DAG-TM Concept Element 11 Terminal Arrival: Self-Spacing for Merging and In-trail Separation

Operational Concept Description

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Prepared for

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Preface

This report was developed from the referenced documents available at the time of publication in order to conform to the required contents of an Operational Concept Description (OCD) as jointly defined by National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) Free Flight Project Office. The majority of the descriptive material has been taken directly from the referenced documents. Modifications have been made to add sections not in previous concept descriptions, to improve readability, and to reflect the most currently available information.

This approach to the development of this document was taken in order to remain faithful to the efforts that are presently being undertaken by the NASA Advanced Air Traffic Technologies (AATT) Project Office, the Tool Developers and the associated NASA AATT contractors.

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1. Scope

The Operational Concept Description (OCD) of Distributed Air Ground Traffic Management (DAG-TM) Concept Element (CE) 11 is intended to provide enough detail to form a basis for further research into the concept. It is not, however, a research plan. The research plan is a separate document being developed by NASA (Reference 1) which describes how the concept presented here will be investigated, and how statements presented here as hypotheses will be tested.

The OCD has a focus of operational and system requirements, and deliberately avoids design information to the extent possible. Specifications are omitted from this document, since capabilities to support the CE 11 concept should evolve as a result of the research to be conducted.

This OCD has the following objectives:

- It provides technical transfer and sharing of information within the NASA research community. It is intended to capture the current thinking of NASA researchers concerning the future ATM environments and capabilities that may be created by this concept.
- It is a guide for a planned program of research in this concept.

It is consistent with the overall Advanced Air Traffic Technologies (AATT) Operational Concept for Air Traffic Management (ATM) (Reference 2).

1.1 Identification

This document applies to the DAG-TM CE 11 entitled "Terminal Arrival: Self-Spacing for Merging and In-Trail Separation".

1.2 System Overview

Purpose: CE 11 will bring greater runway throughput and flight efficiency at busy terminal areas and runways by providing the capability for the flight crew (FC) to adhere to strategic clearances such as maintaining precise time-spacing with other aircraft.

General Nature of the System: The general idea behind the concept is that implementing a distributed control system, possibly involving integrating the Flight Management System (FMS) and Cockpit Display of Traffic Information (CDTI) avionics with the Air Traffic Management (ATM) system, would enable the FC to provide tighter control of the merging and spacing processes. The excess spacing buffers that exist between consecutive aircraft during approach could be reduced. This spacing buffer reduction could increase runway throughput. In addition, voice communications between the FC and the controller should be reduced which may permit additional throughput at busy airports.

This concept is based on the general hypothesis that enabling distributed approach control conducted by the individual participating FCs would provide greater flight efficiency and other benefits and would be more cost effective than providing the air traffic service provider (ATSP) with more automation tools to pursue the same benefits. Future research experiments are to be conducted to prove or disprove this hypothesis.

History of System Development, Operation, and Maintenance: The DAG-TM concept describes potential modes of operation within the Free Flight concept defined by the RTCA Task Force 3 (Reference 3). The goal of DAG-TM is to enhance user flexibility and efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the National Airspace System (NAS).

To explore the DAG-TM concept, the AATT Project formed a DAG-TM Team that met during 1999 and developed a Concept Definition (Reference 4). This document defined 15 DAG-TM “concept elements”, covering ATM operations in all phases of flight. The defined phases were:

- Gate-to-Gate (information access and exchange)
- Pre-Flight Planning
- Surface Departure
- Terminal Departure
- En Route
- Terminal Arrival
- Terminal Approach
- Surface Arrival

In 2000, the AATT Project selected an initial set of four concept elements (CEs) to pursue further concept exploration (research) activities.

- CE-5: En Route Free Maneuvering
- CE-6: En Route Trajectory Negotiation
- CE-7: En Route: Collaboration for Mitigating Local TFM Constraints due to Weather, Special Use Airspace (SUA), and Complexity
- CE 11: Terminal Arrival: Self-Spacing for Merging and In-Trail Separation

In May 2000, a DAG-TM workshop was held at the NASA Ames Research Center to explain to industry the AATT Project’s activities and plans for the concept. The workshop focus was on the four initial CEs being developed. Under NASA Research Announcement Research Task Order 41, a contractor team consisting of System Resources Corporation (now Titan Systems Corporation) and Seagull Technology prepared a detailed description of DAG-TM CE 11 (Reference 5). This OCD document represents an updating and additions to that original description document.

Project Sponsor, Acquirer, User, Developer, and Maintenance Organizations: The NASA AATT Project is the sponsor of DAG-TM CE 11; the developers are the NASA Ames Research Center and the Langley Research Center. At the present time, there is no acquirer, user, or maintenance organization.

Current and Planned Operating Sites: There are no current or planned operating sites.

Other Relevant Documents: Documents relevant to the DAG-TM CE 11 concept are found in Section 2.

1.3 Document Overview

The AATT NAS OCD (in preparation) documents current research and to provide concept guidance for all AATT projects. It was designed with the understanding that each project element would require a separate OCD of a subset or domain in the NAS in which a particular deficiency is addressed. This OCD is intended to provide guidance for DAG-TM CE 11 system requirements development, to address how DAG-TM CE 11 fits into the overall NAS, and to provide a means to help transfer this technology to the FAA.

This document is organized according to a format based on the IEEE J-STD-16-1995 standard. Descriptions of the OCD sections follow.

Section 1. Scope: This section contains a full identification of the system to which this OCD applies. It briefly states the purpose of the system; describes the general nature of the system; summarizes the history of system development, operation, and maintenance; identifies the project sponsor, acquirer, user, developer, and maintenance organizations; identifies current and planned operating sites; summarizes the purpose and contents of this document; describes any security or privacy protection considerations associated with its use; and lists other relevant documents.

Section 2. Referenced Documents: This section lists the number, title, version, date, and source of all documents referenced in this OCD.

Section 3. Current System/Situation: This section describes the background, mission, objectives, and scope of the current system/situation including applicable operational policies and constraints and a description of the current system/situation. The description includes, as applicable:

- The operational environment and its characteristics
- Major system components and the interconnections between these components
- Interfaces to external systems or procedures
- Capabilities/functions of the current system
- Charts and accompanying descriptions depicting input, output, data flow, and manual and automated processes
- Performance characteristics, such as speed, throughput, volume, and frequency
- Quality attributes, such as reliability, maintainability, availability, flexibility, portability, usability, and efficiency
- Provisions for safety, security, privacy protection, and continuity of operations in emergencies

In addition, a description of the types of users or personnel involved in the current system is included. This section also provides an overview of the support strategy for the current system.

Section 4. Justification for and Nature of Change: This section describes new or modified aspects of user needs, threats, missions, objectives, environments, interfaces, personnel, or other factors that require a new or modified system. It summarizes deficiencies or limitations in the current system that make it unable to respond to these factors. All new or modified capabilities/functions, processes, interfaces, or other changes needed to respond to these factors are summarized in this section. In addition, this section identifies priorities among the needed changes; changes considered but not included; the rationale for not including them; and, any assumptions and constraints applicable to the identified changes.

Section 5. Concept for a New or Modified System: This section describes the background, mission or objectives, and scope of the new or modified system and any applicable operational policies and constraints and a description of the new or modified system. The description includes, as applicable:

- The operational environment and its characteristics
- Major system components and the interconnections between these components
- Interfaces to external systems or procedures
- Capabilities/functions of the new or modified system
- Charts and accompanying descriptions depicting input, output, data flow, and manual and automated processes
- Performance characteristics, such as speed, throughput, volume, and frequency
- Quality attributes, such as reliability, maintainability, availability, flexibility, portability, usability, and efficiency
- Provisions for safety, security, privacy protection, and continuity of operations in emergencies

In addition, a description of the types of users or personnel involved in the new or modified system is included. This section also provides an overview of the support strategy for the new or modified system.

Section 6. Operational Scenarios: This section describes one or more operational scenarios that illustrate the role of the new or modified system, its interaction with users, its interface to other systems, and all states or modes identified for the system.

Section 7. Summary of Impacts: This section describes anticipated operational, organizational, and development impacts on the user, acquirer, developer, and maintenance organizations.

Section 8. Analysis of the Proposed System: This section provides a qualitative and quantitative summary of the advantages, disadvantages, and/or limitations of the new or modified system. Major system alternatives, the tradeoffs among them, and rationale for the decisions reached are also provided.

Section 9. Notes: This section contains general information that will aid the reader's understanding of this OCD. It includes an alphabetical listing of all acronyms and abbreviations and their meanings as used in this document, and a list of terms and definitions.

2. Referenced Documents

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21. Swedish, W. J., “Evaluation of the Potential for Reduced Longitudinal Spacing on Final Approach,” Rep. No. FAA-EM-79-7, Aug. 1979.

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3. Current System/Situation

3.1 Background, Objectives, and Scope

In current terminal air traffic control, the TRACON controller is responsible for merging streams of arriving aircraft and putting them on one or more final approaches in the appropriate sequence and properly spaced. The TRACON controller accepts handoffs from en route control and provides the necessary clearances to the Flight Deck via voice communications. The controller's objective is to ensure proper separation is maintained and that all arrival slots are filled whenever there is sufficient demand. Control of the aircraft is transferred to the tower controller who clears the aircraft to land.

3.2 Operational Policies and Constraints

The operational policies and constraints relevant to the present traffic management system are contained in References 6 and7:

- *FAA Order 7210.3S, Facility Operation and Administration*; February 21, 2002; Part 3, Terminal Air Traffic Control Facilities is particularly relevant to this OCD.
- *FAA Order 7110.65N, Air Traffic Control*; February 21, 2002; Chapter 3 – Air Traffic Control - Terminal also contains material that describes the operations of the existing terminal air traffic control system.

3.3 Description of Current System or Situation

As stated in Reference 4, the problem addressed by CE 11 is:

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 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.

Thus, a primary problem that CE 11 services resolves is reducing excessive spacing buffers and spacing gaps between consecutive aircraft during the approach-to-landing phase of flight. Alternately, this problem can be stated as:

Determine what information, systems, and procedures need to be provided to the FC to reduce the amount of excess spacing buffers and inefficient spacing gaps between successive aircraft in order to improve the runway throughput.

Another problem is the need to evolve away from using rigid, fixed routes within the terminal airspace so that aircraft can have the flexibility to maneuver to maintain precise control on inter-aircraft arrival spacing and to maneuver around storm cells while still using ATSP information to provide efficient traffic flow. Here the issue is to determine how to merge and separate while simultaneously each aircraft is using its FMS in conjunction with the ATSP information to determine individual optimum paths to the FAF.

3.4 Users or Involved Personnel

In this section the focus is on the roles and responsibilities of each of the active participants in the present environment or situation. Users and involved personnel are identified in Table 1. Subsections address the roles and responsibilities of the ATSP, the pilot, and the AOC respectively.

Table 1. Users/Involved Personnel for Current Operations

Users or Involved Personnel	Current Operations
Traffic Management Specialist at ATSCSS	
Air Traffic Control Supervisor (ATCS)	
Supervisory Traffic Management Coordinator-in-Charge (STMCIC)	
Operations Supervisors (OS)	
Traffic Management Coordinator (TMC)	
En Route Radar Position – R controller	
En Route Radar Associate (RA) – D controller	
En Route Radar Coordinator (RC)	
En Route Radar Flight Data (FD) Position	✓
En Route Non Radar (NR) Position	
Terminal Radar Position – R controller	✓
Terminal Radar Associate (RA) – D controller	✓
Terminal Radar Coordinator (RC)	✓
Terminal Radar Flight Data (FD) Position	
Terminal Non Radar (NR) Position	
Tower Local Controller (LC)	✓
Tower Ground Controller (GC)	✓
Tower Associate	
Tower Coordinator	
Tower Flight Data Position	
Tower Clearance Delivery Position	
Flight Service Station Specialist (FSSS)	
Airline or Aircraft Flight Operations Center (AOC)	✓
Pilot or Flight Crew (FC)	✓

<u>ATSP Roles and Responsibilities:</u> The air traffic controller sends the following four types of messages to aircraft:

- Clearance. This is a required maneuver for separation, e.g., move to new altitude, new heading.
- ATC instruction. Similar to a clearance but more urgent, e.g., “go around”, “turn left to [new heading]”.
- Advisory. Provides a flight crew with awareness of traffic, weather, turbulence, etc.
- Traffic management directive. Informs flight crew of restricted airspace or RTA assignment.

<u>Pilot Roles and Responsibilities:</u> The IFR aircraft pilot has responsibility for situation awareness flight planning/replanning and execution, and adherence to clearances/instructions issued by the ATSP.

