HUMAN/AUTOMATION RESPONSE STRATEGIES IN TACTICAL CONFLICT SITUATIONS

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Abstract

A human-in-the-loop simulation was conducted that examined off-nominal and tactical conflict situations in an advanced Next Generation Air Transportation System (NextGen) environment. Traffic levels were set at two times (2X) and three times (3X) current day levels and the handling of tactical conflict situations was done either with or without support from Tactical Separation Assisted Flight Environment (TSAFE) automation. Strategic conflicts and all routine tasks performed in today's system were handled by ground-based automation. This paper focuses on the response strategies observed in two scripted tactical conflict situations and how they differed according to whether or not automated resolution support was provided by TSAFE. An examination of the two situations revealed that when TSAFE automation was active, participants tended to provide additional, complementary maneuvers to supplement the tactical vector issued by TSAFE. This also included a greater tendency to use both aircraft in a conflict pair. When TSAFE support was not available, participants tended to use single vector or altitude maneuvers and were more likely to attempt resolutions using a single aircraft as well. Some issues that arose through the operations simulated in this study related to the need for the Air Navigation Service Provider (ANSP) to be able to have final authority over the issuance of TSAFE maneuvers as well as the importance of having awareness of the immediate traffic situation in making effective and safe time-critical decisions.

Background

Despite the recent downturn in the global economy and its negative impact on air travel and operations, the Federal Aviation Administration (FAA) continues to forecast an increase in demand that will see an already stressed system accommodate nearly two to three times more traffic than current levels, and over a billion passengers by the year 2025 [1][2]. Given that the air transportation system was essentially operating at capacity just prior to the downturn, the forecast increase will place a burden on the system that will require clear and definitive changes in a number of areas if the current levels of safety and service are to be maintained or improved.

Because similar increases in air traffic demand have been forecast for some time now, research on a variety of fronts has been ongoing in an effort to address the issues and concerns related to the consequences of such increases. One particular area of research has been separation assurance and how it can be maintained in an airspace system that is more crowded and inherently more taxing on the men and women responsible for providing a safe flow of air traffic. The vigilance that this task entails has been identified as a bottleneck and possible barrier to the ability of the airspace system to accommodate the predicted future demand. Based on this understanding, research has been directed toward finding ways of mitigating the workload associated with the task while maintaining or even improving current levels of safety.

Earlier research in this area dealt with the role that automation could play in helping to maintain separation assurance and its impact on controller workload. One study in particular looked at various levels of automated conflict resolution at traffic levels ranging from current day to three times that level [3]. Part of this human-in-the-loop study compared performance between conditions where a controller participant only had access to a manual trial planning tool for resolving conflicts and one in which the controller also had the ability to call upon an automated strategic conflict resolution tool -a central component of the Advanced Airspace Concept (AAC) [4]. The results of this study showed that the real benefits of the automated conflict resolver were realized as the traffic levels increased. Benefits in this case refer to such metrics as workload reduction, greater maneuvering efficiency, and fewer separation violations.

Despite the fewer number of separation violations seen with automated strategic conflict resolution support tools, a number of them still occurred. This highlighted a missing yet critical component of the broader advanced airspace environment used in the study: a tactical safety layer that would be able to handle emergency and short-term conflict situations.

The Tactical Separation Assisted Flight Environment (TSAFE) is a decision support tool designed to provide that layer of safety through the computation of tactical maneuvers that would avoid a loss of separation (LOS) [4] [5] [6]. Although this tool has undergone considerable fast-time testing and analysis [6] [7], it has had no exposure to human-in-the-loop testing.

Simulation

To address this missing aspect, a study was conducted at NASA Ames in the Airspace Operations Laboratory (AOL) [8] with the main goal of investigating off-nominal, emergency, and tactical safety situations in a high-density, highly automated environment. Comparisons were made between conditions where controllers had support from TSAFE automation to handle initial tactical maneuvers and conditions where they were required to handle the events without such support.

The primary results of this study have been previously published and showed that the overall concept with greater functional allocation and responsibility residing with ground-based automation showed great promise [9]. Results relevant to this paper showed that the participants were able to resolve 75% of the scripted tactical conflicts. Operations with TSAFE support showed a greater ability to resolve tactical conflicts with fewer separation violations occurring than in the non-TSAFE conditions. The number of separation violations with TSAFE also did not appear to be impacted by the level of traffic. Despite these promising results, a number of issues were uncovered that need to be addressed before the concept can move forward.

Purpose

The purpose of this paper is to further examine a specific subset of tactical situations that the Air Navigation Service Providers (ANSP) all encountered with an eye toward providing a window into the strategies employed by them in handling those situations. These strategies will also be used as a comparison to the collaborative efforts of the ANSP and TSAFE tool in the same situation as a means of highlighting the factors that the tool might benefit from incorporating.

The remainder of this paper will present the technical and operational environment that this study used as well as the assumptions that were made in their instantiation. This will be followed by the design and method of the study, which will detail the tactical situations chosen for analysis. Prior to the conclusion, the results of the analysis will be presented followed by case studies that will highlight important issues surrounding the TSAFE tool and the overall concept of which it is a part.

Operational Environment

Ground-based Automation and Technologies

The environment in which TSAFE and the broader Advanced Airspace Concept could be envisioned to be operational assumes high levels of automation and the need for a number of technologies to be in place. This point, coupled with the desire to provide a level of traffic that would be in line with forecasts and could provide a challenge to the automation and the service providers, placed it well into the timeframe of the Next Generation Air Transportation System (NextGen).

To model this environment for the purposes of this study, all nominal aircraft entering the test airspace were capable of conducting trajectory-based operations via datalink communications and Automatic Dependent Surveillance-Broadcast (ADS-B) reporting to a level of Required Navigation Performance (RNP) 1. These aircraft were cleared for all phases of flight provided they could maintain their trajectories. They also had the ability to negotiate trajectory changes with ground-based automation as well as an ANSP directly.

