Airborne Use of Traffic Intent Information in a Distributed Air-Ground Traffic Management Concept:
Experiment Design and Preliminary Results

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Abstract

This paper presents initial findings of a research study designed to provide insight into the issue of intent information exchange in constrained en-route air-traffic operations and its effect on pilot decision making and flight performance. The piloted simulation was conducted in the Air Traffic Operations Laboratory at the NASA Langley Research Center. Two operational modes for autonomous operations were compared under conditions of low and high operational complexity. The tactical mode was characterized primarily by the use of state information for conflict detection and resolution and an open-loop means for the pilot to meet operational constraints. The strategic mode involved the combined use of state and intent information, provided the pilot an additional level of alerting, and allowed a closed-loop approach to meeting operational constraints. Operational constraints included separation assurance, schedule adherence, airspace hazard avoidance, flight efficiency, and passenger comfort. Potential operational benefits of both modes are illustrated through several scenario case studies. Subjective pilot ratings and comments comparing the tactical and strategic modes are presented.

Introduction

A significant research activity within the NASA Aviation System Capacity program is focused upon far-term operations of the National Airspace System (NAS).

A general description of the activity is *Distributed Air/Ground Traffic Management* (DAG TM). NASA has developed a high-level concept of operations for DAG TM consisting of 15 elements spanning gate-to-gate operations[1]. One particular concept element developed to address the en-route flight regime (Concept Element 5)[2] has the potential to increase capacity, flexibility, and robustness of the NAS by distributing responsibility for 1) separation assurance and 2) conformance with local traffic flow management (TFM) constraints between airborne and ground-based systems. In this concept element, pilots of aircraft designated as "autonomous" have the authority to generate and implement new trajectories at their discretion in order to meet individual, company (if applicable), and/or system-level goals. They also have the responsibility for separation assurance and compliance with local TFM constraints established by the ground-based air traffic service provider (ATSP). Aircraft not operating as autonomous aircraft are designated as "managed aircraft," and similar to current operations, their flight crews comply with clearances provided by the ATSP, who maintains responsibility for their separation assurance and flow management conformance.

Information Requirements Research

A predominant research focus in the Free Flight community has been on the type of information required on the flight deck of autonomous aircraft to enable their pilots to ensure separation from other aircraft. Accurate

detection of "conflicts" or predicted loss of separation between aircraft is a key requirement for autonomous aircraft operations. At issue are the relative utility and requirement for inter-aircraft information exchange of the current "state" (three dimensional position and velocity vector) and "intent" of each aircraft (flight plan); this surveillance information forms the basis for trajectory predictions used in automated conflict detection. Additionally, related human factors issues exist, such as determining how pilots would use the surveillance information and how this information should be presented on the flight deck displays, considering usability, display design precedence, and integration with other pilot tasks.

Previous research has indicated that, under *unconstrained* operations (no schedule or airspace restrictions), the exchange of state information between aircraft is sufficient to safely enable airborne self separation in the en route domain[3]. A state-only system has the potential to significantly reduce bandwidth requirements for future surveillance systems such as Automatic Dependent Surveillance - Broadcast (ADS-B), and it reduces the complexity of conformance monitoring and conflict alerting logic. To address the conflict alerts missed by not using intent information, Hoekstra et. al.[3] developed and tested a predictive airborne separation assurance system (PredASAS) that calculates potential off-trajectory conflicts and displays avoidance bands on the heading, airspeed, and vertical speed indicators. This system was designed to provide information regarding which maneuvers would lead to a conflict without the crew needing to "probe" or "try various maneuvers." The conclusion was made that "if all equipped aircraft are fitted with PredASAS, there is no longer a need to know intent information because nobody will turn (or climb/descend) into a conflict." [3]

An additional study conducted at the NASA Ames Research Center suggested that pilots nevertheless preferred to be provided traffic-aircraft intent information, and the preferred source was Flight Management System (FMS) flight plan data[4]. In this study, flight crews were alternately provided with three types of traffic information: state data, Flight Control Panel (FCP) data, or FMS data. The flight crews were given the opportunity to use voice communication channels to communicate directly with other aircraft to gather intent information or negotiate resolutions. Results of the study indicated that pilot preferences for intent information centered primarily on the improved ability to understand the conflict alerts. Intent information type (state, FCP, or FMS) was found to have no effect on separation assurance.

Operational Constraints

Whereas these studies addressed unconstrained operations, little research has been performed on the feasibility of *constrained* operations. Constrained operations are important to consider in concept feasibility and viability analyses. Operational constraints ultimately limit airspace capacity (notwithstanding runway availability limitations), and a concept that does not address capacity limitations is of little practical interest. It is in the more highly constrained conditions that operations will be found to be either fragile or robust to real-world system demands and variability.

