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Concept of Operation for Tactical Separation Assurance in Super-Density Operations

Dallas G. Denery
UARC, University of California at Santa Cruz
Ames Research Center, Moffett Field, California

Huabin Tang and John E. Robinson
Ames Research Center, Moffett Field, California

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National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

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TABLE OF CONTENTS

INTRODUCTION 1
SUPER-DENSITY OPERATIONS 1
TACTICAL SEPARATION ASSURANCE FUNCTION 3
STORY BOARDS FOR TACTICAL SEPARATION ASSURANCE 7
PATHWAY TO IMPLEMENTATION 9
REFERENCES 10

LIST OF FIGURES

Figure 1. Major functions required for Super-Density Operations. 2
Figure 2. Notional depiction of displayed information. 4

CONCEPT OF OPERATION FOR TACTICAL SEPARATION ASSURANCE IN SUPER-DENSITY OPERATIONS

Dallas G. Denery[1], Huabin Tang, and John E. Robinson

Ames Research Center

INTRODUCTION

NASA is committed to supporting the Next Generation Air Transportation System (NextGen) through research and development in select areas. One such area, referred to as Super-Density Operations, is conducting research to develop technologies and procedures that will safely increase throughput in busy terminal area environments that involve multiple airports. As part of this effort there is a requirement to develop a Concept of Operations for Super-Density Operations that is consistent with the Joint Planning and Development Office (JPDO) NextGen Concept of Operations (ref. 1).

This document develops a Concept of Operations for the Tactical Separation Assurance function, one of the functions included in Super-Density Operations. The Tactical Separation Assurance function detects and resolves conflicts that are predicted to occur within a two- to three-minute time horizon. Several conflict-detection and -resolution algorithms for the Tactical Separation Assurance function have already been devised and evaluated (refs. 2 and 3).

The document is organized to first provide an overview of Super-Density Operations. A functional architecture along with a general description of each function and a discussion of the role of automation in the near-term, mid-term, and end-state implementations are presented. This overview of Super-Density Operations is expanded in reference 4. The overview is followed by a more detailed description of the Tactical Separation Assurance function. The next section presents several story boards to illustrate how the Tactical Separation Assurance function is envisioned to be used operationally. The last section presents a suggested pathway to implementation.

SUPER-DENSITY OPERATIONS

A functional architecture for Super-Density Operations is provided in figure 1. The architecture is based on a new concept for airspace operations, referred to as the Advanced Airspace Concept (AAC) (ref. 5). The AAC architecture achieves a high level of safety by including a two-layered architecture for separation assurance, a strategic layer and a tactical layer. The Merging and Spacing and Off-Nominal Recovery functions shown in the figure represent the strategic layer, while the Tactical Separation Assurance function represents the tactical layer. A third layer of protection is provided by an independent collision-avoidance system similar to the Traffic Alert and Collision

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[1] UARC, University of California at Santa Cruz, Ames Research Center, Moffett Field, CA 94035-1000.

Avoidance System (TCAS) that is located on the aircraft. The Extended Terminal Area Routing and Scheduling functions have been added to complete the description of capabilities required for Super-Density Operations. A brief description of each function is provided in the following sections. The descriptions are followed by a brief discussion of the role of automation as applied to separation assurance in the near-term, mid-term, and end-state implementations.

Extended Terminal Area Routing: This function provides optimized routes for efficiently routing en-route traffic to the desired airport and runway and for routing surface traffic to en-route airspace. The routing is based on many factors, including weather and airport configuration.

Scheduling: This function provides a schedule for achieving a smooth flow of arrivals and departures along the defined terminal area routes. The scheduling of flights along the routes is coordinated with the user (i.e., Airline Operations Center, or AOC), the airport, and en-route operations.

Merging and Spacing: This function provides minor adjustments to the schedule and routing to maximize the flow rate along the routes while meeting the separation requirements. This function may be implemented on the ground or in the air.

