multiple users (who would potentially be impacted by the constraint) to achieve a resolution that would prevent the necessity of an operational constraint or at least mitigate the extent of the constraint.

The solution is characterized by user-ATSP collaboration which may vary in form as a function of time horizon (i.e., time to go until a particular flight, or group of flights, are predicted to reach the "constrained airspace"). This corresponds to three stages, categorized as Preemptive User Action, En route Collaborative Decision-Making (CDM), and Initiative Implementation.

The first stage involves traffic upstream of a potentially impacted airspace, but before the local Traffic Management Units (TMUs) establish an en route TFM initiative (trajectory deviations). The user (FD and/or AOC) monitors the predicted status of the NAS for sector complexity, weather, and available airspace. Each user may then evaluate, for each flight, the probability of a TFM initiative (and corresponding trajectory deviations), and the cost/benefit of taking preemptive action to request a flight-plan change to avoid potential problem areas well in advance. Early, self-selected deviations may allow users to mitigate the potential impact of dynamic TFM initiatives on sensitive flights. A preemptive action for any flight will also indirectly benefit other flights by spreading out en route traffic and reducing the probability and extent of TFM initiatives. This is analogous to car drivers making decisions to temporarily use surface streets in order to avoid dynamic congestion reported along a segment of a freeway/expressway.

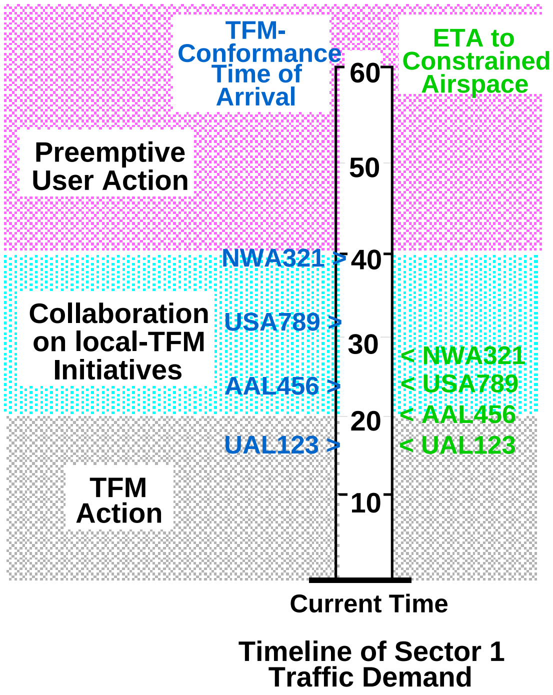


Fig. 4-5: Schematic of En route User-ATSP Collaboration

The second stage occurs as traffic approaches the impacted airspace; it is characterized by a CDM process for mitigating the impact of user deviations arising from en route TFM initiatives. First, the ATSP notifies the affected users of the predicted operational constraint and transfers the data necessary to support user analysis of preferred solutions for potentially impacted flights. The users then communicate their preferred solutions to the ATSP. The initiative is then re-evaluated (e.g., via fast-time simulation) by the ATSP to determine if further deviations are necessary. If time permits, a second round of collaboration may occur.

If the problem is not resolved in time, the process enters the third stage: Initiative Implementation. At this stage, the ATSP uses supporting DST technology to determine what additional action is necessary to off-load the potentially impacted airspace. User preferences, regarding the type of deviation desired, are analyzed by the DST to support the accommodation of such preferences within the ATSP-determined TFM initiative. Examples of TFM initiatives include re-routing, spacing, dynamic assess to SUA or dynamic resectorization (Ref. 9).

During all three stages, user preferences are established by the AOC and/or FD, as appropriate, depending on the constraint, environment, and user equipage/capability.

4.3.7.3 Potential Benefits

- Increased accommodation of user-preferred deviations in constrained en route airspace, due to user options for pre-emptive action and the incorporation of user input/preferences into ATSP's management of traffic flow.

- Increased user efficiency, ATSP productivity and system capacity, due to the adoption of a strategic and collaborative approach to the management of constrained en route airspace.

4.3.8 En route/Terminal Arrival: Collaboration for User-Preferred Arrival Metering

4.3.8.1 Problem

ATSP generally does not accommodate user preferences for arrival metering/spacing processes used to manage arrival delays, while the aircraft is operating in en route, extended terminal (includes terminal and parts of en route) and terminal airspace.

When arrival demand exceeds airport capacity, arrival scheduling is used to maximize throughput while efficiently distributing delay from terminal to en-route airspace. Scheduling is generally based on an estimated time-of-arrival (ETA) based first-come-first-served (FCFS) order with minimum spacing between sequential flights (to avoid conflicts and wake vortices). Spacing criteria, typically defined as a function of runway configuration and meteorological conditions, are applied at runway, approach, and meter-fix (TRACON entry) merge points. Key scheduling factors include the assignment of runway and meter-fix, choice of sequence and the relative sequence of flights in an arrival stream.

In the current system, users are generally unable to influence arrival metering/spacing processes used for managing arrival delays. The extent of arrival metering/spacing may be excessive, and the distribution of delay inequitable, because of inaccuracies in the prediction of arrival traffic load. Accurate metering requires accurate prediction of traffic demand and airspace/runway capacity. In particular, errors in predicted arrival routing and ETAs may cause scheduling errors resulting in excess delays for particular flights. A critical situation, often leading to large ETA errors, involves terminal area traffic that depart their origin airport within the extended terminal area scheduling freeze horizon. Slots for these flights are difficult to plan for and are often based on information such as the flight planned departure time. For those cases, ETA uncertainty is magnified several times by the uncertainties associated with estimating the precise departure time since flights may be subject to significant delays on the ground (e.g., mechanical problems, waiting for the crew to arrive) or even cancellation, without the knowledge of the scheduling system.

