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AIR TRAFFIC CONCEPT UTILIZING 4D TRAJECTORIES AND AIRBORNE SEPARATION ASSISTANCE

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ABSTRACT

This paper presents a concept – with the potential for increasing airspace system-wide efficiency and safety – which combines strategic, 4-D user-preferred trajectories with tactical, Airborne Separation Assistance Systems (ASAS). First, prior research and concepts for improving air traffic management are reviewed. Second, the concept for integrating trajectory-orientation and airborne separation assistance is described. Using an example traffic scenario, we then examine how the conflicts might be resolved using A) current day tactical operations, B) current day tactical operations with airborne separation assistance added, and C) a pure trajectory-oriented approach.

Next the example traffic problem is examined in the context of the proposed mixed Trajectory-Oriented and ASAS Limited Delegation Clearances concept. Trajectory-based operations are first used to precondition the flow, sufficient to avoid overloading local airspace sectors. Subsequently, ground controllers issue limited delegation clearances to aircraft to cross behind, merge with, or follow proximal aircraft. Flight crews execute these clearances using ASAS aircraft automation.

Finally, the paper describes an evolutionary path for implementing the concept. Initially, advanced trajectory tools can be introduced on the ground (ATC), with aircraft requiring only planned upgrades such as the migration to ADS-B communications technology. With the progressive introduction of more Cockpit Display of Traffic Information (CDTI) technology, flight-deck based trajectory tools and data link, flight crews will be able to select preferred routes using trajectory negotiation, and autonomous operations could be facilitated.

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INTRODUCTION

Today's sector-oriented air traffic control (ATC) is characterized by *tactical* controller actions protecting separate sections of airspace. This may cause inefficiencies for individual flights, because controllers can not always be aware of the impact of their actions on downstream sectors.[1] The sector-oriented approach also requires controllers to issue multiple instructions to each aircraft in high-traffic-density sectors. The resulting ATC workload and radio frequency congestion limits the number of aircraft that can be safely managed in a sector at any given time. Different approaches for ameliorating these operating inefficiencies and workload have been proposed and pursued by air traffic management researchers.

TRAJECTORY-ORIENTED APPROACHES

Trajectory-oriented approaches focus on shifting the air traffic control paradigm from one of *tactical* sector-based operation toward *strategic* planning and execution of flight trajectories that span several sectors. Trajectory-based solutions to NAS traffic management are postulated as promoting efficiency by taking a longer-term, flight cost-effectiveness approach, as opposed to simply looking at localized traffic constraints. Major projects devoted to the trajectory-oriented concept include the 1) Programme for Harmonized Air traffic Management in Europe – PHARE,[2] 2) Center TRACON Automation System – CTAS,[3] and 3) Distributed Air/Ground - Traffic Management – DAG-TM.[4] Each is discussed below. The ASAS Limited Delegation concept, which is not based on a trajectory oriented approach, is discussed in the following section.

1. PHARE

PHARE was a European research program conducted from about 1990 to 2000. The concept consisted of a 'contract' negotiated between the air and ground to fly 4D trajectories, often referred to as "4D tubes" in the sky, within given tolerances. The concept required the use of advanced flight management automation and data link tools, which are not available on today's flight decks. Thus one conclusion from the research was that the concept required too much new technology, and that it lacked the flexibility required for dealing with conflict resolution issues.

2. CTAS

The core of CTAS is a sophisticated trajectory synthesizer that predicts trajectories for each flight based on available flight data information from the host ATC computer, accurate aircraft performance models, and other database information. Accurate 4D flight trajectory prediction enables CTAS to create schedules for runway occupancy, final approach and meter fixes; detect future separation violations; recommend shortcuts; and/or provide advisories to controllers that result in efficient descent paths.

The first CTAS tools that were experimentally fielded in the United States were the Passive Final Approach Spacing Tool (P-FAST) and the Traffic Management Advisor (TMA). Both tools were designed to support traffic management rather than air traffic control operations, using the results of trajectory computations for scheduling and sequencing purposes. This information is presented to traffic managers as timelines and load graphs, and to sector controllers as a meter list, a sequence number in the data tag, or runway assignment recommendations.

The next CTAS tool to be fielded is Direct-To (D-2). The D2 tool, currently undergoing further evaluation, allows sector controllers to visualize, and if desired modify aircraft trajectories to provide routing shortcuts that save time and reduce fuel consumption.

Since its original conception, CTAS has been intended to provide more sophisticated 4D trajectory based functions. The Enroute Descent Advisor – EDA[5,6] and the Active-Final Approach Spacing Tool – A-FAST[7,8] are conceptualized to generate conflict free trajectories for arriving aircraft that meet scheduling constraints. Advisories are displayed that enable sector controllers to issue clearances that guide aircraft along de-conflicted trajectories.