Operational constraints can generally be expressed in four categories. *Flow management constraints* are restrictions that must be imposed to make sure traffic flow through the airspace is as high as possible. Flow management constraints in a future system may include a "required time of arrival" (RTA) assignment at a terminal boundary for inbound autonomous aircraft. *Airspace hazard constraints* are present when certain regions of airspace are inadvisable for entry. Examples of such airspace hazards are active special-use airspace (SUA) and convective weather cells. *Performance constraints* include restrictions based primarily on the operating limitations of the aircraft. Restrictions such as maximum operating altitude, speed, or climb/descent rate govern the degrees of freedom available for conflict resolution maneuvers. *Economic constraints* include user-generated operational guidelines that must generally be met a majority of the time for a commercial aviation business to remain viable for the long term. Examples include fuel efficiency, schedule considerations, and passenger comfort.

When constraints of these types are considered in combination with the task of separation assurance, the type of traffic surveillance information provided to the flight crews may play a more critical role in their ability to repeatedly and reliably meet their separation assurance responsibility than in unconstrained operations. This issue extends beyond the minimum requirement for information that enables airborne separation assurance, and it extends beyond the preferences of the flight crew. The study of constrained operations is critical to determining the overall *advisability* of exchanging intent information to enable the NAS participants to achieve all objectives, meet all constraints, and operate with long-term stability in the future airspace operations.

In the experiment, two modes of autonomous aircraft operation, tactical and strategic, were tested for

comparison. The experiment was conducted in the NASA Langley Air Traffic Operations Laboratory, a medium-fidelity workstation simulation of airspace operations that permits pilots to interact in proposed future ATM environments. A more detailed description of the laboratory can be found in reference [5].

Modes of Autonomous Operations

Two viable modes of autonomous operations were studied. They differ in several respects beyond just the level of information exchange.

Tactical mode

Aspects of the tactical mode have been developed and investigated over several years in batch and piloted simulation studies by the NLR (National Aerospace Laboratory of The Netherlands)[3], and it is primarily characterized by simplicity in several respects. It was designed to minimize the requirements placed on supporting technology, including both data link and pilot decision-support automation. Broadcast data-link bandwidth requirements are minimized by employing conflict detection based only on the current aircraft state vector (current position, altitude, ground track, ground speed, and vertical speed). On-board conflict detection algorithms deterministically compare (in the current implementation) the state vectors of traffic aircraft with that of the own-ship. To minimize false alerts associated with extrapolation errors[6], state-vector-based conflict detection is limited in its "look ahead" time horizon. The research of NLR has determined that a 5 minute look-ahead horizon is sufficient for separation assurance.

If a conflict is detected, the pilot is alerted and the conflict resolution algorithm is automatically activated to calculate maneuver advisories for the pilot. These conflict resolution advisories are simple in that they are recommended changes to the own-ship velocity vector. The pilot implements the maneuver by setting heading, airspeed, or vertical speed targets in the FCP to match the advised settings. This procedure is comparable to the pilot's current use of the FCP to comply with a vector for traffic issued by Air Traffic Control (ATC). Concurrently, a conflict prevention system (PredASAS) monitors all possible single-dimensional maneuvers for conflicts, and it indicates to the pilot what maneuvers would cause a new conflict, essentially a "no-go" alerting system. All maneuvers outside of the displayed no-go bands are conflict-free for at least the next 5 minutes, assuming the traffic aircraft do not maneuver during this time.

The resolution maneuvers in this operational mode are tactical in nature because they only resolve the conflict and do not account for a return to the original flight plan or the consideration of external constraints such as RTAs or airspace hazards. This highlights the primary characteristic of the tactical mode, that of the open-loop (manual) nature of meeting constraints. It is hypothesized that the pilot would typically solve problems sequentially: first – resolve the conflict by maneuvering clear; second – avoid any nearby airspace hazards; third – develop an efficient plan to return to course; fourth – make adjustments to meet RTA and other ATC constraints. This approach has the effect of spreading decision-making over time and possibly simplifying the maneuver decisions. After maneuvering safely to resolve the original conflict, the pilot monitors the PredASAS information to determine when it is safe to return to course.

Strategic Mode

The strategic mode is a closed-loop (automated) method of trajectory planning. Any trajectory changes implemented by the flight crew will have been determined a priori to meet all known constraints and optimization criteria while both solving the current conflict and returning the aircraft to course. This approach places greater demand on decision-support automation in that it must generate trajectories for pilot review based on a simultaneous solution of constraints and objectives. More information on future actions of the traffic would allow for earlier detection of many conflict situations and greater flexibility and acceptability of new trajectories. Therefore, the intended trajectory, or "intent," of each aircraft is included in its broadcasted data-link message. This places a greater demand on the data link bandwidth to accommodate the additional information. For this experiment, the intent message was defined to be a series of trajectory change points, although other forms of intent are also being considered[7].