Tactical Separation Assurance: This function provides an independent prediction of a conflict (loss of separation) and, if a conflict is predicted, defines a short-term conflict-free path that resolves the conflict. In doing this task, it provides a layer of safety to protect against an operational error (blunder) or trajectory error introduced by any of the other functions.

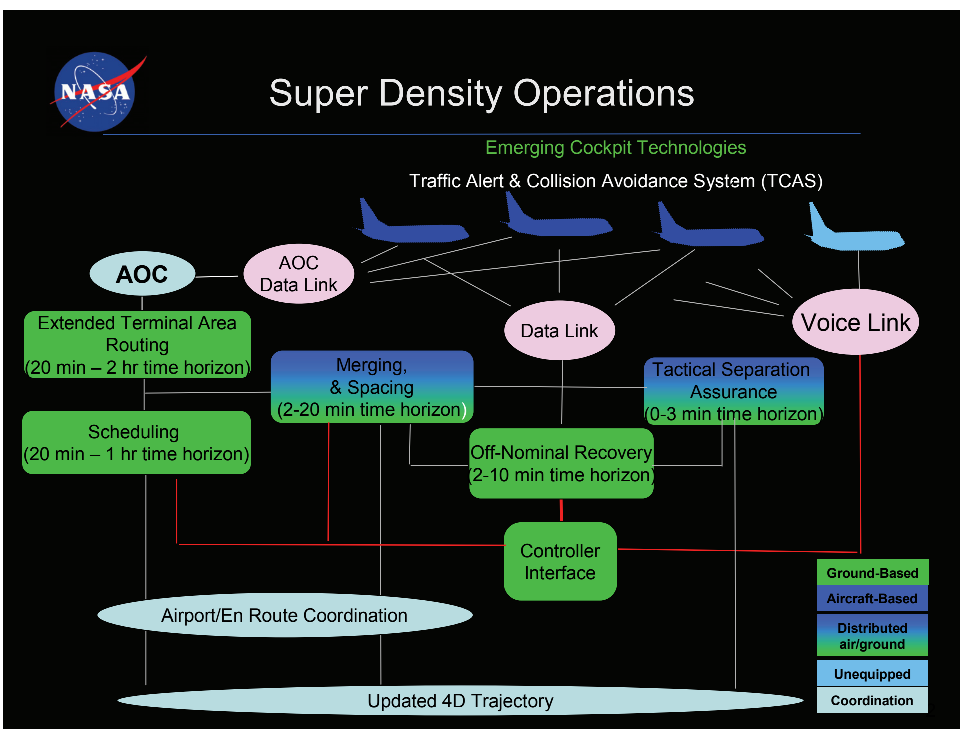

Figure 1. Major functions required for Super-Density Operations.

Off-Nominal Recovery: This function provides options for reinserting an aircraft into the stream of traffic if the aircraft is sufficiently out of conformance that the original sequencing and scheduling cannot be maintained by minor path perturbations or speed control. An aircraft that responds to a resolution issued by the Tactical Separation Assurance function is an example of an aircraft that would have to be reinserted into the sequence.

Controller Interface: This function provides the means by which the controller can interact with the automation and surveillance systems to conduct Super-Density Operations.

In the near-term concept (2015), the controller and pilot procedures are essentially the same as today. The traffic management coordinator uses Traffic Management Advisor and other information sources to schedule the flights along the nominal routes. The controller is responsible for the Merging and Spacing, Off-Nominal Recovery, and Tactical Separation Assurance functions without the benefit of computer-generated advisories. The major difference from today's operations is an improved capability for predicting an impending loss of separation.

In the mid-term concept (2025), the Merging and Spacing, Off-Nominal Recovery, and Tactical Separation Assurance functions provide the controller with computer-generated advisories to assist in the performance of these functions. It is also expected that the controller may delegate merging and spacing to the flight deck under some conditions. However, the controller is responsible for the control of traffic and identifies the function that is appropriate to the situation.