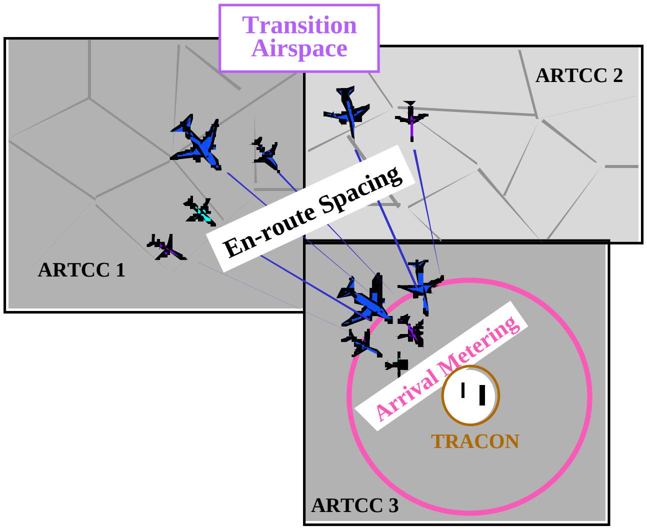


Fig. 4-6: Schematic of Arrival Metering Problem

4.3.8.2 Solution

Users influence arrival handling by submitting preferences for arrival time, meter-fix and runway to the ATSP well in advance of the arrival-planning freeze horizon.

Using arrival-planning DSTs, users (AOC and/or FD) determine arrival preferences (arrival time, runway and meter-fix) that conform to all known NAS constraints. Meter-fix and runway preferences allow the user to influence their arrival routing and taxi time. Arrival time preferences help all users to maintain their arrival schedule; they also enable "hubbing" users to influence the sequencing of flights in their arrival banks. In addition to the nominal preferences, the user could also specify a "delay weighting" for each runway and meter-fix. For example, a user may nominally prefer runway 28-left. However, if the delay for 28-L were to exceed some threshold compared to another runway, the preference would change to the other runway. The same would apply to a meter-fix entry point where a user may prefer to fly a longer path to enter the TRACON from another fix in order to avoid excessive delays along the more direct path.

The user preferences would be transmitted by the AOC (or FD) to the ATSP by datalink; this information enables the ATSP to accurately predict arrival traffic load. The ATSP uses an arrival-planning DST to analyze the arrival preferences submitted by the users, and to then formulate an arrival metering initiative that determines arrival sequence, meter-fixes and runway assignments, while accommodating user preferences to the maximum extent possible. Using datalink, the ATSP transmits information on arrival runways assignments and required times of arrival (RTAs) at assigned meter-fixes to the users (FD and/or AOC).

It is noted that the proposed solution may also be applicable to en route spacing for management of arrival delay. Choice of arrival routing may place a flight through a spacing-reference fix that results in more or less delay than the nominal routing. The user may also want to indicate a delay weighting for its preferred routing (i.e., indicate how much delay is acceptable for the preferred route before an alternative route is preferred). The choice of sequence and desired time of arrival will have a direct impact on the first-come-first served (FCFS) order used to space flights over a particular spacing-reference fix.

4.3.8.3 Potential Benefits

- Increased user flexibility and efficiency for arrivals in congested terminal airspace, due to strategic collaboration between user and ATSP for determining arrival times, runways and meter-fixes.

- Reduced arrival delays, due to efficient arrival metering resulting from improved ATSP predictions of arrival traffic load.

- Increased airline hub operating efficiencies, due AOC's ability to influence sequencing of flights in their arrival bank

4.3.9 Terminal Arrival: Free Maneuvering for Weather Avoidance

4.3.9.1 Problem

Inefficient terminal area re-routing to accommodate the dynamic airspace constraint of bad weather cells.

In current-day fair-weather operations, arriving and departing aircraft in the terminal area are directed along static routes. When bad weather cells block these static routes, the ATSP provides vectoring services to each aircraft to assist in avoiding these weather cells. The uncertainty of cell size and position, the dynamic nature of the cells, and the priority of safety often result in users flying inefficient routes to the runway threshold. Even for low-density arrival traffic, these factors and the need to provide multiple vectoring instructions to all aircraft can significantly increase controller workload.

4.3.9.2 Solution (Flight Deck focus)

Properly equipped aircraft are given authority to maneuver as necessary to avoid weather cells, or to follow such aircraft using self-spacing procedures.

In terminal-area operations with low-to-moderate traffic density, appropriately equipped aircraft are given the authority to use onboard weather detection and interactive/automated route-planning capabilities to navigate around weather cells (and maintain separation from local traffic) without receiving vectoring clearances from the ATSP. This authority may extend as far as autonomous navigation to the runway threshold, or it may be limited to local deviations from a nominal route clearance provided by the ATSP. The flight crew devotes a significant portion of their attention to this task and applies their preferences to routing decisions to the maximum extent possible. The ATSP monitors free maneuvering aircraft, and regains control authority at the termination of this procedure. Additionally, the ATSP provides vectoring services to aircraft that are not equipped for free maneuvering or self spacing, and also provides monitoring services for appropriately equipped free-maneuvering or self-spacing aircraft. For cases where the flight crew attempts, and fails, to find a conflict-free weather avoidance route, automated systems or the ATSP will provide a required deviation.

As an alternative to free maneuvering, aircraft can request to follow a free-maneuvering aircraft around weather cells using self-spacing procedures (described later in sub-section 4.3.11). Due to the rapid changes inherent in convective weather systems, probably no more than one aircraft would be permitted to perform self-spacing from a lead aircraft. Both flight crews would have access to the same weather information, and the lead aircraft would broadcast trajectory intent information to the following aircraft and all others within range via datalink.

4.3.9.3 Potential Benefits

- Increased user flexibility/efficiency in avoiding weather cells, due to FD autonomy

- Reduced ATSP workload, due to delegation of weather avoidance and traffic separation responsibility to the flight crew and reduced voice communications resulting from elimination of vectoring instructions for free maneuvering aircraft.

- Increased terminal area throughput, due to more efficient arrival trajectories for appropriately equipped aircraft.

4.3.10 Terminal Arrival: Trajectory Negotiation for Weather Avoidance

4.3.10.1 Problem

Same as 4.3.9.1, but repeated below for completeness.

Inefficient terminal area re-routing to accommodate the dynamic airspace constraint of bad weather cells.