Conflict detection in the strategic mode is performed using both traffic state information and traffic intent information. The state-based conflict detection is identical to that in the tactical mode. A 5-minute look-ahead horizon was used in the experiment. The intent-based conflict detection deterministically compared the own-ship flight plan to the traffic-aircraft broadcast intent in a search for intent conflicts[8]. Whereas a 15-20 minute look-ahead horizon is thought to be appropriate for intent-based conflict detection, a shorter horizon of 8 minutes was used in the current study to allow more data to be gathered during the limited availability of the subject pilots.

A conflict-alerting decision algorithm was developed to determine when and how to alert the pilot to potential and actual conflict situations. The utility of combining state-based and intent-based conflict detection is that the alerting system can distinguish between a full-fledged conflict alert that requires own-ship action and a situation that will likely be resolved by the traffic aircraft. The latter situation would require no own-ship action but would have the potential for elevating to the former category. Such events include failure of either aircraft to observe priority and/or maneuver flight rules (described below) or an unannounced deviation from the broadcast intentions (i.e., flight plan non-conformance). It is hypothesized that distinguishing within the alerting logic between situations that require or do not require own-ship action would reduce unnecessary maneuvering and therefore improve overall system stability. The alerting logic is described in more detail in reference [5].

In contrast to the tactical mode, the strategic mode uses existing technology on the flight decks of many commercial aircraft to assist in conflict resolution. By coordinating the conflict-resolution calculations with the flight planning and trajectory generation functions of the FMS, a complete re-planning of the local trajectory can be performed, guaranteeing that the new trajectory is within the flight envelope. In addition, the FMS can also be used to close the loop on ATSP constraints. Speed and path strategies that meet an RTA at a downstream fix or airspace boundary can be incorporated into the proposed conflict-resolution trajectory. Resolution strategies can also incorporate predicted locations of convective weather cells and scheduled activation of SUA or any region that would be considered hazardous or inadvisable to enter, assuming this information was made available to the aircraft systems. Since the solution space that meets these constraints would normally be large, trajectory optimization can be performed to achieve a desired goal, such as fuel economy, a comfortable ride, or an early arrival. The FMS can then be used to fly the complete resolution trajectory, potentially reducing the workload of the flight crew.

Conflict resolution advisories for conflicts based on valid intent (i.e., the intruder aircraft is determined to be conforming to its broadcast intent) were calculated using a genetic-algorithm-based optimization routine[9]. This routine was designed to iterate trajectory constraints with the FMS until a conflict-free trajectory that meets all additional constraints (e.g., RTA) is determined. Further iterations are then performed to optimize a selected parameter (e.g., fuel-burn minimization). The trajectory would normally be flown by the FMS. For conflicts requiring own-ship action that are based on state information, resolution advisories identical to those in the tactical mode are presented.

Flight Rules for the Strategic Mode

Two types of flight rules are envisioned for the strategic mode of operation, each providing a distinct benefit. A *maneuver flight rule* is one that governs what types of maneuvers are not permissible in certain situations. The strategic mode incorporates a maneuver flight rule that is designed to prevent near-term conflicts from suddenly appearing. The same rule was applied to the tactical mode, as described earlier in the use of the PredASAS alerting system. The rule states that an aircraft may not implement a change in track, ground speed, or vertical speed that creates a near-term conflict (for the current study, within 5 minutes). The pilot would meet the requirements of this rule by avoiding flight in the direction of a PredASAS band, although transition through a band is permitted. This maneuver flight rule has the additional benefit of providing some predictability in autonomous-aircraft operations, which should aid the ATSP in developing stable strategies for managed-aircraft separation.

A *priority flight rule* defines which aircraft in a given conflict situation is responsible for resolving the conflict. The tactical mode has no priority flight rule in that it assumes every autonomous aircraft shares equal responsibility to resolve conflicts, which is prudent given the limited time horizon for detecting and resolving conflicts. The strategic operational mode also assigns equal responsibility for near-term conflicts. However for conflicts more than 5 minutes away, the conflict geometry is used to determine who has "right-of-way." By assigning resolution responsibility to one aircraft in a conflict pair, predictability should increase, total maneuvering at the system level should decrease (ideally by one-half since generally only one aircraft in a pair would maneuver), and system-level traffic flow stability may be enhanced. For conflicts detected significantly far in advance (perhaps greater than 15 minutes – a subject of future research), the benefits of assigning responsibility are likely to disappear, and therefore priority flight rules would no longer be applied. The application of flight rules as a function of time is shown in figure 1.
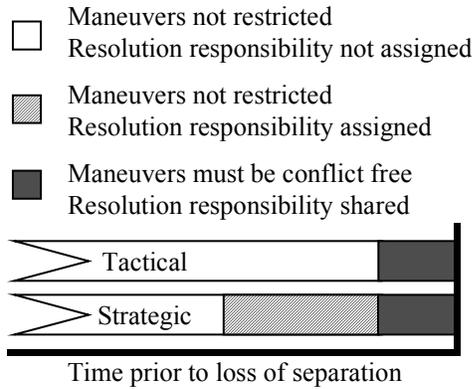
Figure 1. Application of flight rules.

