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Analysis of Conflict Detection Performance for Trajectory-Based Descent Operations

Travis L. Gaydos, Ph.D., Bill Liao Ph.D., Elida C. Smith, and Liya Wang, Ph.D.
The MITRE Corporation
Center for Advanced Aviation System Development (CAASD)
McLean, Virginia
Contact email: tgaydos@mitre.org

***Abstract*—The evolution of time-based metering introduces greater amounts of Trajectory-Based Operations (TBO) in order to improve meter fix delivery accuracy and flight efficiency. Many TBO concepts have been proposed to yield those benefits; among them is the Three-Dimensional Path Arrival Management (3D PAM) concept of operations. 3D PAM operations are accomplished via ground-based automation that provides speed and path advisories to assist controllers in meeting the meter schedule. On-board capabilities enable pilots to accept and efficiently execute the advisory-based clearance. The result is an increased amount of near-idle thrust descent operations and increased use of closed-loop clearances (with full availability of the speed profile and path for each flight). However, these changes, as beneficial as they are, impact how operations are predicted today by fielded en route medium-term conflict detection support capabilities (i.e., time horizon of 3 to 20 minutes). In order to be effective, the current conflict detection automation must be adapted to best support controllers. This paper describes an analysis completed to determine the performance of fielded en route medium-term conflict detection capabilities given these TBO operations and how it may be better adapted via parameter changes. Results show that parameter changes alone will not provide an acceptable level of conflict detection performance due to a high number of false alerts. While more complex changes, in terms of implementation, are less desirable, they may be needed in order to provide an acceptable level of conflict detection performance, with respect to missed and false alerts, for a 3D PAM operations environment as well as for other TBO concepts of operation.**

Keywords-Flight Management System; conflict detection; performance-based descents; air traffic control; en route metering; trajectory-based operations; air traffic management

I. INTRODUCTION

Trajectory-Based Operations (TBO) is a key component of the Next Generation Air Transportation System (NextGen) strategy; improved flight efficiency and Air Traffic Control (ATC) planning are among the many advantages of TBO. The evolution of time-based metering to Time-Based Flow Management (TBFM) plans to introduce greater amounts of TBO in en route arrival/departure airspace in order to improve meter fix delivery accuracy and flight efficiency. Many concepts have been proposed to yield those benefits; among them is the 3D PAM concept of operations, which is a form of TBO.

3D PAM operations are accomplished via a ground-based Decision Support Tool (DST) that provides speed and path advisories to assist controllers in meeting the meter schedule; the advisories provided are both efficient and intended to minimize interactions with other traffic. The concept aims to increase the delivery accuracy of aircraft over a meter fix, while enabling those aircraft to execute more efficient and environmentally-friendly vertical profiles, in order to achieve a desired flow of traffic into the terminal area. On-board capabilities like Area Navigation (RNAV) and the Flight Management System (FMS) enable pilots to accept and efficiently execute clearances derived from the DST advisories provided; these capabilities are required to participate in 3D PAM operations. The resulting efficiency and planning benefits take the form of an increased amount of near-idle thrust descent operations and increased use of closed-loop clearances (with full availability of the speed profile and path for each flight). As beneficial as these change are, they impact how operations are predicted today by fielded en route medium-term conflict detection support capabilities (i.e., time horizon of 3 to 20 minutes), which are not designed to account for 3D PAM operations or more generally near-idle thrust descents. In order to be effective, the current medium-term conflict detection support available via automation for en route airspace traffic management must be adapted to these new TBO operations in order to best support controllers in managing arrival-to-arrival and arrival-to-over-flight operations.

The MITRE Corporation's Center for Advanced Aviation System Development (MITRE/CAASD) was asked by the Federal Aviation Administration (FAA) to determine whether parameter changes alone could help adapt fielded medium-term conflict detection automation to the 3D PAM operations environment. Parameter changes represent one of three key options for modifying fielded conflict detection support provided by the User Request Evaluation Tool (URET) and En Route Automation Modernization (ERAM). The options, which differ with increasing implementation complexity and difficulty, are 1) changing parameters, 2) changing aircraft performance data look-up tables, and 3) changing the trajectory modeler. The parameter values would require the changing of one value while the aircraft performance data change would be more complex due to requiring new look-up

tables for each aircraft type and detailed analysis to calculate the appropriate tables for 3D PAM operations.