<u>AOC Roles and Responsibilities:</u> The AOC dispatcher has the responsibility for scheduling company aircraft and for filing flight plans and amendments that are cooperatively developed with the pilot of the aircraft in question.

3.5 Support Strategy

To be determined

4. Justification for and Nature of Change

4.1 Justification for Change

The justification for change from the system as it operates today consists primarily of the potential benefits that can be realized by DAG-TM CE 11.

- 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 reduced need for close monitoring and communication with the flight crews of appropriately equipped aircraft.

4.2 Description of Needed Changes

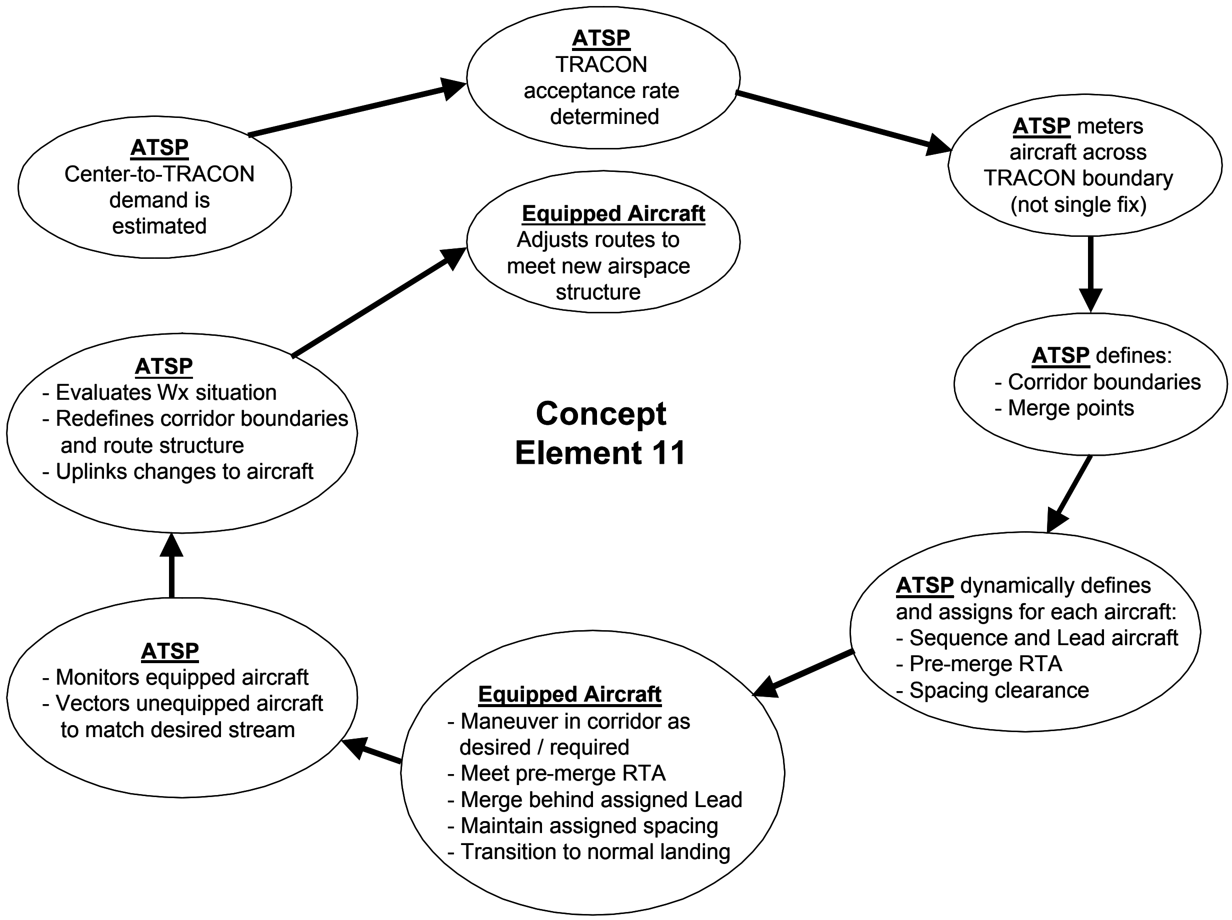
In VMC, aircraft are often able to maintain closer spacing during the terminal approach phase of flight, thereby increasing the capacity of the terminal area and the runway acceptance rate. In the current system, the FCs are often requested to accept responsibility for visual self-separation once they acknowledge they can see the immediately leading aircraft. In this situation, the FC is responsible for determining and then maintaining a safe separation from the immediate Lead aircraft, and is therefore not subject to the ATSP's minimum separation requirements. CE 11 addresses providing similar spacing during IMC via clearances, procedures, and tools to enable precision spacing and threshold crossing.

Figure 1 is a bubble chart of the different aspects of CE 11. It shows the conceptual sequential roles of the ATSP and FC (for properly equipped aircraft) in using both ground system and flight deck technology to improve the approach phase of flight, beginning outside of the Terminal Radar Control Facility (TRACON) and ending at the Final Approach Fix (FAF). Note that the ATSP continues to have extensive involvement in this concept in defining and managing the traffic approach scenario and in conducting the ATSP procedures that enable this concept to work. The roles and responsibilities of ATSP and FC are discussed further in Section 5.4.

Procedures and tools will enable the FCs of equipped aircraft to merge autonomously with another arrival stream and/or maintain in-trail separation relative to a designated Lead aircraft under IMC as they would under VMC, thus potentially increasing arrival throughput. In this investigation, self-merging and spacing applies to aircraft that are subject to spacing requirements during arrival, extending from the terminal area feeder fix (FF) or TRACON boundary to the FAF.

Anticipated procedures for self-merging and spacing involve the ATSP issuing clearances to FCs of properly equipped aircraft for delegated separation tasks while retaining responsibility for separating these aircraft from crossing, non-equipped, and possibly all aircraft. Once the FC receives clearance to merge and maintain spacing relative to a designated Lead aircraft, the FC establishes and maintains a relative position of their aircraft with frequent monitoring and speed/course adjustments.

Figure 1. Sequential Stages of the CE 11 Processes



Under some conditions, information such as Required Time of Arrival (RTA) at the FAF 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. Similarly, RTAs may be used at each traffic stream merge point so that aircraft FMS guidance generates trajectories that are smoothly merged by meeting the associated RTAs.

Self-merging and spacing will make use of datalink capabilities to provide traffic position information. The CDTI and/or advanced flight director/heads up display (HUD) will provide guidance technology as the source of spatial and temporal situation awareness to the FC. Cues within the traffic display will provide information to the FC to enable either manual merging followed by station-keeping or monitoring of automatic 4D trajectory management by the FMS.

4.3 Priorities Among the Changes

The basic change that results from DAG-TM CE 11 is to allow appropriately equipped aircraft to accept the responsibility for self merging/spacing and as such, priorities among the changes is not applicable in this OCD.

4.4 Changes Considered But Not Included

Alternatives have been identified that may have merit in terms of future research that can be conducted. These ideas are briefly mentioned here.

Moving Slots: As an alternative to following the Lead aircraft directly, each FC could instead be displayed an ideal moving slot to stay within, where that slot may be tied to the Lead aircraft or it may be within a stream of slots generated by the DST. The ATSP monitors all aircraft to ensure adequate separation and compliance with the established procedure. For cases where the FC fails to maintain adequate spacing, automated systems or the ATSP will provide a required correction.

The ATSP DST would compute an ideal stream of moving slots and uplink these slots to the aircraft to be displayed on the CDTI. Each FC sees its assigned slot and the slot of the immediate Lead aircraft. In this case, there remains the ideal separation between each aircraft in the stream, but a following aircraft is not as subject to the small variations in the speed and position of the preceding Lead aircraft, as the Lead also is working to remain within its assigned slot.

A mechanization requirement would be that the DST computes and uplinks the desired position and velocity of all aircraft in the string in the form of a train of moving slots. Then, the job of the CDTI would be to display that slot for the FC to capture and track. This could be largely de-coupled from the immediate Lead trajectory, and the FC would focus not on the position relative to the Lead but the position relative to the assigned slot. In this latter case, the ATSP monitors the position of each aircraft relative to the ideal slot position. The controller takes action to vector an aircraft only if it moves to far outside of the assigned slot.

Within this latter environment, the trailing aircraft can either track a moving position tied to the trajectory of the immediate leading Lead aircraft, or it can track an ideal moving slot computed and uplinked by the DST. In the latter case, the string of moving slots is anchored to the trajectory of the String Leader aircraft.

Merging: There are three alternate ways in which the Own aircraft may be guided before it merges behind the assigned Lead aircraft:

- It may be given a “ghost” image of the Lead aircraft as computed and projected on Own’s structured route before the merge point.
- It may be given an RTA at the merge point that is computed based upon the Lead aircraft crossing that point at the appropriate time separation in front of the RTA.
- It may be given a moving slot to capture and track that blends into the track containing the Lead tracking its assigned slot.

4.5 Assumptions and Constraints

This problem description includes a number of inherent assumptions that need to be verified by experimental research. These assumptions include:

- After applying ATSP DSTs to controlling the terminal area approach traffic, there remain significant excess spacing buffers between consecutive aircraft that warrant investigation into methods of further reduction – including FC participation in spacing reduction via enhanced flight deck technology.

· Within the TRACON airspace, the common route segments used by approaching aircraft are of sufficient lengths to allow the FC's to capture and maintain specified spacing at a net reduction in overall ATSP and FC workload.

· ATSP and FC personnel will accept the CE 11 concept as operationally viable and aircraft operators will accept the concept as economically beneficial, given that (a) responsibility for longitudinal spacing between consecutive aircraft will be turned over to the FC's, and (b) this concept is shown to be technically feasible.

This section describes other assumed operational conditions under which CE 11 will be applied. The operational environment includes the airspace structure, routes within this structure, and their constraints; the mix of aircraft types, their equipment, and performance limits; the weather and visibility conditions; the Communications, Navigation, and Surveillance (CNS) infrastructure within the airspace that enable connecting the FC with ATSP; and the ATM capabilities environment. Each of these elements is discussed from the point of view of representing the range of environments that need to be considered.

Airspace Structure and Route Constraints: The CE 11 operating airspace environment consists of the approach sectors, areas, or "zones" within the TRACON ranging from the entry feeder fixes at the TRACON boundary, and the boundary itself, to the final approach fixes and possibly to the runway thresholds.

Within the design of the airspace for CE 11, assumptions are made regarding the nature of the structure:

· There may be separate routes and entry points for slower aircraft, such as turboprops. These routes would be merged with those of the faster aircraft at waypoints close to the FAF.

· Runway closure and re-configuration because of wind shifts are rare-nominal cases that are dealt with at later stages of the research.

Traffic Mix and Equipage: It is assumed that some, but not all, aircraft in the CE 11 scenarios will be equipped with traffic displays with common information and spacing cues presented to the flight crews. Those aircraft without CDTI equipment will be vectored and cleared manually by the controller, as is done today. Two parameters that will affect the use of and operational procedures for the CDTI during approach are the variations in: (a) the types of aircraft within the approach; and (b) the avionics equipment (datalink and FMS/CDTI capability) that is on the aircraft.

Another aircraft type factor is the different type-dependent nominal separations that are used to maintain safety due to wake vortex considerations. These nominal separations are usually defined in spatial terms at the point where the Lead aircraft crosses the runway threshold, and they are a function of the weight of the aircraft – light, large, or heavy. For CE 11 purposes, these nominal separations are converted to time separations and projected back to the FAF.

- The approach airspace can be used by air carrier, air taxi, corporate, military, and private aircraft, each of which will have FCs with different levels of experience and proficiency. This will affect how well a given pilot maintains the desired spacing with respect to the Lead aircraft in a string. This is largely a function of training, flight currency, and motivation on the part of the different FCs to maintain tight separation tolerances.
- It is assumed that a certain minimum set of avionics equipment is required for an aircraft FC to participate in the modes of flight of CE 11. Candidate equipment or capability includes:

- A suitable traffic display with appropriate cues to allow the FC to guide the aircraft during free maneuvering, merging, and in-trail spacing.
- A navigation system with required navigation performance (RNP) rating that supports: (a) broadcast of aircraft state with sufficient accuracy to support the traffic display requirements; and (b) adequate adherence to the intended route to provide safe separation assurance.
- An ability to sense accurately the state of adjacent traffic and the designated Lead aircraft. This may be via ADS-B, existing Threat Alert and Collision Avoidance System (TCAS) mechanization, or Traffic Information Services – Broadcast (TIS-B).
- An autonomous operations planner (AOP) that the FC can use to organize and manage the modes of CE 11. The AOP is considered an extension and enhancement to the FMS. Although elements of the AOP may support operations in other phases of flight, the requirements imposed by those other phases of flight are not considered as a minimum capability for the AOP to support CE 11.
- A two-way datalink may be required, depending upon on how much data the ground side needs for situation awareness and monitoring. This may also be used for data exchange between Lead and following aircraft.
- Aircraft that don't have some (to be defined) minimum capabilities cannot participate actively in CE 11 processes. Such aircraft are termed "unequipped", and they could represent targets that could serve as Lead (if minimally equipped to broadcast their state data).