Flight Deck Display Design

A new cockpit display of traffic information (CDTI) design concept, exercised in the strategic mode for this experiment, was developed to address the issues of effectively integrating (rather than superimposing) state and intent information for conflict detection into a single presentation. The design built on state-only and intent-only display features previously developed and investigated by NLR[2] and NASA Ames Research Center[10]. The aircraft simulation used in the current experiment was a representation of the MD-11 aircraft. The new display features for autonomous operations were therefore integrated into the MD-11 flight-deck display suite, and existing MD-11 conventions were adhered to as much as possible. The Primary Flight Display (PFD) and Navigation Display (ND) were the only displays affected, and an ND control panel was added. The new display design followed the common approach of superimposing traffic data on the ND. The CDTI features are described in reference [5]. The ND with some of the CDTI features is shown in figure 2.

Conflict Alerting

The conflict alerting follows the MD-11 aircraft system alerting convention. The alerting logic is based on three levels of alerting.

A Level 1 alert is used when information must be conveyed to the pilot, but no action is required. This alert level is used primarily in two situations. In the first situation, a conflict is detected based on the state vectors but not on the intent (i.e., the aircraft is planning to change course or altitude before losing separation). If both aircraft are determined to be conforming with their broadcast intent, then no action is required other than to continue to monitor for intent conformance. In the second situation, an intent conflict is detected, but the priority flight rules decree that the own-ship has priority and the traffic aircraft must maneuver. Again, no action is currently required by the own-ship, and the traffic aircraft is "pointed out" to the own-ship pilot. Note that Level 1 alerts only occur in the strategic mode.

A Level 2 alert requires action by the own-ship flight crew. This alert is used when a conflict has been detected, and it is the responsibility of the own-ship flight crew to resolve the situation.

A Level 3 alert requires *immediate* action by the own-ship flight crew. This alert corresponds to the actual loss of separation.
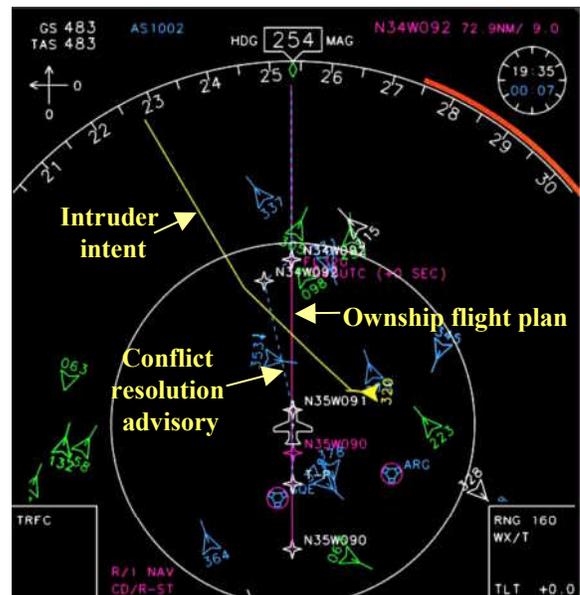

Figure 2. ND as modified to present traffic, conflict, and resolution information.

Conflict Resolution Advisories

The detection of a conflict triggers the calculation of a resolution advisory by the decision support automation. The proposed trajectory is loaded as an alternate route in the FMS and is displayed on the ND for pilot review. A Control and Display Unit (CDU) page was devised for accepting (or rejecting) the trajectory.

If the conflict persists until it is also detected as a state conflict, a set of tactical-maneuver options are displayed to the pilot as a safety enhancement that permits immediate conflict resolution with simple maneuvers (i.e., heading and vertical speed changes). These tactical advisories are

shown concurrently with the alternate FMS-route advisory, providing the pilot a tactical option to clear the conflict alert while the strategic FMS route is reviewed.

Experiment Objectives and Approach

The primary objective of the current experiment was to compare the two proposed operational modes applicable to airborne separation assurance in a constrained en-route environment. The experiment focused on operational aspects that relate to commercial-transport autonomous aircraft as defined by the DAG TM Concept Element 5[2]. A second objective was to assess the usability of the flight-deck display and user-interface design that integrated state-based and intent-based traffic information to reinforce pilot situation awareness.

The experiment focused on the operations of a single autonomous aircraft in en-route cruise flight with variable airspace complexity (i.e., traffic density, weather cells, SUA). Beyond the current research scope were direct interactions with the ATSP, managed aircraft, or other piloted autonomous aircraft. The study did not address multi-person flight crews, crew resource management, or voice communications. Climbs and descents of the own-ship were not studied, nor were the effects of winds or failure modes of decision-support automation or CNS infrastructure. These issues will be addressed in future studies.