Using simulated track data, an analysis of various parameter change effects upon fielded URET/ERAM conflict detection support performance was conducted. This paper provides a summary of the 3D PAM concept and details the analysis method, metrics, parameters evaluated, and conflict detection performance results.

The results and findings presented may be applicable to other TBO concepts besides 3D PAM. The degree of applicability will depend directly on how well a given TBO concept's assumptions align with those of 3D PAM. For example, TBO concepts with a goal of increasing the prevalence of near-idle or efficient thrust descents in en route arrival/departure airspace may have direct applicability to these results. On the other hand, not all TBO concepts require arrival-to-arrival medium-term conflict detection support in this airspace; one characteristic of the 3D PAM concept that drives this need is the complexity added by automation advised path stretching. If the need for arrival-to-arrival conflict detection in arrival/departure airspace is eliminated for a TBO concept, these findings may be less directly applicable.

II. Background

This section describes the 3D PAM concept of operations, the resulting operation changes in the en route environment, and their impact upon medium-term conflict detection.

A. 3D PAM Concept of Operations

Envisioned for the mid-term time frame, the 3D PAM concept's primary objective is to increase the delivery accuracy over a meter fix (thereby, maximizing throughput), while also enabling more efficient and environmentally friendly aircraft vertical profiles [1]. The 3D PAM concept accomplishes this objective by introducing a ground automation DST to provide advisories to the controller—in the form of speed changes and, if necessary, a corresponding path stretch—that are predicted to meet metering times and that minimize the chance for conflicts. The speed advisory takes the form of a Mach/Calibrated Airspeed (CAS) speed profile in which the aircraft will execute the Mach speed in cruise and transition to the CAS during descent. All advisories presented to the controller will have a speed profile, while some may also contain a path stretch. Path stretches take the form of a triangular route extension which can be defined by a place-bearing-distance waypoint based on the aircraft's current flight plan (which is usually in the form of a waypoint along a defined Standard Terminal Arrival (STAR)). If the controller chooses to accept the advisory, he/she will then voice this advisory in the form of a clearance to the pilot. Upon acceptance of the clearance the pilot will execute the advisory speed profile and, if necessary, the path stretch, by utilizing on-board automation capabilities (i.e., FMS). The closed-loop nature of the advisory clearance allows the pilot to use the FMS to execute a more efficient descent path (i.e., near-idle thrust) that also meets the associated metering time. Upon agreement by controller and pilot, the controller will accept the advisory thereby updating flight plan information to reflect the current clearance. The controller will then monitor the flight's execution of the clearance as well as monitor for possible traffic conflicts.

The 3D PAM concept defines two types of conflict detection functionality. The first is referred to as *provisional conflict avoidance* while the other as *active conflict detection*; the latter is the focus of this analysis.

Provisional conflict avoidance refers to conflict detection with a time horizon of up to 20 minutes performed on the predicted flight trajectory before the controller ever sees the advisory or upon initial viewing of the advisory. The provisional conflict avoidance function enables 3D PAM to provide a conflict-free advisory (to the best of its ability) and to provide conflict information about the advisory to the controller upon initial viewing. It does this by providing conflict detection for proposed advisories before any information is displayed to the controller which may include cycling through multiple proposed advisories to find the advisory that meets time constraints with none (ideal) or least number (in practice) of conflicts to show to the controller. Conflict information associated with the "best" advisory that meets time constraints will be displayed to the controller based on the provisional conflict avoidance results.