  - The equipped aircraft may have the FMS with longitudinal autopilot/ autothrottle so that relative spacing can be automatically maintained after the Lead aircraft has been designated. However, each aircraft can also be flown manually where the pilot uses the CDTI to help control airspeed and relative spacing to the designated Lead aircraft.

CNS Infrastructure: It is assumed that the aircraft states are accurately measured (via Global Positioning System (GPS) Wide Area Augmentation System (WAAS)) and available to each flight deck and ground ATSP through some suitable form of data exchange (e.g., TIS-B) or surveillance (e.g., ADS-B). The FMS will use this information for precise guidance, and to compute state and intent messages for ADS-B. Aircraft without FMS will be assumed to have area navigation (RNAV) to follow routes defined by sequences of waypoints. Aircraft without autopilot or autothrottle will have the CDTI to aid the FC to capture and track the desired spacing relative to the Lead aircraft.

Furthermore, it is assumed that digital datalink is available to send digital clearances, controller advisories, flight information, graphical information concerning weather cells and zone boundaries, and adjacent traffic states to the flight deck. It is also assumed that each aircraft can be flown manually or automatically via FMS autopilot / autothrottle.

Voice clearances for merging and in-trail spacing represents viable means for the ATSP to clear the FC to enact use the CE 11 modes. Also, each aircraft FC could have a standard speed profile per aircraft type that is automatically followed if the aircraft is the string leader. Alternatively, the ATSP DST may be able to uplink necessary information to define the desired profile for a Lead aircraft that defines the beginning of a string.

ATM Environment: Three different ATM environments exist in which CE 11 merging and spacing modes may take place:

- No special DSTs beyond today's environment are used (e.g., such as being tested by the Safe Flight 21 Cargo Airline Association Operational Evaluation of ADS-B for approach spacing). Here, the controller/ATSP determines the desired string position of each approaching aircraft. The controller advises the pilot which aircraft is the immediate Lead, the controller clears the pilot to maintain a certain time-spacing relative to the Lead, and the pilot uses the CDTI to help aid capture and tracking of a specific spacing relative to that aircraft.
- Special non-CTAS (Center TRACON Automation System) TRACONS where the ATSP provides information and capability that facilitates use of airborne equipment for merging and spacing by the aircraft and monitoring of the process by the controller.
- Extension of CTAS Active Final Approach Spacing Tool (FAST) (or equivalent DST) where the desired approach trajectory (including waypoints of where to decelerate and where to turn) is communicated to at least the first aircraft in the string. This ensures that the reference speed profile for starting each string is efficient. The DST would also be extended to allow the controller to monitor the progress of aircraft in the string to ensure compliance with the planned arrival schedule. Furthermore, the DST would be used to determine the positions of aircraft on merging routes, possibly compute the ghost positions of these aircraft as projected onto other routes (as a function of range to go to the next merge point), and provide the uplink message to communicate these positions to the flight deck/CDTI.

5. Concept for a New or Modified System

5.1 Background, Objectives, and Scope

In pursuit of CE 11, it is important to review the research, development, and testing that have previously been conducted relative to use of CDTI and related technology developments such as Threat Alert and Collision Avoidance System (TCAS) and ADS-B. This is so that: (a) previously well established technical results can be factored into defining the flight deck avionics requirements; and (b) documented previous research is not repeated. A bibliography of this previous work is presented in Section 2. The following summarizes the review findings.

Pre-1990 CDTI Research: The CTDI concept has been suggested and studied since sometime in the 1940's (Reference 8). Airborne station-keeping equipment has been employed successfully by the military services for many years to maintain safe air-to-air separation in formation flying.

CDTI studies were pursued in the 1970's and 1980's by NASA to investigate potential applications that could increase airport capacity, reduce controller stress and workload, and enhance safety of flight. These studies used simulations of the TCAS, Mode S radar, and other datalink systems to provide a prototype CDTI. Based on these studies, traffic displays were postulated and tested under simulated traffic conditions. In particular, strings of aircraft on approach to landing were set up with pilot instructions to establish and maintain specified spacing by using the CDTI for spacing cues. Pilots and controllers participated in these tests, and much was accomplished in understanding the relative vehicle dynamics, the human factors of traffic displays, and the potential of CDTI to provide throughput benefits. The studies also revealed potential problems such as increased pilot and controller workload and possibilities of traffic flow instability, secondary conflicts, and pilot distraction (References 8 -24).

Installation of TCAS II began about 1990 for the large air carriers. The requirement to carry and use a TCAS II was extended to cover all aircraft carrying more than 30 passengers. Later, aircraft carrying 10-30 passengers were required to carry the TCAS I. In all cases, installations have included some form of traffic display. Thus, via the TCAS program, the inclusion of a cockpit display of adjacent traffic became a reality.

Three elements of the TCAS or other traffic display design are of importance to the CDTI applications:

- Surveillance – The accuracy, reliability, and volume of spatial coverage of the surveillance and the associated accuracy of the tracking algorithm govern to what extent TCAS/CDTI can be used for merging and spacing applications. The TCAS II surveillance system design was primarily the results of initial work performed at MIT Lincoln Laboratory.
- Logic design – This is the conflict detection and resolution (CD&R) logic used to determine which aircraft to display or to indicate which aircraft may pose a threat. This must be interfaced with merging and spacing cues for other CDTI applications. The TCAS II threat detection and collision avoidance logic was primarily developed by the Mitre Corporation. Seven revisions of this software design have been released to the TCAS manufacturers.

- Pilot interface – The human factors aspects of the display and other interface mechanisms used by the pilot are critical for adapting the system to merging and spacing. The TCAS II display design format and other aspects of the flight crew interface were investigated and perfected at both NASA Ames and Langley Research Centers.

During the 1980-1984 time period, NASA Ames and Langley Research Centers both sponsored analytical studies and conducted a series of cockpit simulator experiments to determine:

- What were the important elements that allowed pilots to use the CDTI for in-trail following?
- How could the CDTI be mechanized?
- What benefits might be realized from CDTI implementation?

At least six different cockpit simulator studies of multiple following aircraft in approach strings were made at NASA Langley and Ames to produce data to analyze in-trail dynamics to address these questions.

Post-1990 CDTI Developments: After TCAS was mandated for commercial air carriers, and TCAS I and TCAS II systems with their traffic displays became commonplace, pilots soon began to use these displays for “unofficial” purposes other than collision avoidance. The traffic display could help the pilot/flight crew with situational awareness of other traffic. Pilots started to use the display for in-trail following when cleared for unconstrained transcontinental routes. It became apparent that the TCAS/CDTI would provide many useful applications and that these applications should be identified, documented, and standardized so that operational use could be orderly. These applications have been pursued by the activity of the RTCA SC 186 and SAE G10 committees.

The first “official” use of the TCAS/CDTI for in-trail following control was for oceanic en route flight (Reference 22). Currently, the United States has authorized the use of the TCAS II traffic display for in-trail climb (ITC) and in-trail descent (ITD) procedures when following other aircraft on oceanic routes. The constraints of this operation are that the trailing aircraft FC must see the Lead aircraft on the traffic display and there must be enough initial separation so that the ITC or ITD can be completed without violating acceptable separation as the trailing aircraft passes through the Lead’s altitude. In an enhanced ITC and ITD procedure, the CDTI would provide flight identification, speed, altitude, and range information directly to the FC thereby reducing or eliminating coordination with the Lead aircraft (Reference 23, 24).

On-going CDTI Research and Development: Two on-going technical developments are further enabling the use of CDTI:

- The broadcast of automatic dependent surveillance (ADS-B) where the aircraft broadcasts its precise state and intent based typically on Global Positioning System (GPS) navigation data.

- The broadcast of traffic information service (TIS-B) where the ground radar system determines states of aircraft and broadcasts these to those adjacent aircraft as a supplement to ADS-B or TCAS.

The minimum aviation system performance standards (MASPS) for ADS-B describe nearly 80 potential applications of CDTI based on ADS-B information (Reference 23). These technologies have spurred activity by RTCA to define further acceptable applications, to develop requirements and operational procedures for these applications, and to develop and document minimum operating standards (MOPS) for the CDTI equipment (Reference 24).

Safe Flight 21 (SF21) is a current FAA sponsored cooperative government/industry effort to evaluate enhanced capabilities for Free Flight based on evolving communications, navigation, and surveillance (CNS) technologies (Reference 26). SF21 will demonstrate the cockpit display of traffic, weather, and terrain information for FCs and will provide improved information for controllers. Under SF21, a cooperative government/industry team is conducting a series of operational evaluations (OpEvals) of various ADS-B applications in conjunction with the Cargo Airline Association plans to equip their fleets with advanced TCAS/CDTI based upon ADS-B. In 1999, enhanced visual approaches and see-and-avoid enhancements were the subject of the OpEval conducted by 24 participating aircraft in the Ohio River Valley (Airborne Express facility at Wilmington, IL). This was preceded by extensive cockpit simulation studies conducted to prepare for the OpEval by Mitre (References 27, 28]. In 2000, the OpEval was continued to examine approach spacing concepts using Constant Range and Constant Time Delay spacing cue criteria at the United Parcel Service facility at Louisville airport.

The goal of Capstone, a related project under SF21, is to implement and test traffic, terrain, and weather display technologies on general aviation aircraft flying out of Bethel, Alaska. This project is pertinent in that it is bringing the benefits of the cockpit display technology to the low-end general aviation (GA) user.

Recent NASA and Mitre research has addressed the related use of ADS-B and CDTI to facilitate dual approaches to closely spaced parallel runways in instrument meteorological conditions (IMC) (References 29 - 33). The objective is to maintain throughput and capacity as under visual conditions (VMC). Here the CDTI is used by the trailing aircraft to maintain a constrained longitudinal spacing relative to the Lead aircraft approaching the parallel runway. The concept is to provide adequate separation for both wake avoidance and blunder protection/collision avoidance purposes.

Initial Concept of CDTI within DAG-TM: DAG-TM is based upon the Free Flight premise that the pilot/FC can be more actively engaged in the problem of air traffic management which will provide cost-effective benefits that cannot be matched by implementing more sophisticated ground control. This inherently assumes that the FC has good situational awareness of the surrounding traffic and can use that information to conduct the processes of self separation with respect to interacting trajectories such as crossing paths, overtaking, merging, and station-keeping. This awareness is aided by the CDTI and the various cues presented to the FC on that display. Thus, the CDTI becomes a vital link between the FC, the FMS, digital datalink, collaborative maneuvering with other aircraft, and collaborative decision making with the ATM controller/ATSP and the airline operations control (AOC)/dispatcher.

5.2 Operational Policies and Constraints

The operational policies and constraints relevant to the present traffic management system are contained in References 6 and 7:

- *FAA Order 7210.3S, Facility Operation and Administration*; February 21, 2002; Part 3, Terminal Air Traffic Control Facilities is particularly relevant to this OCD.
- *FAA Order 7110.65N, Air Traffic Control*; February 21, 2002; Chapter 3 – Air Traffic Control - Terminal also contains material that describes the operations of the existing terminal air traffic control system.

These operational policies and constraints will have to be modified to accommodate the modes of CE 11 operation that are described in the following paragraphs. Specifically, the modes of operation that require modification to existing operational policies and constraints are:

- Free Maneuvering Mode
- Merging Mode
- In-trail Spacing Mode

Each of these modes is described in detail in the paragraph entitled "Operational View" below.

5.3 Description of the New or Modified System

A basic premise of CE 11 is that a designated “string leader” aircraft follows a desired speed profile from TRACON entry to the FAF or threshold. The next arriving aircraft is cleared by ATM to merge behind the immediate Lead and then to self-space according to some accepted spacing criterion. This second aircraft then becomes the Lead aircraft for the next (third) arrival aircraft in the string, etc. Various specified spacing gaps are used to account for different wake vortex spacing constraints based upon aircraft type, and allowances for departing aircraft on the runway. Also, natural spacing gaps will occur because of the distribution of arrival aircraft over time. Thus, there will be need to re-start the strings from time to time.

