

PHASE-2 EVALUATION OF A TACTICAL CONFLICT DETECTION TOOL IN THE TERMINAL AREA

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Abstract

A conflict detection and resolution tool, Terminal Tactical Separation Assurance Flight Environment (T-TSAFE), is being developed to improve the accuracy and reduce the false alert rate beyond currently deployed technology. The legacy system in use today, Conflict Alert, relies primarily on a dead reckoning algorithm. By adding altitude intent information for conflict detection and resolution, T-TSAFE may improve conflict detection accuracy.

In addition to verifying T-TSAFE's efficacy over Conflict Alert, an initial human-in-the-loop study suggested possible avenues of tool improvement through heuristic analysis. Results of this analysis were then used to guide a follow-up T-TSAFE investigation, which is described in this paper. This follow-up study tested four experimental conditions. The first two conditions varied conflict detection with and without altitude clearances entered into the tool by the controllers via keyboard. The other two conditions varied the presence of Automatic Terminal Proximity Alert (ATPA), an FAA tool used for monitoring final approach [1]. One of these final approach conditions used regular alerts in the data block without cones and the others used ATPA cones between different aircraft (i.e., a cone graphic shown in the flight display) as a warning for possible compression errors in the final approach.

Entering altitude clearances into T-TSAFE was expected to reduce false alerts but did not, possibly due to the short duration of the runs, which did not allow for a large enough frequency of altitude entries to study the issue adequately. Also, the test conditions did not significantly impact the duration of the alert or the controller's response time to the alert. The subjective data showed that controllers favored the ATPA cones over the T-TSAFE alerts in the data blocks on final approach. Results also indicate manageable levels of workload and situation

awareness, which combined with other results, seem to indicate promise for T-TSAFE as a viable air traffic control tool, pending further research and adaptation.

Introduction

Managing terminal area traffic is challenging due to the density of traffic and complexity of trajectories and separation standards. Conflict Alert is a short time-horizon conflict detection tool currently in operational use in both the en route and terminal area, but it is often inhibited or desensitized in the terminal area because it generates a high number of false alerts. Conflict Alert uses only dead reckoning to determine when aircraft are in dangerous proximity to each other. Safety is maintained in the current system but at the expense of capacity, since controller workload is often considered as a limitation to capacity [2].

[3] augmented the legacy dead reckoning approach with flight trajectory intent information to create a short time-horizon tool called Terminal Tactical Separation Assurance Flight Environment (T-TSAFE). The tool was developed to address the inadequacies of Conflict Alert (CA), which is used in the current air traffic control milieu. A comparison of T-TSAFE against a model of Conflict Alert, in a fast-time environment, found that T-TSAFE reduced the false alert rate and provided an average alert lead time of 38 seconds [3].

The objective of the current work is to develop a reliable and effective conflict alerting system for terminal airspace. Previous Human-In-The-Loop (HITL) research on the predecessor TSAFE tool was conducted in the en-route phase of flight [4] which found some evidence for the efficacy of T-TSAFE in the resolution of tactical conflicts. Subsequent research tested the tool in the terminal environment with current day operations and technology [5] which found that T-TSAFE can be effective in terminal

airspace and provided evidence for T-TSAFE's superiority over Conflict Alert. The follow-up experiment, described in this paper, tested T-TSAFE in the terminal environment, and also varied the presence or absence of altitude intent information. When present, the altitude intent information was used by the conflict detection algorithm and the depiction of the ATPA [1] and T-TSAFE driven cones on the final approach. Eight recently retired controllers served as participants, each controlling simulated traffic in the Southern California TRACON for approximately eight hours. Both conflict detection performance and controller subjective feedback were collected and analyzed, to characterize the performance of the T-TSAFE prototype.

Background

The Federal Aviation Administration (FAA) has forecasted an increase in air traffic demand that may see traffic more than double by the year 2025 [6, 7]. Increases in air traffic will burden the air traffic management system, and higher levels of safety and efficiency will be required. Maintaining current levels of safety will be more difficult in a more constrained and crowded terminal airspace. Thus, automation is proposed to aid the terminal area controllers with the task of assuring separation.

Terminal airspace has proven to be difficult for tactical conflict detection automation. The factors that contribute to this difficulty include dense traffic, frequent large turns made by aircraft, imprecise flight plans, a complex set of separation standards and the fact that the aircraft operate close to the minimum separation standards leading to compression errors (horizontal separation violation) on approaches [3]. In the current-day environment, Conflict Alert, a legacy system, was shown to be inaccurate at times, which falsely alerts the controller at an undesirable rate [8]. An analysis of Conflict Alert shows that in the terminal area, controllers respond to alerts 56% of the time [9], which suggests a high false alert rate.

TSAFE, the Tactical Separation Assisted Flight Environment, is a tool conceived at NASA Ames Research Center, that assists air traffic controllers in the detection and resolution of short-term conflicts between aircraft. Most of the research on the parent TSAFE tactical tool has focused on en-route airspace.