In current-day fair-weather operations, arriving and departing aircraft in the terminal area are directed along static routes. When bad weather cells block these static routes, the ATSP provides vectoring services to each aircraft to assist in avoiding flight through weather cells. The uncertainty of cell size and position, the dynamic nature of the cells, and the priority of safety often result in users flying inefficient routes to the runway threshold. Even for low-density arrival traffic, these factors and the need to provide multiple vectoring instructions to all aircraft can significantly increase controller workload.

4.3.10.2 Solution (ATSP focus)

User and ATSP collaboratively plan a user-preferred trajectory around bad weather cells.

Timely and accurate weather information will be available via datalink to both the user (FD and/or AOC) and ATSP. The user transmits weather avoidance trajectory preferences to the ATSP. Using an appropriate DST, the ATSP computes a nominal conflict-free weather avoidance arrival trajectory that accommodate user preferences; this trajectory is then uplinked to the FD for execution. ATSP monitors the execution of the nominal trajectory for conflicts and transmits trajectory deviations as necessary for conflict avoidance. It is emphasized that the ATSP retains full responsibility for separation assurance.

4.3.10.3 Potential Benefits

- Increased user efficiency in avoiding weather cells, due to accommodation of user preferences in ATSP planning for trajectory deviations.

- Reduced ATSP workload, due to reduced voice communications resulting from elimination of vectoring instructions for free maneuvering aircraft.

- Increased terminal area throughput, due to more efficient arrival trajectories for appropriately equipped aircraft.

4.3.11 Terminal Arrival: Self-Spacing for Merging and In-Trail Separation

4.3.11.1 Problem

Excessive in-trail spacing buffers in arrival streams reduce runway throughput and airport capacity, especially in conditions of poor visibility and/or low ceilings.

In terminal area environments for which arrival demand approaches or exceeds capacity, aircraft landing rates are significantly lower under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). In order to compensate for uncertainties in aircraft performance and position, the ATSP applies in-trail spacing buffers to arrival streams under IMC in order to ensure that minimum separation requirements between successive aircraft are met. The resulting generous arrival spacing reduces runway throughput below its capacity to accept aircraft.

4.3.11.2 Solution (Flight Deck focus)

Appropriately equipped aircraft are given clearance to merge with another arrival stream, and/or maintain in-trail separation relative to a leading aircraft.

In VMC, aircraft are often able to maintain closer spacing during the approach, thereby increasing the capacity of the terminal area and the runway acceptance rate. In the current system, the FD is often requested to accept responsibility for visual self-separation once they acknowledge they can see the leading aircraft. In this situation, the FD is responsible for determining and then maintaining a safe separation from other aircraft, and is therefore not subject to the ATSP's minimum separation requirements.

Self spacing will enable the FD to autonomously merge with another arrival stream and/or maintain in-trail separation relative to another aircraft under IMC as they would under VMC, thus significantly increasing arrival throughput. Self spacing applies to aircraft that are subject to spacing requirements during arrival, from the feeder fix up to the final approach fix.

Anticipated procedures for self spacing involve the ATSP transferring responsibility for in-trail separation to properly equipped aircraft, while retaining responsibility for separating these aircraft from crossing traffic. Once the FD receives clearance to maintain spacing relative to a designated leading aircraft, the FD establishes and maintains a relative position with frequent monitoring and speed/course adjustments. Under some conditions, information such as required time of arrival (RTA) at the final approach fix may be provided by an appropriate ATSP-based DST, thereby enabling accurate inter-arrival spacing that accounts for differing final approach speeds or wake vortex avoidance. ATSP monitors all aircraft to ensure adequate separation. For cases where the flight crew fails to maintain adequate spacing, automated systems or the ATSP will provide a required correction.

Self spacing is expected to make use of datalink capabilities to provide position information and CDTI and/or advanced flight director/HUD guidance technology to provide spatial and temporal situation awareness to the flight crew. FD-based DSTs will provide information to enable manual station-keeping and/or monitoring of automatic 4D trajectory management.

4.3.11.3 Potential Benefits

- Increased arrival capacity/throughput in IMC, due to a reduction in excessive spacing buffers resulting from the ability of appropriately equipped aircraft to operate as if they were in VMC.

- Reduced ATSP workload, due to transfer of separation responsibility to the flight crew of appropriately equipped aircraft.

4.3.12 Terminal Arrival: Trajectory Exchange for Merging and In-Trail Separation

4.3.12.1 Problem

Same as 4.3.11.1, but repeated here for completeness.

Excessive in-trail spacing buffers in arrival streams reduce runway throughput and airport capacity, especially in conditions of poor visibility and/or low ceilings.

In terminal area environments for which arrival demand approaches or exceeds capacity, aircraft landing rates are significantly lower under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). In order to compensate for uncertainties in aircraft performance and position, the ATSP applies in-trail spacing buffers to arrival streams under IMC in order to ensure that minimum separation requirements between successive aircraft are met. The resulting generous arrival spacing reduces runway throughput below its capacity to accept aircraft.

4.3.12.2 Solution (ATSP focus)

Trajectory exchange between FD and ATSP to improve the accuracy of FD-based and ATSP-based DSTs for accurate merging and in-trail separation with minimal buffers.

FD will transmit relevant information on aircraft and trajectory parameters (e.g., aircraft weight, position, velocity components, estimated time of arrival at trajectory change points, planned final approach speed, local winds) via datalink to the ATSP. This information will allow the appropriate ATSP-based DST to accurately predict aircraft trajectories, thereby enabling it to plan conflict-free trajectories for accurate merging/spacing with minimal spacing buffers. The ATSP-computed trajectory will be transmitted via datalink to the FD for accurate execution by the FMS. The flight crew and ATSP monitor trajectory conformance. It is emphasized that the ATSP retains all responsibility for ensuring adequate spacing. An ATSP-based DST may provide speed advisories to the aircraft’s FMS in order to fine-tune the aircraft's trajectory; however, it is especially important to avoid a situation where the ATSP “remotely” flies the aircraft, and the flight crew is not effectively in the loop.

