3rd USA/Europe Air Traffic Management R&D
Seminar Napoli, 13-16 June 2000

Trajectory Orientation: A Technology-Enabled Concept Requiring a Shift in Controller Roles and Responsibilities

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Abstract

Trajectory orientation is a procedural concept that enables en route controllers to plan and coordinate trajectories across sector boundaries while efficiently maintaining separation and conforming to flow-rate constraints. Today's sector-oriented procedures are characterized by an emphasis on controller actions to protect their sector's internal airspace. In contrast, a trajectory orientation emphasizes controller actions that work cooperatively across sectors and depend on each other for well-planned, nominally conflict-free flow of traffic. As an alternative to the technical modernization of current practices, a trajectory orientation represents the operational goal for which decision support technology should be developed. An en route operations assessment, including a literature review and structured interviews with controllers from the Cleveland and Denver Centers, was conducted to determine the core issues that inhibit a trajectory orientation in today's operational environment. Results indicated that the most significant problem was the controller's inability to perform accurate strategic planning. This problem was decomposed into low-level issues that can be solved using a combination of Free Flight technology currently being researched and new procedures. In addition, several concepts for new controller roles, responsibilities, and procedures were evaluated for their potential in achieving a trajectory orientation. Two concepts, one inspired by the EUROCONTROL multi-sector planner and one based on the Upstream R-side/D-side Team, were determined to be most likely candidates for achieving a trajectory orientation.

Introduction

In support of Free Flight, many new tools and technologies are being developed to improve the efficiency of the National Airspace System (NAS) through evolutionary enhancements. Automation enhancements to current practices will offer immediate benefit. However, the greatest potential for improvement will come from new practices and procedures enabled by new decision support tool (DST) technologies. A case in point is the En route Descent Advisor (EDA), a Center-TRACON Automation System (CTAS) DST under development at the NASA Ames Research Center (Reference 1). EDA assists controllers with the separation and flow-rate conformance (i.e., time-based metering and/or distance-based spacing) of air traffic in en route airspace. Although utilization of conflict probe and metering tools within today's "sector-oriented" operational paradigm will provide some Free Flight benefits, significantly greater benefits would be realized by a shift to a "trajectory-oriented" operational paradigm. This is the goal for developing EDA.

Trajectory orientation is a procedural concept that enables en route controllers to plan and coordinate trajectories across sector boundaries while efficiently maintaining separation and conforming to flow-rate constraints (i.e., time-based metering and/or distance-based spacing). This concept requires a new set of en route controller roles, responsibilities, and procedures that will enable controllers to efficiently plan across sectors. The role of new DST technologies is to enable trajectory oriented operations, which in turn, will be a large step toward realizing the full economic and workload benefits envisioned by Free Flight proponents.

The content of this paper focuses on presenting the trajectory orientation concept, identifying issues in today's operations that inhibit it, and suggesting solutions to enable it. In the following section, EDA is discussed sufficiently to highlight DST capabilities necessary to support trajectory orientation. This is followed by a detailed overview of the trajectory orientation concept. The Research Approach section outlines the objectives of this research and the operations assessment approach to meet those objectives. Next, the Results/Discussion section discusses three topics. The first topic addresses procedures and techniques in today's operations that inhibit a trajectory orientation in addition to proposing viable solutions. The second topic discusses the advantages of tactical conflict detection. The third topic compares different controller operational concepts in their ability of orchestrating a trajectory orientation.

Background

EDA or EDA-like DSTs are the primary enabling technologies that make trajectory orientation possible. EDA will enable controllers to more easily accommodate user-preferred trajectories while efficiently assuring traffic separation and conformance with flow-rate restrictions. EDA will accurately detect separation and flow-rate conformance problems up to 20 minutes into the future (generally across 1-2 sectors). The CTAS trajectory-prediction accuracy that supports such advisories has undergone extensive field-testing and validation (References 2-3). The controller is also provided with resolution advisories that are nominally problem-free over a 20-minute time horizon (i.e., conflict-free and in conformance with air traffic control (ATC) constraints such as required time of arrival, spacing restrictions, and crossing restrictions).[*] Trial planning capability allows the controller to direct EDA advisories according to their own operational preferences. A significant economic and workload benefit will be enabled by EDA's capability to develop path-independent flow-rate conformance advisories. Instead of forcing flow-constrained flights in trail to establish spacing, EDA allows controllers to delay merges and minimize deviations from user-preferred trajectories. This approach reduces the concentration of metered flights in any one sector thus distributing the workload across sectors and away from the final merge point.

EDA and the trajectory orientation concept mesh well with the NASA Advanced Air Transportation Technologies goal of developing longer-term technologies that will support user flexibility and distributed air-ground (DAG) traffic management (Reference 4). EDA will provide controllers with the decision support needed to manage a Free Flight environment characterized by:

- Significant reduction in procedural restrictions
- Significant increase in dynamically-imposed flow restrictions (to mitigate capacity overloads)
- Significant increase in dynamic flight replanning by the user

The long pole in the tent is the challenge of transitioning flights to/from high-density terminal areas. Economically, it does not make sense for the user/ATC community to heavily invest for en route savings only to lose those benefits upon transition to a congested airport. Many concepts, ranging from "trajectory negotiation" to "free maneuvering." have been proposed to maximize user flexibility in en route airspace. In any case, the EDA/trajectory orientation combination may be viewed as an enabling step to "transition" Free Flight aircraft smoothly and efficiently to and from the terminal area.

The Trajectory Orientation Concept

Trajectory orientation is a concept, developed at NASA Ames Research Center (Reference 1), that offers an alternative to today's sector-oriented ATC operations. Trajectory orientation requires a fundamental shift in thinking about inter-sector coordination.