For flights that maintained their trajectory, ground-based automation was responsible for the detection and resolution of strategic conflicts (greater than three minutes). Following the detection of a conflict, an algorithm generated a resolution for one of the aircraft, which was then uplinked directly to that aircraft without ANSP involvement.

The technologies assumed for the flight deck also allowed for the ground-based automation to remove some of the routine tasks that contribute to workload in today's environment and would become crippling in tomorrow's. For example, datalink communications used for strategic separation assurance also enabled the automated transfer of communication, which removed the need for handoffs, check-ins, and point-outs.

Display

The removal of the tasks and responsibilities just mentioned also aligned with display requirements that would be necessary for the traffic levels used in this study. Current day levels of traffic were assumed to be roughly 15 to 18 aircraft occupying a sector at any given time. For the two (2X) and three (3X) times levels of traffic that were used in this study, the current DSR display paradigm would not have been acceptable. Figure 1 presents what the display would look like if each aircraft was associated with a full datablock as they are today at 3X levels of traffic.

Figure 1. Current day DSR display at 3X traffic.

To avoid the excess workload that such a display would produce as well as to focus on the responses of ANSP's to off-nominal situations, all aircraft operating nominally-on trajectory with fully functioning equipage-had target symbols that were low-lighted and limited datablocks that displayed their assigned altitude. For aircraft that did not fit this nominal category, changes were made to make their status more salient to the ANSP. For example, aircraft that had a change in status from nominal Trajectory-based Flight Rule (TFR) operations to Instrument Flight Rule (IFR) operations were highlighted in green. Aircraft that were off trajectory were displayed as large, cyan chevrons. This was done to draw attention since an aircraft in such a congested environment not on its trajectory would have short-range, ballistic conflict probing and would thus have the potential to cause many problems. Figure 2 shows an example of how these display changes were presented to the ANSPs in the study.

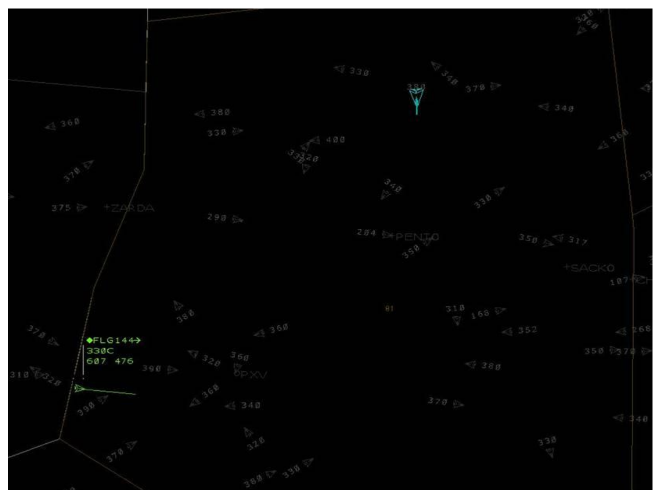

Figure 2. Modified DSR display at 3X traffic.

Method

Experimental Design

The full-scale design of this study included both air- and ground-side components. Because this paper focuses on the ground-side aspect of the study, only the design related to that portion will be presented. A fuller account of the overall study can be found in [9].

The ground-side portion of this study was a 2x2 within-subjects design. The first independent variable was Tactical Maneuver Initiator, which referred to the expected source of the maneuver to avoid a tactical conflict. The two levels of this variable were TSAFE and ANSP. In the TSAFE condition, the TSAFE automation was expected to issue the tactical maneuver to avoid a loss of separation. For the ANSP condition, the participant did not have the support of the TSAFE automation and was expected to issue the appropriate tactical maneuvers directly.

The second independent variable was Traffic Density. This referred to the instantaneous traffic counts that were maintained in the test sector at a given time. The two levels of this variable were 2X and 3X, with X signifying a multiple of current day traffic. Current day levels were estimated to be at a high monitor alert parameter (MAP) value of between 15 and 18 aircraft. The 2X and 3X levels of traffic were therefore approximately 30 and 45 aircraft in the test sector respectively.

Participants

For the ground-side portion of this study, a total of six participants took part over the course of two sessions. Out of those six, three were recently retired. The other three were current front line managers from different centers across the US. While data was collected for all six participants, the analyses in this paper will focus on the active ANSPs in order to ground the results in the most current context. Pseudopilots controlled the execution of aircraft maneuvers. Two pilots were assigned to each controller, one limited to performing the scripted actions on a small set of aircraft and the other managing a list of aircraft for potential actions. These individuals were all either students or graduates of San Jose State University's aviation program.

Apparatus

To provide a realistic and familiar environment to the participants at the AOL, equipment very similar to what is currently in place at the centers was used. This included large, 28" Barco displays with Display System Replacement (DSR) keyboards and trackballs as input devices (see Figure 3).

For the test environment and interface with which the controllers operated, the Multi-Aircraft Control System (MACS) program was used [10]. This is a JAVA based software program developed by Thomas Prevot and his development team at the NASA Ames Research Center. MACS has the capability to emulate the current day system and is also able to be scaled to incorporate future, developmental concepts and functionalities.

Figure 3. Equipment used in the AOL.

Through the development and configuration of MACS for this study, a number of changes and additions were made to the current display and the operations underlying what was presented to the participants. More detail is given here to provide a better understanding of how the participants engaged in the resolution of off-nominal and tactical conflicts.

As presented in Figure 2, all aircraft that were on their 4D trajectory operating under Trajectory Based Flight Rules (TFR) were low-lighted and basically left untouched by the ANSP. These aircraft were visible enough, however, to allow for the ANSP to engage in monitoring tasks much like they do today. Aside from a voice or datalink communication from the flight deck, the initial indications for something off nominal were a green highlighted target symbol indicating that the aircraft was now flying IFR, or an enlarged cyan target symbol indicating that the aircraft was off track.

Conflict probing was based on a 12 minute look ahead for all aircraft in and around the test sector. However, because the focus of this study was partially on tactical conflicts and an automated conflict resolver was expected to clear strategic conflicts, pending conflicts were not presented to the participant until the time to LOS was within three minutes. Once inside this time threshold, the involved aircraft were presented to the participant in red with full datablocks and the time to LOS appended to the first line.