4.3.12.3 Potential Benefits

- Increased arrival capacity/throughput in IMC, due to a reduction in excessive spacing buffers resulting from the exchange of trajectory information between user and ATSP.

4.3.13 Terminal Approach: Airborne CD&R for Closely Spaced Approaches

4.3.13.1 Problem

During instrument meteorological conditions (IMC), independent approaches to closely spaced runways are not permitted under current procedures.

In the current ATM system, arrival capacity/throughput at airports with closely spaced runways is significantly reduced during IMC operations because independent approaches are not permitted for runways that are less than 4,300 ft apart (3,400 ft apart for airports equipped with a Precision Runway Monitor)

4.3.13.2 Solution

Appropriately equipped aircraft may conduct closely-spaced independent approaches by utilizing surveillance data, on-board avionics and new air-ground procedures to ensure safe separation.

Surveillance is provided by FD transmission of differential GPS-based positions and velocities to all other aircraft. CDTI and FD-based specialized collision alerting algorithms warn FD of possible traffic threats, and provide guidance for traffic avoidance maneuvers. ATSP-based DSTs will assist controllers with missed approach management in case of an abort of a closely spaced approach. This technology is expected to allow simultaneous independent approaches to be conducted in IMC to runways with a minimum spacing of 2,500 ft.

4.3.13.3 Potential Benefits

- Increased arrival capacity/throughput rate during IMC, due to execution of closely spaced approaches.

4.3.14 Surface Arrival: Intelligent Routing for Efficient Active-Runway Crossings and Taxi

4.3.14.1 Problem

Inefficient taxi operations due to active runway crossing delays, verbal clearances, and radio frequency congestion.

In current day operations, studies have shown that surface operations are inefficient and prone to high workload levels, radio frequency congestion, and communication errors Also, the requirement for pilots to write down the clearance and read it back to ATSP for verification unnecessarily increases workload for both pilots and controllers and reduces the efficiency of the entire system. A large contributing factor to inefficient taxi operations is the requirement for pilots to stop after runway turn off to contact ATSP via radio for a taxi clearance.

Additionally, the communication between two ATSP entities, the ATC Tower and ATC Ground Controller, in the current system is based on "current status", is not tightly coupled, and may take into account future status of only a few minutes. In other words, the Ground Controller must currently route an aircraft that has just landed to hold before an active runway. The Ground Controller, in communication with the Tower Controller, then assesses whether there is a sufficiently long gap to allow for an aircraft that is waiting to cross safely, and issues a command to cross. This, in essence, describes a "just in time" system, in which flow problems are dealt with on an "as needed" basis. Active runway crossings at some airports (DFW and BOS, for example) have been identified as one source of gate arrival delays. Through the use of predictive algorithms, the ATC Tower, Ground Controller and aircraft can coordinate for efficient active runway crossing.

4.3.14.2 Solution

ATSP uses an Intelligent Ground System (IGS) and datalink technology to coordinate aircraft for efficient active runway crossing.

The development of an Intelligent Ground System (IGS) would allow for improved coordination between ATSP entities, the ATC Tower and ATC ground controller, thereby improving traffic flow. The IGS would detect gaps in the arrival stream, utilizing the predictive arrival capabilities of an approach DST. The IGS, using modeled aircraft data, can then be used to direct appropriately equipped aircraft to efficiently cross the active runway during these gaps or "windows" in the arrival stream (see Fig. 4-7). The IGS-proposed clearances are displayed to the ATSP via an interface that allows controllers to interact with the IGS and enter any additional constraints known to them.

To address the communication problems, datalink technology will be used for surface operations clearances and other communications. Either before touchdown, or immediately after runway turn off, pilots will receive their taxi clearance from the ATSP via datalink text message. Pilots will acknowledge the clearance by pressing datalink response buttons located on the instrument panel, while retaining a text display of their clearance. The amount of verbal communication is reduced, thus lowering workload, frequency congestion, and opportunities for communication errors. Also, datalink may decrease or eliminate the need to stop while receiving a taxi clearance, thus increasing taxi efficiency. This concept requires two-way datalink capability between ATSP and FD, increased knowledge of aircraft locations by ATSP, and communication protocols between user, gate, and ATSP.