It is clear that computationally, a ***near*** optimal set of de-conflicted trajectories, taking into account airline operations center (AOC) preferences and flow management constraints can be generated for controllers. However, the practical execution of these optimal trajectories faces a number of operational challenges, including:

- Uncertainties in the trajectory prediction due to unknown conditions and input parameters not factored in
- Human factors issues for controllers and flight crews in modifying, communicating, and monitoring trajectories under time pressure
- Imprecise execution of clearances on the flight deck by flight crews or flight management automation systems

Erzberger and Paielli[9] proposed dealing with these issues by automating most of the air traffic management and communication functions, and having controllers and simple, certifiable automation supervise the trajectory-based functions that automate the airspace. This concept as proposed requires, however, a significant amount of additional automation, and a comprehensive re-organization of the airspace.

3. DAG-TM

The Distributed Air Ground - Traffic Management – DAG-TM[4,10] project, specifically en route concept elements 5 and 6, propose the use of a trajectory-oriented approach, distributed between air and ground elements, to investigate the feasibility and potential benefits of trajectory negotiation and autonomous flight deck operations, respectively. DAG-TM places particular emphasis on human factors issues by trying to focus on the development of automation and procedures that provide controllers and flight crews with advanced tools for managing, modifying, and communicating trajectories.

The trajectory-oriented approach to ATM has been investigated in several research projects. Recently, high fidelity, human-in-the-loop DAG-TM simulations have been conducted at NASA's Ames Research Center. A detailed description of the experimental conditions and the results of these experiments can be found in Prevot et al.[11] and Lee et al.[12.]

In summary, in these experiments 4D trajectory-based operations resulted in:

- A significant reduction in the variance of the inter-arrival spacing at the metering fix; indicating that aircraft were delivered more consistently
- More efficient descent paths, i.e. many aircraft were able to remain longer at a higher altitude, and then flew uninterrupted idle descents
- Reduced sector controller workload at the low altitude position, which is responsible for merging aircraft at the meter fix
- No workload increase in the high altitude feeder positions, which set up the trajectories for the low altitude position
- Better (self-reported) performance by the controllers than in a current day control condition

The main problems encountered in this experiment were:

- Trajectory de-confliction along the paths to the metering fix
- Usability of some of the ground automation tools, especially the responsiveness of the trial planning tool that the controllers used to generate new trajectories

A detailed description of these results and recommendations on how to resolve the problems can be found in Prevot et al.[11]

Airborne Separation Assistance Systems and Limited Delegation

A parallel research effort targeted at improving air traffic efficiency is aimed at utilizing Airborne Separation Assistance Systems (ASAS) to achieve two significant benefits: 1) improve flight crew situation awareness, and 2) lower controller workload by using limited delegation of spacing tasks to the flight crew. This concept (in its original form) does not rely on trajectories to facilitate controller issuance of strategic clearances. Controllers instead temporarily delegate tasks like merging behind or following a lead aircraft to flight crews of appropriately equipped planes. The flight crew is then responsible for achieving and maintaining a cleared time-interval or distance relative to the lead aircraft using advanced aircraft automation and displays. Studies have shown that this approach can reduce controller workload without negatively impacting pilot workload.[12, 13]

In summary, the ASAS concept addresses local separation, provides for good safety margins, introduces redundancy into the separation assurance process, and enables efficient local conflict resolution strategies. Some shortcomings of this concept to consider include:

- No global traffic flow strategy
- Reduced predictability of flight paths
- Controllers need to tactically direct aircraft to a proper position from which the goal of the limited delegation clearance is achievable

Eurocontrol studies have investigated limited delegation operations when providing miles-in-trail flows of aircraft operating in extended terminal areas. Specific procedures were developed to allow controllers to issue a limited delegation clearance and initial vector in a single clearance.

In addition to the ASAS Limited Delegation concept described above, DAG-TM's concept element 11 (*Terminal Arrival: Self-Spacing for Merging and In-Trail Separation*) uses limited delegation clearances for time-based, in-trail approach spacing in the Terminal Radar Approach Control (TRACON) environment. Issuance of these spacing clearances is reliant on CTAS-generated scheduling of aircraft across a metering fix, and dependent on said aircraft meeting the allotted 'time slot.' In DAG-TM, therefore, CTAS and CDTI trajectory-oriented tools and procedures facilitate ASAS/limited delegation tool-use and procedures in the TRACON.

In the following section a concept is proposed for combining the trajectory-based approach with an ASAS/limited delegation approach in the same airspace.

Concept Definition

The concept is defined as follows:

(1) Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and,
(2) maintain local spacing between aircraft with airborne separation assistance.