The desired spacing of the aircraft behind the designated Lead may be based upon one of the following cues:

- Speed targets on the airspace indicator.
- History trail of the Lead (e.g., where the Lead was 90 seconds ago).
- Constant-time predictor with acceleration cue (e.g., where the CDTI-equipped aircraft will be 90 seconds from now).

ATSP View: It is assumed that the ATSP/DST determines the desired sequence and spacing of arrival aircraft and this information is provided to the flight crew by voice or datalink. The FC maintains these sequence and spacing until the aircraft crosses the designated end point. The ATSP maintains responsibility of protecting the arrival aircraft from other aircraft and of monitoring the performance of each aircraft along the string to ensure that each aircraft maintains safe separation limits.

The primary roles of the ATSP are indicated in Figure 1 in Section 4.2. These include the following activity:

- Calculate and communicate the assigned separation (spacing) time with respect to the designated Lead for each participating aircraft.
- Estimate and possibly uplink trajectory predictions of non-FMS, non-state broadcast equipped aircraft as needed.
- Provide separation assurance between all aircraft, including streams and for non-participating aircraft.
- Monitor the arrival merging, flow rate, and conformance to the assigned spacing time.
- Using some kind of alerting mechanism, advise participating aircraft of predicted deviations from the designated separation value.
- Provide means to terminate the CE 11 process because of abnormal situations such as airport closure, equipment failure, or pilot request for route deviation.

Pilot View: For the in-trail spacing mode, it is assumed that the succession of Own aircraft are positioned such that their FCs can quickly capture and maintain spacing relative to the designated Lead aircraft.

For the merging mode, it is assumed that each equipped aircraft is positioned and is given necessary information to merge behind the designated Lead or Lead Ghost.

For the free maneuvering mode, it is assumed that each aircraft FMS or FC guides the aircraft along the desired path. Own either: (a) merges and spaces with a Lead Ghost projected onto this path; or (b) uses an RTA to control speed to arrive at the next merge point at a time that is consistent with merging with the Lead aircraft arriving on the other route.

Operational View: For the purposes of addressing the phases of flight being considered within CE 11, the flight approach process is divided into three operational modes mentioned above. The CE11 concept involves the simultaneous application of these modes – they overlap and interact, and it's the integration of these three modes that provides the overall benefits. The In-Trail Spacing mode is used to fine-tune the spacing, while keeping throttle movements small and adhering to a nominal deceleration schedule. The Merging Mode is performed simultaneously with the other two to handle merging streams. If done right, it might be simply a monitoring task requiring only minor adjustments. The Free Maneuvering Mode is used by the flight crew to make gross adjustments to achieve the assigned spacing, leaving the throttles essentially alone.

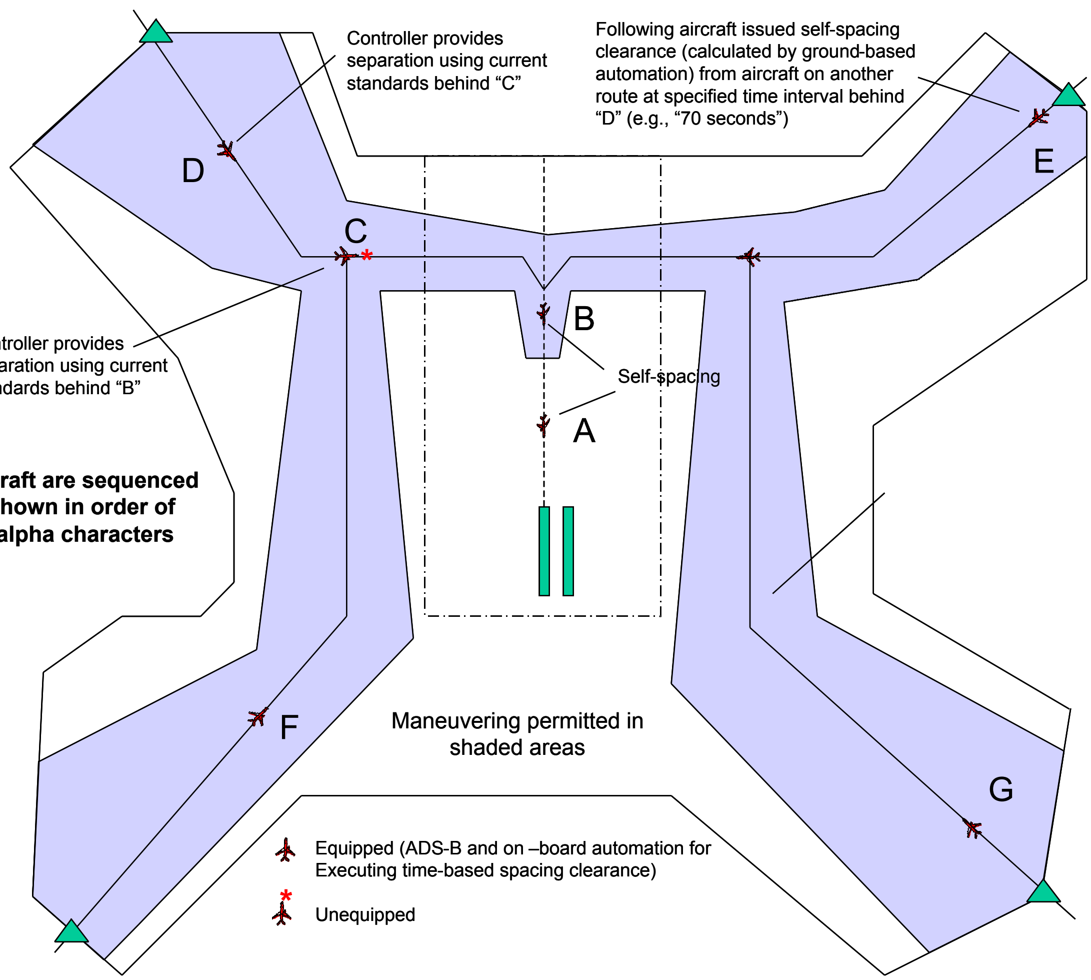
Each of these modes has different operational complexity, technical capability, and potential benefits:

In-Trail Spacing Mode

The in-trail temporal Spacing mode of flight along either a flexible arrival route or while maneuvering with the structured arrival route. Here, aircraft are in a common stream, or flying along a common path (e.g., post merging) that crosses the FAF and leads to the designated runway for that string. Each equipped aircraft FC is responsible for maintaining a specified temporal separation from a designated Lead aircraft in the same string or stream.

The spacing mode is directed to in-trail spacing control of multiple aircraft that either form a string along a fixed route or form a stream within an approach zone. Such a string is depicted in Figure 2 that shows traffic approaching an airport under a south flow configuration. In Figure 2, Aircraft B is tracking Lead Aircraft A on the extended final approach to Runway 18R.

Figure 2. Approaching Aircraft on Common Route Segments



In this mode of flight, the FC is given the authority to implement reduced spacing between their aircraft and the preceding Lead aircraft while in a single arrival string or stream ending at a stabilized approach point (e.g., FAF). Optimal arrival spacing is defined not in the spatial sense such as a fixed distance between aircraft, but rather in the temporal sense, whereby geometric spacing is continually tightened as the aircraft reduce speed. This results in the achievement of a tighter desired separation time between aircraft once the trailing aircraft reaches the stabilized approach point. In this way, all participating aircraft are able to maintain the higher speed profiles that support maximum flow across the runway threshold. The target separation is based on an accurate Estimated Time of Arrival (ETA) for the preceding Lead aircraft at the runway threshold that is derived from knowledge of the final approach threshold crossing speeds of both aircraft.

In order to implement this spacing management, the trailing aircraft would require certain information. First, the target separation time between it and the designated Lead aircraft would be calculated by the ATSP and transmitted via addressed datalink or voice to the trailing aircraft FC. This target separation time calculation could be based on either wake vortex behavior predictions taking into account the Lead aircraft type and configuration and current local weather conditions; runway occupancy time estimate; or regulatory separation requirements between the particular aircraft types.

Additionally, the target separation time between the two preceding aircraft (Lead and Lead + 1) may be required for more accurate prediction of the speed profile of the immediately preceding aircraft. Regular frequent updates of the Lead aircraft state and trajectory information through broadcast datalink may be required to generate the dynamic temporal-spacing guidance cues.

The spacing guidance cues could be provided to the FC on the CDTI for manual control, or the guidance requirements could be provided to the autopilot/autothrottle system through the FMS for hands-off active automatic control. In the absence of broadcast trajectory information for the Lead aircraft (e.g., non-ADS-B equipage such as for Aircraft C in Figure 2), an alternate trajectory prediction would be required, possibly supplied by an ATSP DST.

Merging Mode

The merging of multiple routes, or streams of aircraft. Each aircraft FC is responsible for adjusting in-trail position consistent with proper merging and then spacing behind the designated Lead aircraft approaching from another stream (and arrival zone).

The concept of merging aircraft from several streams, or routes, onto a common route is also depicted in Figure 2. Here, Own Aircraft E on the northeast diagonal leg is to merge behind Lead Aircraft D which is approaching from the northwest to the extended base leg. The merge will take place when Aircraft E turns from its base leg onto the extended final approach leg behind D which has previously turned onto this leg.

During this mode of operation, the processes of merging aircraft onto a common arrival route and time-spacing management along such routes are implemented simultaneously. Before or upon entering the terminal area, participating aircraft on both free maneuvering and structured arrival routes are provided sequence assignment instructions that may include time spacing behind another aircraft on a separate arrival route. The multiple routes later merge onto a common approach route. Each aircraft would follow its route but adjust speed and vertical profile while merging with another arrival stream to position itself in terms of meeting minimum geometric separation requirements while following temporal-spacing guidance cues to fall in behind the assigned Lead aircraft. Additionally, the aircraft may undergo multiple stream merges in this way before ending up in the final arrival stream prior to landing.

There are two ways each equipped aircraft may be guided before it merges behind the assigned Lead aircraft:

- It may be given a "ghost" image of the Lead aircraft as computed and projected on its own route before the merge point.
- It may be given an RTA at the merge point that is computed based upon the Lead aircraft crossing that point at the appropriate time separation before the RTA.

Free Maneuvering Mode

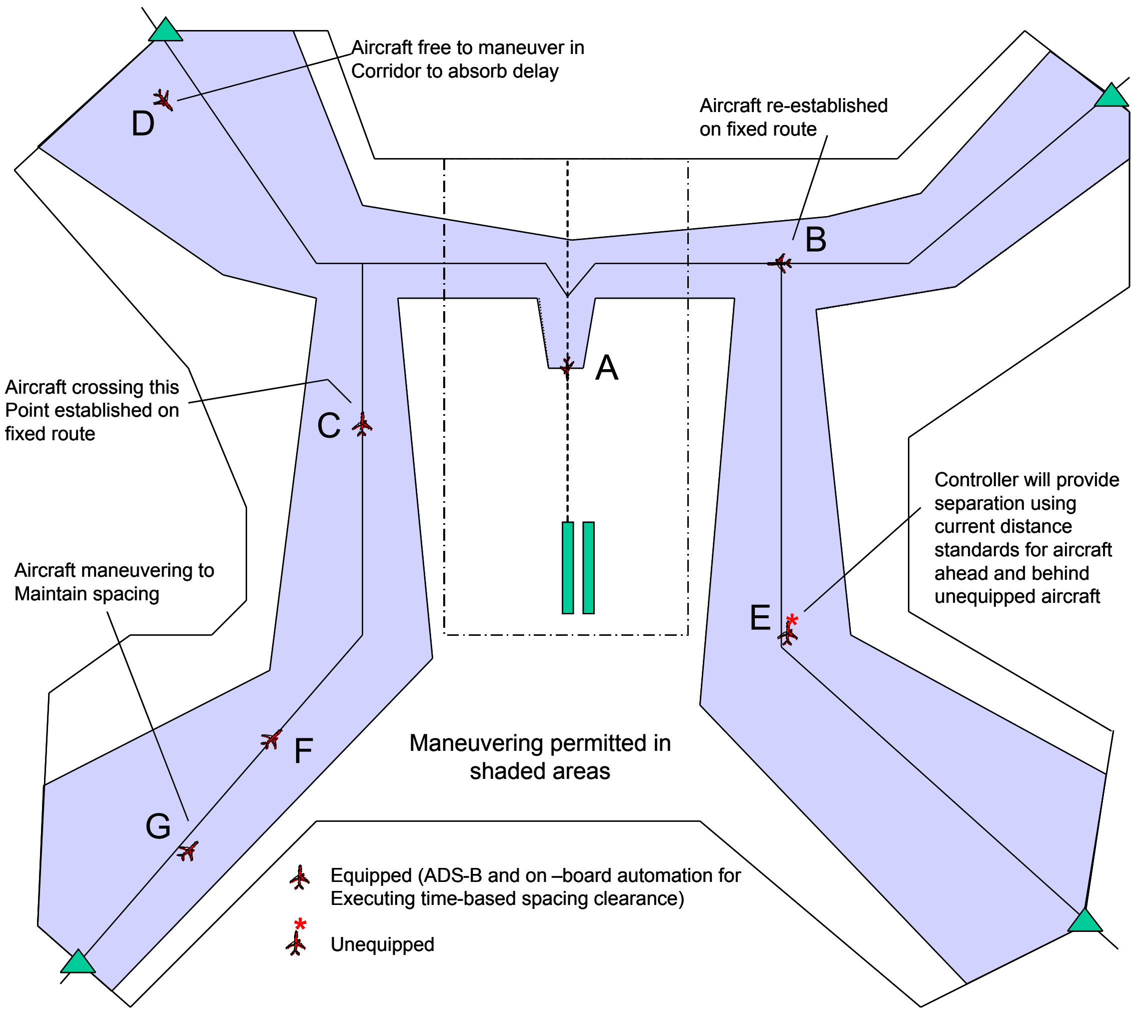
The self-guidance and separation of each equipped aircraft within arrival corridors, or zones. Here, the aircraft FC is cleared to adjust the flight path as needed within a defined approach corridor during the initial arrival phase of flight. During this process, the FC or FMS defines its own route leading to the future merge point. (Some aircraft will remain on fixed routes within this corridor.) In the Free Maneuvering mode, the FC establishes and maintains the necessary longitudinal spacing. The hypothesis is that ATSP precludes lateral separation issues by: (a) metering aircraft in the stream across an arrival boundary ("pre-organizing" the stream to have the right sequence and to not have lateral conflicts); (b) assigning spacing or RTA clearances that match the sequence coming into the TRACON such that aircraft will not be passing each other with inadequate separation; (c) keeping streams adequately separated from other streams; and (d) being responsible for over-flight separation from the streams.