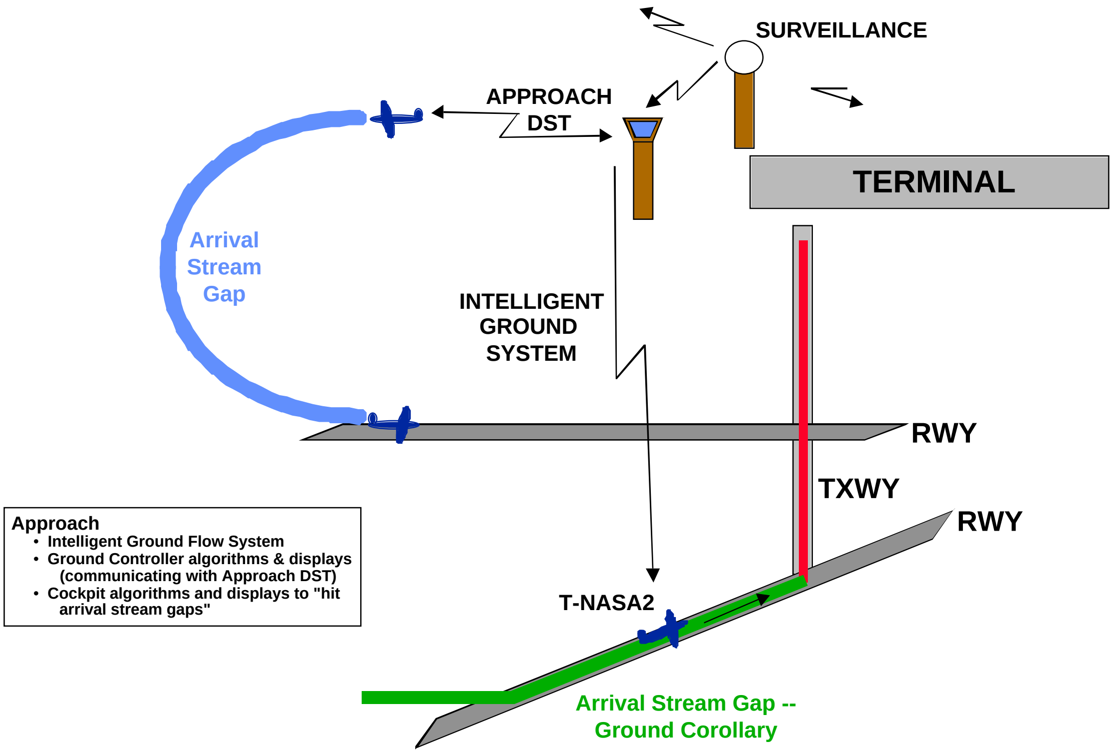


Fig. 4-7: Intelligent Ground System for Efficient Active-Runway Crossing

4.3.14.3 Potential Benefits

- Reduced delays in gate arrival, due to decreased active runway crossing hold delays.

- Increased taxi efficiency, due to datalink capabilities which may decrease or eliminate the need to stop while receiving a taxi clearance.

- Reduced workload, due to decreased verbal communication, frequency congestion, and opportunities for communication errors.

4.4 Storyline for Nominal DAG-TM Operations

In order to illustrate the connectivity and modality of the various Concept Elements (CEs), this section presents a storyline description for DAG-TM operations under nominal conditions. This storyline is a hypothetical narrative of events, set in the year 2017, for two flights from the New York City area to the San Francisco Bay area, operating under a DAG-TM paradigm.

North American Airlines (NorthAm), a commercial passenger carrier, operates flight NAA888 from New York Kennedy (JFK) to San Francisco (SFO). Trans Continent Airlines (TransCon), another carrier, operates flight TCA123 from Newark (EWR) to San Jose (SJC). Both aircraft are state-of-the-art 800-passenger Boeing 797 mega-jets; however they have different levels of onboard equipage, reflecting different avionics options purchased by the two airlines based on their business objectives. The NorthAm aircraft has a full level of equipage for DAG-TM and can therefore take advantage of all options offered by the DAG-TM paradigm of operations, including autonomous operations (e.g., free maneuvering, self spacing). The TransCon aircraft has an intermediate level of equipage for DAG-TM and can take advantage of some of the options offered by the DAG-TM paradigm of operations, including trajectory negotiation but excluding autonomous operation.

Both flights depart at the same time from airports in the New York City area and fly to airports in the San Francisco Bay area, using the same aircraft type (Boeing 797). Therefore they are generally in the same region of airspace at all times during their flight. This allows the storyline to illustrate different modes of operation (e.g., free maneuvering and trajectory negotiation) where applicable. NAA888 will be used to illustrate autonomous operations where the aircraft is authorized by the ATSP, in appropriate situations, to define and execute trajectories with no further approval required from the ATSP. TCA123 will be used to illustrate ground-controlled operations where the aircraft flight crew negotiate user-preferred trajectories with the ATSP (who has final approval authority).

In the following narrative, the term “ATSP” covers various entities such as ground controllers, departure controllers, traffic flow managers, en route controllers, arrival controllers, etc. The narrative frequently refers to applicable CEs, indicated in bold type, as appropriate. Although air traffic operations use “Zulu time” (or GMT), all times presented in this storyline have been converted to U.S. Eastern Time (ET) for convenience.

Pre-Flight Planning

~0400 Users access databases that provide accurate and up-to-date information on NAS states, including weather data, SUA status, airport delays, flow initiatives, predictions of dynamic density and airspace loading **(CE 0)**.

After accessing NAS state information from the appropriate databases, the AOCs of each operator/airline use pre-flight planning DSTs to prepare preliminary flight schedules and plans for all of the day’s flights, based on the hierarchical criteria of safety, integrity of schedule, and optimization of individual flights. These flight plans are then transmitted to the ATSP via datalink.

The TransCon AOC transmits a preliminary flight plan proposal for Flight TCA123 to the ATSP via datalink, with a preferred EWR departure time of 0750 ET and a preferred SJC arrival time of 1310 ET. The proposal includes key parameters of a nominal user-preferred trajectory from EWR to SJC, including basic information on preferred routing, altitudes and speed profiles **(CE 1)**.

The NorthAm AOC also sends a preliminary flight plan to the ATSP for NAA888, with a preferred JFK departure of 0750 ET and a preferred SFO arrival time of 1310 ET. However, this flight plan contains fewer details about the preferred routing (indicating only “JFK free flight to SFO”), altitudes and speed profiles **(CE 1)**.

0500 Negotiations between the ATSP and airspace users commence. These negotiations are facilitated by direct exchange of data on schedules and preferred routings, altitudes and speed profiles **(CE 0)**. The ATSP utilizes current and predicted NAS state data and the flight plan proposals submitted by all users and uses a traffic flow management DST to determine which flights will be subject to departure restrictions and/or assignment of a controlled time-of-arrival (CTA). Among other things, it is determined that morning departures from the New York City area to the San Francisco Bay area will not be subject to any departure restrictions or assigned CTAs.

0645 Using a trajectory planning DST, TransCon’s AOC determines a nominal user-preferred trajectory for TCA123 **(CE 1)**, utilizing current information on predicted winds and temperatures aloft, turbulence, SUA status, traffic density/complexity and flow constraints **(CE 0)**. The nominal trajectory request is transmitted to the ATSP via datalink.

The NorthAm AOC also computes a nominal free flight trajectory for NAA888 **(CE 1)**, utilizing current information **(CE 0)**. However, the AOC is not required to send this nominal trajectory to the ATSP for approval, due to the autonomous flight capabilities of NAA888 (note that a preliminary flight plan was filed with the ATSP at approximately 0400 ET). Instead, the flight plan is sent via datalink from the AOC to the FD of NAA888 shortly after the crew has boarded the aircraft. The flight crew uses the FMS to review the nominal trajectory and make minor modifications as necessary. With several known "VIP" passengers on board, the captain enters into the FMS a preference for turbulence avoidance even at the expense of fuel.