It is intended that the concept:

- Take full advantage of the traffic flow management benefits of the trajectory-oriented approach.
- Reduce to a minimum any additional conflict resolution buffers arising out of prediction uncertainty.
- Reduce controller workload.
- Minimally impact flight crew workload.
- Have a positive effect on controller and flight crew traffic awareness.
- Limit the deviations from the 4D path to short-term deviations mostly due to speed changes, thereby minimizing the medium to long-term prediction uncertainty.
- Minimize lateral route and/or altitude changes for local separation assurance.

The concept is discussed in detail using a hypothetical traffic problem in transition (en route to terminal) airspace. First, the operational airspace and traffic problem are described. Second, the advantages and limitations of independent self-spacing and trajectory-based operations are discussed, followed by a visualization of how combining these elements can result in a feasible, widely beneficial solution.

<u>Example Traffic Problem</u>

A single, generic traffic problem is used throughout the balance of this paper to illustrate the effects of different air traffic management concepts and strategies. The problem "start point" is diagrammed in Figure 1. For all concept discussions the traffic situation is depicted for two time snapshots – T1 and T2 – that would take place approximately five and ten minutes after the start point. These snapshots show how the traffic situation might unfold, if a particular strategy or concept were applied to solve the problem. Please note, these snap shots are for illustrative purposes only, the traffic depictions are ***not*** to scale, and thus may make events appear to unfold faster than they would in reality.

Figure 1 depicts an air traffic problem comprising four aircraft. Planes A, B, and C are arrivals on converging routes into the same airport. The routes merge at a "metering fix," which could be a TRACON corner post or one of many other merge points. Aircraft D is crossing two arrival streams, flying from the south to the north. Obviously, in current day operations altitude changes are among the most effective strategies for resolving separation problems. For purposes of this hypothetical situation, please assume that altitude separation between aircraft in this transition airspace is *not* feasible, and that lateral separation must, therefore, be achieved.

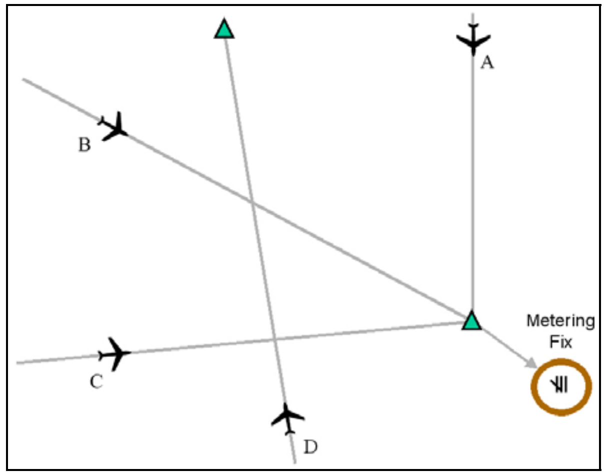

Figure 1. Traffic problem. A, B, and C represent arrivals that need to cross the metering fix, and D is an overflight crossing the arrival stream.

Figure 2 shows the same problem at the later time T1; assuming no action is taken to resolve the traffic conflicts. The radius of the solid circles around the aircraft is 2.5 nautical miles (NM). Whenever these circles intersect, the respective aircraft are closer than the legal separation requirement of 5 NM in enroute airspace.

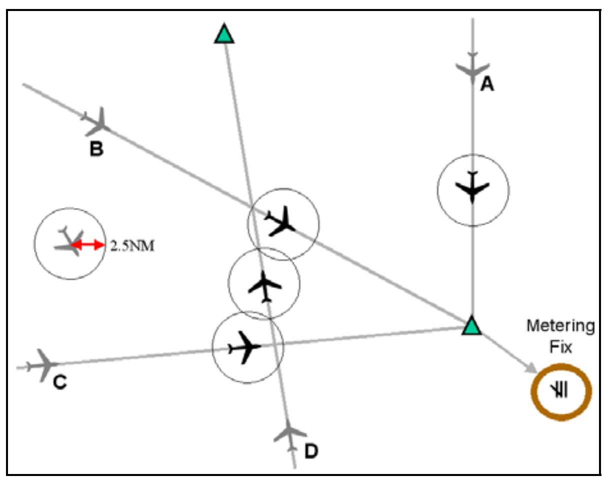

Figure 2. Example traffic problem at Time T1.

At time T1 (Figure 2) aircraft D has violated safe separation with arriving aircraft B and C. At T2 (Figure 3) aircraft A, B, and C arrive at the metering fix at approximately the same time, also violating minimum safe separation requirements.