Today's sector-oriented operations are characterized by controller emphasis on actions to protect their sector's internal airspace. The primary focus is on the planning and tactical separation of aircraft within their sector. This planning also includes consideration for constraints, such as crossing restrictions, both within the sector and within close proximity to the sector boundary (to facilitate a hand-off to the next sector). The hand-off process is used to ensure that incoming flights are at least tactically separated. However, there is little visibility or control over the conformance of incoming flights with flow-rate restrictions. The sector closest to flow-restricted airspace not only has the greatest concentration of impacted flights, but also the greatest potential responsibility for conformance. Sector-oriented operations generally involve just enough cooperation between adjacent sectors to permit a handoff, but not enough to achieve an efficient flow of traffic.

Trajectory orientation, on the other hand, focuses on efficient flight planning that nominally conforms to all ATC constraints within a time horizon (e.g., 15-20 minutes) independent of airspace boundaries. In addition to separation, this approach emphasizes the upstream strategic planning of actions to conform to flow-rate restrictions in downstream sectors. The result is a distribution of workload away from the flow-impacted airspace. Instead of controllers operating relatively independently, with the main focus on protecting their sector's internal airspace, the controllers would work cooperatively across sectors and depend on each other for well-planned, conflict-free flow of traffic.

Trajectory orientation will require new roles, responsibilities, and procedures for en route controllers that could potentially be quite different from today's operations. Trajectory orientation is the ATC counterpart to the orientation of a pilot in operating his/her aircraft. Pilot actions not only consider their current state and tactical challenges (e.g., weather and traffic avoidance), but also their strategic goal to complete the trajectory (i.e., they maintain a continuously updated trajectory plan for completion of the flight).

Two example cases are presented next to illustrate two specific differences between sector-oriented and trajectory-oriented operations. Figure 1 depicts a sector orientation for the first case. In this example, the aircraft in Sectors 1 and 2 are compliant with all constraints within their respective sectors as well as any Sector 3 handoff constraints. However, to solve a downstream capacity problem, traffic management requires a 20 nm spacing at the Sector 3/4 boundary for aircraft A, B, and C. This restriction corresponds to an approximately 20-minute time horizon from their current positions in sectors 1 and 2. In today's environment, the delay maneuvers for spacing conformance would most likely occur in Sector 3, the downstream sector. This is illustrated in Figure 1 by the vector deviations to aircraft A and C within Sector 3 airspace.

Figure 2 illustrates the trajectory-oriented version of the first example. In this case, the delay maneuvers to meet the spacing requirements would occur in the upstream sectors. The longer time horizon allows the upstream sectors to use speed control to achieve most, if not all, of the spacing requirement. Additional action by the downstream controller (Sector 3) is only needed to adjust

[*] The key to EDA is the integration of flow-rate conformance and conflict detection and resolution (CD&R) advisories. Integration not only reduces conflict-probe false-alarm and missed-alert rates when needed most (under high-density delay conditions), it leads to more-efficient traffic plans that are nominally conflict free.

for unplanned disturbances (i.e., actions required by exception rather than the rule).

Figure 3 depicts a sector orientation for the second case. For this example, traffic management still requires a 20 nm spacing at the Sector 4 boundary. However, they also “pass back” a spacing restriction of 40 miles in trail at the Sector 1/3 and 2/3 boundaries to assist the Sector 3 controller with absorbing the required delay for the final spacing at the Sector 3/4 boundary. In this example, the Sector 1 controller must delay aircraft A 35 nm to achieve the 40 nm spacing at the Sector 1/3 boundary. However, this is an unnecessary delay because there are no aircraft in Sector 2 that must be spaced between aircraft A and B. In fact, aircraft C is the only aircraft in Sector 2 during this time period and because it is ahead of the aircraft in Sector 1, aircraft C requires no delay at all. If the controller in Sector 1 was aware of this, he/she could have delayed aircraft A 15 nm instead of 35 nm. As such, Aircraft A crosses the Sector 3/4 boundary with 16 nm of excessive spacing

In Figure 4, DST technology enables upstream controllers to determine the accurate relative spacing between aircraft in adjacent sectors due to downstream constraints. This allows the controllers in Sectors 1 and 2 to effectively coordinate downstream spacing while maximizing the independent operations of both sectors (Reference 25). Because of this capability, traffic management would not need to artificially pass back spacing requirements to the upstream sectors. This prevents inefficient gaps or missed slots that prevent airspace from being used to its true capacity.

Although not explicitly depicted in Figure 3, the pass back procedure commonly used by traffic management highlights another problem. Pass back procedures rarely result in a seamless transition of merging streams for the downstream controller. Using the sector geometry and traffic management constraints depicted in Figure 3, a seamless transition requires a projected spacing of 20 nm in the downstream sector (i.e., Sector 3) between aircraft currently positioned in Sector 1 and Sector 2 in addition to 40 nm between aircraft in the same sector. In other words, even if the aircraft in a given sector are each appropriately spaced relative to other aircraft in that sector, anything other than a projected 20 nm “relative” spacing between aircraft in Sector 1 and aircraft in Sector 2 would require the Sector 3 controller to delay one of the streams to achieve the final spacing.

The problems with the pass back procedures as described above can be solved with a transition toward a time-based metering environment. This is because flow conformance of aircraft due to metering is measured relative to time rather than to other aircraft. However, even with meter-fix delay times displayed on an upstream sector’s plan view display, the tactical and gross nature of today’s techniques and procedures leaves the upstream controller ill-equipped to plan the actions necessary to accurately absorb the required delay. The downstream controller must then plan new actions to meet the required metering times. Ironically, the accuracy of the metering is often invalidated by the imprecision of today’s delay tactics.