In the end-state concept (2035), the system is largely automated. Under routine conditions, the Merging and Spacing and Tactical Separation Assurance functions are performed without controller intervention. The Off-Nominal Recovery function is highly automated but is likely to require some controller interaction. It is assumed that a controller is responsible for monitoring the health of the system and is able to engage in the control of traffic if required or in cases such as when an aircraft is unable to receive data-link.

TACTICAL SEPARATION ASSURANCE FUNCTION

This section contains a more complete description of the Tactical Separation Assurance function and its operational use in the near-term, mid-term, and end-state concepts.

Near-term concept (2015): In the near-term concept, the Tactical Separation Assurance function is the responsibility of the controller. A conflict-detection capability is included to assist the controller in identifying potential conflicts, but the controller is responsible for resolving the conflicts without the benefit of computer-generated resolution advisories.

The controller procedures, interfaces, and responsibilities are similar to those used with Conflict Alert (CA) (ref. 6), and those being planned for Automated Terminal Proximity Alert (ATPA) (ref. 7). Although the displays for ATPA have not yet been completely defined, a notional depiction of the CA and the planned ATPA displays is provided in figure 2. The figure shows a sequence of in-trail traffic designated by the characters "H" moving from left to right along a defined course. The sideways V represents a site-specific landmark. A Conflict Alert results in the characters "CA" being added to the upper line of the data block where they are blinked. A CA also results in an audible warning. ATPA provides a “Cautionary Alert” and an “Immediate Attention Alert” based on time to predicted loss of separation. A “Cautionary Alert” causes the display to show a cone (see fig. 2) in yellow. The apex of the cone begins at the aircraft track and extends along the direction of flight. The length of the cone is related to the separation requirements. An “Immediate Attention Alert” turns the ATPA display orange. In the figure, the orange cone indicates an “Immediate Attention Alert” for EFG650 and EFG423.

The “Immediate Attention Alert” is activated when the predicted loss of separation is less than a predefined time, T_{IA}. The “Cautionary Alert” is activated when the time to a predicted loss of separation is greater than T_{IA} but less than a predefined time, T_C, where $T_C > T_{IA}$. Depending on the phase of flight, it is expected that the values for T_{IA} and T_C will range between 22 and 60 seconds and between 45 and 120 seconds, respectively. Because the intended purpose of ATPA is to allow the safe control of traffic as near to the separation minima as possible while Conflict Alert is to protect against a potential collision by generating an alert of a potential or actual infringement of separation minima, the Conflict Alert is activated when the predicted loss of separation is less than a predefined time, T_{CA}, where $T_{CA} \leq T_{IA}$.

The controller may decide that a tactical resolution is necessary at any time, independent of the alert status. The displays and alerts are provided to improve the controller’s awareness of the situation, but they do not require a controller response. If the controller decides that a resolution is required, the controller determines the resolution and transmits it to the flight deck via voice.