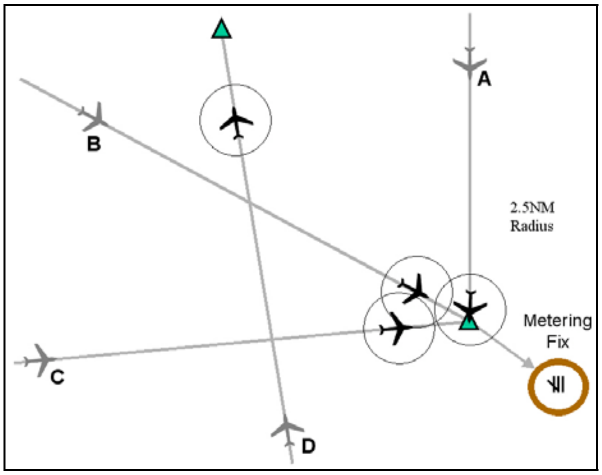

Figure 3. Example traffic problem at Time T2.

In order to provide for the safe and efficient flow of traffic, the following has to be accomplished:

1. Overflight aircraft D needs to be separated from arrivals A and B.

2. Arrival aircraft A, B and C need to be delivered to the metering fix, closely spaced, but safely separated. (Assume a target distance of six NM in trail.)

3. The route changes necessary to accomplish (1) and (2) above need to be minimized, in terms of course deviation and flight crew workload.

Resolution Using Tactical Sector-Based Operations

In current day operations, tactical maneuvers are used to ensure aircraft separation within a sector. If altitude changes are not possible or feasible, controllers issue heading clearances (vectors) to flight crews, to manage separation. These heading vectors are selected such that they keep the aircraft on a conflict-free path for several minutes to make sure that separation remains guaranteed, in case the controller can not give another instruction to the aircraft quickly, or radio communication is lost. As a consequence of this, the vectors can sometimes appear excessive, when in fact this strategy is necessary to ensure safety.

Figures 4 (showing resolution at time T1) and 5 (showing T2) illustrate one way a controller might handle the traffic problem, given the current day environment and restrictions.

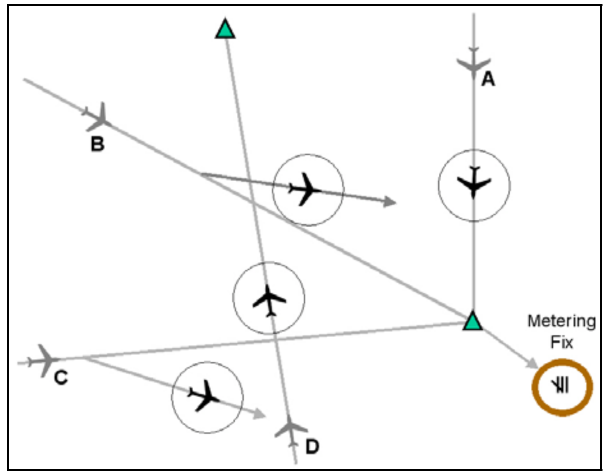

Figure 4. Example solution to traffic problem with tactical operations at Time T1.

In Figure 4 aircraft B is turned thirty degrees left to be sequenced behind A, and increase the separation with D. The controller will have to monitor B and turn the aircraft back toward the metering fix when it is safely behind A. Aircraft C is turned thirty degrees to the right to remain separated from D. The controller must monitor this situation to decide when to turn C back toward the metering fix (its original route).

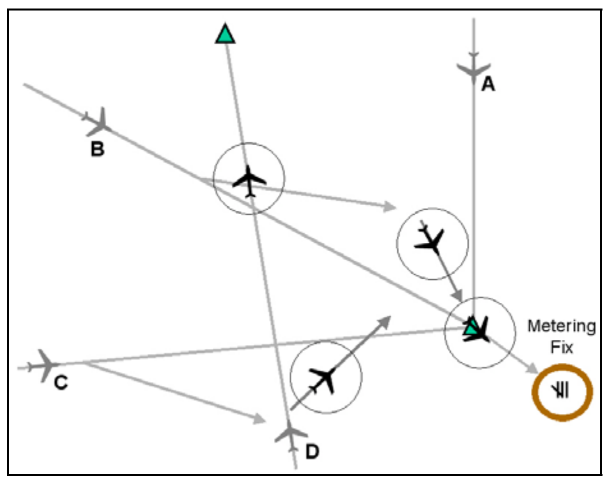

Figure 5. Traffic solution at Time 2.

As the traffic progresses, B and C are turned back toward their original routes or the meter fix. Controller workload and safety concerns often result in additional delay between the times a clear path is available and the air traffic control instruction is issued, leading to additional spacing between aircraft. In this instance C cannot be turned back directly toward the metering fix, because separation with B still needs to be established. The controller has to monitor the situation until turning C behind B appears appropriate.