This display method was consistent across conditions, but in the TSAFE conditions there were additional items included in the fourth line of the datablock. These items included the aircraft callsigns involved in the conflict, followed by either the turn direction and heading that TSAFE has computed for the maneuvering aircraft or "other," which notified the ANSP that TSAFE would not be issuing a clearance for that aircraft. This last bit of information was often used by the ANSP in determining which aircraft to use in performing a maneuver in conjunction with the TSAFE maneuver to expedite conflict resolution. There were issues with this, however, which will be described in the Results section.

Test Airspace

The airspace that was selected for this study was based, in part, on that used in a previous separation assurance study [3]. The test sector was a combination of overlapping medium high- and high-altitude sectors in Indianapolis center (ZID). The combined sectors were ZID 81 and ZID 91, with the test sector being referred to as ZID 91 (see Figure 4). The altitude stratum for this combined sector was set at flight level (FL) 240 and above with an overall geographic area of 7,561 square nautical miles.

The decision to use this particular sector was based, in part, on the availability of pre-existing traffic scenarios for the area that could be built upon and crafted further to suit the aims of this simulation. An additional and important consideration was also the characteristics of ZID 91. Referring to Figure 4, the sector is fairly narrow in the East-West direction which provided a constrained area that would require quick, tactical actions in off-nominal situations. Additionally, the Pocket City (PXV) waypoint shown in the southeast quadrant of ZID 91 is a common "hot spot" for this sector with a great deal of converging and crossing traffic-this was well represented in the test scenarios. This characteristic coupled with the steady flow of transitioning aircraft to and from Louisville International Standiford Field Airport (SDF) provided for a complex environment that well suited the goal of providing challenging situations to the participants and automation.

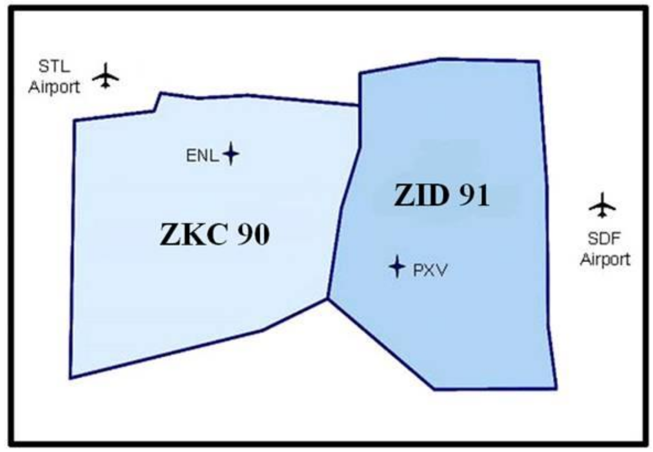

Figure 4. Test airspace with ZID 91 shown to the east. Notice SDF airport further to the east.

Test Scenarios

The test scenarios that were adapted for this study were originally developed from live traffic and then scaled to reach the desired 2X and 3X levels of traffic. The resulting scenarios were composed of approximately 65% overflights and 35% transitioning aircraft and included a varied fleet mix with a mostly homogeneous level of advanced equipage.

Added to this base were a number of scripted off-nominal, tactical conflict, and emergency situations that were designed to test the responses of the ANSPs and the automation. Because the focus of this paper and its analyses are on response strategies to tactical conflict situations, only those scripted events will be described below.

While there were a number of tactical conflicts that were scripted for this study, the following two were selected for analysis and discussion based on their repeatability and consistency in presentation for each of the three participants:

Trajectory mismatch

This scripted situation was designed to reflect when the ground-based system did not share the same representation as the flight deck. In this case, as shown in Figure 5, the expected trajectories for flights A and B would have flight A turn in a northeasterly direction at the PXV waypoint and run parallel to flight B at the same altitude. However, the actual path flown by flight A would have it continue straight along its original path past PXV. This would result in a short-term conflict with less than three minutes to loss of separation. Another similar case of this category involved an aircraft that, instead of flying straight past its expected turn point, makes an unexpected turn north directly into the path of another aircraft at the same flight level forcing a short term conflict with less than three minutes reaction time.

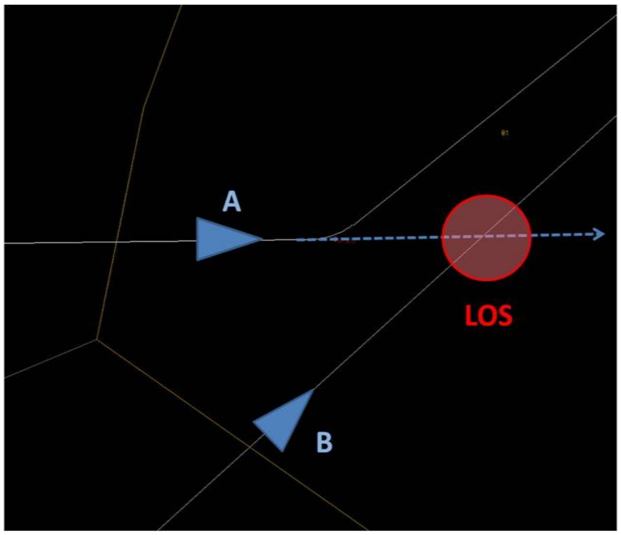

Figure 5. Scripted tactical conflict situation involving a trajectory mismatch.

Low rate of climb

This scripted situation involved a climbing aircraft from SDF airport with crossing traffic that would normally have a safe buffer of vertical separation. However, at the start of flight A's climb (see Figure 6), the pseudopilot placed the vertical speed at the lowest level possible. This pushed back its Top Of Climb (TOC) point and gave the aircraft an unexpectedly slow rate of climb, which placed flight A and B into direct conflict with short time to act.