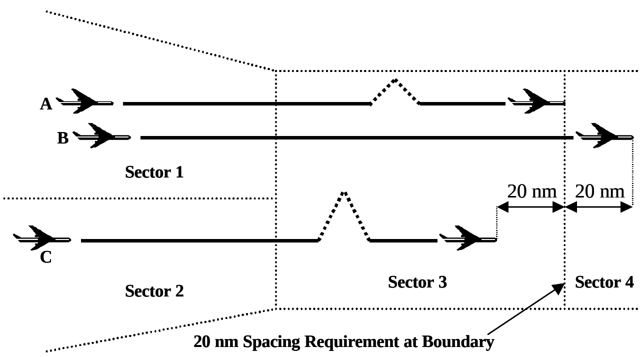

Figure 1. Sector Orientation Example #1

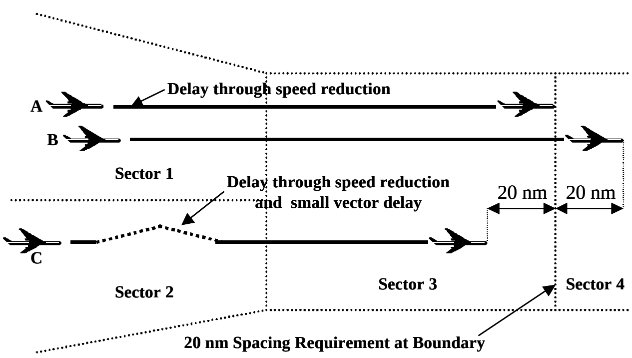

Figure 2. Trajectory Orientation Example #1

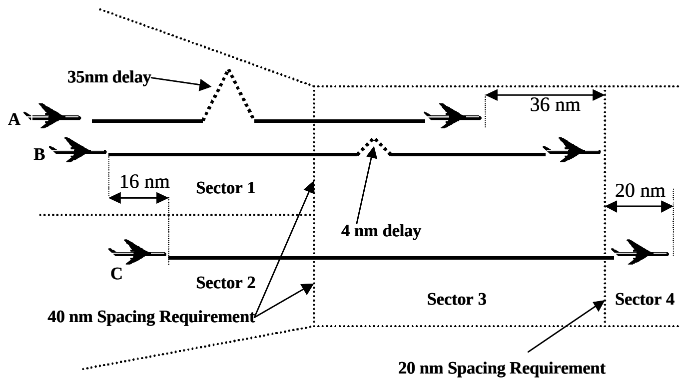

Figure 3. Sector Orientation Example #2

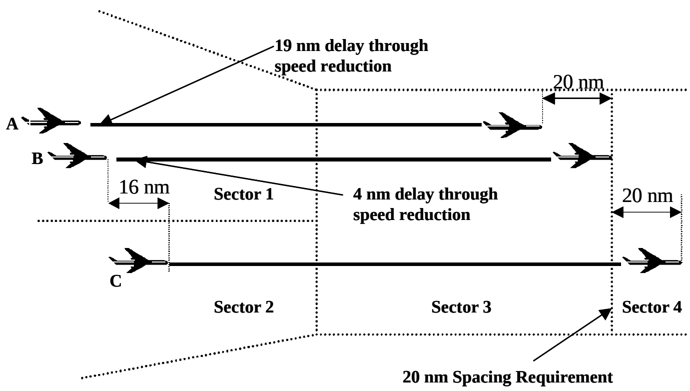

Figure 4. Trajectory Orientation Example #2

In summary, the strategic nature of trajectory orientation offers several advantages when supported by DST technology. The efficiency of flow-rate conformance (delay absorption) is increased in three ways. First, the strategic planning reduces the need for tactical corrections (interruptions) since each maneuver action is calculated to nominally result in conformance. Second, as depicted in example 1, this approach enables greater use of speed control by increasing the time horizon for conformance. Third, as depicted in example 2, excessive spacing between aircraft can be significantly reduced because DST functionality provides relative spacing information between aircraft in adjacent sectors. With respect to workload, as depicted in both examples, trajectory orientation results in a more even distribution of workload from the downstream sector (where traffic is converging) to sectors further upstream.

Although the examples presented above are useful in describing a trajectory orientation, they only focus on the aspects related to inter-sector coordination. The other key aspect, "where the rubber meets the road," relates to the complementary subject of intra-sector coordination. The operational roles and responsibilities of individual controller positions (e.g., radar (R-side) and radar associate (D-side)) define the building blocks from which inter-sector procedures may be created. Evaluating these roles and responsibilities is the primary objective of this research. The results of this evaluation are discussed in the section on Evaluation of Candidate Controller Roles, Responsibilities, and Procedure.

Research Approach

The top-level objectives of this research were:

1. Determine the core issues in today's en route operations that inhibit a trajectory orientation.
2. Identify potential technology and procedural solutions that address those issues.
3. Evaluate specific candidate concepts to determine which have the highest potential of achieving a trajectory orientation.

An assessment of today's en route operations was performed to meet the goals of this study. The assessment included a literature review of current en route operations (References 5-9). In addition, future Free Flight concepts (References 10-16) were researched because of their potential impact on current operations. Controller participation from the Denver and Cleveland Air Route Traffic Control Centers was supported by the regional offices of the Federal Aviation Administration (FAA) and the National Air Traffic Controllers Association. Denver Center was chosen because it has been a research site for several DST development efforts at NASA Ames Research Center and was within close proximity of the principal researcher. Cleveland Center was chosen because of the complexity of the air traffic it manages on a daily basis. Located between Chicago and the Northeast Corridor, it is the busiest Center in the USA with over 2.6 million operations in 1999 (Reference 17). Each sector within Cleveland Center must handle arrival, departure and over-flight traffic on a regular basis.