This example illustrates that current day tactical operations are safe, but at the same time workload intensive, and that they can lead to inefficiencies, albeit necessary to provide the required degree of safety. The additional complication of the existing sector-based airspace organization can lead to further inefficiencies as described, for example, in Leiden and Green (2000)

Resolution Using Limited Delegation of Spacing Operations to Flight Crew

One approach pursued in the Eurocontrol "Freer-Flight" program[14] as well as DAG-TM's CE 11 is to delegate part(s) of the localized spacing task to appropriately equipped and positioned aircraft.[15] By instructing flight crews to maneuver relative to another aircraft, controllers are relieved of elements of the monitoring task, which is often required, as explained in the previous section. Experimental results[13] indicate that this approach shifts the controller's attention toward the areas where the planning of merging and crossing situations takes place and then reduces controller workload as the aircraft converge. This shows that less monitoring is required.

At the current time only speed based self-spacing algorithms are being considered for near-term implementation, similar to those analyzed in Hoffmann, et al.,[13] Abbott,[16] Kelly and Abbott,[17] and Sorensen and Goka.[18] This type of algorithm can be used, for example, to "merge behind", "follow in trail", or "cross behind" other aircraft. "Merge behind" or "cross behind" delegations of local separation responsibility are often associated with waypoints defining the location of the merge point or the intersection. The research indicates that aircraft equipped with spacing automation can be expected to meet their target distance within less than one NM +/-. Therefore, a target distance of six NM can be considered appropriate to make sure a separation distance of five NM is ensured at the merge or cross point. Consider the traffic example described earlier in the context of limited delegation clearances.

Figures 6 and 7 show how the traffic situation unfolds if only limited delegation clearances are issued, without any additional flight path changes. In this example aircraft speed is the only control parameter.

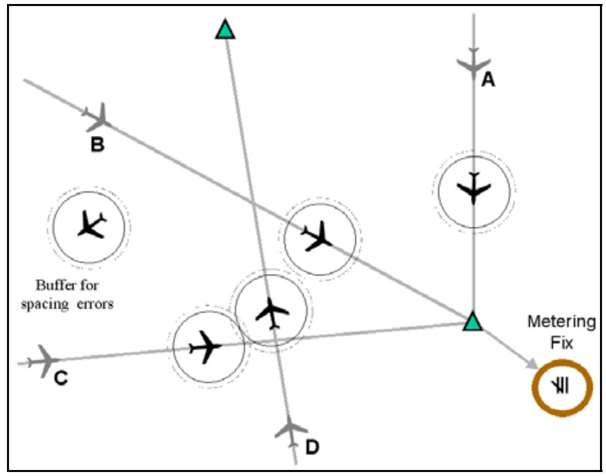

Figure 6. Traffic situation at T1 with delegation of speed control and no route changes.

In Figure 6 aircraft B is instructed to merge six NM behind A at the metering fix. D is instructed to cross six NM behind B, and C to cross six NM behind D. However, at the time the clearances are issued, the aircraft pairs are too close together to achieve the required spacing in time, using speed control alone. The same situation holds true at time T2, see Figure 7. Speed control is insufficient to establish the minimum separation by the time the aircraft reach the metering fix.

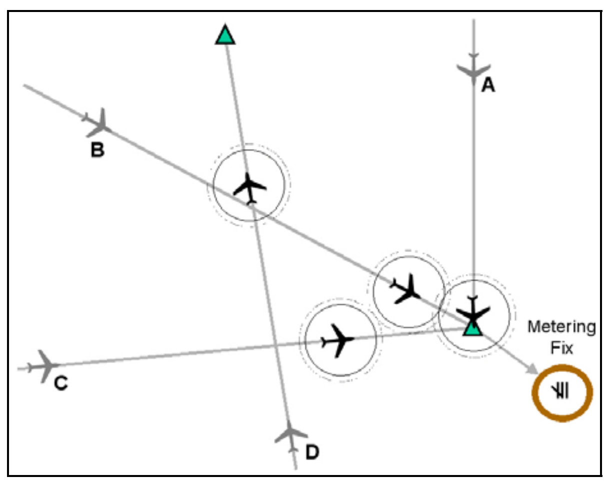

Figure 7. Traffic situation at T2 with delegation of speed control and no route changes.

In order to solve the problem in today's environment controllers have to issue heading changes ("vectors") to manage the conflicts and merging trajectories

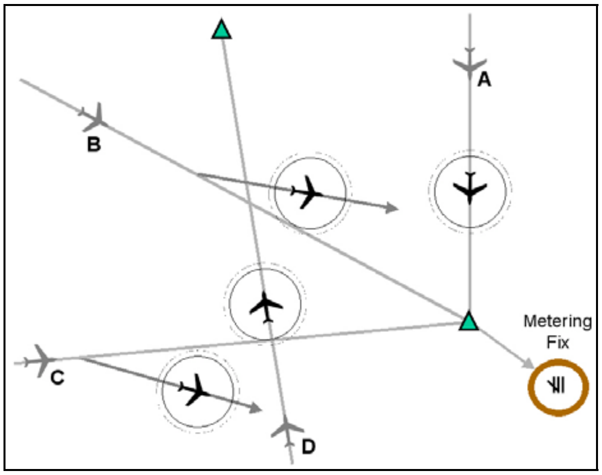

Figure 8. Airborne separation assistance added to the current day environment at T1.