TSAFE

The instantiation of the TSAFE algorithm and its incorporated automation into this simulation environment was an early version that operated according to simple guidelines. For this study, the only maneuver that the TSAFE automation issued was a vector for a single aircraft. The time horizon for this issuance was set at three minutes or less to predicted loss of separation at which point the calculated maneuver was sent directly to the selected maneuvering aircraft.

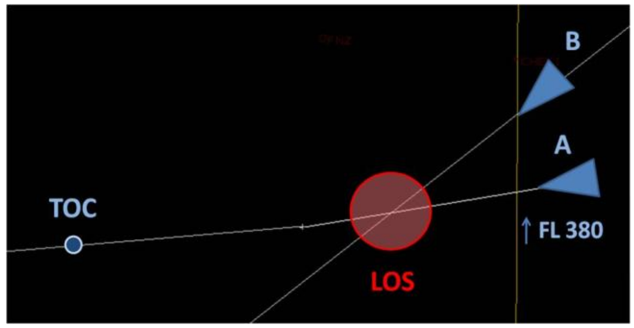

Figure 6. Scripted tactical conflict involving a climbing aircraft with a low rate of climb.

Procedure

This entire study was run over the course of two weeks, with one week devoted to each team. There were three participants per team, and each was assigned to a single workstation. The data collection sessions were 30 minutes each and were run in parallel, with all three participants working on a problem simultaneously. However, the run schedule was designed to avoid any of the three participants working on the same problem at the same time (i.e., participants were always working different problems from one another). Following each session, the participants filled out short questionnaires and then–following a break–rotated to a new workstation as part of the design necessary to include the flight-deck portion of the overall study.

During the session, most of the routine tasks that ANSPs perform today were removed. The task of the participant, therefore, was to monitor the traffic conditions and handle any of the situations that arose both through scripted and unscripted events. This involved handling emergency situations such as loss of cabin pressure, datalink requests from the flight deck, or tactical conflict situations. The participants were able to use trial planning functionalities for avoiding conflicts either laterally or vertically (or a combination) and for regaining the trajectory of aircraft once they were off. Datalink communications were also available for transmitting clearances directly to aircraft as well as for the automated transfer of communications.

Results

It should be restated here that the overall results of this study have been published in Prevot et al. [9]. The purpose of this paper is to examine and describe the strategy similarities and differences used by the automation and the ANSP participants in handling the selected tactical conflict situations described in the Test Scenarios subsection.

The small sample size and the sometimes varied nature of the ANSP responses did not lend itself to conducting inferential statistics. Therefore, what follows is a descriptive analysis of those response strategies to specific instances of conflicts that were common among the three ANSPs and the automation. This will be followed by examples that highlight some of the issues that are important to operations in the environment tested in this study.

Trajectory mismatch

This particular category of scripted conflict was perhaps the most consistent and reproducible of the ones used. There were two specific cases that led to the three participants issuing tactical maneuvers in all four conditions (TSAFE and ANSP across 2X and 3X).

2X

For the first case where an aircraft failed to make its expected turn, Table 1 presents the basic findings for what occurred in the TSAFE condition. The first column from the left represents the participant performing the maneuver, the second column contains what maneuver was done to the aircraft that either missed or made an unexpected turn (Off Track A/C), the third column contains what maneuver was done to the nominal, On Track aircraft, and the last column shows whether or not a loss of separation (LOS) occurred.

Because TSAFE was limited to issuing vectors to one aircraft as it was originally intended, the results for this and subsequent sections for that condition will be with respect to what the ANSP may have done in addition to the vector that TSAFE issued. Aircraft that were issued a vector from TSAFE are denoted by a (T).

By observation of Table 1, one can see that the ANSPs did not allow the conflict resolution to proceed by TSAFE maneuver alone: two of the ANSPs followed the issuance of a TSAFE vector with an altitude clearance (labeled as “Combination”) for the same aircraft, and one complemented the vector with an altitude clearance for the other aircraft in the conflict pair.

Table 1. 2X TSAFE/Collaborative Maneuvers

	Off Track A/C	On Track A/C	LOS
P1	Combination (T)		No
P2	Vector (T)	Altitude	No
P3	Combination (T)		Yes

While the combination vector and altitude maneuver successfully avoided a loss of separation for one ANSP, it did not for another. This was not an isolated case where the same maneuvers met with differing success. A common cause of this was the timing of the maneuvers issued. For these types of cases where a loss of separation occurred, the secondary maneuver was often not issued in time to avoid it.

Table 2 presents the maneuvers issued by the ANSPs for the same conflict situation but without TSAFE automation-they were responsible for issuing clearances to resolve the conflict. In this case -unlike in the TSAFE condition- the ANSPs uniformly issued one type of clearance: altitude. However, it appears as though participant 2 (P2) tended to favor using both aircraft in the pair to resolve the conflict rather than just one. This apparently was a successful approach in this instance as he was able to avoid a loss of separation in both conditions whereas his cohorts were not.

Table 2. 2X ANSP Only Maneuvers

	Off Track A/C	On Track A/C	LOS
P1	Altitude		Yes
P2	Altitude	Altitude	No
P3	Altitude		No

3X

The results for maneuvers performed at the 3X level of traffic density in the TSAFE condition were nearly identical to those observed at the 2X level. Table 3 presents these maneuvers where it can be seen that the only difference is that P3 relied on the vector from TSAFE alone rather than the combination maneuver used in the 2X condition. This did not, however, result in avoiding a loss of separation much like it did not in the 2X condition. And although the same strategy of using both conflict aircraft was successful for P2 in the 2X condition, it was not in 3X where a loss of separation occurred.

Table 3. 3X TSAFE/Collaborative Maneuvers

	Off Track A/C	On Track A/C	LOS
P1	Combination (T)		No
P2	Vector (T)	Altitude	Yes
P3	Vector (T)		Yes

Although the strategies used were similar at the 2X and 3X levels of traffic in the TSAFE conditions, this was not the case in the ANSP conditions. Table 4 shows that instead of all of the participants opting to use altitudes to resolve the conflict, each one used a different strategy. Each strategy was apparently equally viable as all of them resulted in the avoidance of a separation violation. Another departure from what was observed at the 2X level of traffic was that each ANSP managed to successfully resolve the scripted conflict through the maneuvering of just one aircraft.