En-route prototypes have been developed and HITL studies were performed at NASA Ames [4, 10]. These studies compared conflict detection and resolution done manually by the controller to conflict detection and resolution performed by TSAFE. The concept of operations in these studies required new technologies such as Automatic Dependent Surveillance-Broadcast (ADS-B) and a Required Navigation Performance (RNP) of 1.0, making it a mid- to far-term concept. All the aircraft in the test airspace were capable of performing trajectory-based operations via data link communications. For the flights that maintained their trajectory, TSAFE was responsible for the detection and resolution of strategic conflicts. Trajectory changes to resolve conflicts were uplinked directly to the aircraft without the controller's involvement. Overall results showed that using TSAFE resulted in better resolution of tactical conflicts and fewer separation violations than without TSAFE in an en-route flight environment. More recent research adapted TSAFE to the terminal environment and to the current day concept of operations [5].

The new algorithm for tactical conflict detection (T-TSAFE) developed by [3] aims to address the inadequacies of Conflict Alert in terminal airspace and incorporates some of the recommendations made by [9], e.g., using a single analytic trajectory that takes into account both flight intent information and the current state of the aircraft. In addition to the flight plan, T-TSAFE takes into consideration Area Navigation (RNAV) departure routes, segments of nominal TRACON routes, speed restrictions, and altitude clearances inferred from the recorded track data. [3] compared the T-TSAFE algorithm with a model of the Conflict Alert algorithm using recorded data from Dallas/Fort Worth TRACON that included 70 operational errors between January 2007 and April 2009. An analysis of fast-time simulation data showed that T-TSAFE would have prevented most of these operational errors and that T-TSAFE also yielded a false alert rate of 2 per hour with 38 seconds of lead alert time, giving the controller more time to address conflict situations before they became critical. When the algorithm has information about where and which aircraft will level off, fast-time analyses showed further significant reductions in false alerts. The potential benefit from additional altitude intent information was the rationale for

asking controllers to enter some commanded altitudes in the current investigation.

Subsequent to T-TSAFE's fast-time study [3], a HITL study also tested T-TSAFE in the terminal airspace (Phase-1 study) [5]. Results provide additional evidence for T-TSAFE's efficacy, the possible usefulness of altitude entries keyed-in by the controller and T-TSAFE's superiority to Conflict Alert in detecting conflicts while minimizing the false alert rate.

While the Phase-1 study investigated controllers' usage of the Automated Terminal Proximity Alert (ATPA) cones, which were used to automatically depict minimum separation between the aircraft on final approach, the Phase-2 study (the focus of this paper) investigated the presence or absence of the ATPA cones. Either the ATPA cones were shown to provide warnings or the T-TSAFE alerts were shown in the data block of the aircraft on final approach. ATPA is currently being tested by the Federal Aviation Administration (FAA) in the final approach phase of flight [1]. The tool provides controllers with visual warnings if the minimum separation criteria is being exceeded or has the potential for being exceeded. The controllers can in turn give commands to pilots to make necessary maneuvers. ATPA may also allow the controllers to achieve better arrival rates by maintaining precise separation between aircraft. The tool shows the controller a cone, whose narrow end is placed on the aircraft icon and its length is based on the required separation between the two aircraft flying-in-line (Figure 1).

Although ATPA is one attempt by the FAA to bring NextGen tools into present day air traffic control operations, the tool only measures compression errors between aircraft on final approach. It does not provide information on loss of separation provided by the T-TSAFE alerts in the data block of the aircraft. One of the Phase-2 objectives is to examine final approach operations using either ATPA cones or T-TSAFE conflict detection. The Phase-2 study also examined altitude entries keyed-in by the controllers and altitude resolution advisories provided by the T-TSAFE system (Table 1).

Method

This section describes details of the Phase-2 investigation, which examines T-TSAFE under current-day operational conditions. This follow-up phase tested three T-TSAFE operating features: altitude entries, ATPA cones, and altitude resolution advisories. These are the three key features being explored in this paper (Table 1).

More specifically, this follow-up phase compared ATPA cones (Figure 1) with T-TSAFE alerts in the final approach area. In this figure, two aircraft are depicted on a trajectory leading to one parallel runway with the other two depicted on another trajectory leading to the other parallel runway, with two of these aircraft showing a compression error (DAL220D and DAL423). This follow-up phase also investigated the feasibility of having controllers enter the level-off altitudes into the automation, which they also gave to the pilots as verbal commands for the purpose of reducing the number of false alerts. Prior studies [3] have shown that the rate of false alerts drops dramatically if altitude intent information can be provided to the conflict detection automation. With altitude information, the algorithm knows where aircraft will level off and will not predict conflicts based on a presumption of continued descent. To shed further light on this issue, this study included three conditions that required the controllers to enter altitudes at which they verbally commanded aircraft to level off. This study also included a condition that tested vertical resolution advisories that were offered by the T-TSAFE algorithm.