Active conflict detection provides medium-term conflict detection functionality (time horizon 3 to 20 minutes) and information to help the controller monitor aircraft that are executing a 3D PAM advisory. This functionality starts after controller acceptance of a 3D PAM advisory and during FMS execution of the advisory (i.e., after flight plan update based on the advisory). This functionality is performed today by URET/ERAM conflict detection. The assumption is for URET/ERAM conflict detection to continue to provide active conflict detection functionality in a 3D PAM environment incorporating the 3D PAM advisory information and accounting for arrival-to-arrival conflicts in arrival/departure airspace. Human-In-The-Loop (HITL) simulation results indicated that controllers needed an active conflict detection function in arrival/departure airspace to detect all varieties of conflicts because the automation-advised path stretches (for the 3D PAM-eligible operations) are generally different than what controllers would have done if left to their own means for metering traffic [3]. The complexity introduced by the automation advisories and overall closed-loop nature of the operations (in order to more accurately and efficiently meet the metering schedule) are what drive the need for medium-term conflict detection. The functionality to detect arrival-to-arrival conflicts exists today but is often inhibited for some conflicts in arrival/departure airspace through the use of arrival stream filters.

B. 3D PAM Operations Impact on Medium-Term Conflict Detection

As a result of the operational changes to the arrival/departure airspace environment that TBO concepts like

3D PAM introduce, a need for good conflict detection support for controllers has been identified (via 3D PAM validation activities). More specifically, a new conflict detection need for arrival-to-arrival interactions in en route arrival/departure airspace is desired; arrival-to-over-flight interactions are already supported by URET/ERAM conflict detection today but would also need to be adapted to accurately predict 3D PAM operations. In order to best support traffic management, conflict detection in URET or ERAM would need to have a wider set of conflicts to detect (than it does today) and would have to account for the new conduct of operations. With respect to URET/ERAM conflict detection, some of these changes may introduce new challenges while others may be advantageous. Figure 1 presents the three major changes to the environment introduced by 3D PAM operations that are hypothesized to have an impact on URET/ERAM conflict detection:

1) More aircraft flying near-idle thrust descents
2) Availability to the automation of full speed profile (i.e., Mach and CAS) to meter fix
3) Variable path stretch maneuvers (defined by the advisory) and more closed-loop clearances (where the same information is known by the pilot, controller, and automation)

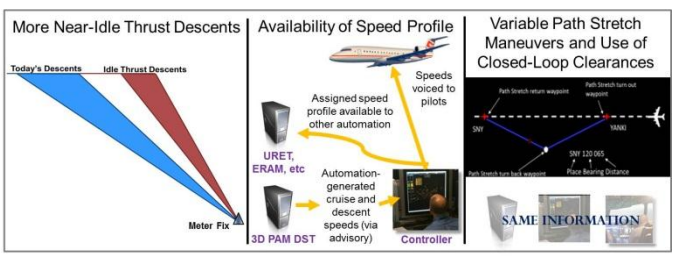

Figure 1. Airspace Environment Changes Introduced by 3D PAM

The first environment change reflects more aircraft flying near-idle thrust descents. Recall that the 3D PAM concept's objective is to increase the delivery accuracy over a metering fix while also enabling more efficient and environmentally friendly aircraft vertical profiles [1]. A major component of more efficient and environmentally friendly aircraft profiles being achieved is allowing aircraft to fly near-idle thrust descents. Aircraft flying near-idle thrust descents will be different than today's operations; the vertical profiles will change with respect to the descent gradient and descent speeds. All of this makes conflict detection more challenging for current URET/ERAM conflict detection which has parameters settings, aircraft performance data, and trajectory modeling fit to best predict today's operations (which contain significantly less near-idle thrust descent operations).

The second environment change is the availability of the aircraft speed profile (Mach/CAS speed profile) to automation. The 3D PAM concept will provide an easier method for update of speed information for an aircraft by allowing this information to be updated with controller acceptance of the 3D PAM advisory. This update may increase the accuracy of speed information about the aircraft even though today's system is only able to receive the cruise (Mach) portion of the advisory. Speed information would be passed to URET/ERAM conflict detection and utilized by the URET/ERAM conflict detection trajectory modeler, possibly providing performance advantages. On the other hand, the future descent speed (i.e., the CAS the aircraft will transition to in descent) has no way today to be passed to URET/ERAM which may be a disadvantage to conflict detection performance. Even if that information were able to be passed, the current trajectory modeler of URET/ERAM conflict detection is not equipped to utilize that information. There is potential to increase the trajectory prediction accuracy of URET/ERAM conflict detection by receiving that descent speed information; however, the trajectory modeler would need to be modified to utilize it.