Table 4. 3X ANSP Only Maneuvers

	Off Track A/C	On Track A/C	LOS
P1	Altitude		No
P2		Vector	No
P3	Combination		No

Alternate Trajectory Mismatch Case

The results for the following case refer to a situation where the aircraft makes an unexpected turn that resulted in a short term conflict. Although different in nature, both situations progressed similarly.

2X

Similar to what was observed for the TSAFE conditions in the previous case, the participants in this situation often provided additional maneuvers to complement the vector issued by TSAFE. Table 5 presents a summary of what maneuvers were issued at the 2X level of traffic where it can be seen that each participant approached the situation differently. P1 was able to use both aircraft in the conflict pair with one vectored via TSAFE and the other given an altitude clearance for extra separation. In this case this seemed to be the best solution to resolving the conflict because P1 was the only one to avoid a loss of separation.

Table 5. 2X TSAFE/Collaborative Maneuvers

	Off Track A/C	On Track A/C	LOS
P1	Vector (T)	Altitude	No
P2		Vector (T)	Yes
P3		Combination (T)	Yes

The strategies used in the ANSP condition were different from those used in the TSAFE condition. Table 6 presents these differences as well as how the participants approached the problem differently from one another. However, this did not matter as they all successfully avoided a loss of separation.

Table 6. 2X ANSP Only Maneuvers

	Off Track A/C	On Track A/C	LOS
P1	Vector		No
P2		Altitude	No
P3	Combination	Vector	No

3X

At the 3X level of traffic, this particular conflict proved to be quite difficult to handle regardless of whether the TSAFE automation was available or not. Table 7 presents the maneuvers used in the participants’ attempts at resolving the conflict. The strategies used follow the same trend as seen in previous examples with additional maneuvers and aircraft being used. As just alluded to, however, these maneuvers were not successful for any of the participants as they all resulted in a loss of separation.

Table 7. 3X TSAFE/Collaborative Maneuvers

	Off Track A/C	On Track A/C	LOS
P1		Combination (T)	Yes
P2	Vector	Vector (T)	Yes
P3	Vector (T)	Altitude	Yes

This was likewise the case in the ANSP condition where, despite the different approaches used by each of the participants, a loss of separation was unavoidable (see Table 8).

Table 8. 3X ANSP Only Maneuvers

	Off Track A/C	On Track A/C	LOS
P1		Combination	Yes
P2	Vector	Combination	Yes
P3		Altitude	Yes

Low Rate of Climb

The following results relate to a scripted conflict that involved a departure aircraft climbing at an unexpectedly and abnormally low rate that produced a short term conflict with an overflying aircraft. There were two different cases of this conflict, both nearly identical with the exception of the overflight aircraft used in the conflict. Because of the greater challenges involved in reliably reproducing this conflict in every run, full data sets across all of the conditions were not available for each of the three participants. Therefore, the 2X results will involve those related to one of the Low Rate of Climb conflicts and the 3X results will relate to the other.

2X

Despite this conflict involving a transitioning aircraft, each of the three participants at the 2X level of traffic attempted to resolve the conflict through vectoring alone. Table 9 shows that participants 1 and 2 used vectoring on both aircraft in the conflict pair with differing success in terms of avoiding a loss of separation. Participant 3 relied on the vector issued by TSAFE but did not have the time available to avoid the loss of separation.

Table 9. 2X TSAFE/Collaborative Maneuvers

	Departure	Overflight	LOS
P1	Vector	Vector (T)	No
P2	Vector	Vector (T)	Yes
P3		Vector (T)	Yes

The same scripted conflict at the 2X traffic level in the ANSP condition played out rather differently for each of the three participants. Table 10 presents the results for this condition. P1 vectored both the departure and overflight aircraft (at 85 degrees) but was unable to avoid the separation violation. P2 also had a separation violation for this same conflict, but, for unknown reasons, did not even attempt to resolve it beforehand. From the data logs and recording it appears as though nothing else was taking place at the time so it is unclear why nothing was done. In the case of P3, the departure aircraft's climb was unexpectedly delayed such that it missed the initial conflict with the scripted overflight. Upon resumption of the climb, however, a short term conflict was caused with another overflight, which P3 was able to resolve by stopping the climb of the departure aircraft.

Table 10. 2X ANSP Only Maneuvers

	Departure	Overflight	LOS
P1	Vector	Vector	Yes
P2			Yes
P3	Stop Climb		No

3X

Similar to how the conflict at the 2X traffic level was approached in the TSAFE condition, the participants used primarily vectoring to resolve a similar scripted conflict at 3X traffic with greater success (see Table 11). P1 was able to avoid a loss of separation by using both aircraft through a combined altitude and TSAFE vector for the overflight aircraft and a vector for the climbing departure aircraft. P2 and P3 were able to successfully rely on the vector issued by TSAFE to the overflight in avoiding a LOS.

Table 11. 3X TSAFE/Collaborative Maneuvers

	Departure	Overflight	LOS
P1	Vector	Combination (T)	No
P2		Vector (T)	No
P3		Vector (T)	No

While the participants mostly relied on vectoring to resolve the conflict in the TSAFE condition, they uniformly (see Table 12) went with a simpler approach in the ANSP condition: each stopped the departure aircraft's climb before it was able to proceed further into the conflict. It must be noted here, however, that P1 was not the actual issuer of the altitude stop. In this case, the strategic auto resolver was able to issue the clearance before P1 could do so. One cannot say that this would have been the same clearance that P1 would have issued on his own, but it is interesting to see that this clearance was not followed by any other and it was the same one issued by the other two participants.

Table 12. 3X ANSP Only Maneuvers

	Departure	Overflight	LOS
P1	Stop Climb*		No
P2	Stop Climb		No
P3	Stop Climb		No

Case Studies

The following section is meant to complement the results just presented by providing actual examples of how certain events unfolded. The purpose of doing so is to provide greater context to the results as well as to highlight some of the issues related to the operations simulated in this study.