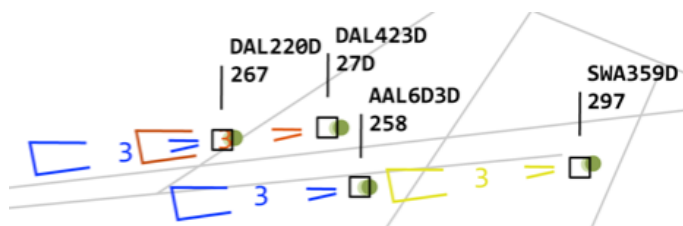


Figure 1. Automated Terminal Proximity Alert

Experiment Matrix

The four experimental conditions are shown in Table 1. The altitude intent information has the potential for reducing false alerts, thus three conditions – B, C and D required that controllers

enter assigned altitudes via keyboard (Figure 3) as compared to Condition A that did not require any altitude entries. The ATPA cones were absent in Condition C, where T-TSAFE alerts provided the warnings for potential loss of separation minima. Conditions A, B and D used ATPA cones (Figure 1) to provide warning for the potential loss of separation between aircraft on final approach. In addition, Condition D provided vertical resolution advisories to the controllers. Four traffic scenarios were exercised with each of the conditions for a total of 16 runs.

Table 1. Experiment Conditions

T-TSAFE Test Condition	A	B	C	D
Altitude Entry (Keyboard)	N	Y	Y	Y
ATPA Cones	Y	Y	N	Y
Altitude Resolution Advisories	N	N	N	Y

Air Traffic Control Tools and Procedures

The study simulated five arrival streams to and one departure stream from Los Angeles International Airport (LAX) using current airspace and procedures within the TRACON. The scenarios were designed to create situations that would result in a loss of separation between aircraft unless a controller intervened. Occasionally, the controllers were able to successfully avoid conflicts for extended periods due to early interventions. It was therefore necessary to add conflicts to the scenarios using observers collaborating with pseudo pilots. Each scenario involved heavy current-day traffic, with all LAX traffic under Instrument Landing System (ILS) simultaneous rules. The controllers worked the East Feeder and Zuma feeder sectors, and Downey and Stadium approach sectors in the Southern California TRACON, rotating positions after each run.

T-TSAFE uses 1000 feet minimum vertical separation, wake turbulence lateral separation standards, and a look-ahead time of 120 seconds to calculate conflicting trajectories. It also predicts wake encounters and physical losses of separation, and uses flight plan information, standard procedures, and dead reckoning to predict conflicts. T-TSAFE alerts the controllers to a conflict by placing the number of seconds to predicted Loss of Separation (LoS) at the end of the first line in the data block, and the call sign of the conflicting aircraft in the third line of the data

block, both in red (Figure 2). If more than one other aircraft is involved in a conflict, the third line shows the call sign of the aircraft closest to a loss of separation. The controller can also roll the cursor over any aircraft showing a conflict, causing the data blocks of all other conflicting aircraft on the display to turn yellow for five seconds.

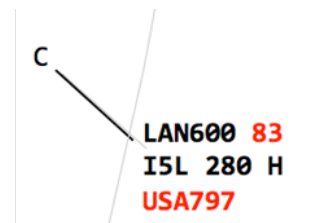


Figure 2. T-TSAFE Data Tag

Altitude resolution advisories are shown in magenta color to the controller, in the second line of the data block. The assigned altitude entered by the controllers via keyboard is shown in green color in Figure 3. As soon as the T-TSAFE algorithm receives altitude intent from the controller’s input, it no longer detects the conflict and removes it from the data block. The green assigned altitude stays until the aircraft ascends or descends 300 ft above or below the assigned altitude.

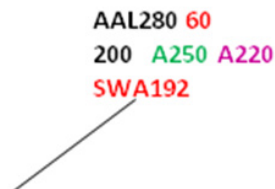


Figure 3. T-TSAFE Altitude Resolution and Altitude Entries

Experiment Procedures

The study was conducted over a two-week period with two teams of controllers, each participating for a week. Each controller team consisted of four controllers that had retired less than two years ago from Southern California TRACON. Both controller teams were briefed on the T-TSAFE concept, the T-TSAFE interface, and the conditions of the study. During each week, the controller team completed sixteen runs, four runs in each of the four different conditions, rotating through four different

traffic scenarios. Controllers also rotated between sector positions after each run. Pseudo-pilots flew all the aircraft in the scenarios. All controllers completed questionnaires after every run and took part in a debrief session at the end of the study.

Results

The objective of the Phase-2 study was to test the impact of altitude entries, compare ATPA cones with T-TSAFE alerts on final approach, and provide an initial test of altitude resolution advisories. The metrics discussed in the paper include the following: total number of alerts, total number of false alerts, workload and usability of the T-TSAFE interface.

Alerts and False Alerts

Figure 4 shows some variability in the total number of alerts across the four conditions, i.e., alert frequency per controller per run. On average, each controller dealt with about four to six non LoS alerts per run (LoS alerts were not considered since most of them appeared as a result of an unexpected simulation artifact). The condition without ATPA may have generated more alerts, because this was the only condition where alerts in the final approach were not suppressed, i.e., the final approach flight phase used T-TSAFE alerts rather than ATPA for conflict detection, so it makes sense that this condition generated more T-TSAFE alerts than the other three conditions.