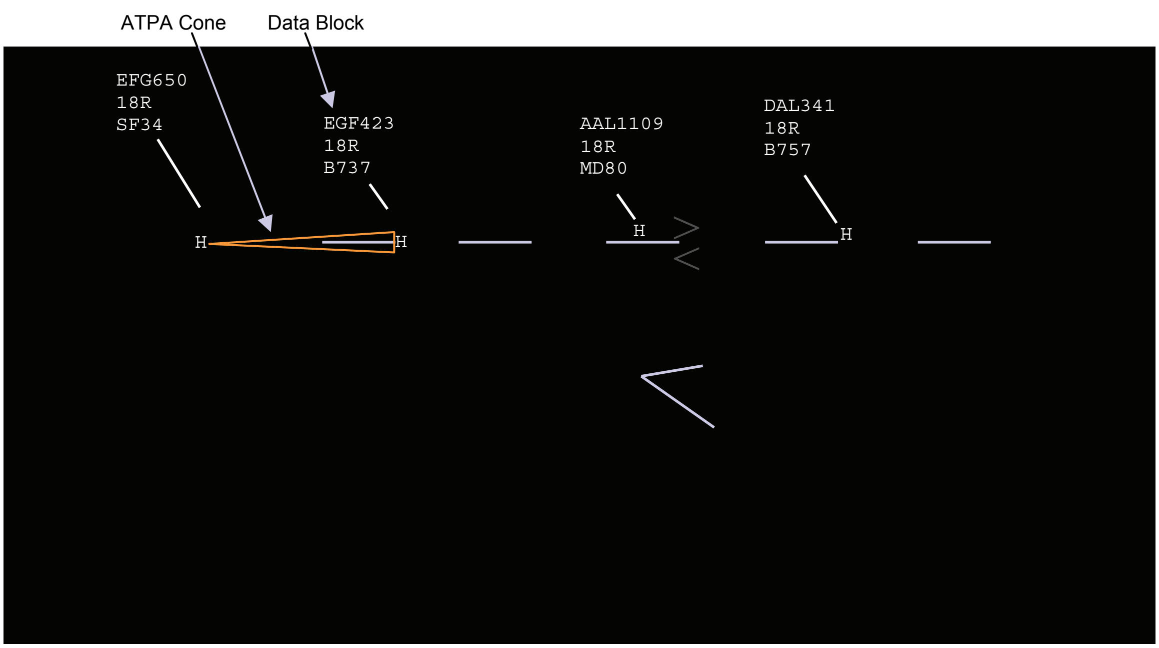

Figure 2. Notional depiction of displayed information.

The major difference between the near-term Tactical Separation Assurance function and that used today for CA and proposed for ATPA is the use of improved trajectory predictions and a strict use of Federal Aviation Administration (FAA) separation standards to provide the controller with earlier alerts and reduced false-alert rates. The improved conflict-detection algorithm drives both the CA warnings and the ATPA displays. The improved trajectory-prediction algorithm, referred to as the Flight Intent Algorithm, uses knowledge of area navigation system (RNAV) routes and site-specific terminal area procedures to infer the intended flightpath of the aircraft. The Flight Intent Algorithm combines this limited-intent information with dead-reckoning trajectory predictions to define the trajectories that are examined for a conflict. A comparison with other approaches to conflict detection using fast-time simulation of recent arrival and departure operations, some of which included operational errors, demonstrated that this algorithm achieves a significantly reduced false-alert rate with slightly improved alert lead times (ref. 3).

<u>Mid-term concept (2025)</u>: The major differences from the near-term operation are in the improvement of the conflict-detection algorithm and in the addition of automation to assist the controller in resolving a conflict involving one or more aircraft pairs. The conflict-detection algorithm differs in that it is modified to take advantage of improved surveillance data and knowledge of specific terminal routes to provide a better understanding of the intended flightpath of an aircraft, thereby potentially allowing earlier detection of an impending loss of separation and a reduced false-alert rate (ref. 2). The conflict-resolution automation assists the controller by identifying a clearance that results in a 2-minute conflict-free flightpath for each aircraft that must be maneuvered to avoid the conflict (ref. 3). It is expected that 2 minutes is adequate for the Off-Nominal Recovery function to intervene.

The algorithm for resolving a conflict results in a set of speed, altitude, and/or vector changes. Since there are usually many possible resolution clearances, they are prioritized. Each item in the prioritized list is a set of maneuvers for the aircraft involved. Depending on the location and the encounter geometry of the aircraft involved, the priorities of the clearances may be different. For example, during sequential final approaches, the relative speeds of the aircraft are small and speed maneuvers may be preferred over vector or altitude clearances. Also altitude clearances may be more efficient and less interrupting than vector clearances and so are preferred. On the other hand, in the downwind and base turn area, altitude and vector clearances may be preferred over speed maneuvers. To minimize interference with the Traffic Collision Avoidance System (TCAS), three additional rules are used in developing a prioritized list of clearances. First, because a TCAS Resolution Advisory (RA) is restricted to "climb" or "descend," the Tactical Separation Assurance function resolutions are restricted to the horizontal plane when there is concern that a TCAS RA may also be activated. Second, horizontal resolutions are prioritized so as to reduce the likelihood of inducing a TCAS RA. Third, when possible, altitude resolutions are restricted to those that do not cause the two aircraft to cross each other's altitude. A trial maneuver set is then selected from the prioritized list and validated by computing the trajectories that would result from the trial maneuver set using realistic aircraft performance parameters and determining if the resulting separations meet the separation standards. If the resolution does not provide a 2-minute conflict-free path, the process is repeated using the next trial set of maneuvers within the prioritized list. A detailed description of the algorithm is contained in reference 3.