A total of fifteen controllers and traffic management personnel were briefed on EDA functionality and the trajectory orientation concept. A formal set of questions was utilized to determine the extent and nature of how controllers perform strategic planning for separation and flow-rate conformance. The controllers were interviewed for four categories of information:

- Specific examples of scenarios, events, and procedures for which they felt that DST technology may not be sufficiently accurate to predict aircraft trajectories.
- Specific examples that would inhibit a trajectory orientation.
- Requirements for decision-support capability and usability that would enable them to perform their jobs most efficiently under a trajectory orientation.
- Operational advantages and disadvantages of the set of candidate concepts for controller roles and responsibilities.

Results and Discussion

Operations Assessment

The single most important issue identified from the operations assessment is the inability of controllers to perform accurate strategic planning (i.e., time horizon of 15-20 minutes) that includes the intentions of both the upstream and downstream controllers as well as the intentions of the aircraft. This section decomposes strategic planning issues into smaller issues that are more easily understood and are thus more likely to have solutions. The focus of this section is to identify and address issues related to strategic detection and resolution of conflicts and flow-rate conformance problems. More detailed results of this research are included in Reference 18.

One important point from the controller interviews is the fundamental fact that controllers have been trained to act and think tactically, not strategically. Emerging DST capabilities have demonstrated, under limited conditions in the field, the ability to enable more strategic planning by controllers. However, simply making DSTs available to controllers would not necessarily result in strategic planning because the controller's mindset and procedures are still based on a tactical culture and environment that dates back several decades.

In addition, controllers are reluctant to strategically resolve flow-rate conformance and conflict problems (a fundamental requirement of the trajectory orientation concept). This reluctance is due, in large part, to the general uncertainty, and lack of predictability, they expect over a strategic time horizon. To clarify these issues further, results from the controller assessment are summarized below. Eight core issues were identified as obstacles that prevent or inhibit controllers from performing effective strategic planning. These issues are ranked here in terms of their impact on enabling a trajectory orientation:

1. Controllers are not responsible for resolving conflicts or meeting flow-rate constraints of other sectors.
2. Strategic resolutions may be insufficient in resolving conflicts or meeting flow-rate constraints.
3. Inter-sector resolutions may interfere with an adjacent controller's plans.
4. Strategic resolutions may lead to conflicts with other aircraft because of inadequate situation awareness.
5. Strategic resolutions have a lower priority compared to other controller tasks.
6. Conflicts may resolve themselves because they are actually false alarms.
7. Conflicts may resolve themselves because of unpredictable events.
8. Strategic resolutions may lead to conflicts or flow-rate conformance problems with other aircraft because of simultaneous and conflicting actions by adjacent controllers.

The following sections describe these core issues in greater detail and present potential solutions.

1. Controllers are not responsible for resolving conflicts or meeting flow-rate constraints of other sectors.

The current ATC system clearly assigns responsibility and control authority to individual sectors. Although there are exceptions, generally speaking, controllers are only responsible for resolving conflicts that occur in their own sectors. Similarly, controllers are responsible for meeting flow-rate constraints at their respective exit boundaries or metering fixes. The advantage to these methods is that in the case of an operational error (e.g., violation of the minimum separation rule), the fault is readily determined. The disadvantage is that there is no impetus for controllers to collaborate on trajectory oriented inter-sector planning. Without such inter-sector planning, achieving a trajectory orientation is not possible.

Potential Solutions: Unlike many of the other issues discussed below, the solution for this issue requires changes to many aspects of today's ATC operations. New tools and procedures must evolve that give controllers confidence that trajectory-oriented planning is beneficial to all sectors. Only when all eight issues pertaining to strategic planning are addressed will the right conditions exist for pro-active, widespread participation in trajectory-oriented, inter-sector planning.

2. Strategic resolutions may be insufficient in resolving conflicts or meeting flow-rate constraints

Inadequate strategic resolutions would most likely be caused by controllers using manual “rule of thumb” approaches that are too gross for the given scenario. Such approaches do not accurately account for variations in wind and true airspeed, or trajectory and conflict geometry. The controller's experience and skill becomes an important factor in calculating a resolution advisory that is sufficient, but not excessive. The challenge becomes more difficult for strategic time horizons because position uncertainties tend to grow linearly with time.

Potential Solutions: A solution for inadequate resolutions due to conflict geometry and wind variation is DST automatic resolution and/or trial-planning capability that addresses both separation and flow-rate conformance requirements, with consideration for trajectory-prediction uncertainty.

3. The inter-sector resolution may interfere with an adjacent controller's flow-rate conformance plans.

As an example, if two aircraft in an upstream sector (see External case in Figure 5) will conflict five minutes into the downstream sector, the upstream controller is required to resolve the conflict before the aircraft is handed off. When spacing constraints are required in the downstream sector, the conflict resolution might interfere with the aircraft spacing plans of the downstream controller. He/she would then need to resolve the new problem and issue an additional clearance to the aircraft. One method currently employed by controllers to avoid this situation is to handoff the aircraft early so the downstream controller can resolve both the conflict and the spacing conformance. The drawback to this method is that the controllers are dealing with the traffic tactically rather than strategically, which is particularly inefficient for delay (metering) situations.

Potential Solutions: The solution is for strategic (upstream) planning of resolution maneuvers aided by DST functionality that accounts for downstream flow-rate conformance. The technology must support a common situational awareness across sectors to ensure that plans and actions are complementary.