The concept of aircraft flying in flexible, free maneuvering, arrival zones is depicted in Figure 3, again for a generic TRACON. The flexible zones are shown shaded in green. Aircraft G which is to merge behind Lead Aircraft F is on a different route than F, but it maintains proper spacing relative to F as both aircraft head toward a point where they will be on a common structured route.

In this mode, structured arrival routes are replaced with or conceptually broadened into arrival regions or zones. Instead of entering the terminal area via an arrival fix and following fixed structured routes thereafter, participating aircraft cross an "arrival zone boundary" and are provided authority to maneuver laterally within designated arrival zones that are segregated from departure corridors. The sizes of the arrival and departure zones could be static or could be dynamic to optimize terminal operations for inbound and outbound pushes or for weather considerations. Aircraft would be responsible for separation assurance, for remaining inside the arrival zones, and for merging into close-in arrival streams based on sequence assignments provided by the ATSP.

In this mode of flight, aircraft would have the authority to maneuver tactically for weather avoidance, separation, spacing, or descent profile management without clearance from the ATSP. Non-participating (e.g., non-equipped) aircraft, such as Aircraft E in Figure 3, would remain on structured arrival routes (or vectored paths) and receive all clearances from the ATSP. Although CE 11 does not specifically address the management of departures, the arrival operations would be designed in such a way as to not unduly impact departure operations.

Figure 3. Free Maneuvering Zones and Aircraft

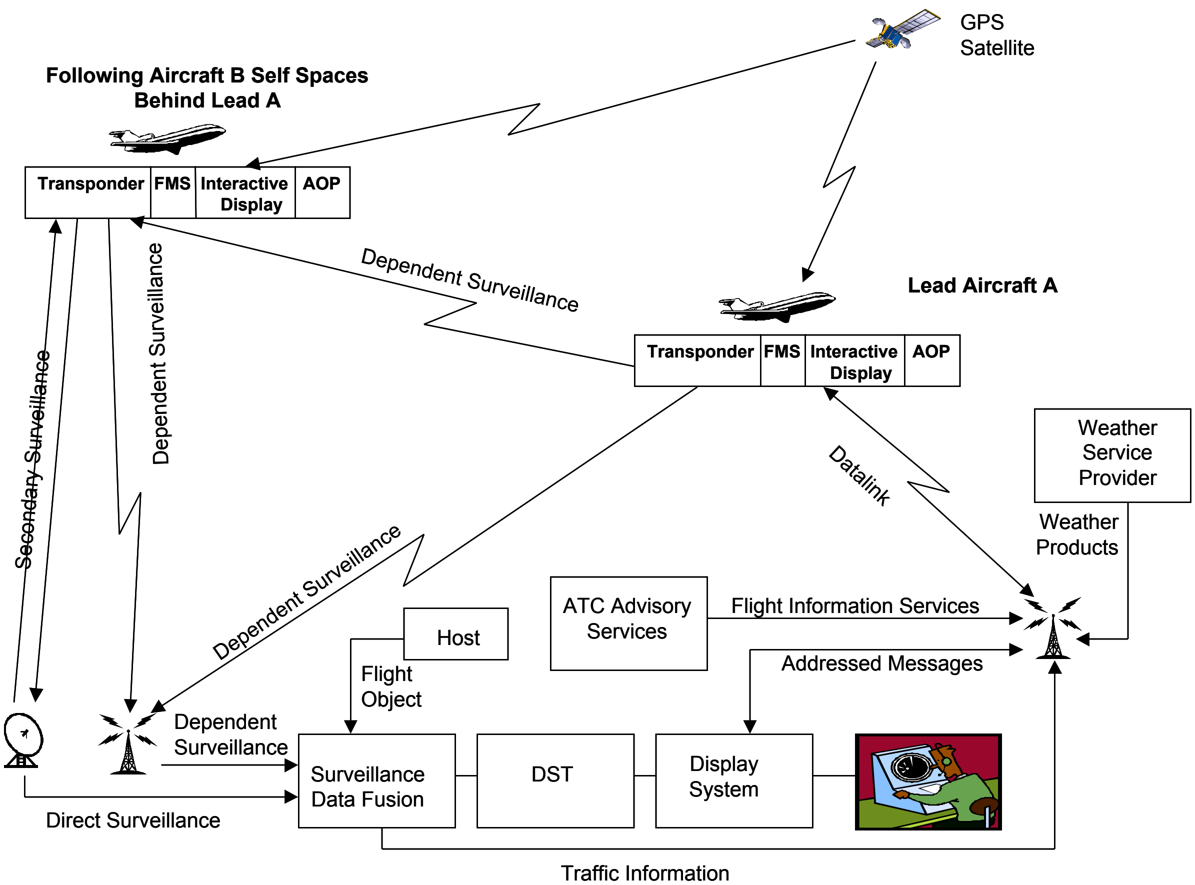


Functional/Architectural View: Figure 4 is a high level architectural view of those NAS systems and services that are envisioned for supporting CE 11. Current and future air traffic systems and services which are general to ATM but not specifically utilized in CE 11 are not shown.

The two aircraft (Lead A and Follower B) shown are members of a formed string. Each maintains accurate state information and trajectory conformance using GPS as the primary navigation input to the FMS. Each aircraft broadcasts state and intent information to aircraft and ground receivers. The ATSP uses secondary surveillance as a backup to the aircraft broadcast information, and the SSR measurements are fused with the state broadcast data for improved total situation awareness.

Two possible additional uplink messages come from the ATSP to the participating aircraft. One is the ATSP flight information including weather, winds, atmospheric conditions, zone boundaries, and regular Automated Terminal Information System (ATIS) information. The weather data may be generated by either the ATSP or a commercial weather service. The other message is the ATM clearance and advisory information such as assigned Lead aircraft, assigned spacing (time) interval, RTA for merges, and general clearances for setting up the string and turning over self spacing responsibility to the FC of each aircraft.

Figure 4. High Level System Architecture of CE 11



The functions created by CE 11 are described at a high level in the following paragraphs. These functions are based upon the description of roles and responsibilities (see Section 5.4) and operational scenarios (Section 6). In the following discussion, the nominal In-Trail Spacing function is illustrated from both the ATSP and FC points of view.

ATSP: Nominal In-Trail Spacing Function

Figure 5 shows the operational process that the ATSP approach controller goes through when clearing and then monitoring the actions of a flight crew that is using CDTI for in-trail spacing. The ATSP first determines if the aircraft is appropriately equipped. If not, the aircraft is vectored as is currently done during the approach. If equipped, then the ATSP determines if the aircraft is positioned properly to easily capture the designated spacing behind the Lead for subsequent following. If not, the controller vectors the aircraft into a position that facilitates ease of capture. Then the ATSP clears the aircraft in terms of issuing the identity of the Lead and the desired spacing that Own aircraft is to maintain behind the lead; these quantities come from the Decision Support Tool (DST).

After the Own aircraft is cleared for in-trail spacing, the ATSP continues to monitor the spacing process as the aircraft transitions through the approach zone. If Own's spacing falls outside of some acceptable tolerance with respect to the Lead, the ATSP issues a corrective advisory to Own. If the resultant action on Own's part is not satisfactory, the controller takes over spacing responsibility and vectors the aircraft to the FAF. If Own does an adequate job of spacing relative to Lead, the ATSP continues to monitor the progress until Own crosses the FAF. Thereafter, Own is cleared to land.

Flight Crew: Nominal In-Trail Spacing Function

Figure 6 shows the operational process that the flight crew goes through when cleared to use their CDTI to capture and then maintain a designated spacing behind a designated Lead aircraft. On or before the time the FC enters the TRACON, the request in-trail spacing permission. ATSP determines if airspace conditions warrant and if the aircraft is properly equipped. If not, the ATSP denies the request and continues to vector the aircraft through the approach.

If the FC and aircraft are trained and equipped, and conditions warrant, the ATSP clears the FC to execute the in-trail spacing procedure. This includes issuing the designated Lead aircraft and the desired spacing. These parameters are entered into the CDTI. Thereafter, the FC captures and maintains desired spacing behind the Lead until FAF is reached. They are then cleared to land.

Figure 5. ATSP Operational Sequences for Nominal In-Trail Spacing

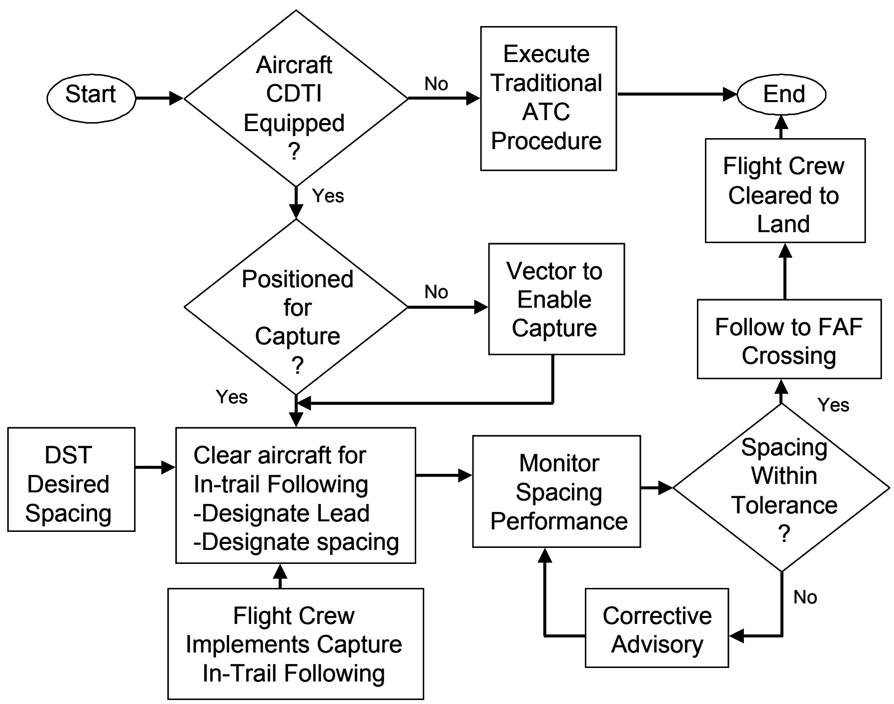
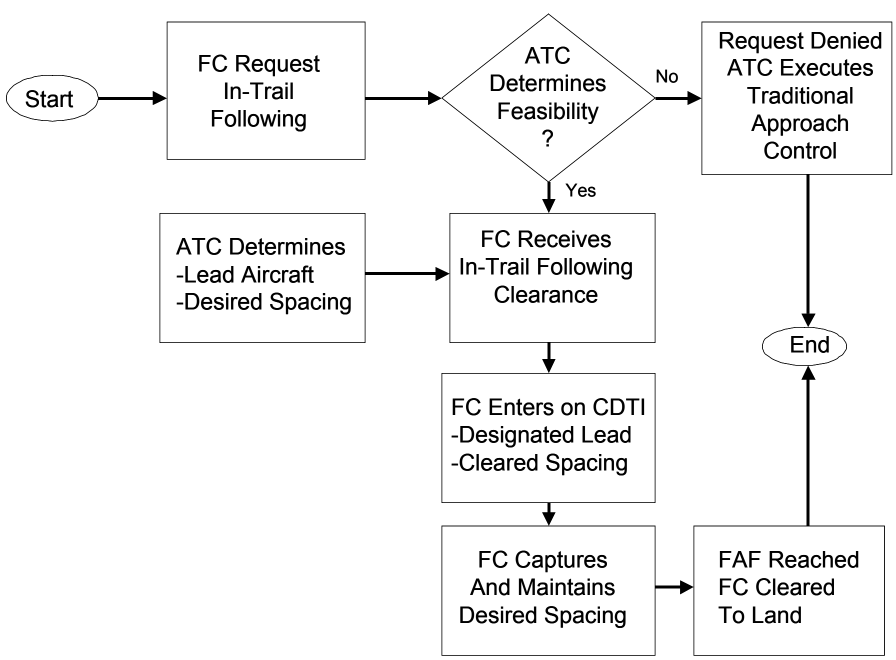