Finally, the third environment change involves variable path stretching and increased use of closed-loop clearances. Variable path stretching is a change that primarily drives the need for arrival-to-arrival conflict detection but does not actually adversely impact conflict detection performance because the advisory is a closed-loop clearance, so automation is aware of the intended path that will be flown. 3D PAM advisories provide the potential advantage for there being an increased number of aircraft on closed-loop clearances during periods of metering. The closed-loop clearances are either achieved by the advisory allowing the controller to leave the aircraft on its original flight plan or providing a closed-loop path stretch maneuver to absorb delay. Today, on the other hand, metering time delay is typically accomplished through the issuing of open-loop clearances by controllers in the form of vectors. Having the controller and automation both aware of the flight's lateral path has the potential to increase trajectory prediction accuracy of URET/ERAM conflict detection. 3D PAM implementation is envisioned to also provide an easy method for the controller to update the flight plan with route change information via acceptance of the 3D PAM advisory. Since URET/ERAM conflict detection can currently receive and utilize path information, this environment change can provide advantages for conflict detection; however, the added requirement of arrival-to-arrival conflict detection in this airspace creates a much more challenging task.

III. Description of Analysis

A. Scope

The goal of this analysis was to determine the minimum change required for URET/ERAM conflict detection software of today (or the near-term future) to provide an acceptable performance level in an environment with 3D PAM operations. To accomplish this, an analytical approach was selected to add changes that progressively build upon the current system (in an iterative fashion) until an acceptable performance level is reached. This approach allows for easier understanding of the minimum functionality needed to achieve an acceptable performance level.

The solution space of system change options that could be made to URET/ERAM conflict detection was as follows:

1) Modify existing parameters
2) Define new aircraft performance data look-up tables
3) Change trajectory modeler

The difficulty and cost of implementing the system changes increases as one proceeds down the list of options.

B. *Method*

The 3D PAM concept's controller DST was prototyped and matured through a series of validation activities. The prototype is referred to as the Efficient Descent Advisor (EDA) and was developed by the National Aeronautics and Space Administration (NASA). Using this prototype, the FAA completed various validation activities, including HITL simulations, for the 3D PAM concept [2]. This analysis builds upon 3D PAM HITL simulation #7 which was conducted at the NASA Ames Research Center [10]. Simulated data consisting of a synthetic [1] scenario and synthetic tracks (produced by a trajectory modeler shown to be similar to real world tracks as a result of 3D PAM operations) were analyzed. While ideally one would want to use real operational data, it was not feasible to do so since the 3D PAM concept is not yet operational in the National Airspace System (NAS). A set of 3D PAM flight trial data does exist that would, in theory, allow for a synthetic scenario to be generated based on the flight trial data; however, a decision was made not to use it given the constraints of the analysis effort. The synthetic scenario and synthetic tracks used were believed to be realistic enough for this analysis, but it is important to point out that the results are influenced by synthetic scenario design and the synthetic tracks used.

The synthetic scenario was developed by Saab-Sensis and the synthetic tracks were produced by NASA's Center TRACON Automation System (CTAS) Trajectory Synthesizer. CTAS is software which contains, among other capabilities, the 3D PAM DST prototype EDA. CTAS interacts with an en route airspace simulation environment, enabled by different software received by NASA, known as the Multi-Aircraft Control System (MACS). Together, CTAS and MACS can be thought of as a 3D PAM operations simulation platform. The synthetic scenario design used in the analysis reflected one arrival corner post of the Denver Air Route Traffic Control Center (ARTCC) (ZDV) along with some modifications to the STAR procedure design (compared with existing procedures). The level of traffic in the synthetic scenario was slightly above what would be observed in today's environment. A detailed description of the airspace and routes simulated can be found in [9-10].