After issuing the initial heading change, the controller has to monitor until the aircraft are in a position to achieve a desired target distance at the merge point, and then clear them direct to the metering fix. Figure 9 shows B merging behind A, and C merging behind B. The efficiency of this mixture of tactical operations with limited delegation clearances depends heavily on the controllers' skill and decision support tools to estimate the appropriate heading changes that position the aircraft enough to delegate the spacing task to the flight deck.

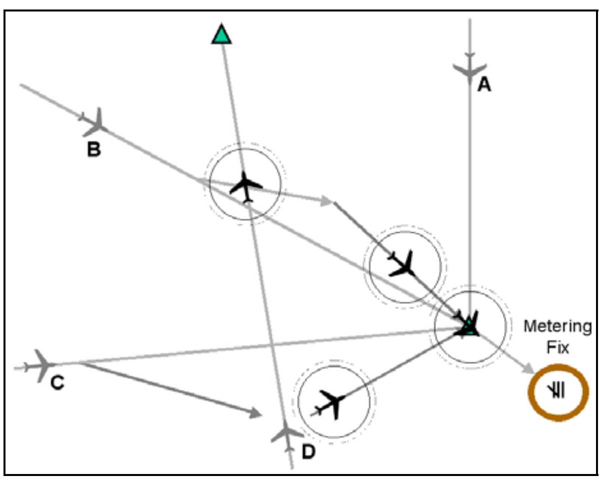

Figure 9. Airborne separation assistance added to the current day environment at T2.

One problem with this combination is that the aircraft trajectories are unpredictable, thus not providing the benefits of trajectory-based operations, discussed in the following section.

<u>RESOLUTION USING TRAJECTORY-BASED OPERATIONS</u>

Trajectory-based operations shift the air traffic control paradigm from tactical to strategic. Complete 4D trajectories are generated for each flight and used for traffic management purposes, such as scheduling and sequencing, and for ATC purposes such as conflict detection and resolution, re-routing, and arrival time management. Trajectories can be generated by the airborne flight management system or by ground automation such as CTAS (see earlier discussion). The idea is to generate conflict-free trajectories ahead of time, and let the aircraft automation or the sector controllers guide the aircraft along these trajectories. These trajectories are planned to meet time constraints for traffic flow management purposes, and thus include necessary route modifications to comply with metering restrictions.

As a consequence of uncertainties in the environmental conditions aloft, as well as in the aircraft's navigation and operational performance, trajectory predictions can be inexact. One way of compensating for these uncertainties is to plan for extra separation between aircraft. In this example three NM have been added to the minimum separation of five NM to account for trajectory prediction uncertainties. This means that if the predictions were perfect, all aircraft should miss each other by eight NM.

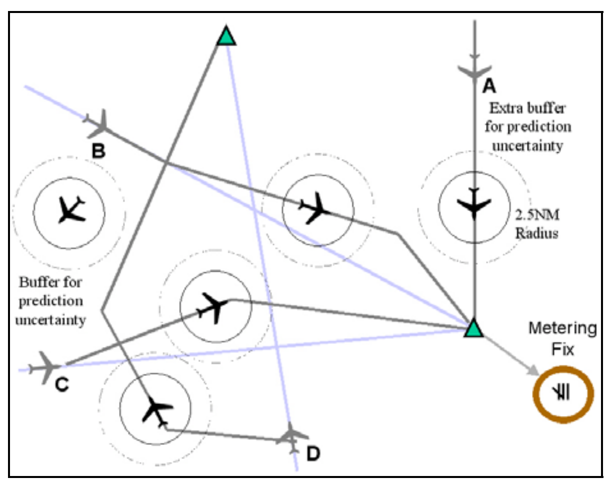

Figure 10. Trajectory-based approach at T1, if eight NM separation was used during the de-confliction to account for the prediction uncertainty.

Figure 10 depicts a set of trajectories that provide eight NM buffers for the example scenario traffic.

The figure further indicates how integrating the time-constraints into the trajectory planning process results in a well-prepared merge situation at the metering fix.