4. Strategic resolutions may lead to conflicts with other aircraft because of inadequate situation awareness.

A primary reason that strategic resolutions lead to conflicts with other aircraft is inadequate situation awareness across sectors. Controller situation awareness can be negatively affected by lack of data, high workload, complacency, or lack of vigilance. Regardless of the cause of inadequate situation awareness, or which sector it occurs in, the result is the controller's mental picture of the airspace does not accurately reflect all aircraft. Consequently, the controller may determine a resolution advisory that can lead to conflicts or flow-rate conformance problems with those aircraft.

Potential Solutions: The problem for conflicts due to inadequate situation awareness can be mitigated by DST functionality that provides situational awareness cues on several levels. At one level, such cues may be integrated as part of the trial planning and/or automatic resolution advisories for separation and flow-rate conformance. This would augment a controller's situational awareness by alerting the controller to cases where resolution plans cause other problems. At a more basic level, situational awareness can be enhanced by DST cues that call a controller's attention to situations requiring greater scrutiny (e.g., a flight that is not correlated with it's predicted path).

5. Strategic resolutions have a lower priority compared to other controller tasks.

The FAA controller handbook, referred to as 7110.65 (Reference 6), states:

> "Give first priority to separating aircraft and issuing safety alerts as required in this order. Good judgment shall be used in prioritizing all other provisions of this order based on requirements of the situation at hand."

No controller interviewed for this study considered separating aircraft, based on a conflict detection time horizon of 15 to 20 minutes, a "first priority." Obviously, controllers would deal with tactical conflicts before the strategic conflicts/flow-rate conformance problems because the safety of the aircraft is more imminent. In the event that there are no tactical conflicts, the controller in most situations would be inclined to perform low priority tasks, such as housekeeping, over strategic resolution. As one controller stated, "twenty minutes is an eternity to a controller," but twenty minutes is also the preferred time horizon for efficient flow-rate conformance. Ironically, the lack of strategic planning today results in a higher tactical workload that, in turn, reduces the opportunity to perform strategic planning.

Potential Solutions: The solution requires a fundamental change to the environment that controllers have been trained to support. It also implies a shift in controller roles and responsibilities. The circumstances presented to controllers in any given situation must have adequate solutions, via new tools and procedures, to give them confidence that by acting and thinking strategically, they are improving the overall traffic flow and are not increasing their workload.

6. Conflicts may resolve themselves because they are actually false alarms.

Prediction errors occur because of uncertainty in actual ground speed, altitude rate, and radar track when a controller projects each aircraft's trajectory. The controller may falsely predict a conflict situation that, if left alone, would have resolved itself.

Potential Solutions: The solution for prediction errors and the resulting false alarms is through automated 4D trajectory predictor algorithms, such as those residing in the User Request Evaluation Tool (URET), and the CTAS En route Descent Advisor (References 2, 19-21, 26). These algorithms have been studied for several years and are well-suited for addressing this particular problem. Effectiveness can be improved by including functionality to accurately reflect or model the intentions of the pilot and/or adjacent controllers.

7. Conflicts may resolve themselves because of unpredictable events.

The longer the conflict detection time horizon, the higher the probability that something unpredictable or unintended will occur that results in the conflict resolving itself. For example, the pilot of one of the conflicting aircraft may request an altitude and/or speed change (e.g., due to turbulence) or a heading change (e.g., due to a weather cell in its path) prior to the conflict becoming tactical (i.e., within the time horizon of today's radar controller). In these cases, granting the pilot request resolves the conflict.

Potential Solutions: Since this issue pertains primarily to separation conflicts, rather than flow-rate conformance problems, one solution is for the controllers to delay a conflict resolution until the probability is high for the conflict to occur. This is discussed in detail in the section on Tactical Detection vs. Strategic Detection of Conflicts and Flow-rate Conformance Problems.

8. Strategic resolutions may lead to conflicts or flow-rate conformance problems with other aircraft because of simultaneous and conflicting actions by adjacent controllers.

This case is rare, but was the cause for a near-miss between two aircraft. Simultaneous trajectory changes to aircraft in two separate, but adjacent, sectors can lead to what otherwise would have been a preventable conflict. In this case, the controller has adequate knowledge of aircraft in adjacent sectors to determine a strategy to resolve a conflict in his sector that would not interfere with aircraft in the adjacent sectors. However, the controller does not know the actions being performed simultaneously by a controller in an adjacent sector unless one of the controllers takes the initiative to coordinate with the other. The simultaneous actions have the potential to negate the intended effect, resulting in another conflict or flow-rate conformance problem. Following normal sector-to-sector communication procedures would prevent this case from occurring, but the fact that it does occur is a cause for concern.

Potential Solutions: Although a rare problem, the solution for conflicts and flow-rate conformance problems due to simultaneous actions in today's operations is to emphasize correct procedures related to sector-to-sector communication.

In a future DST environment that supports trial planning and automatic resolution, this problem can and must be avoided because controller trust in the DST is at stake. As one controller stated, "Trust is hard to gain, but easy to lose." The option that appears to be most favorable is “cross-referencing.” Cross-referencing tests any newly created trial plan, whether controller-derived or computer-derived, against all active flight plans as well as all pending trial plans that correspond to other sectors. If the newly created trial plan conflicts with any of the other plans, then the controller is notified of the discrepancy and must decide on a new course of action.

Tactical Detection vs. Strategic Detection of Conflicts and Flow-rate Conformance Problems.

Early in this research, the assumption was made that strategic detection (15 – 20 minute time horizon) of conflicts and flow-rate conformance problems would generally result in the most optimal/efficient resolutions. However, after the analysis of the strategic planning issues in the above section, it became apparent that the inability of controllers to perform accurate strategic planning was due to their concerns about strategic detection and resolution of conflicts (specifically as presented in problems #5-7 above) rather than the strategic detection and resolution of flow-rate conformance problems. Two points are discussed below that suggest a trajectory orientation is still achievable despite a strategy that permits tactical detection of conflicts.