TSAFE Resolutions

Although the results showed that the ANSPs largely preferred to perform additional maneuvers in conjunction with TSAFE, there were six cases where the ANSP did rely solely on a TSAFE vector. What follows is intended to give a good example of TSAFE operating in a manner that it was intended with the computed vector allowing enough clearance between the two aircraft to provide adequate separation.

Figure 7 presents the initial conditions for a tactical conflict that forced a TSAFE resolution. This example was taken from the Low Rate of Climb scripted conflict where it can be seen that SWA339 is climbing to its cruise altitude of flight level (FL) 360 at a reduced rate of climb. This is taking the aircraft into the path of ASQ1360 that is at level flight at an altitude of FL 350. The first alert of the conflict comes when the pair has two minutes remaining before loss of separation.

Following this initial display of the conflict, TSAFE computes and uplinks a resolution that has the aircraft at level flight (ASQ1360) turn 59 degrees to the left to a true heading of 115 degrees (see Figure 8). This vector adequately provides enough separation between the aircraft and the ANSP did not need to provide any additional maneuvers.

Figure 7. Tactical conflict between an overflight (ASQ1360) and transitioning departure (SWA339) aircraft with a low rate of climb.

Figure 8. TSAFE maneuver uplinked to ASQ1360 that clears the tactical conflict with SWA339.

ANSP Resolutions

The instantiation of TSAFE in this study was based on the original specifications that involved the computation of a vector designed for a single aircraft. In this study's trajectory based environment, such vectors would often result in extra work required of the ANSP in managing the vectored aircraft's trajectory and attempting to put the aircraft back onto its original trajectory.

While this was definitely a necessity at times in order to avoid a loss of separation, there were also times when a single altitude change would have worked just as well. Using altitude in this case allows for the aircraft to remain on its trajectory, thus reducing the extra steps and potential problems associated with tactical vectors.

The following example was taken from the scripted conflict situation that involved a Trajectory Mismatch. As seen in Figure 9, AAL280 has failed to make its expected turn at the PXV waypoint and has proceeded directly into a short term conflict with AAL529.

Figure 9. Tactical conflict between AAL280 and AAL529 resulting from a Trajectory Mismatch.

In this particular case, two of the three ANSPs used a vector and combined vector and altitude maneuver respectively to resolve this conflict. One ANSP, however, managed to successfully use an altitude maneuver. Upon awareness of this short-term conflict, the ANSP immediately issued a descent to FL 290 for AAL280, which was already off trajectory. This clearance alone, however, would likely not have been enough to provide the necessary separation in time assuming a nominal rate of descent. Therefore, the ANSP also followed up the altitude clearance with an expedited rate of descent. In doing so, a loss of separation was avoided that did not involve extra vectoring of aircraft already off of their trajectory or taking aircraft off of their trajectory, which could, in either case, cascade into a larger problem.

Issues with Automation Collaboration

The results for response strategies showed that in the TSAFE conditions, the ANSPs often preferred to use the vector issued by TSAFE as part of a more elaborate set of maneuvers in resolving a conflict. In essence, this required the ANSP to collaborate with the TSAFE automation in formulating the proper response. However, the success of this collaboration was dependent upon the stability of the automation's response given the fact that the ANSP would have to work with that response.

This dependence on a stable response from the automation did, however, cause problems when the response was unpredictable. Figure 13 presents an example where a short-term conflict in the TSAFE condition was detected with three minutes to loss of separation. At this moment the ANSP would normally await the TSAFE resolution to be formulated so that an additional or complementary maneuver could be executed. The problem, however, was that a stable response was not forthcoming from TSAFE until there was one minute remaining. In Figure 10, one can see that at the first time step (T1), NWA612 had been selected as the maneuvering aircraft and that it would be issued a right turn to heading 087. Moments later, this clearance was modified such that the heading would be to the left to 009. This was followed by a reversal where the other aircraft (FLG144) was selected as the maneuvering aircraft. This was followed by another reversal where NWA612 was actually given a right turn to heading 115. This consumed valuable time and reduced the number of options that the ANSP had available to collaboratively and safely resolve the conflict.

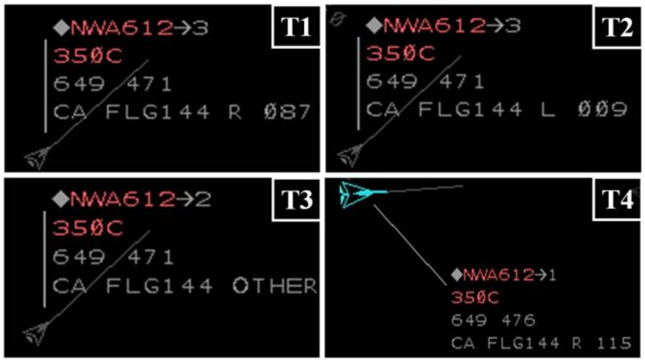

Figure 10. An example of unpredictability on the side of automation that impacted effective collaboration.

This was just one example, but it was not an isolated case. Such uncertainties also led to occasional efforts by the ANSP to preempt the automation by issuing a clearance to one of the aircraft before TSAFE was able to. This was not always successful though, because the ANSP would often issue a clearance, then TSAFE would issue a different clearance to the same aircraft, or the clearances may have been for different aircraft but conflicted with each other, which resulted in the pair coming closer together. These situations often resulted in confusion and further problems that the ANSP would inevitably need to deal with.

Situation Awareness

The final example is one in which the resolution of one tactical conflict resulted in additional conflicts, which relates to the issue of situation awareness in an advanced airspace environment.

This example was taken from the scripted conflict that involved an overflight and a transitioning aircraft with an abnormally low rate of climb. In this case, as shown in Figure 11, the overflying aircraft (ASQ1360) was issued a TSAFE vector right to a true heading of 192 degrees. The ANSP complemented this vector with his own by also taking the transitioning aircraft (SWA339) to the right, but allowing it to continue its climb.