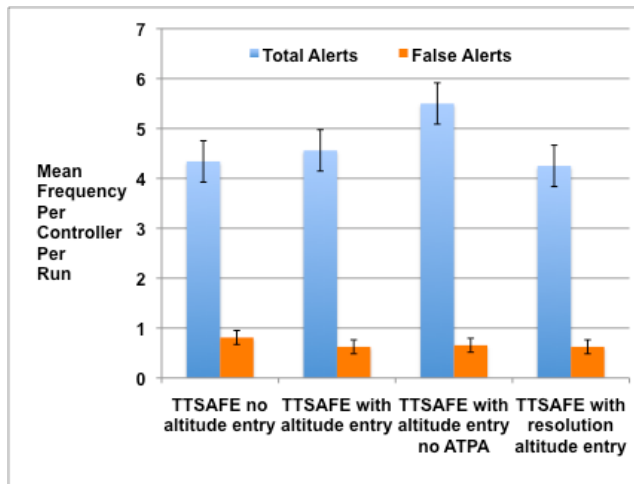


Figure 4. T-TSAFE Alerts and False Alerts (No LoS Alerts Only)

A false alert was defined as a situation where an alert was provided, the two aircraft did not lose separation, and the controller did not intervene (i.e., ignored the alert), from 60 sec before the alert start time through the predicted loss of separation time. The average number of false alerts, per controller per run, was very low (less than one alert) and varied little across the conditions (Figure 4). Contrary to the expectation, the altitude entries did not reduce the number of false alerts. This may have occurred because controllers did not use the altitude entry feature very often, i.e., only once or twice each run (Figure 5). Therefore, the number of altitude clearances given for the purpose of de-confliction provides insufficient data to evaluate the impact of altitude entries on the number of false alerts.

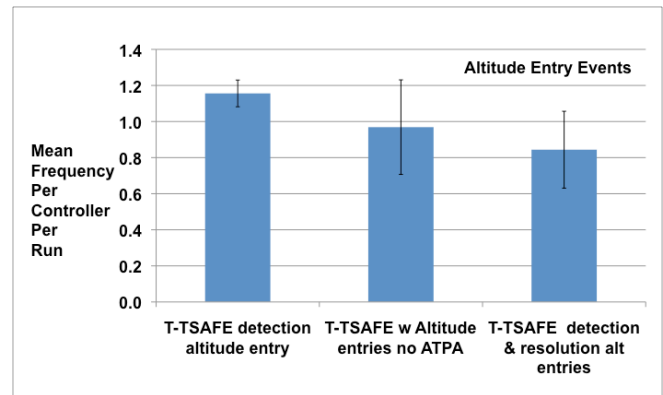


Figure 5. Frequency of Altitude Entries (Mean Value per Controller per Run)

Duration of Alert, Response Time and Lead Alert Time

The duration of alert was defined as the time between the alert onset and the time when the conflict was resolved. The duration of the alert is dependent on several factors, one factor being the look-ahead time that the T-TSAFE algorithm used to predict conflicts. The average duration of non LoS alerts across all conditions ranged from 28-37 sec (Figure 6).

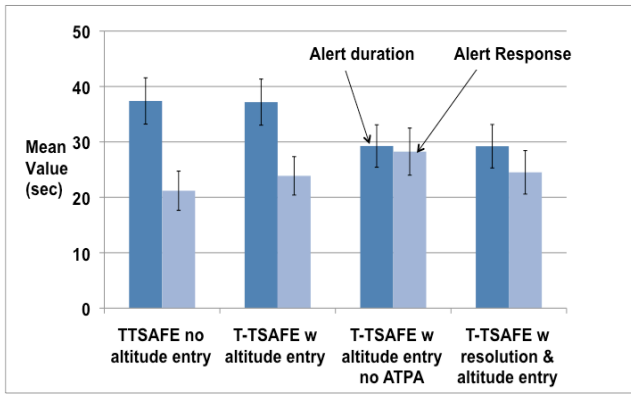


Figure 6. Mean Duration and Response time to an Alert (Seconds per Controller per Run)

The response time to an alert was measured as the difference between the onset of the alert and the time the pseudo pilot responded to the controller’s command. Figure 6 shows an overall response time of approximately 25 seconds, on average, across all conditions. It seems the duration of the alerts was more than adequate for the controller to see the conflict, determine a resolution, issue the ATC command to the pilots, and then, for the pilots to implement the ATC command. Also, controller feedback indicated that they used the “time to predicted loss of separation,” provided in the data block, to prioritize their tasks. Their feedback also made it clear that, in the TRACON environment, controllers often address other high-priority emerging situations first, and act to resolve conflicts in the last 25-30 sec prior to the predicted loss of separation.