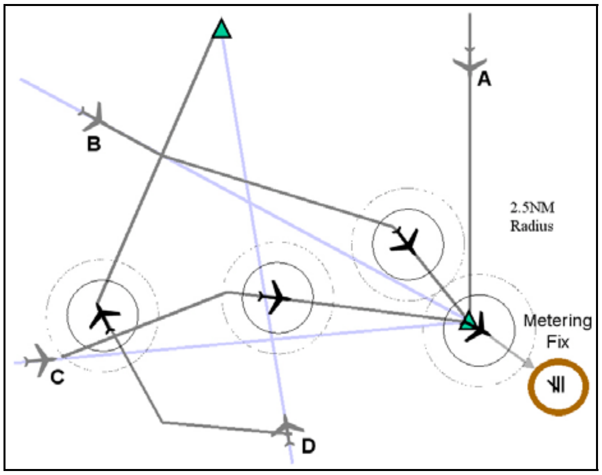

Figure 11. Trajectory-based approach at time T2, if eight NM in-trail spacing was used during the scheduling process.

Figure 10 shows that aircraft B and C have been re-routed to meet their scheduled time of arrival at the metering fix on conflict-free trajectories. Aircraft D was given a significant re-route because no direct path providing eight NM separation through the arrival paths of B and C was possible. Once planned and communicated, the controller should not have to perform any additional actions to handle the arrival flow. As indicated in Figure 11, the aircraft should arrive at the metering fix on schedule without conflicts, if the schedule was generated accounting for the uncertainty in the trajectory-predictions.

Resolution Using the Proposed Concept: Combine Trajectory-Orientation and Airborne Separation Assistance Systems

The concept proposed here is similar to one outlined by Graham, et al.[19] In their theoretical discussion of absolute navigation (i.e., trajectory-based operations), versus relative navigation (i.e., ASAS-type operations), the authors propose that absolute navigation operations should be utilized for traffic flow management purposes, while relative navigation operations should be used to handle separation issues. The results discussed in an earlier section indicate, however, that trajectory-oriented operations can provide benefits for the air traffic controller *in addition* to the traffic flow manager. Earlier discussions in this paper also indicate that ASAS-type operations are most effective if the aircraft are preconditioned properly.

If ASAS operations are used for localized separation requirements, the trajectory-oriented set of generated routes need only provide separation buffers that reflect the tolerances, which can be assumed achievable with local ASAS operations. Therefore, the six NM buffers assumed before should be sufficient.

The trajectory-oriented approach can ensure that the airspace is not overloaded at any given time. Required Times of Arrival (RTAs) can be sent from scheduling tools to meter aircraft into high-density areas. Crossing, merging and in-trail following activities would be handled by relative spacing operations. In contrast, passing situations and head on conflicts would be resolved via trajectory changes, since they require route or altitude modifications that are not part of the proposed spacing function.

The traffic problem could be handled as illustrated in Figures 12 and 13. The excess spacing buffers required for trajectory de-confliction can be reduced with ASAS (e.g. from three NM to one NM). Therefore, the overflight aircraft D can be planned to pass through the arrivals B and C with only a minor route modification for aircraft B and D. The schedule at the metering fix can be planned more aggressively, because the buffers between aircraft can also be reduced at the merge point. The schedule can be communicated to the flight deck, which can input the time as an RTA.

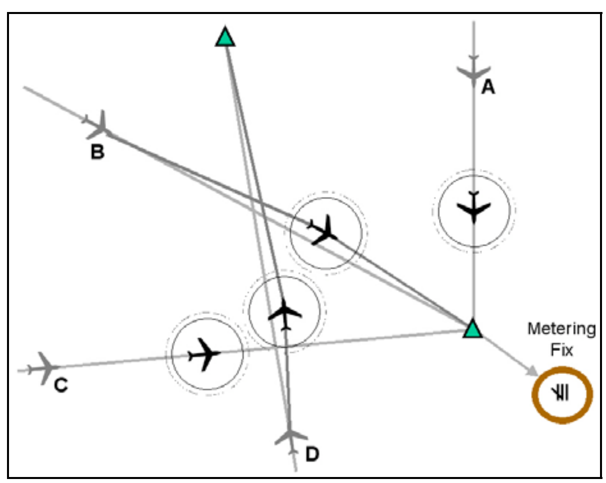

Figure 12. Solution to traffic problem with proposed concept at T1.

Whenever aircraft encounter local spacing problems, relative operations would be used. In figure 12 aircraft D crosses six NM behind B, and C crosses six NM behind D. These modifications can be accomplished with minor route changes by the controller and speed changes managed on the flight deck, without overloading the controller. When the separation situation is resolved, aircraft can resume their original trajectories, speeding up or slowing down slightly to make up for the intermediate speed changes or trajectory deviations. Once on time at the next merge point, relative operations can again be used to fine-tune the merge.