Figure 11. Scripted conflict that resulted in a TSAFE vector for ASQ1360 and vector for SWA339 in transition.

Shortly thereafter, what was once a conflict involving a pair of aircraft now involved three because the vectoring of the transitioning aircraft, while allowing it to continue its climb, brought it directly into the path of two more aircraft (see Figure 12). This first resulted in a TSAFE vector being issued to AAL1142, which turned it right to a true heading of 316 degrees to avoid SWA339. Meanwhile, the ANSP had stopped the climb of SWA339 at FL 330. However, this was the same altitude of AAL460 to the west that was already in conflict. This forced an additional TSAFE vector for AAL460 that turned it left to a true heading of 018 degrees and was followed by a descent clearance from the ANSP down to FL 320.

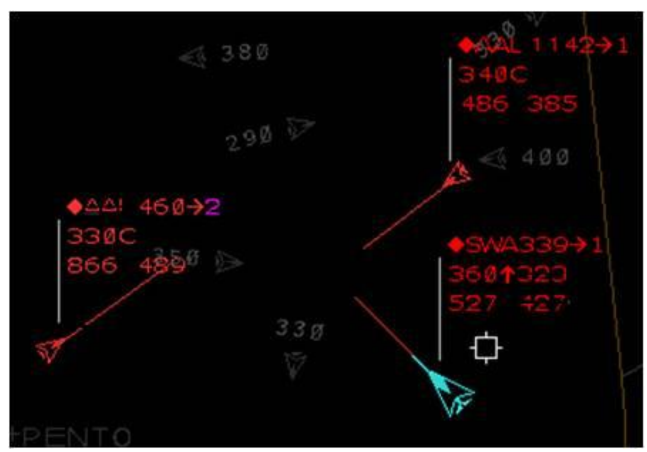

Figure 12. Conflicts resulting from SWA339's earlier vector by the ANSP.

The unfolding of this situation eventually saw a total of four aircraft maneuvered, with each one moving off of its trajectory and requiring extra work from the ANSP to get them back on. Similar situations occurred during the course of the study. What emerged from some of the feedback from the ANSPs was that at times they did not have sufficient awareness of the surrounding traffic to safely maneuver aircraft in a tactical manner. This was an issue because in this environment, aircraft that were on their trajectories and operating according to trajectory based flight rules were low-lighted on the display and basically operated in the background without any intervention by the ANSP. While this was necessary for the ANSPs to be able to handle traffic at 2X and 3X density levels, it also became a problem when the ANSP was required to quickly gain an understanding of the immediate airspace and traffic situation from which critical, time sensitive decisions would have to be made. Suggestions were offered on how this situation might be improved, which will be addressed in the following section.

Discussion

The results just presented highlighted a number of issues relevant to both the operation of the TSAFE automation as well as how the ANSP can collaborate with this type of automation in handling tactical, off-nominal situations. What follows is a discussion of the similarities and differences between the strategies used in short-term conflict situations in both a TSAFE and non-TSAFE environment, and how they can be or have been incorporated into the design of the automation. This will be followed by a short discussion on the issues presented in the case study examples and some of the feedback received by the ANSPs concerning ideas for a better and safer approach to working with the automation more effectively.

Response Strategies

Two different types of scripted short-term conflicts were presented where it was shown that different strategies were used both between the conflict situations as well as between the TSAFE and ANSP conditions.

Trajectory Mismatch

For the Trajectory Mismatch conflicts, collapsing across the two examples showed that in the TSAFE conditions at both the 2X and 3X levels of traffic the ANSPs largely felt the need to provide maneuvers in addition to those issued by TSAFE. In the 12 total conflict cases across the three participants, the TSAFE vector was solely relied on only twice. All of the other cases involved either issuing an altitude clearance in conjunction with the vector or maneuvering the other aircraft as well. This stands in contrast to the strategies used in the ANSP conditions where, of the 12 cases, seven involved a single maneuver for a single aircraft. Of those seven, five were an altitude clearance, which highlights the importance of having an extra degree of freedom in resolving short-term conflicts.

In terms of the number of aircraft used, there was also a noticeable difference between the TSAFE and ANSP conditions. The TSAFE conditions showed that of the 12 cases across the traffic levels, the second aircraft was maneuvered in five of the cases. In the ANSP conditions, however, a second aircraft was only used three times.

Given the number of variables present in each individual conflict situation, it is difficult to determine if one particular maneuver provides more benefit over any of the others. The context dependent nature of each conflict situation may not even warrant such an exploration. There were times when one maneuver successfully avoided a loss of separation and others where that same maneuver failed to do so. It is likely that an important factor in this regard is the timing of the conflict detection, resolution issuance, and response from the flight deck.

One tempting avenue to take in looking at benefits is in the number of separation violations that occurred. For the TSAFE conditions, at the 2X traffic level, a separation violation resulted in three out of the six cases. This number increased at the 3X level where a separation violation occurred in five out of the six cases. A very different story emerged in the ANSP condition, however, where at the 2X traffic level there was only one separation violation. This number increased to three out of the six cases at the 3X traffic level.

It should be stressed here that despite these loss of separation results, they relate to a specific subset of instances and should not be generalized to the overall concept of TSAFE and the operational concept used in the study. In fact, as reported in

Prevot et al. [9], the total number of separation violations for scripted conflicts was actually lower in the TSAFE conditions compared to the ANSP conditions.

Low Rate of Climb

This particular conflict situation was inherently different than the Trajectory Mismatch conflict in that it involved a transitioning aircraft with an abnormally low rate of climb. This gave the participants a greater chance to use altitude as a resolution than in the Trajectory Mismatch case since that was one of the factors producing the conflict. Interestingly, in the TSAFE condition across the 2X and 3X traffic levels, an altitude clearance was only used once out of the six cases; and that clearance was given to the overflying aircraft after it was issued a vector by TSAFE. All of the other five cases involved vectors for either one or both aircraft in the conflict pair. This is quite different from what was observed in the ANSP condition where a vector was used only once. With the exception of the case where the participant did nothing, all other resolutions involved using a stop altitude on the climbing aircraft.