0700 Using a trajectory evaluation DST, ATSP evaluates the requested user-preferred trajectory for TCA123, based on information about other requested and cleared trajectories, projected SUA activity, localized high-density airspace and flow constraints, and transmits its approval to the TranCon AOC and the TCA123 FD via datalink **(CE 1)**.

Surface Departure

0710 The NorthAm AOC consults with the flight crew of NAA888 to determine a desired push-back time **(CE 2)** and forwards this information to the ATSP. The AOC also forwards the flight crew's request for free-flight departure clearance from JFK if the predicted local traffic complexity and weather conditions will permit; this clearance will allow the flight crew to plan and execute a departure route and climb profile without requiring approval from the ATSP, while accepting the responsibility to maintain separation from other aircraft **(CE 3)**.

After consultation with the crew of TCA123, the TransCon AOC transmits to the ATSP (via datalink) a desired push-back time **(CE 2)** and a preferred departure trajectory **(CE 4)**.

0730 Using DSTs for surface movement and departure planning, the ATSP at JFK determines and transmits to NAA888 the actual pushback time, departure runway, and an efficient taxi route to the departure runway **(CE 2)**. ATSP also grants NAA888 clearance to assume authority for free-flight departure routing after takeoff, up to the top-of-climb point **(CE 3)**.

Similarly, the ATSP at EWR determines and transmits to TCA123 the actual pushback time, departure runway, and an efficient taxi route to the departure runway **(CE 2)**. The ATSP also determines a departure trajectory that accommodates (to the extent possible) routes, fixes and speeds requested by the TCA123 flight crew **(CE 4)**, and transmits it to the FD via datalink.

0750 NAA888 and TCA123 depart their gates and taxi directly (and efficiently) to their respective departure runways; since the flight crews have received and acknowledged the entire taxi clearance via datalink **(CE 0)**, they do not need to stop along the taxiways for additional clearances. The flight crews of both aircraft monitor their taxi progress using a moving map display that includes taxi clearance guidance and the locations of other aircraft and ground vehicles on the airport surface. ATSP personnel at JFK and EWR monitor the aircraft's progress on the airport movement areas.

Terminal Departure

0800 NAA888 receives takeoff clearance from the ATSP. Its FMS has already determined a nominal user-preferred conflict-free climb trajectory, using up-to-date information on terminal area traffic and airspace constraints (including noise abatement procedures). The flight crew has reviewed this trajectory and decided to accept it without modification. NAA888 takes off, and its FMS then implements the nominal departure trajectory while a FD-based CD&R DST searches for potential traffic conflicts **(CE 3)**.

TCA123 takes off after receiving clearance from the ATSP. Immediately after takeoff, its FMS executes the user-influenced departure trajectory received from the ATSP before pushback **(CE 4)**.

0805 A FD-based CD&R DST alerts the NAA888 flight crew to a potential conflict with another departing aircraft. The ATSP has also been alerted to the potential conflict by their ATSP-based CD&R DST, and they monitor the situation closely. The CD&R DST onboard NAA888 provides a conflict avoidance advisory to the flight crew who review and then execute the suggested maneuver. After completion of the maneuver, NAA888 resumes its nominal departure trajectory.

The ATSP is alerted by their CD&R DST that a conflict is predicted to occur between the departing TCA123 and an arrival aircraft. Utilizing broadcast information on TCA123's states (position, velocity components, weight, equipage level, etc.) and nominal departure trajectory parameters, an ATSP-based DST plans a trajectory modification for TCA123; the resulting trajectory avoids the conflict and results in minimal deviation from the planned departure trajectory. The ATSP reviews and transmits the trajectory to TCA123 via datalink. The ATSP instructs TCA123 via voice to execute the trajectory modification just transmitted by datalink for conflict avoidance, and to then resume its nominal departure trajectory.

En Route

0825 TCA123 and NAA888 approach their top-of-climb points and prepare to begin cruise flight.

NAA888 is contacted by the ATSP and cleared to "proceed present position, autonomous mode, direct SFO." Upon reaching the initial cruise altitude, the flight crew of NAA888 use the FMS to execute the nominal free flight trajectory determined by the NorthAm AOC during pre-flight planning; a FD-based CD&R DST continues to search for conflicts with local traffic.

After leveling off at the initial cruise altitude, the flight crew of TCA123 use the FMS to execute the nominal user-preferred trajectory approved by the ATSP during pre-flight planning.

0845 A FD-based CD&R DST alerts the flight crew of NAA888 to a potential conflict predicted to occur 17 minutes later. The “intruder” is identified as Global Airways flight GLA234, a Boeing 797 equipped for autonomous operation, whose crew has also been alerted by their own FD-based CD&R DST. An ATSP-based CD&R DST has alerted controllers who monitor the situation, but do not intervene because the time-to-conflict is greater than the threshold for intervention, and both aircraft are operating in an autonomous mode. Flight rules governing this particular encounter dictate that the two fully equipped aircraft share the conflict resolution maneuver. The CD&R DST aboard NAA888 generates a trajectory modification that provides half of the required resolution maneuver. The NAA888 flight crew reviews and executes the maneuver, and immediately thereafter the datalink broadcast message is automatically updated with the new trajectory information, including intent **(CE 5a)**. Fifteen seconds later, the NAA888 flight crew observe that the intent message broadcast from GLA234 indicates a new trajectory that accounts for the remainder of the resolution maneuver. The NAA888 CD&R DST verifies through aircraft state information received via datalink that GLA234 is tracking its broadcast trajectory, and the conflict alert ceases.

An ATSP-based CD&R DST predicts a potential conflict, predicted to occur 12 minutes later, between TCA123 and the minimally-equipped Econo Airlines flight ENA789. The ATSP contacts the flight crews of both aircraft to inform them of the predicted conflict and to request their trajectory deviation preferences for conflict resolution. Since ENA789 has been experiencing some air turbulence, the flight crew declare a preference to climb to a higher altitude (the flight crew of TCA123 also convey their preference to the ATSP). Using their CD&R DST, the ATSP determines that the altitude change requested by ENA789 would resolve the conflict, and authorizes ENA789 to climb to the requested altitude. TCA123 proceeds without any trajectory deviation.