The first point is that, even with accurate DSTs, wind uncertainties over a 20-minute time horizon can still result in detection errors along the flight path that are significantly large relative to the 5 nm separation criteria (Reference 22). Depending on the conflict geometry, this can result in false alarms or missed alerts that needlessly distract the controller. However, those same detection errors are much smaller relative to typical traffic management spacing requirements of 10-40 nm. Consider the case where two merging aircraft are currently predicted to be spaced 5 nm apart but the requirement is for 20 nm spacing. Even with an uncertainty of +/-3 nm in a DST advisory, the upstream controller can nominally plan to absorb all the delay leaving the downstream controller with the responsibility for correcting any unacceptable deviations that develop. With the nominal conformance plan, the downstream controller only needs to intervene by exception, rather than by the rule. When required, such exceptional actions would only require fine-tuning compared to the original delay-absorption plan.

The second point is that waiting to resolve a separation conflict tactically is not nearly as inefficient as waiting to resolve a flow-rate conformance problem tactically. The maximum amount an aircraft needs to be maneuvered to resolve a conflict would be slightly greater than the separation criteria (e.g., 5 nm in radar-controlled en route airspace). In comparison, delays for flow-rate restrictions (e.g., arrival metering) can typically exceed 4 min (approximately equivalent to 20-30 nm of flight). A longer time horizon is required for efficient flow-rate conformance than for conflict resolution.

The purpose of mentioning these two points is to suggest that a trajectory orientation could still be achieved by detecting conflicts on a tactical time horizon rather than a strategic horizon. In contrast, detecting flow-rate conformance problems on a tactical time horizon would clearly inhibit a trajectory orientation – strategic detection is mandatory. Lastly, tactical detection of conflicts would reduce the number of false alarms and missed alerts because the reduced time horizon limits the growth of trajectory-prediction uncertainties such as wind and pilot/controller intent.

One final point concerning tactical vs. strategic detection of conflicts needs to be clarified. When considering time horizons, it is important to distinguish between problem detection and problem resolution. Regardless of whether a conflict is detected/alerted on a tactical or strategic time horizon, if it involves a flow-restricted flight, the resolution should be strategic in nature (i.e., in conformance with flow-rate restriction and nominally conflict-free to the meter fix). The point is that if it is necessary to re-plan a flight to resolve a problem, automation-assisted resolutions should help the controller avoid new problems in the foreseeable future. For example, if a flight must be re-planned for a metering delay, the re-plan should be nominally conflict-free to the meter fix. Alternatively, if a metered flight falls into conflict while in conformance, the conflict-resolution action should be nominally in conformance with the metering restriction. In summary, if the controller must throw a stone, they might as well use the decision support technology to aim the stone to hit two birds. This hybrid concept allows the best aspects related to problem detection and resolution to be combined.

Evaluation of Candidate Controller Roles, Responsibilities, and Procedures

The goal of this section is to summarize the findings of this evaluation and present details regarding the two concepts that were down selected for further study.

Table 1 presents a comparative summary of the seven concepts that were evaluated. This set of concepts was formulated in an attempt to reflect the various options under consideration in the USA and Europe. The study evaluated each candidate concept against a set of generic conflict and flow-rate conformance problems. These problems were further expanded to consider the generic range of possible aircraft/airspace combinations that were originally illustrated in Reference 24 and are depicted here in Figure 5. A major element of the evaluation was a qualitative analysis of the controller coordination required by each concept. The findings are organized and summarized in Table 1.

Table 1 Candidate Concept Comparison								
Candidate Concept		1 URET	2 EURO CONTROL PHARE	3 Upstream D-side	4 Upstream R-side	5 EURO CONTROL MSP	6 NASA AC	7** Upstream Team
Position responsible for planning strategic resolution		Down stream D-side	Down stream D-side	Upstream D-side	Upstream R-side	MSP	AC	Either Upstream position
Position responsible for coordination		Down stream D-side	Down stream D-side	Upstream D-side	Upstream D-side	N/A	AC	Upstream D-side
Position responsible for issuing strategic clearance and monitoring for compliance		Upstream R-side	Down stream D-side	Upstream R-side	Upstream R-side	MSP	Upstream R-side	Either Upstream Position
Strategic clearance becomes effective where/when?		Upon issue	Sector boundary	Upon issue	Upon issue	Sector boundary	Upon issue	Upon issue
Strategic planning coordination required between R-side and D-side position?*	Intra-sector	Yes	Yes	Yes	No	N/A	N/A	No
	External	No	No	Yes	No	N/A	N/A	No
	External Intruder	Yes	Yes	Yes	Yes	N/A	N/A	No
	Inter-sector	No	No	Yes	Yes	N/A	N/A	No
Number of sectors that require coordination* (Sectors adjacent to the sector responsible for strategic planning)	Intra-sector	0	0	0	0	N/A	1	0
	External	1	0	0	0	0	1	0
	External Intruder	1	0	1	1	0	2	1
	Inter-sector	2	0	1	1	0	2	1
* For the purposes of comparison, the assumption is made that both aircraft will be issued resolution advisories. In many cases, the controller may choose to focus on one aircraft, which would reduce the coordination that is indicated by this table.					** Assumes CPDLC is available			