A 2-by-2 within-subjects experimental design was used to address the research objectives. The primary independent variables were operational mode (tactical and strategic) and operational complexity (low and high).

Operational complexity, for the purposes of this experiment, was assumed to be a function of traffic density and airspace hazard density. Research has shown that traffic density is correlated with operational complexity[11]. Traffic density approximating recorded 1997 levels were used for the low complexity condition and was tripled for the high complexity condition. Airspace hazard density was added as an additional relevant complexity factor of constrained operations.

Sixteen active commercial transport pilots participated in the study. Each flew a scenario in each of the four conditions represented in the 2-by-2 experimental design described above. These level-cruise scenarios each consisted of three segments (i.e., flight legs), and each segment contained a conflict situation. Three types of conflict situations were used in this experiment, one per

segment. The "state-only" conflict occurs when only the state trajectories threaten a conflict. The "intent-only" conflict occurs when only the intent trajectories threaten a conflict. The "blunder" conflict is similar to the "state-only" conflict, but the intruder aircraft does not adhere to the planned trajectory change in the broadcast intent message, and the aircraft remains in conflict.

Each segment was terminated with an RTA constraint at a fix. The subject pilot was tasked to ensure separation from the traffic aircraft and avoid airspace hazards while meeting the RTA constraint. In order to assess workload impact, the subject pilot was given a secondary task involving periodic monitoring and reporting of aircraft system status. Additionally, the pilot was prompted every two minutes to record a real-time assessment of workload on a seven-point scale from *very low* to *very high*.

Preliminary Results and Discussion

Preliminary results are presented in two parts. In the first part, three case studies from the recorded data set are presented to illustrate aspects of the tactical and strategic modes as flown by subject pilots in the experiment. In the second part, subjective ratings and comments by the pilots comparing the tactical and strategic modes are given. These data represent only a fraction of the total data acquired, and further analysis and reporting of additional results is planned.

Case Studies

Some of the differences seen between the two modes of operation, tactical and strategic, will be illustrated by showing how various pilots solved the same traffic situation using the tools and procedures associated with each mode. These illustrative flights have been chosen to highlight some of the differences between the two modes and do not necessarily represent typical performance by all of the pilots. In general, it was found that when a pilot fully utilized the set of tools offered, they were able to successfully complete their tasks of maintaining separation, meeting an RTA, and operating in an efficient manner. There were only two out of 192 experiment segments where the pilot lost separation; one in each mode of operation. Interestingly, both occurred in low complexity airspace. The data indicate that both situations may have developed through a lack of familiarity with the tools and experience in self-separation situations.

Case 1: State-only conflict

The first case study will illustrate how two pilots reacted to a state-only conflict. In this conflict type, the state vectors of the intruder and the own-ship are initially in conflict, i.e., threaten a loss of separation. However, the intruding aircraft has a trajectory change point (TCP) in its flight plan that occurs between three and five minutes before loss of separation which would take the aircraft out of conflict. Therefore, in a state-only conflict, if both aircraft follow their flight plans, there will be no intrusion. Both of the subject pilots in this case study saw exactly the same conflict geometry with identical background traffic and airspace hazards. The only difference was the mode of operation. The relevant recorded tracks are shown in Figure 3. Other background aircraft and airspace hazards are not shown.
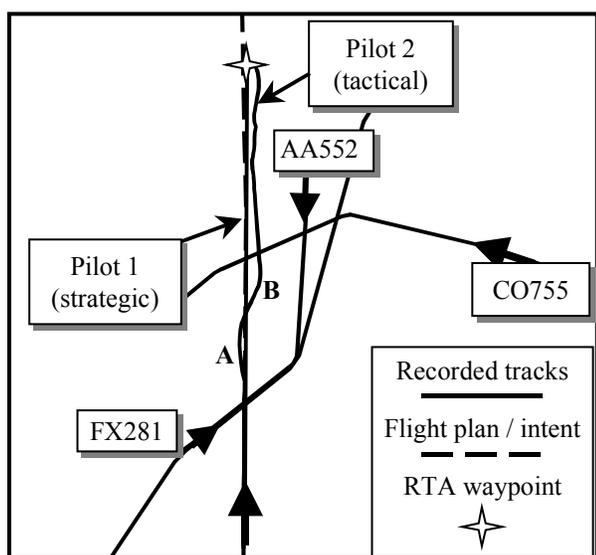

Figure 3. Recorded tracks of the state-only conflict scenario case study.

Pilot 1 operated in the strategic mode. Early in the scenario, he made use of the ability to display the intended trajectories of several nearby, converging aircraft, including FX281 and AA552. Pilot 1 took no action, apparently satisfied that FX281 would pass well in front and AA552 would pass well behind. A short time later (point A in figure 3), a Level 1 alert was displayed for CO755, the intended intruder. Such an alert indicated that if both aircraft continued along their flight paths, there would be no loss of separation and therefore no action was required by either aircraft. Over the next two minutes, the pilot monitored the progress of CO755 with the flight plan displayed. Once the intruder started its left turn (and the state vectors were no longer in conflict), the Level 1 advisory disappeared. Pilot 1 made no maneuvers during

the scenario, and he consistently rated his workload low throughout the scenario.