Figure 6. Flight Crew Operational Sequence for Nominal In-Trail Spacing



5.4 Users/Affected Personnel

In this section, the roles and responsibilities of the ATSP/controller and the participating aircraft/flight crew for CE 11 operations are summarized.

ATSP Roles and Responsibilities: Here, we first discuss the full responsibility of the ATSP as air traffic manager, and air traffic controller using automation and DSTs. We then discuss issues related to the controller interfacing with the FCs. These functions are depicted in Figure 1.

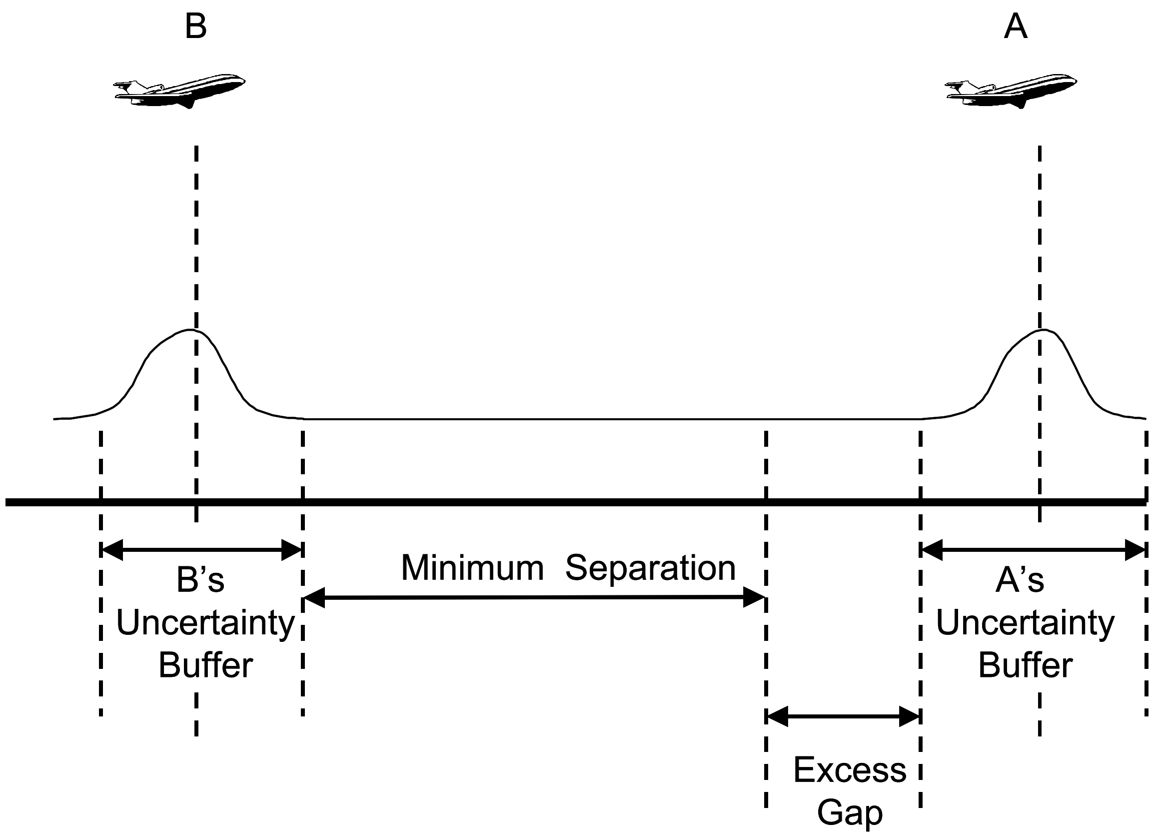
The ATSP responsibility for enacting the CE 11 methodology begins well before the participating aircraft enter the TRACON. There is a collective activity between airport, TRACON, and surrounding Centers that determines the acceptance rate of the runways, the airspace capacity as affected by weather and other non-approach-to-landing aircraft, and the demand for airport landing operations. (This activity is aided by knowing the flight plans of each aircraft that desires to land; that is, there is an aircraft operator/airline role involved, too.) The runway acceptance rate, airspace capacity, and runway throughput demand set up the traffic management process for the greater terminal area (i.e., out to beyond top-of-descent). This process determines the desired sequence and schedule of aircraft entering the TRACON with intention of landing. In turn, the desired schedule sets up the metering processes to bring aircraft from the surrounding Centers to the TRACON approach zone boundaries and feeder fixes.

Within the TRACON, the ATSP defines the nominal routes and route segments leading to the runway, the merge points for those routes, the FAF, and the approach zone boundaries. If the boundaries are changed because of dynamic density or weather restriction considerations, that also is the responsibility of the ATSP. For the free maneuvering mode, the approach zone boundaries are published in a navigation database and are static for nominal operations. These geometric definitions are done well in advance of the particular flights involved. In a far term scenario, dynamic zone definition could be done during the flight process, but before the aircraft crosses into the zone.

The TRACON ATSP is also responsible for the traffic management process governing the aircraft sequence and schedule. That is, the TRACON ATSP takes over sequence management of the aircraft from the Center ATSP. Landing schedules are accepted or modified depending upon the dynamics of the TRACON, airports, and runways involved. The ATSP determines which runways are in use using information on flight plans, winds, weather, and departing traffic. It determines the desired schedule of landing operations taking into consideration departing traffic, conditions of the runway (e.g., wet surface, icing), weight and class of the aircraft, wake vortex and runway occupancy factors.

Inherent in the landing schedule are the safety reasons which established acceptable relative minimum-plus-a-buffer spacing between successive aircraft at or just before the time points that each Lead of each aircraft pair crosses the runway threshold. The ATSP sets these threshold crossing time points in the schedule to maintain minimum spacing (a spatial distance) and to allocate enough additional buffer to account for variations in the final approach trajectory of each aircraft because of differing speed profiles and winds. This variation in spacing is illustrated in Figure 7. The role of ATSP controlled landing scheduling is to remove unnecessary "gaps" between aircraft and to reduce the "buffers" within the landing schedule by reducing the trajectory uncertainties. (The premise of CE 11 is that the FCs can control the relative spacing between Own and Lead aircraft better than ground ATSP thereby allowing for reduced buffers. Nevertheless, it is still the ATSP responsibility to set the minimum plus buffer spacing parameters based upon safety considerations.) The desired spacing is converted to an equivalent time spacing between consecutive aircraft, which is built into the landing schedule.

Figure 7. Minimum Spacing, Spacing Buffer, and Excess Spacing Gap



The ATSP takes the landing schedule and backs it upstream along each route and route segment leading to the particular runway. This process then establishes the schedules for crossing the FAF and the merge points (route waypoints in the flight plan) for each aircraft approaching the given runway.

The ATSP uses the waypoint schedules to assign an RTA to each FMS equipped aircraft to be used by the aircraft FC to facilitate safe merging at particular merge waypoints. The ATSP also uses the landing sequence and relative time spacing between aircraft to assign first the Lead aircraft for each participating aircraft to follow and then the incremental time spacing that the following aircraft is to maintain relative to the Lead.

The ATSP is responsible for determining if conditions warrant allowing the properly equipped aircraft and FCs to choose their own flexible approach route, to merge with other participating aircraft, and to self-space thereafter. The ATSP issues the clearances to each participating FC to designate its Lead aircraft, to set its spacing parameter and RTAs, and to take over responsibility for merging and self-spacing until the ATSP takes that responsibility back.

Thereafter, it remains the responsibility of the ATSP to monitor the progress of the self-merging and in-trail spacing process to ensure that this is done with some pre-established threshold of spacing compliance. The ATSP is responsible for issuing warning if compliance is not being met and to take over the separation control if safety is being compromised. At the same time, the ATSP remains responsible for protecting the approaching aircraft from other traffic such as departures, over flights, and pop-ups.

Even in busy terminal areas and during rush periods there will be necessary gaps in the approach traffic because of the somewhat random nature of arrivals from the Centers or deliberate gaps to allow for departures or crossing traffic. Thus, each string that is formed by the ATSP is of specific duration, and new strings must be started throughout a day’s operations. The String Leader aircraft sets the reference approach trajectory for subsequent aircraft in each string, and so it is important for good traffic flow that these String Leader reference trajectories are fast and efficient. It is the ATSP responsibility to ensure that the String Leader follows such an efficient trajectory, either by FC reference to one published in the airport approach charts or one in which the ATSP clears the String Leader FC along an efficient speed profile.

The ATSP maintains the ability to take over responsibility of the approach process at any time to account for non-normal events such as runway change, missed approach, emergency operation, non-compliance to spacing standards of one or more aircraft in a string, or some other dynamic situation. The ATSP is responsible for making the call – employ the CE 11 applications or not.

The ATSP continues to be responsible for those non-equipped or unable-to-participate aircraft involved in the approach process. This includes determining if such aircraft need to be segregated from participating aircraft or mixed into the strings but still controlled by the ATSP.

Much of the ATSP responsibility for the CE 11 service pre-supposes a certain level of automation on the part of the ATSP. For terminal areas without this automation, many of the previously mentioned ATSP roles and responsibilities can still be executed, but without the precision that automation provides. The minimum requirements in ATSP automation to mechanize the CE 11 service remains as a research topic.

Flight Crew Roles and Responsibilities: Here, we discuss the combined roles of the flight crew interacting with their on-board avionics (e.g., FMS, CDTI, datalink interface) in terms of mechanizing and utilizing the CE 11 processes and associated ATSP services.

Up to crossing into the TRACON, the FC responds to clearances given by Center ATSPs to arrive at the approach zone boundary or entry fix according to a metering schedule. The FC receives and evaluates from the ATSP the conditions of the operational environment within the approach zone in terms of boundaries of the approach zones, any restricted airspace defined by weather cells or other traffic, airspace and surface winds, availability of flexible maneuvering, and conditions of the assigned runway. The FC determines their desired reference speed V_{ref} for runway threshold crossing. The FC evaluates the airspace ahead based on uplinked graphic weather and that sensed by aircraft weather radar.

If a flexible route is to be used within the approach zone, the FC may interact with the FMS in computing that reference trajectory. Alternately, the FC manually guides the aircraft within the space allocated for free maneuvering.

At the time the participating aircraft crosses into the TRACON approach zone, the FC is assigned its position in an arrival string, the immediate Lead aircraft, and the desired spacing parameter via uplink or voice clearance from the ATSP. If one or more RTAs are to be used for merging control, these are also uplinked to the FC. The FC enters or approves entry of these parameters into the FMS and CDTI logic. The FMS regulates speed along the approach path if RTAs are used. The logic computes and displays the appropriate spacing cue with respect to the Lead or Lead's ghost on the CDTI.