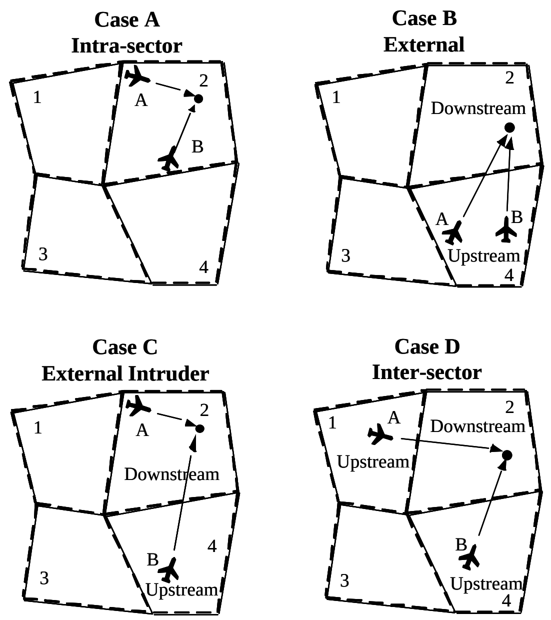

Figure 5. Conflict Scenarios

The two candidate concepts that were selected for further study include:

- Candidate #5 Multi-Sector Planner
- Candidate #7 Upstream (sector) Team

Candidate concepts #1 (URET) and #6 (Airspace Coordinator (AC)) were not selected because of the amount of inter/intra-sector coordination required between controllers. Candidate concepts #3 (Upstream D-side) and #4 (Upstream R-side) were not selected, in favor of #7 (Upstream Team), because #7 combined the best features of both with few of the disadvantages of either. A detailed description of each candidate concept and the evaluation results is presented in reference 18. The down-selected candidates are described next in greater detail.

All the candidate concepts, with the exception of the MSP and the AC, assume that electronic flight strips or some other replacement to paper flight strips is available. This is based on overwhelming sentiment from the controller interviews that the current D-side workload is too high to allow for strategic planning during peak periods (at the time when strategic planning is most critical). The high workload associated with the D-side position results primarily from managing paper flight strips. Controllers that had some experience with electronic flight strips via URET spoke highly of the concept. Since significant work has been done in this area, the candidate concepts assume it will be implemented.

Candidate 5 EUROCONTROL MSP

This candidate is based in part on the EUROCONTROL concept that proposes a new Multi-Sector Planner (MSP) position (References 23 and 27). The EUROCONTROL MSP concept combines controller functions with traffic management functions. However, for the purposes of this study, the MSP candidate concept represents only one aspect of the full EUROCONTROL MSP concept (i.e. that aspect related to the planning, and contracting of user-ATM negotiated trajectories).[†] The reference is made here to give credit for inspiring the inter-sector coordination aspect evaluated in this study.

Each MSP monitors a group of sectors within a Center. The number of MSPs per Center will depend on traffic density and other criteria to be determined. The MSP is responsible for strategic planning of aircraft within his/her defined airspace. The MSP issues clearances based on advisories from the DST via controller-pilot data link communication (CPDLC) that become effective at the boundary of the next sector. The MSP is responsible for monitoring of compliance.

Advantages

This concept requires minimal inter-sector coordination if any. By limiting flight plan changes to ones that are initiated after the next-sector's boundary, this concept does not require the MSP to coordinate with the current sector to issue a clearance. From the perspective of the next downstream sector, the MSP change simply appears as the current flight plan when the flight comes under that sector's control. The MSP effectively "inserts" the flight plan update in between the two sectors. In this way, the MSP position is autonomous, which will permit him/her to focus specifically on achieving a trajectory orientation.

Disadvantages

On the surface, this concept appears to be the best candidate for achieving a trajectory orientation. However, there are several issues that were identified in the assessment worth discussing. To begin with, there is a risk that the effectiveness of the MSP position at the busiest Centers would be limited during peak periods of traffic – a time when trajectory orientation is most needed. The risk is related to the number of sectors the MSP must serve. This issue may be answered through controller-in-the-loop simulation. Reducing the number of sectors per MSP position to improve efficiency could result in diminishing returns when compared to the other sector-based candidate concepts.

Second, since the resolution becomes effective at the sector boundary, it can become obsolete if the upstream R-side issues a tactical clearance to the aircraft after the MSP has issued the strategic clearance via CPDLC. This causes a problem because the DST resolution is based on the assumption that the aircraft would follow the original flight plan until the sector boundary.

In addition, it is necessary that the MSP work seamlessly with the controllers/sectors in his/her jurisdiction. Otherwise, controllers would be very resistant to what they might view as outside interference with their basic roles and responsibilities. A strong understanding of the operations and traffic flow of all sectors in his/her domain is necessary to avoid impeding the actions of the controllers in those sectors. The controllers expressed the opinion that the MSP position would require a controller who is highly skilled and well respected amongst his/her peers. Otherwise, it is unlikely that the concept would be effective in achieving a trajectory orientation.

The MSP also would have authority to issue clearances, but whether he/she should be responsible for an operational error (i.e., violation of the 5 nm standard) needs to be determined. For example, the MSP might fail to adequately monitor for compliance of a strategic clearance that results in a tactical operational error. Who is responsible for the error, the MSP or R-side controller who "owns" the aircraft at the time of the operational error? Operational acceptance of this concept requires answers to these questions.

Candidate 7 Upstream Team

This concept was proposed based on feedback from controllers at the Denver Center and is essentially a combination of Upstream D-side and Upstream R-side concepts. These two concepts shared a common characteristic favored by the controllers, namely that the upstream sector resolves downstream problems. This minimizes inter-sector coordination compared to some of the other concepts and would allow controllers to be more focused on strategic planning. The controllers disliked the aspect of the Upstream D-side characteristic that only the D-side controller would have access to EDA-like decision support. From a workstation perspective, they thought it would be most efficient to have both R-side and D-side positions supported by the decision support capabilities. Certainly this would be more convenient for the R-side if he/she was the only controller working a sector during slower periods of air traffic. On the other hand, the primary drawback of the Upstream R-side candidate, based on controller feedback, was its heavy dependence on the R-side position to support strategic planning tasks during busy periods (a time when the R-side is already experiencing high workload). This dependence may

[†] Program for Harmonized ATM Research in Eurocontrol (PHARE) Demonstration 3 (PD3).

inhibit a trajectory orientation during periods when it is needed most.