[9] noted that if the duration of the alert is too short or long, it could become a nuisance factor that leads to lower levels of trust in the system. The duration and lead time of the alerts found in our investigation were generally adequate for the controllers to respond (Figures 6 & 7), with an average alert lead time ranging from 52.5 to 55.2 sec across the four conditions, which compares favorably with the 20 seconds suggested minimum [9]. While not statistically significant, the controllers received an alert slightly earlier in Condition D, where T-TSAFE provided alert resolution parameters. Here, the lead alert time of 55 sec was more than adequate for the controllers to respond to the alert.

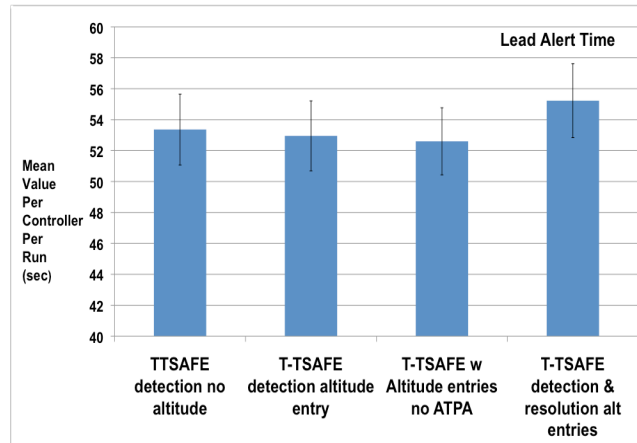


Figure 7. Mean Alert Lead Time (Time to Predicted Loss of Separation) by Condition

Controller Workload

Participants completed the NASA TLX workload questionnaire [11] after every run. Data were collected on each of the six TLX workload measures. In addition, a seventh variable measuring overall workload combining all six of these measures was derived. The overall workload variable, also known as the “composite” measure, once derived, was then scaled down to match the 1-to-5 range for direct comparison with the other six measures (1=very low, 5=very high). Also, the “performance” measure was analyzed on an inverse scale, so a higher score would actually mean less performance. Results on all seven of these measures, comparing the four experimental conditions, are summarized in Figure 8.

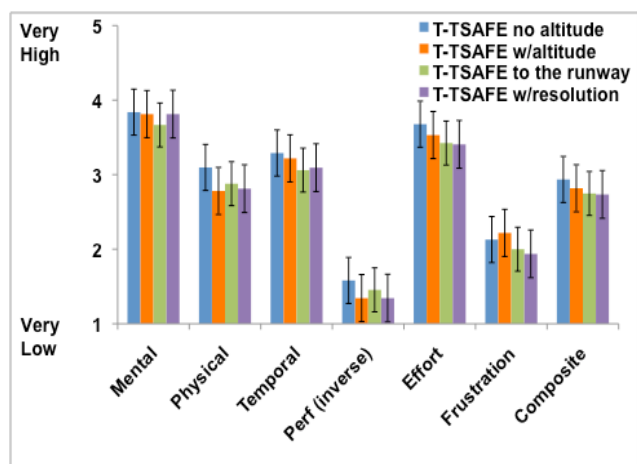


Figure 8. Workload by Condition

While showing potentially interesting trends, all workload differences across the conditions should be viewed with some caution since none of them reached statistical significance. Figure 8 provides some evidence that using T-TSAFE alerts all the way to the runway would elicit lower workload than the other three conditions on some scales (i.e., mental demand, temporal demand), which might have occurred because there was no need for adaptation between T-TSAFE alerts and ATPA within the same simulation run. When resolutions were offered to the controller, the mental workload was slightly higher but other workload components were lower, perhaps suggesting that resolution advisories were helpful to the controllers, even though this required an evaluation of the advisories leading to slightly higher mental workload. While making sense, these trends should be viewed as tentative, since the scale differences are generally slight. However, it seems that these trends are possibly relevant, since they are also consistent with situation awareness results described in the next section. It would have been interesting to see how large the scale differences would have been, if a larger pool of controllers were available to participate in the experiment, which would also increase the statistical power of the analyses.

In contrast to the small scale differences between the conditions, Figure 8 clearly shows that workload assessments across all NASA TLX subscales and conditions collectively show overall workload as low to moderate. This would suggest that workload was low enough to be manageable, but high enough to prevent tedium and vigilance decrement.

Situational Awareness

Participants completed an abbreviated version of the Situational Awareness Rating Technique (SART) scale at the end of each simulation run [12]. The participants responded to questions on the demands the situation posed on them and their understanding

of the situation offered to the user by the displays and procedures. They also responded to a question on attention capacity that refers to the user's skills and attention needs. The situational awareness scales ranged from 1-to-7, i.e., from very low to very high situational awareness.