Similar to the Trajectory Mismatch case, the use of both aircraft in the conflict pair was greater in the TSAFE conditions than in the ANSP conditions. Of the six cases, a second aircraft was maneuvered in three of them, while the second aircraft was never used in the ANSP condition.

Unlike the Trajectory mismatch conflict, however, the strategy differences between the TSAFE and ANSP conditions did not have any impact on the number of separation violations that occurred. For the Low Rate of Climb conflict cases, two separation violations occurred in both the TSAFE and ANSP conditions, and were limited to the 2X traffic level. One interesting finding was that of all the cases examined, the only maneuver that successfully avoided a separation violation every time was when the ANSP stopped the climb of the transitioning aircraft.

Case Studies and Lessons Learned

The first two cases presented were simply examples of the TSAFE automation functioning in an ideal manner as it was intended, and a different approach taken by the ANSP in resolving a conflict. In the former case, TSAFE issued a vector that successfully avoided a conflict. The latter case involved the ANSP using an altitude clearance with an expedited descent. This contrast highlights a fairly obvious functionality that the TSAFE automation would benefit from and that is the ability to use altitude clearances in its resolutions. Since the conclusion of this study in 2008, this functionality has been added and successfully tested [7].

Even with this added functionality, however, there is still the issue of how the ANSP can effectively collaborate with the TSAFE automation in resolving tactical conflict situations. One of the problems that negatively affected this effort was the instability that the automation occasionally suffered from in finalizing a resolution. This was a problem because the ANSP was often awaiting a finalized resolution so that an additional and complementary maneuver could be issued. This problem uncovered a larger issue of where the automation fits within the hierarchy of operators within this environment. In this study, the TSAFE automation acted independently and required the ANSP to react to its decisions. A solution offered by the ANSPs following the study that could circumvent the issue of TSAFE uncertainty was to give the ANSP the power to override or “turn off” TSAFE when necessary. This would allow the ANSP to develop a strategy and plan based on a stable situation without the need to waste valuable time waiting to react. Meanwhile, additional work has gone into the development of TSAFE with the goal of improving the stability of resolution generation.

Another concern that came out of the case studies was that of situation awareness. In the example used, one fairly straight forward conflict turned into a difficult and complex situation due to the participant’s unawareness of the surrounding traffic situation. This poses a problem because the same changes necessary to accommodate such high levels of traffic are the same ones that contribute to this lack of awareness. And it is this awareness that is critical in developing safe and informed decisions in resolving tactical conflicts. One possible solution offered by the ANSPs that could help with this problem is the highlighting of aircraft in the immediate vicinity of the tactical conflict. In doing so, it is believed that the information gained from being made aware of the surrounding traffic would help in developing a better understanding of the traffic environment.

Conclusion

The results presented in this descriptive analysis highlighted some of the different strategies used by the ANSP participants when operating in an environment with and without TSAFE automation. The overall results presented by Prevot et al. [9] showed that the TSAFE automation and overall concept used for the study were acceptable and viable as a path worth further exploration. However, as discussed in this paper, some changes first need to be made in how the automation performs and how the ANSPs collaborate with it. Steps have already been taken in adding functionality to TSAFE with the inclusion of altitude maneuvers and increased stability in resolution computation. Further inquiry may be beneficial into the idea of incorporating combined lateral and vertical maneuvers into the algorithm as well as the issuance of clearances to both conflicting aircraft much like the ANSPs did when operating with TSAFE. The addition of such changes would not, however, resolve some of the larger issues related to the integration of the human and automation in this environment. The issues discussed here were that of hierarchy and situation awareness. Some initial steps toward resolving these issues were offered by the participants where they suggested that being able to override the TSAFE automation when necessary and highlighting surrounding aircraft that were initially low-lighted could potentially provide the necessary stability and awareness needed to more successfully separate aircraft in tactical situations than without such changes.

References

[1] Joint Planning and Development Office. *NextGen*. http://www.jpdo.gov/nextgen.asp

[2] Federal Aviation Administration (2009). *FAA Aerospace Forecast Fiscal Years 2009-2025.* Washington, DC, p.31.

[3] Prevot, T., J. Homola, & J. Mercer (2008). *Human-in-the-Loop Evaluation of Ground-Based Automated Separation Assurance for NextGen*. ICAS-AIAA-ATIO Conference, Anchorage, Alaska, Sept. 2008.

[4] Erzberger, H. (2001). *The Automated Airspace Concept*. 4th USA/Europe Air Traffic Management R&D Seminar, Santa Fe, NM, USA.

[5] Erzberger, H., K. Heere (2008). *Algorithm and operational concept for solving short range conflicts.* ICAS 2008-8.7.5, Anchorage, Alaska, Sept 15-19, 2008

[6] Paielli, R.A., H. Erzberger (2005). *Tactical Conflict Detection Methods for Reducing Operational Errors*. Air Traffic Control Quarterly, Vol. 13(1).

[7] Paielli, R.A., (2008). *Tactical Conflict Resolution using Vertical Maneuvers in Enroute Airspace*. ICAS-AIAA-ATIO Conference, Anchorage, Alaska, Sept. 2008.

[8] Prevot, T. et al. (2006). *The Airspace Operations Laboratory (AOL) at NASA Ames Research Center.* AIAA-2006-6112, AIAA, Reston, VA.

[9] Prevot, T., J. Homola, J. Mercer, M. Mainini, & C. Cabrall (2009). *Initial Evaluation of NextGen Air/Ground Operations with Ground-Based Automated Separation Assurance*. Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009), Napa, CA.

[10] Prevot, T. (2002) *Exploring the Many Perspectives of Distributed Air Traffic Management: The Multi-Aircraft Control System MACS*. In S. Chatty, J. Hansmann, & G. Boy. (Eds). HCI-Aero 2002, AIAA Press, Menlo Park, CA. pp 149-154.

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