The ATSP clears the FC to use their avionics to enact flight along the flexible reference path, to use RTAs or a ghost Lead to control merging, and to use the spacing cues on the CDTI to control subsequent in-trail spacing. This transfers the in-trail spacing responsibility to the FC. This FC responsibility remains in effect until either the aircraft has crossed the FAF or landed, or the ATSP/controller has resumed control.

The FC steers their aircraft along the reference (lateral and vertical) path and controls speed to maintain tight spacing within a pre-specified tolerance. The FC informs the ATSP if they are unable to accept this responsibility or they are unable to continue self-spacing after the process has begun. At the appropriate time after crossing the FAF, the FC transitions to the normal landing process.

Table 2 identifies all potential users or involved personnel, based upon CE 11 operations. It is identical to Table 1. The users involved before and after CE 11 are the same. Their roles and responsibilities change in accordance with the preceding discussion.

5.5 Support Strategy

To be determined

Table 2. Users or Personnel Involved in CE 11 Operations

Users or Involved Personnel	CE 11 Operations
Traffic Management Specialist at ATSCSS	
Air Traffic Control Supervisor (ATCS)	
Supervisory Traffic Management Coordinator-in-Charge (STMCIC)	
Operations Supervisors (OS)	
Traffic Management Coordinator (TMC)	
En Route Radar Position – R controller	
En Route Radar Associate (RA) – D controller	
En Route Radar Coordinator (RC)	
En Route Radar Flight Data (FD) Position	✓
En Route Non Radar (NR) Position	
Terminal Radar Position – R controller	✓
Terminal Radar Associate (RA) – D controller	✓
Terminal Radar Coordinator (RC)	✓
Terminal Radar Flight Data (FD) Position	
Terminal Non Radar (NR) Position	
Tower Local Controller (LC)	✓
Tower Ground Controller (GC)	✓
Tower Associate	
Tower Coordinator	
Tower Flight Data Position	
Tower Clearance Delivery Position	
Flight Service Station Specialist (FSSS)	
Airline or Aircraft Flight Operations Center (AOC)	✓
Pilot or Flight Crew (FC)	✓

6. Operational Scenarios

In the following discussion, we illustrate three conditions of CE 11 operation – nominal, rare-nominal, and failure. Each is defined, and narrative scenarios are used to describe the interplay between FC and ATSP during the operational process.

Normal or Nominal Condition: The normal, or nominal, condition for CE 11 is where all air and ground systems function as expected under normal conditions, traffic is in a steady state condition in terms of approach airspace used, routes and zones are not blocked by weather cells, and the runway in use is not changing.

Scenario 1

Delta 452 (DA452), a B757, is CDTI and FMS equipped and is about to enter the DFW TRACON over the boundary whose center point is the Bonham BYP feeder fix after travel from Atlanta. DA452 datalinks down to Approach Control that its V_{ref} speed is 137 kt and that it wishes to use the free maneuvering and in-trail following procedures to expedite the approach process. Approach Control datalinks up acknowledgement and activates computation of landing sequence and desired temporal spacing at landing to meet wake vortex constraint for a B757 following the appropriate Lead (which happens to be an MD80). Seconds later, Approach Control assigns DA452 the No. 23 position in the landing sequence behind the previously assigned No. 22 Lead aircraft and assigns the standard separation parameter as 75 sec. No. 22 is American 1088 (AA1088), an MD80 inbound from Chicago on the same STAR. Approach Control clears DA452 to merge with and maintain 75 sec behind AA1088 to the Runway 18L FAF.

DA452 FC identifies, designates and enters AA1088 as the Lead and 75 sec as the distance parameter on the flight deck CDTI. DA452 FC chooses to let the FMS define the direct route to the waypoint defining the intersection with the base leg; thereafter the FMS steers the aircraft along this direct path while maintaining appropriates separation with respect to the Lead. Simultaneously, the FMS automatically closes and maintains the specified distance with respect to AA1088, as represented by AA1088's projected position on DA452's route. Thereafter, the FC monitors the separation throughout the approach phase of flight leading to the FAF.

Likewise, Approach Control monitors this process to ensure that nominal progress is made.

After DA452 crosses the FAF, the DA452 FMS automatically switches to Final Approach Control frequency, and the FC is cleared to land. DA452 FC resumes manual control of the aircraft, disengages the FMS and CDTI spacing cue, and proceeds to a normal landing behind AA1088. Because tight spacing control was maintained between the two aircraft up through FAF crossing, an average time savings of 8 sec was gained in the inter-arrival spacing.

Rare-Nominal Condition: The rare-nominal conditions for CE 11 exist when unusual weather (such as a preponderance of storm cells blocking nominal approach routes or zones) occurs, a runway change takes place, or there is a disruption of a string because of a missed approach or a FC that is not maintaining proper positioning. In the following scenario, a major weather cell blocks the nominal approach zone so that the participating aircraft must be diverted and merged with traffic within a different approach zone.

Scenario 2

AA401, an MD80, is in-bound from DEN to DFW via the BOWIE3 STAR passing through the northwest approach zone defined by the Bowie (UKW) feeder fix. A major summer convective weather storm is passing through the area. At 100 nmi to go to DFW and during the initial part of AA401's descent, Bowie Approach Control communicates with Ft. Worth Center and AA401 to say that the Bowie approach zone is closed because of a large weather cell. All Bowie traffic is being diverted to the northeast approach zone defined by the BYP feeder fix.

AA401 is FMS and CDTI equipped and so the AA401 FC requests use of a flexible route and RTA to maneuver along the direct path to and then merge with Bonham traffic. Ft. Worth Center and Bonham Approach Control cooperate to compute an RTA of 0952 GMT at the KARLA intersection within the Bonham zone. This also includes assignment of AA401's sequence number and nominal spacing behind UA55, a B737, approaching from ORD.

The Ft. Worth Center/Bonham Approach ATSP automation links the KARLA waypoint, RTA, designated Lead (UA55), and spacing parameter (65 sec) for use after crossing KARLA to AA401. The ATSP also uplinks the latest graphical depiction of weather cells in the immediate area. AA401 FC acknowledges, enters these parameters in the FMS via the CDTI, and activates the FMS to maneuver to these parameters. The FMS makes local adjustments to the route leading to KARLA to bypass small cells north of DFW. Thereafter, the FC monitors the flight with respect to on-board weather radar supplementing the uplinked weather data and the CDTI depiction of adjacent traffic leading to the Bonham zone. The ATSP monitors the flights of AA401 and UA55 to ensure that the merge at KARLA is smooth and within acceptable spacing tolerances for the subsequent traffic string leading to DFW.

Failure Condition: The failure conditions for CE 11 are those events where equipment fails, human errors disrupt normal operation, or operational conditions abruptly change so that nominal or rare-nominal operation cannot continue. Each of these conditions needs to be defined and analyzed so that safe recovery processes can be developed which revert to a more manual traffic management process. In the following scenario, a surveillance failure causes a major disruption.

Scenario 3

It is in the middle of an arrival rush during a normal busy day at DFW. Arrivals are coming from all four approach zones leading to the "south flow" operations on Runways 18R and 18L. Even though visibility is limited, because of the density of arrivals, CDTI merging and in-trail spacing procedures are being used to increase landing rates and runway throughput.

Suddenly in the midst of this process, the ATSP surveillance function that fuses radar tracking data with ADS-B state messages broadcast from each participating aircraft fails. The ATSP is no longer able to monitor compliance of spacing constraints between consecutive aircraft in the approach strings. DFW Approach Control automation notifies

Ft. Worth Center to shut off all entering traffic. Ft. Worth Center controllers subsequently put approaching aircraft in holding patterns until the DFW problem is resolved.

The Glen Rose Approach controller takes over manual control of each of the seven aircraft in the CDTI-driven approach string within the Glen Rose zone. The controller continues to observe relative positions of the aircraft via radar tracking (today's technology). Starting with the No. 2 aircraft, the controller vectors each aircraft to the right or left of the nominal route and then back to the route to open more space between the aircraft. No. 2 is vectored to the right and then back. No. 3 is vectored to the left and then back, etc. CDTI driven spacings of 60, 75, and 90 sec are opened to the equivalent of 75, 90, and 105 sec in spatial distance terms.

Each participating FC is fully aware of the problem and can optionally cooperates to open the spacing via the CDTI. That is, upon controller clearance, the FC can enter the diversion maneuver and new temporal spacing parameter on the CDTI, and then follow the maneuver guidance cues to path stretch to the desired new spacing.

After the last aircraft in the string is re-spaced, Glen Rose Approach notifies Ft. Worth Center that the southwest approach flow can be continued but with a lower acceptance rate than before the equipment failure. This lower rate and manual approach control is continued until the surveillance equipment is repaired or restored to nominal operation.

7. Summary of Impacts

7.1 Operational Impacts

The NAS operational impacts, including planned NAS architecture components, of the CE 11 are discussed in the following paragraphs. The following changes from the NAS 4.0 mature baseline, expressed in terms of technology and infrastructure, are needed to support the concept. These are described in the area of Communications, Navigation, Surveillance, Automation, Weather, and Traffic Management.

- **Communications:** Within the NAS 4.0 baseline, ground-to-air communications with participating aircraft within the approach zones of the TRACON are both by datalink and voice. Datalink communications are both broadcast and addressed. The ATSP broadcasts or provides pre-flight advisories and information on winds aloft, graphical weather cell location and intensity, and for free maneuvering, the geometric boundaries of the approach zones. For participating aircraft without ADS-B, the ATSP uplinks state information of adjacent aircraft.
- To mechanize CE 11, aircraft specific advisories and clearances, sent via addressed datalink include the assigned Lead aircraft and the assigned time spacing the following aircraft applies to self-spacing behind the Lead. For environments with ATM automation and DSTs, the desired speed profile may be computed and uplinked to the first Leader aircraft in a given string. For the merging mode, either the ghost image or actual position of the Lead aircraft on a merging route may be uplinked to be projected onto the following aircraft's route. If the RTA capability of the FMS is used to facilitate merging, that RTA is uplinked to the aircraft.
- Air-to-ground communications include the participating aircraft accepting assignment of following the specified Lead or ghost, acceptance of assigned RTA if appropriate, and acceptance of approach speed profile is uplinked from ATM automation. Air-to-air communications occurs through ADS-B.
- Voice communications are procedurally used when the ATSP takes over control of specific aircraft because of emergency or non-compliance with intended merging and spacing assignments. In a terminal environment where a DST is not used, the controller may use voice communications to vector aircraft for proper merging followed by assignment of Lead aircraft and desired spacing to a CDTI-equipped aircraft.
- CE 11 requires that special messages be created for ground-to-aircraft and aircraft-to-ground communication, as just described. Special avionics software will be required to facilitate implementation of the CDTI with proper presentation of other aircraft, spacing cues, and airspace constraints. Similarly, DST software will be required to extend planned NAS capabilities to include mechanization of CE 11. However, no new communications systems or hardware should be required for flight crew or ATSP implementation.

Navigation: There are no new functional navigation requirements imposed on the ATSP by CE 11. In terms of the aircraft avionics, the CDTI is an additional layer of information on the multi-function display; its design is primarily one of software. It is assumed that the on-board navigation system has a RNP level with sufficient accuracy to support merging and in-trail spacing applications. It is also assumed that this information is used for state and intent broadcast.

Surveillance: Participating aircraft within CE 11 will be equipped to broadcast their state and possibly their intent information computed in the FMS and to receive this information from adjacent aircraft. State and intent information are broadcast at 1 Hz. Intent information extends to the runway threshold, and contains the FAF as a waypoint. Participants without FMS will not broadcast intent.

The ATSP surveillance function will fuse broadcast state information with that obtained from area radars (SSRs). The intent information provides the ATSP with a forward look of the intended path the participating aircraft will fly.

The only new surveillance function beyond current plans for NAS is the added capability of the ATSP to monitor the progress and relative states of the participating aircraft during the three flight modes. This includes the capability to assess actual and future separations, to determine when the aircraft is outside of acceptable separation assurance conformance limits, and to provide alerts to the controller for immediate response.

Automation: The ATSP functions within CE 11 are presented in Figure 1. As described previously, new ATSP automation within the DST beyond current NAS plans includes capabilities to compute and display:

- The desired sequence and pair-wise spacing between consecutive aircraft in the sequence strings.
- The RTA for each participating aircraft to facilitate smooth merging.
- Possible means to change approach zone boundaries to adapt to convective weather cell locations.
- Means to monitoring the merging and in-trail spacing processes for desired separation conformance.
- Alerting mechanism when conformance is not met to point of affecting safety.

These automation functions are supported by appropriate two-way datalink between aircraft and ATSP DST.