Pilot 2 operated in the tactical mode. He made several maneuvers early in the scenario: a climb probably to avoid FX281, and a left turn probably in response to the turn of AA552. While returning to course and altitude (point A), Pilot 2 received a conflict alert on CO755, the intended intruder. His response of turning farther to the right to pass behind it was unfortunate, considering the upcoming planned trajectory change of CO755 (unknown to Pilot 2). CO755 began its left turn toward the own-ship, requiring another evasive maneuver (a climb) by Pilot 2 (point B). At the new altitude, Pilot 2 encountered 3 more successive conflicts, all unplanned in the experiment. Due to excessive maneuvering, the pilot was unable to meet the time and altitude constraint at the final waypoint of the scenario. This pilot encountered a total of six separate alerts on three different aircraft where only one was intended. Pilot 2 also failed to complete three out of five secondary tasks (aircraft systems monitoring and reporting). His self-assessment of workload was consistently higher than Pilot 1 throughout the segment.

This case study was an illustration of a conflict type for which the preferred course of action would be to take no action other than to monitor the other aircraft. Intent information was required to determine that separation would be maintained if the aircraft conformed to their intent. State information was required to provide the traffic advisory information and to monitor for conformance. The scenario illustrates a benefit of combining state and intent information in conflict alerting. Without this approach, as demonstrated in the case study, a pilot may be subjected to unnecessary problem solving.

Case 2: Intent-only conflict

In the intent-only conflict type, the aircraft state vectors are not initially in conflict. However, a planned TCP by the intruder aircraft results in trajectories that threaten a loss of separation. Conflict detection systems that use the intent information are able to detect the conflict before the TCP maneuver, whereas state-based systems would not alert the pilot until the TCP maneuver has been completed. In the following case study, AA686 was the intended intruder and was climbing towards its planned cruise altitude that coincided with that of the own-ship (FL320). The level off would occur approximately four minutes before loss of separation. The relevant recorded tracks are shown in Figure 4.
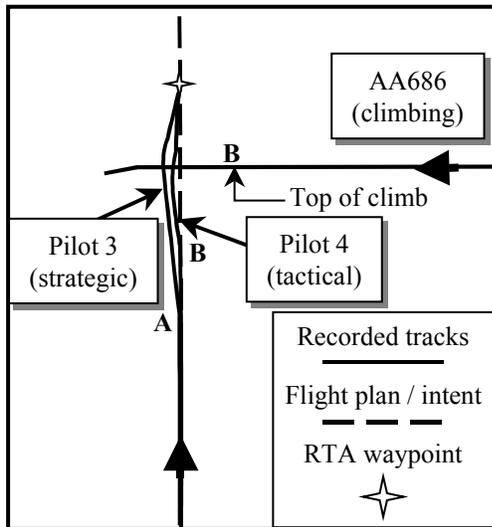
Figure 4. Recorded tracks of the intent-only conflict scenario case study.

Pilot 3 flew the scenario in the strategic mode. The pilot was initially observed to be studying the intent (i.e., the broadcast portion of the flight plans) of many of the aircraft. At 5:45 into the simulation (point A), a Level 2 traffic alert indicated a conflict with AA686, with loss of separation to occur more than seven minutes into the future. A resolution trajectory calculated by the automation was displayed to the pilot, indicating an additional waypoint that would avoid loss of separation with AA686 and return the own-ship to the RTA waypoint. Pilot 3 accepted the resolution advisory through the CDU, and the alert symbology disappeared. Over the next several minutes, the pilot was observed to watch the passage of AA686 at very low ND range settings to verify that the new trajectory avoided loss of separation with AA686. This indicated that while this particular pilot was willing to accept the offered resolution, he did not fully trust the system and felt compelled to closely track the separation until AA686 had passed behind him. Pilot 3 was able to meet all given constraints.

Pilot 4 flew the same scenario in the tactical mode. Pilot 4 received his first alert on AA686 at 9:20 when AA686 leveled off at FL320 (point B). This was three and a half minutes later than Pilot 3 was alerted to the conflict. Pilot 4 elected to immediately turn to the left. Shortly thereafter, Pilot 4 initiated a climb to FL330, possibly because he was unsure whether the turn would be sufficient to resolve the near-term conflict. At 11:30, while the own-ship was climbing, an alert appeared on another aircraft flying opposite direction at FL365. Between this time and 12:40 the pilot made 3 major heading changes to the right, left, and then right. It is unclear why the pilot made three heading changes instead

of just one. As the original intruder, AA686, passed beneath the own-ship, Pilot 4 maneuvered to recapture his lateral path and descended shortly thereafter. He was able to successfully maintain separation and reach the altitude and time constraints at the RTA waypoint.