0930 Updated weather information now available **(CE 0)** indicates that a region of strong headwinds lies approximately 150 miles ahead of NAA888. The NorthAm flight crew use a FD-based flight planning DST to design a trajectory deviation that diverts the aircraft away from the region of strong headwinds, while conforming to local TFM constraints. Upon execution of the trajectory by the flight crew, the FMS changes the aircraft’s course to follow the new trajectory, while a FD-based CD&R DST continues to search for potential traffic conflicts. Since NAA888 has been cleared to operate in autonomous mode, the flight crew does not need permission from the ATSP to alter course. The new flight intent information is included in the datalink message broadcast to the ATSP and other aircraft within broadcast range **(CE 5b)**.

Having also received the updated weather information **(CE 0)**, the TCA123 flight crew contact the TransCon AOC and request their input to plan a new trajectory that diverts the aircraft away from the predicted region of strong headwinds that lies along their current trajectory. Using a FD-based trajectory planning DST, the flight crew design a nominal conflict-free user-preferred deviation that avoids the region of strong headwinds, while conforming to local TFM constraints. The trajectory request is transmitted via datalink to the ATSP via datalink. The flight crew is confident of receiving approval, since an effort was made to anticipate ATSP constraints in the generation of the trajectory. The ATSP evaluates the request with the assistance of a trajectory planning DST. The nominal trajectory is found to meet all local TFM and traffic constraints, and the ATSP approves the request via datalink **(CE 6b)**. The TCA123 flight crew use the FMS to execute the new trajectory, while broadcasting an updated intent message via datalink.

1045 Updated traffic density/complexity data now available **(CE 0)** suggests that an airspace sector on the current route of NAA888 may “go red” within the next 30 minutes due to traffic congestion. If this trend continues, the ATSP will have to impose restrictions on traffic in the local airspace to keep their workload within acceptable limits. NAA888 is presently 25 minutes upstream of this airspace sector. The flight crew contact their AOC, who inform them that NAA888 is carrying a large number of passengers with connecting flights at San Francisco; therefore, an on-time arrival is a high priority. Working with their AOC, the NorthAm crew decides to take pre-emptive action by re-routing the flight **(CE 7)**. The crew uses the autonomous flight planning capability of the FMS to design a new trajectory with a small deviation and a corresponding speed increase that routes the aircraft away from the predicted region of congested airspace without changing the estimated time of arrival at SFO. After execution of the trajectory by the flight crew, the FMS changes the aircraft’s course to follow the new trajectory. Since NAA888 has been cleared to operate in autonomous mode, the flight crew does not need permission from the ATSP to alter course. The new flight intent information is included in the datalink message for broadcast to the ATSP and other aircraft within broadcast range. Meanwhile, a few other aircraft that were due to arrive in the same congested airspace at approximately the same time as NAA888 also take preemptive action for similar reasons.

The congested airspace also lies in the path of TCA123. However, the flight crew consult their AOC and decide not to take pre-emptive action, hoping that the deviations of other flights will ease the congestion and eliminate the necessity of an ATSP-imposed operational constraint.

1110 Although the preemptive actions of NAA888 and other flights have mitigated the extent of the airspace congestion/complexity, it is still predicted to exceed the ATSP’s threshold. Using datalink, the ATSP notifies TCA123 (and other affected users) of the predicted operational constraint and supplies data for user analysis of preferred solutions. Using trajectory planning DSTs the TCA123 flight crew and the TransCon AOC work together to plan a preferred deviation that satisfies all known local constraints. The proposed deviation is transmitted to the ATSP via datalink. The ATSP evaluates the proposed deviations of TCA123 and other affected aircraft in the area, and determines that the corresponding trajectories will result in airspace complexity measures that are within acceptable limits **(CE 7)**. The ATSP approves the proposed deviation of TCA123 (and other aircraft); the flight crew of TCA123 use their FMS to execute the trajectory deviation.

En Route / Terminal Arrival

1215 ATSP predicts that the arrival rate into San Francisco airport will temporarily exceed its runway capacity, resulting in metering of the arrival traffic flow at SFO between 1300 and 1330 (ET). At this time, NAA888 is approximately 300 miles away from its destination. Using datalink, the ATSP notifies the NorthAm AOC (and all other affected operators) of the metering constraint, and supplies relevant data for user analysis of preferences for arrival time, meter-fix and runway. NorthAm has a “bank” of several flights (including NAA888) arriving at SFO between 1300 and 1330 (ET). Due to the large number of connecting passengers on board NAA888, the NorthAm AOC decides to assign a high arrival priority to this flight relative to other NorthAm flights in the arrival bank. Using an arrival planning DST, the NorthAm AOC determines a set of desired arrival times as well as preferred meter-fixes and arrival runways for all flights in its arrival bank (implicit in this information is a preferred arrival sequence for all flights in the NorthAm arrival bank). All of these arrival preferences are transmitted to the ATSP via datalink.

Affected by similar arrival metering restrictions at San Jose airport, the TransCon AOC is notified of SJC metering constraints by the ATSP who also supplies relevant data for user analysis of preferences for arrival time, meter-fix and runway. Unlike NorthAm, TransCon does not have an arrival bank into SJC around the scheduled arrival time of TCA123, and consequently does not need to assign a relative priority to this flight. Using an arrival planning DST, the TransCon AOC determines a preferred meter-fix and arrival runway for TCA123, based on a desired arrival time equal to the scheduled time of arrival. All of these arrival preferences are transmitted to the ATSP via datalink.

The ATSP uses an arrival planning DST to analyze the arrival preferences submitted by NorthAM, TransCon and other operators, and to then formulate an arrival metering initiative that determines arrival sequences, meter-fixes and runway assignments, while accommodating user preferences to the maximum extent possible **(CE 8)**. Using datalink, the ATSP transmits information on arrival runways assignments and required times of arrival (RTAs) at assigned meter-fixes to NAA888, TCA123 and other users **(CE 0)**.