In the Upstream Team concept, both the R-side and D-side are supported by EDA-like capability. The R-side would manage all tactical conflicts, and as the team leader, delegate strategic problems to the D-side depending on workload and other circumstances. If the R-side was too busy with tactical situations, the D-side would work alone on strategic planning, otherwise the strategic planning would be shared between both positions. Until CPDLC becomes available, the R-side must concur with the D-side resolution. Prior to the availability of CPDLC, the R-side would be responsible for issuing clearances to implement the strategic plans. With CPDLC, the R-side would have the option to delegate clearance communications to the D-side position as appropriate. This approach maximizes a controller team's flexibility to manage their traffic and workload. If the sector team includes a new controller to be checked out, the R-side team leader could require concurrence with D-side resolutions prior to D-side issuance of clearances. This provides a method for the more experienced controllers to supervise and mentor the less experienced with minimal risk (analogous to what occurs in a flight deck between a senior captain and a junior first officer). With or without CPDLC, the controller who resolves the conflict is responsible for monitoring the aircraft for compliance (e.g., if the R-side issues the clearance, the R-side must monitor for compliance).

This concept can reduce inter-sector coordination if the supporting DST technology is configured to distribute problem alerts/advisories to the appropriate sectors.

Advantages

By having EDA-like DSTs available to both controllers, this team concept appears to be the most effective of all the concepts for consistently supporting strategic planning. As stated before, strategic planning is the single most important criteria for achieving a trajectory orientation. The team concept allows for a balancing of workload between the R-side and D-side positions. If the R-side is not too busy with tactical conflicts, both controllers can work on aircraft conflicts further out on the time horizon, possibly to 20 minutes out. In contrast, if the R-side was busy with tactical conflicts, the D-side would perform all the strategic planning, but perhaps only work on conflicts with time horizons of 10-15 minutes out. This concept has a natural ebb and flow that should work well to smooth out the conflicts for air traffic patterns that have their own peaks and troughs.

Another advantage to this concept is its robust nature to the elemental changes that the ATC system will experience during the evolution to Free Flight. For example, it is fully effective with or without CPDLC. In contrast, the MSP concept requires CPDLC. In this concept, aircraft can be strategically planned whether or not they are equipped with CPDLC. Furthermore, in comparison to the MSP concept, the Upstream Team may plan resolutions that include immediate action rather than being restricted to flight plan changes that are initiated after the boundary to the next sector.

Disadvantages

One disadvantage to this concept is the need to provide EDA-like DST capabilities for both controller positions at each sector. The most significant disadvantage, however, is the risk associated with implementing Upstream-Team based procedures. The operational viability of this concept rests on the dependence between sectors to receive traffic flows that are nominally planned to be in conformance with ATC constraints. Like posts supporting a picket fence, each post must carry its weight. Each downstream sector is, in turn, an upstream sector to someone else. The added workload to plan nominal conformance upstream translates into a lower workload in the next sector. Assuming that the net workload remained constant, but was redistributed, the airspace would benefit from a more predictable and robust flow of traffic. In any case, most if not all sectors must adopt the practice to realize the net benefit.

Conclusion

Trajectory orientation is a concept that, coupled with advanced en route DST capabilities, enables controllers to facilitate fuel-efficient, conflict-free trajectories across several sectors of airspace while conforming to flow-rate constraints. An operations assessment determined core issues in today's en route operations that inhibit a trajectory orientation. In addition, seven concepts for new controller roles, responsibilities and procedures were evaluated for their potential in achieving a trajectory orientation. Two concepts, one inspired by the EUROCONTROL MSP concept and one based on the Upstream Team concept, were determined to be most likely candidates for achieving a trajectory orientation. Further research will focus on developing detailed controller procedures and requirements for supporting DST capabilities to facilitate trajectory-oriented ATC operations. In addition, a controller-in-the-loop simulation will be developed for procedural and DST concept validation.

Biography

Mr. Kenneth Leiden is a senior research engineer with Micro Analysis and Design, Inc., in Boulder Colorado. He is currently the technical lead on human factors and human performance modeling for NASA's En route Descent Advisor project. Mr. Leiden has thirteen years of modeling, simulation, and design experience covering a wide range of applications, from human performance modeling of advanced air traffic control concepts to the design of avionics algorithm for guidance and navigation. He has a B.S. in Aerospace Engineering from the University of Colorado in 1985.

Mr. Steven Green joined NASA Ames Research Center in 1985 as a research engineer for Air Traffic Management automation. One of the four CTAS "founders," he lead the development and field testing of the CTAS Descent Advisor (DA), and was the principle investigator for the development/evaluation of air-ground integration concepts including CTAS-FMS integration, en-route trajectory negotiation, and data exchange to enable user-preferred trajectories. Mr. Green manages NASA's en route ATM research, co-leads NASA's Distributed Air-Ground research, and serves as the government co-chair of RTCA SC-194/WG-2 on FMS-ATM-AOC Integration. Mr. Green received a B.S. (Aeronautical and Mechanical Engineering) from the University of California at Davis in 1985, a M.S. degree in Aeronautics & Astronautics from Stanford University in 1988, and is an instrument-rated pilot.

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