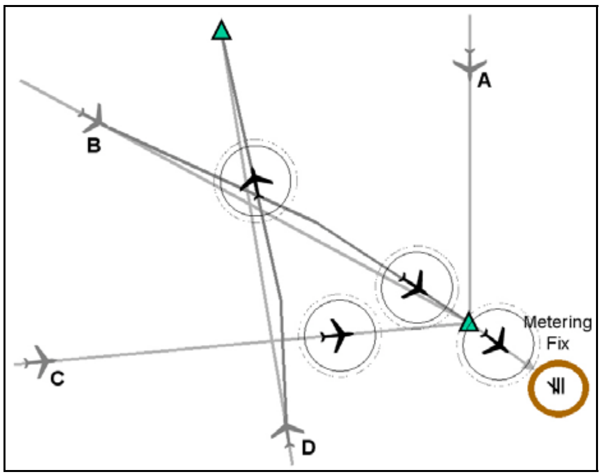

Figure 13. Solution to traffic problem with proposed concept at T2.

At T2 (Figure 13) B merges behind A, and C merges behind B. By delegating the relative spacing task to the flight deck an efficient and flexible flow will be maintained, *without* increasing the controller's workload.

In order to apply this concept successfully, the trajectories should be planned with nominal speed profiles that avoid using the edges of the aircraft's operating envelope. This is fuel-efficient and allows room for speed changes for spacing operations.

Concept Implementation

Automation

Initially, advanced trajectory tools can be implemented on the groundside, while the aircraft need only make planned upgrades such as the switch to ADS-B technology and improvements to the traffic displays. A suitable set of CTAS-based tools and human-factors recommendations is described in Prevot et al.[11] Earlier field test observations on CTAS trajectory tools can be found in McNally et al. [20]. The development of the Enroute Descent Advisor[6] will facilitate generating conflict free trajectories. Additionally, the controller's toolset should include a simple spacing/merging algorithm that provides spacing visualization and advisories on demand, to support controlling unequipped aircraft and monitoring equipped aircraft. A similar state-based spacing algorithm can be implemented on the flight deck. With Cockpit Display of Traffic Information (CDTI) technology progressing, flight-deck based trajectory tools and data link introduced, flight crews will be able to plan and execute preferred routes given trajectory negotiation with the ground. Appropriate flight deck tools are described in Johnson, Battiste and Bochow.[21]

Data link can be used to communicate trajectory clearances and intent, in addition to limited delegation clearances. More revolutionary concepts like DAG-TM's CE5 that include autonomous aircraft operations could also be supported by this concept with flight crews responsible for creating conflict-free trajectories and then switching to spacing operations autonomously when they need to merge or cross behind other aircraft.

Airspace

The use of the concept is not restricted to any particular type of airspace. It is likely most powerful, if used during all phases of flight. Trajectory planning starts pre-flight and can be updated throughout the flight. Aircraft can be spaced behind each other to expedite departures, continue to follow their trajectories in en route airspace while occasionally slowing down or speeding up temporarily to avoid other aircraft, and use self-merging and spacing when entering congested arrival airspace. Self-spacing can be maintained until the lead aircraft has landed. Whenever necessary or desirable the trajectories can be modified to accommodate new traffic flow requirements, weather conditions, or airline scheduling constraints.

While concept use throughout the entire airspace might be desirable, significant benefits may be gained by implementing it initially in only very congested airspace and the surrounding sectors. High and low altitude arrival sectors that have to handle high traffic loads are particularly compelling early application candidates. High altitude sector controllers can set up trajectories preparing aircraft for the low altitude merge into the terminal approach airspace, and pair up aircraft that will follow each other into the TRACON. The low altitude controller can then issue self-merging and additional spacing clearances to fine-tune the feed into approach sectors taking approach controller-requested spacing preferences into account.

Research

Research is planned at NASA Ames Research Center to further investigate this concept. Initial concept evaluations will be conducted in fast time and real time with the Multi Aircraft Control System (MACS[22]) and advanced CDTI single piloted simulators. The DAG-TM simulation environment described in Prevot et al.[23, 24] will be used for evaluating the concept with pilot and controller participants. Recent early tests at Ames Research Center with researchers acting as pilots and controllers were promising in terms of efficiency, safety and workload.

Concluding Remarks

Four-D trajectory and Airborne Separation Assistance System operations are often deemed incompatible concepts because the former is by its nature strategic, the later tactical. The air traffic concept proposed in this paper is defined as

(1) Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and,
(2) maintain local spacing between aircraft with airborne separation assistance.

This concept integrates the two approaches, showing a potential for maintaining high safety *and* improving efficiency over today's sector-based systems. The concept can be implemented evolutionarily, and a paradigm shift by air traffic controllers is not required. It can build on existing tools and strategies, can provide immediate and emergent benefits, and is compatible with advanced DAG-TM concepts. A key advantage of the concept is that the full benefit of trajectory-based operations can be realized *without* having to generate completely de-conflicted routes with 'buffers' for prediction uncertainty. A second advantage, given that flight crews monitor 'local' situations in *addition* to ground controllers, is a further level of operational safety – a second set of eyes.

Research is planned to further develop and evaluate this concept.

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