Figure 9 shows the mean ratings on situational awareness across the four test conditions. While statistical significance was not observed in comparisons among the four test conditions, trends consistent with those found in the workload data are seen, even though these differences are also slight. Again, these trends may provide some useful information, due to their consistency with workload results described in the previous section, hence, it would have been interesting to analyze the data from a larger pool of controller-participants, which would increase the statistical power of the analyses. Figure 9 shows slightly less attention demand when T-TSAFE alerts, rather than ATPA cones, are displayed on final approach (ATPA cones are used under all conditions except the T-TSAFE alerts to the runway condition). As with the workload trends, this might reflect less attentional demand, since under this condition, there is no need for adaptation between T-TSAFE and ATPA alerting mechanisms. Also consistent with the workload trends, some increased attention demand was observed under the condition where resolution advisories are offered, again possibly reflecting resolution advisories that need to be evaluated, which could have the effect of increasing attention demand and mental workload. Unlike the tentative trends between the conditions on the Attention Demand scale, responses to the "Understanding" component of situational awareness do not show condition differences, but rather, show consistently high levels of situation awareness, suggesting that the procedures and displays of the conflict detection and resolution tool are adequate. Finally, "Attention Capacity" assessments fell within the moderate range across all conditions, indicating that the participants were focused, but not overwhelmed by the task.

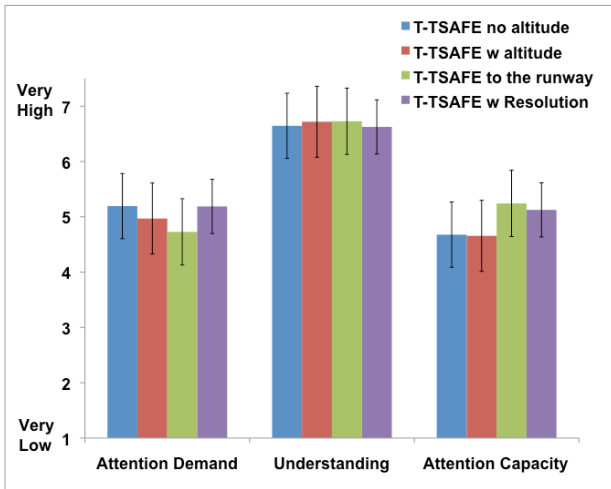


Figure 9. Situational Awareness by Condition

Comparison of T-TSAFE with ATPA Alert

The participants also responded to various questions, comparing T-TSAFE alerts with ATPA cones on the final approach. They answered questions on alert acceptability and their confidence in the timeliness, accuracy and ability to help maintain separation. Participants also responded to questions about the extent to which they needed to compensate for the alerts. Again, ratings ranged from 1-to-5, or very low to very high. Figure 10 depicts the responses provided by the controller participants. Statistically significant ANOVA differences were observed between the T-TSAFE alerts and ATPA cones used on the final approach (separation, accuracy and acceptability), $p < 0.05$. Trends show that the controllers showed preference for the ATPA cones, which was further substantiated during open-ended discussion, i.e., the participants indicated that ATPA cones aided with better maintenance of separation on the final approach, facilitated in part, by the visual graphics provided by the ATPA cones.

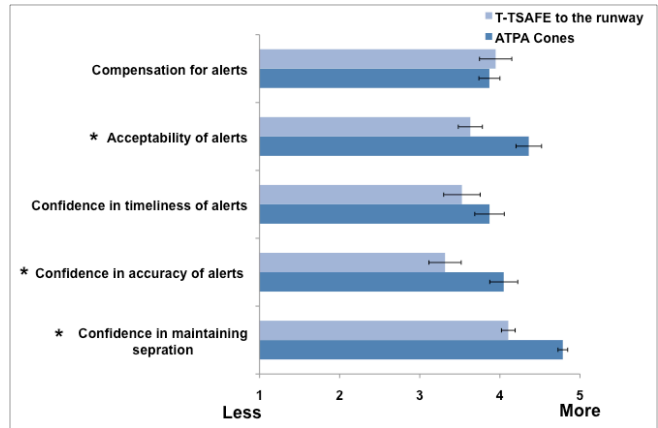


Figure 10. Subjective Responses for T-TSAFE Alerts vs. ATPA (* $p < 0.05$)

Complacency in Automation

A Complacency Potential Rating Scale was used to collect data on automation-induced complacency [13]. [14] defined complacency as “a psychological state characterized by a low index of suspicion.” Automation is often identified as a significant factor that induces complacency. Procedures, roles and responsibilities are also potential factors that induce complacency. According to [15], reliability in automation engenders excessive trust and over-reliance in pilots. [13] identified four factors that may be related to over-trust or complacency in automation. These are confidence, reliance, trust, and safety in automation. Some examples of scale items that measure different complacency constructs are shown in Table 2.

Table 2. Examples of Statements Used to Measure Complacency in Automation

Confidence	T-TSAFE with conflict detection and resolution provides reliable conflict detection.
Reliance	T-TSAFE without altitude entry has made the controller’s job easier.
Trust	T-TSAFE in the final approach without ATPA is more likely to be correct than manual conflict detection.
Safety	I feel safer having T-TSAFE with altitude entry than relying on manual conflict detection.