Weather: The ATSP or commercial weather service provides accurate winds aloft, atmospheric conditions, and graphical weather information to aircraft and ATSP DST. These data are updated regularly by downlinking of measured wind and temperature by participating aircraft. This function is expected to be part of the future NAS architecture.

Traffic Management: There are no changes required for strategic traffic management, that is at the Command Center level. Local traffic management participates in setting the arrival acceptance rate the airport can handle which in turn affects metering up to the TRACON. It also sets up the arrival sequence as manifested by the sequence and schedule of aircraft crossing into the TRACON. If CE 11 is in use, the runway throughput should increase which will be reflected in the acceptance rate used for traffic management. Thus, no new traffic management functions within the projected NAS architecture are required.

7.2 Organizational Impacts

To be determined

7.3 Impacts during Development

DAG-TM CE 11 is at a very early stage of development. As such, it is difficult to determine the impacts on the user, acquirer, and maintenance organizations during development. It is however required that FAA Air Traffic Controllers participate in the development process during demonstration and test phases. Significant impacts are however expected on the user, developer, and on the ATM system personnel during development because of the major ATC paradigm shift that will be caused by CE 11.

8. Analysis of the Proposed System

8.1 Summary of Advantages

The following is a list of the potential benefit mechanisms from CE 11, discussed in the context of the metrics associated with AATT goals of:

- Capacity
- Flexibility
- Efficiency
- Predictability
- Safety
- Access
- Environment
- Scalability
- Economy

Capacity: The capacity-related potential benefits of CE 11 service are as follows:

- CDTI-equipped aircraft provide the FC increased situation awareness and the ability to maintain tighter in-trail spacing control. Thus, excess safety-related separation buffers used by controllers today can be reduced, increasing operational densities and runway throughput.
- An increased volume of airspace can be utilized by FMS-equipped aircraft in that they are not constrained to follow a fixed route structure. Flexible approach route free maneuvering capability allows efficient by passing of weather cells and more direct routes from approach zone entry to the FAF.
- In today's system, controller workload is a strong function of traffic volume since every aircraft is individually managed. Under CDTI/FMS-based merging and in-trail spacing control, equipped aircraft do not need to be managed by the ATSP and therefore controller workload is a weaker function of traffic volume. Thus traffic volume could be permitted to increase while using the same level of controller resources.
- Close trajectory management by FMS-equipped aircraft flight crews allows increased RTA conformance, which leads to increased throughput along a system of merging routes.

Flexibility: The following flexibility-related potential benefits of CE 11 have been identified.

- FC preferences of flexible routes for FMS-equipped aircraft are implemented directly by the FC and may not require ATSP approval.
- The ability to free maneuver within designated approach zones increases the FC available and realizable routing options to convective weather cell problems.

- The option of not needing to adhere to a fixed route structure and ability to use the entire approach zone airspace allows more efficient flight plan options for equipped aircraft.
- Since FCs can constantly monitor their trajectories relative to adjacent approach traffic, these trajectories can be more tailored to FC preferences in terms of maintaining lateral and vertical separation as well as specified in-trail spacing.

Efficiency: The following efficiency-related potential benefits for CE 11 have been identified. These are separated into benefits to Users/FCs and to the ATSP.

Users and Flight Crews

Users should experience reduced operating costs (time and fuel) and reduced delays, due to:

- Increased predictability of operations.
- Capability for maneuvering along optimized routing.
- Reduced excess spacing buffers.
- Reduced excessive merging and spacing maneuvers.
- Reduced voice communications normally required within the TRACON for vectoring approach traffic.
- As the percentage of FMS/CDTI equipped aircraft increases, these users should experience reduced delays, since they are a subset of the total traffic and the ATSP can handle them more efficiently.

Air Traffic Service Provider

- The ATSP has decision support for ATC clearance advisories.
- The ATSP has reduced voice communications since there is little voice contact with equipped aircraft after their FCs have been given FMS / CDTI-based maneuvering, merging, and spacing clearances.
- Because many aircraft will have merging, in-trail spacing, and self-separation control capability via FMS / CDTI, the ATSP can focus more on aircraft that do not have these capabilities. Therefore, the curve of workload as a function of traffic density will be below that experienced by today's ATC system.
- ATSP can focus on traffic management and less on traffic control.

Predictability: The following predictability-related potential benefits of CE 11 have been identified.

- FMS-equipped aircraft may broadcast their intent in terms of using flexible routes. When the intended route changes, the new intended route is broadcast, and the predictability of that aircraft's trajectory with respect to other aircraft and the airspace is more assured by other aircraft and the ATSP.
- Participating FCs can diligently monitor merging and in-trail spacing clearance adherence and provide high predictability of their aircraft trajectory.

- Increased trajectory adherence increases the predictability of intended path conformance, which in turn increases the predictability of arrival traffic throughput.

Safety: The following safety-related potential benefits for CE 11 have been identified. These are limited to direct safety benefits that have not been implied in the other benefit areas:

- Both CDTI-equipped aircraft and the ATSP have greater traffic situation awareness concerning potential conflicts or spacing clearance violations. This redundancy reduces the probability of separation assurance failure.
- The FC of each CDTI-equipped aircraft is fully involved in maintaining separation and resolving conflicts with all surrounding aircraft. In today's ATC system, a single approach controller team must divide their attention among all aircraft within their sector or zone. Therefore, the concept of FC participation in the control of merging, spacing, and self-separation within the approach zone leads to increased safety.

Access: The following access-related potential benefits for CE 11 have been identified. This refers to the ability of FCs to obtain access to airport, airspace, and ATC services.

- The concept of maneuvering along flexible approach zones to account for dynamic traffic and weather conditions allows greater access to all TRACON airspace and more continuous access to the airport than does a fixed route environment that exists today.
- Flexible routing within designated approach zones provides improved access to off-route airspace within that zone.

Environment: The following environmental potential benefits of CE 11 have been identified:

- More efficient flexible trajectories means less fuel is burned per flight, providing improved environmental benefits as well as conserving the non-renewable resource – jet fuel.
- The use of flexible approach zones and routes within those zones open possibilities of improving and spreading out of the noise footprint of approaching aircraft.

Scalability: The following scalability-related potential benefits of CE 11 have been identified. Scalability refers to the capability of the air traffic system to continue to operate successfully with continually increasing traffic volumes. Scalability has two aspects, operational and economic.

Operational

- Each additional equipped participating aircraft contributes its own surveillance infrastructure and provides its own separation assurance. This system accommodates growth better than a centralized system that may have limits in capacity to handle traffic growth.
- Whereas the current paradigm of centralized human planner / controller does not scale with large traffic growth, a distributed system of self-separating FCs of participating aircraft that grows with the traffic is readily scalable.

- The CE 11 ideas postulated for approach traffic within TRACON airspace is scalable back through before top of descent within the terminal transition airspace. Furthermore, the concept is scalable to departing aircraft traffic as well.

Economic

- Capital and recurring costs of infrastructure and operations for a single TRACON service provider may be reduced.
- Operating costs of airspace and airport users will be reduced because of more efficient flight, decreased airport delays, and reduced aborted landings due to inclement weather events.

8.2 Summary of Disadvantages/Limitations

If DAG-TM CE 11 operations fulfill the objectives set for the concept, there are few, if any disadvantages or limitations inherent in the concept. This does not mean that it has been proven that the benefits achievable with CE 11 exceed the implementation costs (e.g., research, development, equipage). This question, and other research issues are identified in the DAG-TM Concept Definition Document (Reference 4) and will be investigated during DAG-TM research.

In the Research Plan, the issues that apply to CE 11 are grouped into 5 categories. The topics that appear under each category are shown here to illustrate the breadth and depth of the intended research activities underway to address these issues.

- Operations
  - Tolerance to positional errors
  - Maximum closing rates
  - Later FMS routes
  - Mixed-equipage integration and segregation
  - Time Horizons
- Human Factors
  - Roles and responsibilities
  - Workload management and task balancing
- Data Exchange
  - Content, frequency, accuracy
  - Datalink mechanism
- Decision Support
  - Overall functionality: FMS designed for self-spacing operations
  - Interface (display, input, alerting)
  - Guidance
- Procedures

_ Self-spacing operations

_ ATSP monitoring

_ Transfer of responsibility

_ Rare-nominal and failure conditions of operation

8.3 Alternatives and Tradeoffs Considered

The CE 11 concept is still in an early stage of development, although there has been substantial human-in-the-loop simulation work to examine the feasibility of using the CDTI for in-trail spacing and the FMS for directing free maneuvering. The main issues concerning CE 11 revolve around validation / refinement of the basic concept and development of the operational and technical details. Validation of the concept should be done with airline and ATSP operations staffs at an early stage to confirm the concept is correctly defined and addressing areas with the most potential payoff. Functionality and FC-controller relationships can be refined through discussions with the same staffs. Lessons learned from previous NASA and Mitre research can be used to directly refine the basic technical areas of investigation.

Concurrently, development of key technologies for the concept can progress in preparation for the development of a CE 11 prototype system. A list of required avionics development efforts includes:

- Development of the FMS so that it can compute flexible routes that are within the confines of zonal boundaries, adequately spaced from convective weather cells, able to meet an RTA at a downstream merge point, and are fuel optimal. This includes abilities to change boundary and weather cell constraints as defined by up-linked information from the ATSP.
- Development of the CDTI in-trail spacing cues and other information to allow the FC to designate the Lead aircraft, to set the desired temporal spacing, to guide to the spacing parameter either via flight director or automatically via the FMS, to monitor spacing adherence, and to monitor lateral and vertical separation from adjacent aircraft. This includes ability to compute and use ghost projections of Lead aircraft if the Lead is not on the same route as the participating aircraft.
- Development of datalink interface to enable the FC to interact with the ATSP when requesting a flexible route, being cleared to use the RTA or ghost for merging control, being cleared to maintain a fixed temporal spacing with respect to the designated Lead, and returning primary separation responsibility back to the controller.

There is a spectrum of ATSP DST requirements ranging from using today's STARS environment where the controller would verbally clear an aircraft FC to use its CDTI for in-trail spacing control (and no special DST requirement) to an advanced DST which might build upon emerging Active FAST capability. The different environments need to be defined, and associated DST technology needs to be developed consistent with ATSP needs within CE 11.

For both avionics and ATSP DST requirements, there is the open question of what are the minimum equipment and training requirements for an aircraft or flight crew to participate in CE 11. Also, there is the issue of what terminal areas can actually benefit from the concept in terms of traffic density, airspace constraints, and amount of training required to enable the traffic managers to utilize the concept.

In parallel with needed technology developments, there is also a need to develop the flight crew-traffic manager procedures. Furthermore, these need to be expanded to include provision for handling aircraft with different speed envelopes and different levels of equipment.

9. Notes

Abbreviations and Acronyms

4D	4-dimensional
AATT	Advanced Air Transportation Technologies
ADS-B	Automatic Dependent Surveillance – Broadcast
AFAST	Active Final Approach Spacing Tool
AOC	Airline Operations Center
AOP	Airborne Operations Planner
ATIS	Automated Terminal Information System
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
BYP	Bonham Fix
CD&R	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic Information
CE	Concept Element
CNS	Communication, Navigation, and Surveillance
CTAS	Center-TRACON Automation System
DAG	Distributed Air Ground
DEN	Denver
DFW	Dallas – Ft. Worth
DME	Distance Measuring Equipment
DST	Decision Support System
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAST	Final Approach Spacing Tool
FC	Flight Crew
FD	Flight Deck
FF	Feeder Fix
FMS	Flight Management System
GA	General Aviation
GMT	Greenwich Mean Time
GPS	Global Positioning System
HUD	Heads Up Display
IEEE	Institute of Electrical and Electronic Engineers
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ITC	In-trail Climb
ITD	In-trail Descent
KT	Knot
MASPS	Minimum Aviation System Performance Standards
MFD	Multi Function Display
MOPS	Minimum Operational Performance Standard
NAS	National Airspace System

NASA	National Aeronautics and Space Administration
NMI	Nautical Mile
No	Number
OCD	Operational Concept Description
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTCA	RTCA, Incorporated
SF21	Safe Flight 21
SFO	San Francisco
SSR	Secondary Surveillance Radar
STAR	Standard Arrival Route
SUA	Special Use Airspace
TCAS	Threat Alert and Collision Avoidance System
TFM	Traffic Flow Management
TIS-B	Traffic Information Services – Broadcast
TM	Traffic Management
TRACON	Terminal Radar Control (Facility)
UPS	United Parcel Service
VMC	Visual Meteorological Conditions
V_{ref}	Reference (landing) velocity
WAAS	Wide Area Augmentation System