In this case study, Pilot 3 benefited from the strategic mode in three ways: knowing the intentions of the intruder aircraft, having plenty of time to determine a satisfactory resolution, and having an automated system load a viable solution into the FMS for review and acceptance. Pilot 4 had little notice of the conflict and thus may have felt pressured into making quick maneuver decisions before determining what other conflicts may result from the maneuvers. Research at the NLR has suggested that intent conflicts such as this would not normally be an issue, provided that each aircraft is equipped with a conflict prevention system such as PredASAS and that conflict-generating maneuvers (such as the level-off of AA686 in this scenario) are not permitted[3]. For this to be a viable approach, the conflict prevention system may need to be integrated with the FMS in order to override such maneuvers.

Case 3: Blunder conflict

The third conflict type that was presented to the pilots was a blunder, or non-conformance, conflict. The scenario geometry is similar to the state-only conflict, but in this case, the approaching aircraft fails to maneuver at or after the planned TCP. A loss of separation would therefore occur if the own-ship pilot fails to maneuver. In the experiment, the intended intruder was AC303, and a TCP was placed three and a half minutes prior to loss of separation. The relevant recorded tracks are shown in Figure 5.

Pilot 5 flew the scenario in the strategic mode. For the first several minutes of the flight, Pilot 5 was observed to carefully scrutinize the traffic data with frequent changes to the ND range. At 6:30, a Level 1 alert on AC303 was displayed (point A), indicating a possible threat but no action currently required. The pilot immediately displayed the flight plan for this aircraft. At 8:45 (point B) AC303 blundered through its TCP, failing to follow its broadcast intent; the alert changed to a Level 2 alert indicating that action will be required. Two seconds later, the pilot initiated a 16 degree heading change away from the intruding aircraft. Over the next three minutes, Pilot 5 made four minor heading changes to minimize the distance between himself and the intruder, essentially fine-tuning the resolution for minimum path deviation. The closest

approach point was 5.1 nm. After the intruder had passed behind own-ship, the pilot engaged FMS navigation to recapture his flight plan. He successfully met the time and altitude constraints at the RTA waypoint. The pilot was consistently late performing the secondary task.
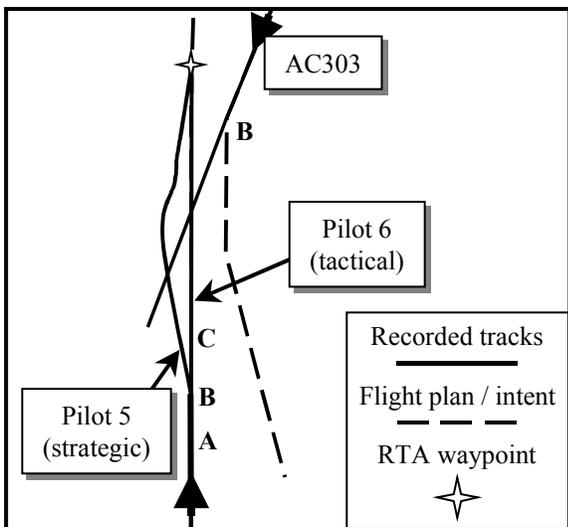

Figure 5. Recorded tracks of the blunder conflict scenario case study.

Pilot 6 flew the same blunder scenario in the tactical mode. As with all of the pilots, Pilot 6 spent the first several minutes scanning the traffic. At 6:30, Pilot 6 was alerted to a conflict with AC303 (point A). Note that Pilot 5 received a Level 1 alert (traffic advisory with no action required) in the strategic mode at this point. The tactical mode has no Level 1 alert because intent information is not available. At the time of the conflict alert, Pilot 6 had just started his secondary task and decided to complete it before resolving the conflict. This indicates that the pilot understood he had five minutes until loss of separation and did not need to act immediately. At point C, the pilot initiated a gradual descent to FL310. He maintained his course and continued to scan the traffic. At 12:00, the intruder passed overhead, clearing own-ship by 1200 ft. Half a minute later, Pilot 6 initiated a slow return to his target altitude. He was able to easily meet the constraints at the RTA waypoint. The pilot was also very prompt with performing the secondary tasks.

This case study illustrates how the tactical mode appears better suited for blunder scenarios, particularly those where the blunder leaves little time to react. In both modes, the pilot is alerted at the same time to the possibility of loss of separation. The tactical-mode pilot was immediately instructed to resolve the conflict and was given resolution advisories to do so, allowing plenty of time to chose and execute a maneuver. The strategic-mode

pilot was advised, however, not to take action prematurely but to keep watch on the traffic aircraft. Since broadcast intent would presumably be followed more often than not in an operational system, the strategic approach to reduce unnecessary maneuvering while heightening the pilots awareness of the potential intruder may still yield benefits.