The Complacency Potential Rating Scale was adapted and used to collect data for all controller positions across all conditions. The scale uses a 5-point Likert scale that ranges from ‘strongly disagree’ to ‘strongly agree’. Some of the questions in the rating scale were reversed to ensure reliability in the responses. The scale was adapted to ask questions about the pairing automation and procedures that the controllers used.

Figure 11 shows the controller complacency ratings, comparing conditions that required altitude input to those that did not require the input. Statistically significant ANOVA differences were found among these conditions on the two complacency factors of confidence, $F(2,14)=4.17$, $p<0.05$, and reliance, $F(2,14)=4.31$, $p<0.05$, with post hoc comparisons that indicate higher levels of confidence under the T-TSAFE with conflict detection and resolution condition, as compared to the other conditions. These results reinforce the trends across the conditions shown in Figure 11, indicating that controllers reported higher confidence, reliance, trust and safety levels, when T-TSAFE offered both conflict detection and resolution advisories. This might suggest higher complacency levels when the tool starts offering resolution advisories to the users. The trends also indicate slightly lower levels of trust in automation on the same four sub-scales, under the conditions that require controllers to input assigned altitudes to the conflict detection and resolution tool. This might suggest that the altitude entries help to keep the controllers engaged and vigilant towards the conflict prediction and resolution functions provided by the tool, and therefore, reduces complacency levels. During open ended discussion, the controller participants indicated that, generally, automated detection works better than manual detection of conflicts and resolutions.

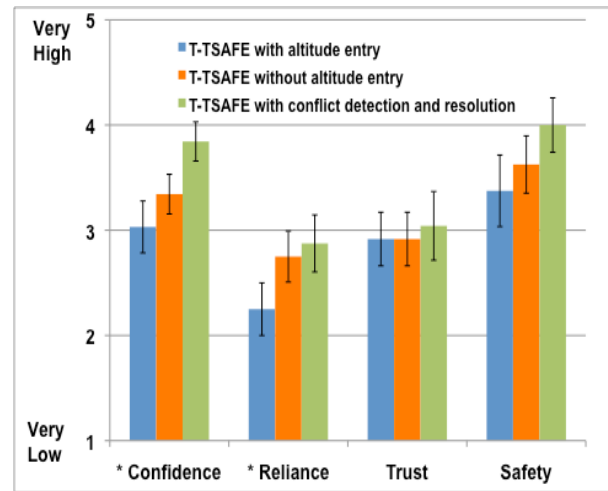


Figure 11. Complacency in Automation by Condition (* $p<0.05$)

Previous research has examined automation complacency [16, 17] and the extent to which over-reliance on automation can lead to operational errors (e.g., in the case of occasional automation failures). This might suggest that very high or very low levels of automation complacency are not desirable, but rather, optimum levels of automation complacency would be somewhere between these two extremes.

Figure 12 shows the controller complacency ratings comparing the type of conflict detection and alerting mechanism on the final approach, i.e., T-TSAFE alerts vs. ATPA cones. The controllers clearly show higher levels of trust in the ability of the automation to provide reliable and trust-worthy warnings in the conditions where ATPA is available in the final approach phase of flight. These trends are reinforced with statistically significant ANOVA differences found between the two conditions on the complacency scales of confidence, $F(1,7)=14.52$, $p<0.01$, trust, $F(1,7)=8.80$, $p<0.05$, and safety, $F(1,7)=10.29$, $p<0.05$. During open-ended discussion, the controller participants indicated that the graphics provided by the ATPA cones aided them with better flow management and efficiency on the final approach. This might suggest a somewhat higher potential for controller complacency when using ATPA cone graphics, as compared to using a conflict detection and alerting tool without graphics, even though in this study, most of the average complacency scores, were neither very low, nor very high.

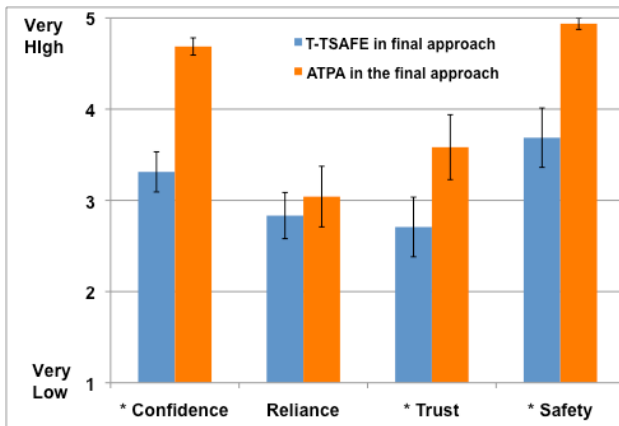


Figure 12. Complacency in Automation by Condition (* p < 0.05)

Ease of Procedures and Acceptability

The controller participants also rated on a scale of 1-to-5 their subjective responses towards ease and acceptance of procedures during different conditions (Figures 13 and 14).