1235 TCA123 and NAA888 reach their top-of-descent points and begin their descent.

Terminal Arrival

1240 ATSP transmits updated RTAs (at the meter-fixes) to TCA123 and NAA888 as they continue their descent into the San Francisco Bay area.

1245 Shortly before entry into the Bay TRACON (terminal area), the NAA888 flight crew learns from updated information now available **(CE 0)**, that a localized system of scattered bad weather cells has moved into the terminal area. Some of these cells lie along their nominal descent trajectory. The flight crew of NAA888 request the ATSP for authority to free maneuver through the system of weather cells in the terminal area, while accepting responsibility for maintaining separation from local traffic **(CE 9)**; the ATSP grants clearance. The flight crew maneuver the aircraft around the more intense weather cells, while the FD-based CD&R DST searches for potential conflicts with aircraft in the vicinity. NAA888 then resumes its nominal descent trajectory to the final approach fix.

Some of the bad weather cells also lie along the nominal descent trajectory of TCA123, but the aircraft does not have the equipage to free maneuver around weather cells. Having determined that a deviation to the north of the weather cell system would minimize excess fuel burn (due to more favorable winds), the flight crew sends a preference for north deviation to the ATSP. The ATSP uses a trajectory planning DST to determine a nominal conflict-free weather avoidance descent trajectory that accommodates user preferences **(CE 10)**, and transmits it to the FD via datalink. The TCA123 flight crew execute the modified trajectory using the FMS.

1255 ATSP advises the flight crews of TCA123, NAA888 (and other flights) that despite low ceilings due to fog over the San Francisco Bay area, both SJC and SFO will continue to operate at near-visual rates with all arriving aircraft maintaining minimum IFR separation standards (no buffers). This is enabled by accurate merging/spacing capabilities provided by FD-based and/or ATSP-based DSTs.

As NAA888 nears an arrival merge point (where two or more arrival streams merge) for SFO, the ATSP advises the flight crew that it has been cleared to merge with another arrival stream and then maintain minimum IFR in-trail separation relative to another inbound NorthAm aircraft (NAA642) by performing self-spacing **(CE 11)**. Executing the appropriate procedures for self-spacing, the NAA888 flight crew merge with the other arrival stream behind NAA642, and follow it to the final approach fix.

Meanwhile, TCA123 (which is not equipped for self-spacing) is also nearing an arrival merge point for SJC. Utilizing broadcast information on TCA123's states (position, velocity components, weight, equipage level, etc.) and nominal trajectory parameters, an ATSP-based arrival-spacing DST plans a trajectory modification for TCA123; the resulting trajectory is nominally conflict-free and enables merging and spacing with minimum IFR in-trail separation **(CE 12)**. The

ATSP transmits the trajectory modification to the FD via datalink; the flight crew use the FMS to merge with another arrival stream and proceed to the final approach fix.

Terminal Approach

1300 NAA888 crosses its final approach fix at SFO. The flight crew use their CDTI on final approach to monitor separation with another aircraft flying an approach to a closely-spaced runway. The FD-based collision avoidance system sounds an alert and provides a collision avoidance advisory as the other aircraft begins to veer towards NAA888 on a collision course, due to confusion about which runway it was supposed to use **(CE 13)**. Before the NAA888 crew can react, the alert disappears as the “intruder” aircraft aborts its approach and executes a collision avoidance maneuver. NAA888 continues on its final approach and lands safely.

Surface Arrival

1305 Immediately after TCA123 and NAA888 land and exit the runways via high-speed taxiways, the ATSP transmits to each aircraft via datalink an efficient taxi routing to the assigned gate. The flight crews receive and acknowledge the clearance without stopping the aircraft, and proceed on their taxi routes unaffected by the near-zero visibility due to the morning fog covering the San Francisco Bay area **(CE 14)**. The flight crews of both aircraft monitor their taxi progress using a moving map display that includes taxi clearance guidance and the locations of other aircraft and ground vehicles on the airport surface. ATSP personnel at SFO and SJC monitor the aircraft’s progress on the airport movement areas.

1309 TCA123 and NAA888 arrive at their assigned gates within 1 minute of schedule.

4.5 Off-Nominal Considerations

The illustrative operational scenario presented in Section 4.4 applies to nominal conditions; it assumes, for instance, that there are no equipment failures, no major weather systems that disrupt operations by significantly reducing airspace and/or runway throughput, and no flight diversions to alternate airports. However, these and other considerations are important because off-nominal conditions, although infrequent, often drive procedures and system performance/certification requirements. Although not directly addressed in this document (version 1.0 of the DAG-TM Concept Definition), off-nominal conditions will be considered by the DAG-TM Team in future work.

5. CONCLUSION

A concept definition for Distributed Air/Ground Traffic Management (DAG-TM) has been prepared by a multi-disciplinary team formed by the Advanced Air Transportation Technologies (AATT) project office. The DAG-TM concept, characterized by distributed decision-making between the flight deck, ATSP and AOC, is a NAS operations concept that increases user efficiency/flexibility and system capacity.

This concept definition is written at a fairly high level of detail, with most of the specific functionality, related performance and required operational procedures to be defined by results from future research activities described in the DAG-TM Research Plan (Ref. 2). Changes and refinements to this DAG-TM Concept Definition will be reflected in updated versions of this document.

5.1 Cooperative Research Efforts

It is recognized that other efforts within several ATM research organizations, including the European community, offer a variety of approaches to free flight. A common understanding of the similarities and differences between these concepts and the DAG-TM concept will not only accelerate progress towards more efficient ATM system operations, but will be essential to the identification and resolution of issues related to global interoperability.

5.2 Recommendations

The DAG-TM Team offers the following recommendations:

- This DAG-TM concept definition should be evaluated as one potential extension of the various Free Flight implementation approaches currently under consideration.

- The research needed to investigate and evaluate this DAG-TM concept definition (including the operational procedures necessary to transition to various DAG-TM concept elements) should be assessed, prioritized and funded.

- An effort should be undertaken to explain this DAG-TM concept to the ATM research community and various advocate organizations.

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