As in the near-term implementation, the conflict-detection algorithm generates a “Cautionary Alert,” an “Immediate Attention Alert,” or a “Conflict Alert,” depending on the time to a predicted loss of separation. In a “Cautionary Alert” situation, the ATPA displays are shown in yellow. In an “Immediate Attention Alert” situation, the ATPA displays change to orange. For a “Conflict Alert” the characters “CA” are added to the upper line of the data block.

How and under what conditions the resolution is presented is subject to debate and will be a matter of research. Two options are considered here. In the first option the controller can call on the Tactical Separation Assurance function to provide a suggested conflict resolution for a “Cautionary Alert,” an “Immediate Attention Alert,” or a “Conflict Alert” by a simple manual entry. The conflict-detection alerts are used only to increase the controller’s awareness of a potential loss of separation but not to directly cause the resolution to be displayed. The concern with this approach is that it requires a manual entry in a high-workload situation. Another option being considered is similar to the first option with the exception that in a “Conflict Alert” situation the resolution is automatically displayed in a simplified format. The concern with this approach is that it may replace an existing advisory that the controller still believes will resolve the problem or result in conflicting advisories if both are retained. With either option, upon requesting a conflict resolution, the Tactical Separation Assurance function generates a clearance that results in a 2-minute conflict-free flight-path for each aircraft that requires maneuvering to resolve the conflict. If the controller accepts the resolution advisory, the controller provides the resolution to the flight deck via voice and data-link and upon concurrence by the flight deck is used to automatically update the trajectory information for that flight. If the controller issues a clearance that is not generated by the Tactical Separation Assurance function, the controller must enter it manually into the system or the flight will be treated as a nonconforming flight that is managed by the Off-Nominal recovery function.

<u>End-state concept (2035)</u>: In the end-state concept the Tactical Separation Assurance function is similar to that for the mid-term concept except that the controller is no longer responsible for routine separation of traffic. The conflict-detection algorithm still generates a “Cautionary Alert,” an “Immediate Attention Alert,” or a “Conflict Alert.” However, since the controller is no longer responsible for separation assurance, these alerts control which function is responsible for the aircraft involved in the conflict at a given instant in time. For a “Cautionary Alert” or an “Immediate Attention Alert,” the functions responsible for managing the involved flights at the time of the alert receive notice of the alert but continue to manage the flights (i.e., Merging and Spacing or Off-Nominal Recovery function). For a “Conflict Alert,” there is a transition of control of the involved flights from the functions in control at the time of the alert to the Tactical Separation Assurance function. The Tactical Separation Assurance function generates the necessary 2-minute conflict-free path that is automatically transmitted to the appropriate aircraft via voice and data-link and upon concurrence by the flight deck is used to automatically update the trajectory information for that flight.

The “Cautionary Alert,” “Immediate Attention Alert,” and “Conflict Alert” for aircraft in conflict are also shown on a plan-view display so that a controller in charge can monitor the overall health of the system. The controller in charge can request an automatically generated 2-minute conflict-free maneuver for an aircraft in conflict or intervene in the management of a specific flight at any time. The controller is also required to handle special cases such as those in which an aircraft is not equipped to receive data via data-link.