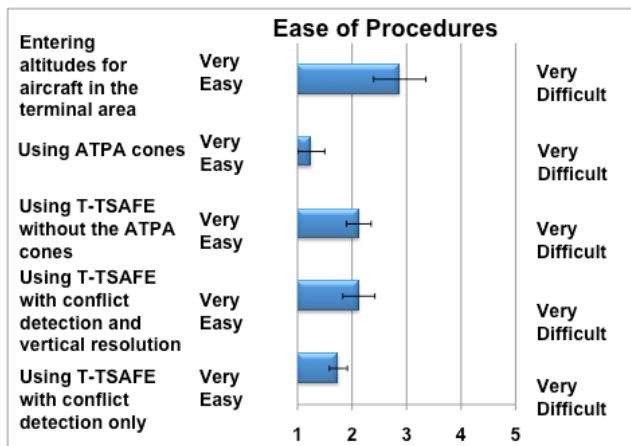


Figure 13. Subjective Ratings on Ease of Procedures for Different Functions

Controller ratings indicate that entering commanded altitudes via the keyboard was more difficult and less acceptable, as compared to all other procedures. This is consistent with results in which the controllers reported higher workload under the altitude-entry condition. Also, the ATPA cones stand out in terms of ease of use and acceptability. As indicated earlier, the controllers reported higher levels of trust in the conditions where ATPA cones were available. The controllers also indicated

slightly higher levels of acceptability for conditions where the tool offered both conflict detection and resolution as compared to conflict detection only, even though the condition with conflict detection was reported as only slightly easier to use.

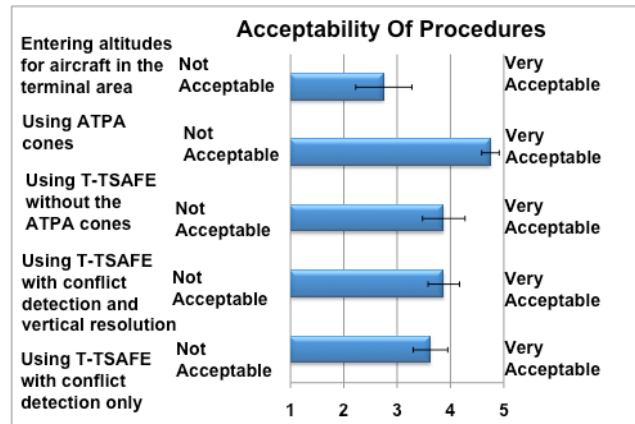


Figure 14. Subjective Ratings on Acceptance of Procedures

Summary

Initial and follow-up human-in-the-loop air traffic control simulation experiments were conducted, to test the human factors of a new conflict detection and resolution tool, Terminal Tactical Separation Assurance Flight Environment (T-TSAFE). While the initial investigation verified T-TSAFE as an improvement over the legacy conflict detection system currently used in the field, it also revealed aspects of the T-TSAFE system that require further investigation [5]. To address this need, a follow-up experiment was conducted, testing T-TSAFE under four experiment conditions. The first two conditions varied conflict detection with and without altitude clearances entered into the tool by the controllers via keyboard. The second and third conditions varied the presence of Automatic Terminal Proximity Alert (ATPA), a tool used for monitoring final approach, i.e., one condition used regular alerts in the data block and the other used ATPA cones between different aircraft as a warning for possible compression errors in the final approach. Finally, a fourth condition tested altitude resolution advisories.

For each 35 minute simulation run, an average of 4-6 alerts were generated, with slightly more alerts

in the No-ATPA condition. In the No-ATPA condition, T-TSAFE alerts were not suppressed in the final approach phase, as they were under the other 3 conditions, so this condition would be expected to generate more T-TSAFE alerts. Also, T-TSAFE kept false alerts to a minimum, with less than one false alert, on average, across all conditions. Results on alert/false-alert frequencies combined with feedback provided by the controller participants, seem to suggest that T-TSAFE performs better when compared to Conflict Alert, and reinforces results generated from our initial Phase-1 T-TSAFE study. Results on other objective measures suggest that alert durations and lead alert time were both adequate for the controllers to respond to the alert – a finding that was substantiated through guided discussion with the controller participants and previous research [9]. Finally, entering altitude clearances into T-TSAFE was expected to reduce false alerts but did not, possibly due to the short duration of the runs and the low frequency of altitude entries, which did not provide enough data for a complete analysis.

Subjective results indicated that controller workload across all conditions was low enough to be manageable, yet high enough to prevent tedium and vigilance decrement. Controller situation awareness was similar across all conditions and adequate. Also, higher levels of automation complacency were found under the ATPA and Conflict Detection and Resolution Advisory conditions, even though, across most conditions, complacency levels were found to be moderate. Finally, ATPA cones were preferred over T-TSAFE alerts on the final approach, mostly due to the graphics provided by ATPA. This particular issue will be explored further in the third phase of T-TSAFE testing, with two conditions of final approach cones, which will be driven, by either (1) ATPA logic or (2) T-TSAFE algorithms. Overall, results seem to suggest potential promise of T-TSAFE, pending further research, testing and adaptation.

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