Initial Subjective Data Results

Pilot Ratings

A post-simulation questionnaire asked the pilots to contrast the tactical and strategic operational modes from nine operational perspectives. These included: flight safety, flight efficiency (minimized fuel consumption and time to destination), overall workload, maintaining situational awareness, identifying conflicts, resolving conflicts, alerting accuracy (no false alarms), alerting reliability (no late alarms or missed alarms), and the usefulness of the conflict prevention (no-go) bands. The pilots rated these parameters on a scale from 1 to 9, where 1 = *tactical absolutely better*, 5 = *tactical same as strategic*, and 9 = *strategic absolutely better*. The results from the questionnaire are shown in Figure 6, and they indicate that the strategic operational mode was preferred in seven of the nine operational categories.
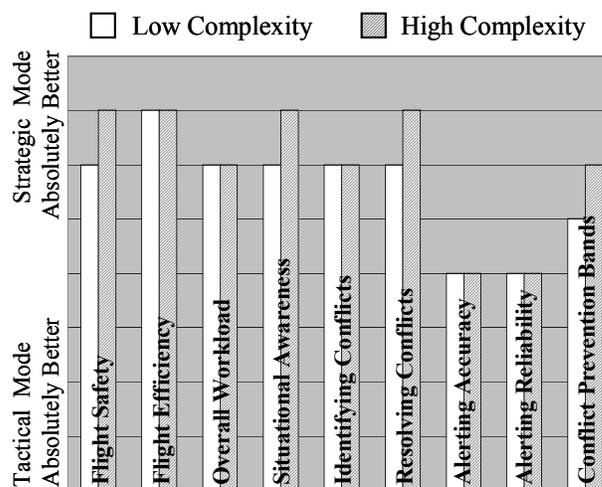

Figure 6. Pilot median ratings for comparison of tactical and strategic operational modes.

Pilot Comments

The pilots were also given the opportunity to provide expanded written comments regarding tactical vs. strategic operational modes with respect to four topic areas. Representative responses favoring strategic and tactical modes are presented.

Flight safety and efficiency

Strategic mode: *"With strategic I was able to look ahead farther and more quickly assess the most critical target both in terms of time and magnitude of flight path changes required. With tactical, I felt surprised by conflicts, especially vertical."*

Tactical mode: *"Strategic mode in high density offered too much clutter for my comfort level. I felt the tactical only was safer and more efficient because it was quicker and easier to use and required less brain RAM. As traffic density decreased, the advantages of one over the other decreased."*

Pilot workload and attention

Strategic mode: *"Strategic is much better – allowed me to 'stay ahead' rather than just react to conflict alerts."*

Tactical mode: *"Tactical was less workload due to less info, but more stressing to resolve due to time element. Pilots like to be in control and know what's coming."*

Traffic information & conflict-management tools

Strategic mode: *"Strategic allows more conflict prevention in that I could take earlier, smaller state changes, or avoid them entirely by knowing other aircraft's intent."*

Tactical mode: *"Often times too much information is given, i.e., if this guy maybe does this, then you may have a conflict. Often works better when it's in black and white. Either you do or you don't, plus no gray area. I found tactical better/easier because less information was available."*

Acceptance of the self-separation task

Strategic mode: *"Once you used the strategic mode and trusted it, the workload dropped. There were more opportunities to pick up targets and not rely on the 'brain' to make the right choices."*

No pilot comments were received that specifically expressed a positive association between the tactical mode and acceptance of the self-separation task.

Conclusions

Preliminary results indicate that pilots in both modes were generally able to meet the operational constraints. Functional differences between the modes were evident in scenario case studies. In scenarios with conflicts based only on state vectors, pilots operating in the strategic mode were less frequently observed to maneuver unnecessarily.

Under tactical situations, pilots sometimes caused several additional conflicts in their maneuvering to resolve the initial conflict. In scenarios with conflicts based initially on intent, strategic-mode pilots generally took advantage of the ability to resolve the conflict earlier than the tactical mode allowed. In blunder scenarios, the lack of intent information in the tactical mode generally resulted in resolution of the conflict before the blunder occurred.

Subjective data results indicated a consistent pilot preference for the strategic mode of operations over the tactical mode. However, supportive and constructive statements were received for both strategic and tactical modes, indicating the following conclusions. The pilot community is diverse, and it may be difficult initially to achieve universal acceptance of a common set of tools and procedures. The subject pilots had a wide variety of understanding of the difference between tactical and strategic operational modes, given the short time available for familiarization and for building experience and trust. Although the strategic operational mode is relatively immature and undeveloped relative to the tactical mode, the experiment highlighted many potential benefits of the strategic mode to aid in meeting realistic operational constraints, indicating that further development and exploration of the strategic mode is warranted.

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