STORY BOARDS FOR TACTICAL SEPARATION ASSURANCE

The purpose of the story boards is to assure that the concept of operations for the Tactical Separation Assurance function leads to a similar set of procedures for a wide range of possible scenarios. To illustrate the similarity in operation in different situations, complete story boards are presented for two scenarios: 1) both aircraft are in three-dimensional (3-D) conformance and on the same route and 2) the aircraft are on different routes with one of the aircraft being out of 3-D conformance. An aircraft is said to be in 3-D conformance if it is on the assigned horizontal route at the correct altitude. Mid-term operations together with the first option where the controller must make a simple manual entry to be provided with an automatically generated resolution are used as the basis for developing the primary story board for each scenario. Differences in near-term and end-state operations are then discussed.

<u>Aircraft A1 and A2 are in 3-D conformance on the same route:</u>

Situation: Aircraft A1 and A2 are on downwind. A1 is flying at 210 knots ground speed. A2 is assigned an airspeed based on altitude and winds that would position A2 behind A1 with the correct spacing. Because of errors, the clearance leads to A2's closing on A1 faster than expected, causing a potential loss of separation. The hypothesized sequence of actions in case of such an error follows:

Mid-term implementation follows:

- A loss of separation is predicted to occur at a time less than T_C but more than T_{IA}, thereby activating a "Cautionary Alert."
  - A yellow ATPA cone, which extends from the trailing aircraft, A2, in the direction of flight, is displayed on the controller's screen.
  - The "Cautionary Alert" can be transmitted to the automation within the Merging and Spacing function for use if required.
  - The "Cautionary Alert" can be transmitted to the aircraft for use via voice and/or data-link if required.
  - The controller continues to use the Merging and Spacing function to provide speed and path adjustments to maintain spacing.
- A loss of separation is predicted to be less than T_{IA} seconds, thereby activating an "Immediate Attention Alert."
  - The ATPA cone on the trailing aircraft is changed to orange on the controller's screen.
  - The controller reviews the situation, determines that a resolution is required, and requests a tactical resolution advisory from the Tactical Separation Assurance function.
  - The Tactical Separation Assurance function generates a suggested 2-minute conflict-free path for A2 that resolves the predicted conflict.
  - The controller accepts the automatically generated 2-minute conflict-free path and transmits the resolution in the form of a clearance to the flight deck of A2 via voice and data-link.
  - Upon concurrence by the flight deck the resolution is used to automatically update the trajectory information for that flight.

Near-term implementation follows:
In the near-term implementation, the scenario is the same except that the controller is required to define a resolution without the benefit of a computer-generated advisory.

End-state implementation follows:
In the end-state implementation, the system is largely automated. The Merging and Spacing function maintains control over the involved flights until a "Conflict Alert" is issued. For a "Conflict Alert," the Tactical Separation Assurance function automatically generates a 2-minute conflict-free path that is transmitted to the appropriate aircraft via data-link and computer-generated voice without requiring controller intervention.

Aircraft A1 and/or A2 are out of 3-D conformance:

Situation: A1 is following a nominal terminal area arrival route. A2 is a departure from a nearby airport along an RNAV departure route. A2 incorrectly believes that it was given a clearance to do a "direct to." In executing the "direct to," A2 is on a path that will lead to a loss of separation with A1. A1 is under responsibility of the Merging and Spacing function. It is recognized that A2 is not following the assigned clearance and is being managed by the Off-Nominal Recovery function. Both aircraft are in radio contact with the terminal radar approach control facilities (TRACON). The hypothesized sequence of actions in case of such an error follows:

Mid-term implementation follows:

- A loss of separation is predicted to occur at a time less than T_C but more than T_{IA}, thereby activating a "Cautionary Alert."
  - ATPA displays are presented in yellow on the controller's screen. (The actual displays to be used in this situation have not yet been defined.)
  - The "Cautionary Alert" can be transmitted to the Merging and Spacing and Off-Nominal Recovery functions for use if required.
  - The "Cautionary Alert" can be transmitted to the aircraft via voice and data-link for use if required.
  - The controller or controllers continue to use the Merging and Spacing and Off-Nominal Recovery functions to provide strategic resolutions to A1 and A2, respectively.
- A loss of separation is predicted to be less than T_{IA} seconds, thereby activating an "Immediate Attention Alert."
  - A1 and A2 ATPA displays are changed to orange on the controller's screen.
  - The controller reviews the situation, determines that a tactical resolution is required, and requests a tactical resolution advisory from the Tactical Separation Assurance function.
  - The Tactical Separation Assurance function generates clearances that will provide 2-minute conflict-free paths for both A1 and A2 that resolve the predicted conflict (a resolution involving only one of the aircraft was not found).
  - The controller accepts the automatically generated clearances and transmits the clearances to the two aircraft via voice and data-link.
  - Upon concurrence by the flight deck the resolution is used to automatically update the trajectory information for that flight.

Near-term implementation follows:

- In the near-term implementation the scenario is the same except that the controller is required to determine a resolution without the benefit of computer-generated advisories.

End-state implementation follows:

- In the end-state implementation the system is largely automated. The Merging and Spacing and Off-Nominal Recovery functions maintain control over aircraft A1 and A2, respectively, until the “Conflict Alert” is issued. Upon activation of the “Conflict Alert,” the Tactical Separation Assurance function generates 2-minute conflict-free paths for A1 and A2 that are transmitted to the appropriate aircraft via data-link and computer-generated voice without requiring controller intervention. The resolution is automatically added to the trajectory information for the involved flights.

PATHWAY TO IMPLEMENTATION

The pathway to implementation is highly uncertain and will depend on further research. Nevertheless, it is advantageous to at least envision how this capability may eventually be implemented into the National Airspace System (NAS).

In preparation for the near-term time frame, NASA will engage with the FAA to determine the feasibility and benefits that would be derived by modifying the ATPA and CA to include an improved conflict-detection capability based on some of the concepts developed as part of the NASA Airspace Systems Program. Although a direct comparison has not yet been conducted, fast-time simulation of recorded arrivals and departures in a busy terminal area has demonstrated that the Flight Intent Algorithm with a strict use of FAA minimum separation requirements may provide earlier detection of a conflict with a lower false-alert rate than those currently being used with CA and ATPA. A next step would be to conduct a more thorough evaluation of the different approaches to conflict detection and take the best of each approach to develop the conflict-detection algorithms that would form the basis of the automation included in the near-term Tactical Separation Assurance function.

Similarly, in the mid-term time frame, it is proposed to work with the FAA in the development and evaluation of the algorithms for conflict resolution. Although an initial conflict-resolution algorithm has been developed under the NASA Airspace Systems Program, it has not been tested in simulation with FAA controllers. The next step will be to further refine the algorithm through controller-in-the-loop simulations. In parallel, the conflict-resolution algorithm will be tested against live traffic data to determine its ability to successfully resolve a conflict. Upon FAA concurrence, the algorithms will be evaluated by active controllers in a shadow mode at an FAA-selected facility. The shadow-mode evaluation will be followed by a field evaluation. Upon successful completion of the field evaluation, the technology will be transferred to the FAA for implementation into the terminal area automation system.

In the end-state time frame, the Tactical Separation Assurance Function is meant to automatically detect and resolve conflicts without controller intervention. The clearances would be automatically transmitted to the flight deck via data-link and upon concurrence by the flight deck they are uploaded into the flight management system (FMS) or flight control system for execution. This scenario clearly represents a major departure from the mid-term concept where the automation provides the controller with resolution advisories but the controller is still responsible for separation. The transition will depend on confidence that the automation will lead to safe and acceptable operations. To gain the necessary level of confidence, the resolution advisories provided in the mid-term concept will be monitored and evaluated for accuracy, robustness, and acceptability and a comprehensive risk analysis will be conducted. In parallel, the end-state version of the Tactical Separation Assurance function will be tested in fast-time simulations to assure statistically significant results and in human-in-the-loop simulations to understand the feasibility of controller intervention in emergency situations. Initial use of the Tactical Separations Assurance function for controlling traffic will be in low-density traffic conditions with controller oversight. As confidence improves (based on use in low-density conditions and safety analysis), the end-state Tactical Separation Assurance function will be used with increasing levels of traffic until it is accepted for routine operations.

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