Figure 2 depicts a flow diagram of the overall analytical process which will be covered in detail in the following paragraphs. The synthetic scenario was run in MACS software along with the 3D PAM DST prototype software, EDA, to simulate 3D PAM operations (see blue box in Figure 2). All advisories were accepted and implemented with no other modifications made to the aircraft trajectories; therefore, there is no controller influence on the tracks. The effect of controller influence was removed so it would not cause confusion in interpreting the results of the analysis. While in real life the active conflict detection function would have to incorporate prediction changes as a result of controller actions, for this analysis the assumption was that generally controllers would let aircraft fly the 3D PAM advisories; this assumption allowed for a reasonable answer. Some realism was traded in order to have much more interpretable results that would allow for the most overall knowledge to be gained. Assuming no controller intervention isolates the performance of automation and provides the opportunity to study missed alerts, which is often not the case with controller influence. It is recommended to ultimately validate any system changes via a controller HITL simulation.

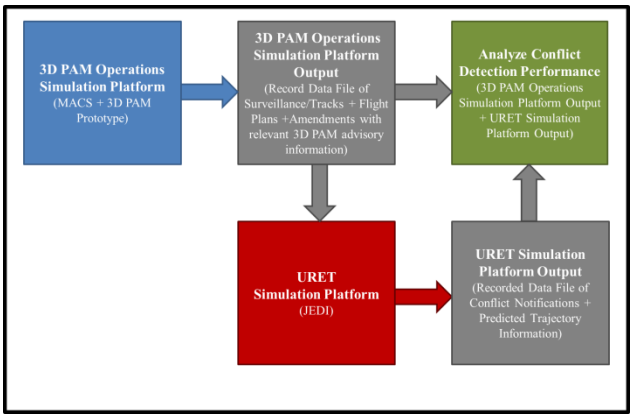

Figure 2. Flow Diagram of the Analytical Process Employed

All track and advisory/flight plan information (i.e., output from the 3D PAM operations simulation platform) is recorded as a data file (see grey box in Figure 2). This recorded data was then formatted in a way to be able to rerun the scenario using MITRE/CAASD's URET Simulation Platform, the Joint En route Decision support system Infrastructure (JEDI) (see red box in Figure 2). The synthetic tracks produced by the 3D PAM operations simulation platform were treated as truth data (i.e., surveillance) in JEDI. Also, all advisory information was treated as it would be passed in real life (i.e., through the flight plan). This means that only path stretch and cruise (Mach) advisory information could be provided to automation through amendments; information such as the future descent speed was not passed to JEDI. The conflict notification and predicted trajectory information (output of the URET simulation platform) was recorded and is shown by the grey box in lower right corner of Figure 2. The URET simulation platform output was then analyzed and compared to the 3D PAM operations simulation platform output to determine the conflict detection performance and trajectory prediction performance (see green box in upper right corner of Figure 2).

[1] The term synthetic is used here to explicitly distinguish lab modeled/simulated tracks and scenarios versus operational tracks and scenarios observed in the real world.

Wind error and weight variation were excluded from this analysis to get a better understanding of exactly how parameter changes were influencing results. Doing so ensured that the particular wind error for this simulation was not concealing information about the gains that could be made through the application of parameter changes. As future work it is recommended that all URET/ERAM changes be tested using a set of robust scenarios with realistic and varying levels of wind and weight error.

C. Description of Parameter Changes

The focus of this analysis was to determine the impact, or lack of impact, that specific parameter changes have upon URET/ERAM conflict detection performance in an environment with 3D PAM operations. The parameters selected to be evaluated were based, almost entirely, on promising results from the Separation Management and CRA studies [4-5]. Only today's values and the values suggested by studies described in [4-5] were considered for this analysis because the findings of those studies reflected the most promising parameter values (i.e., values determined to provide the most reduction in false alerts while causing little to no rise in missed alerts). Based on results of those studies and assuming uniform application of conflict detection parameters (i.e., not a different set of parameter values for 3D PAM operations) testing more aggressive parameter values would have caused an unacceptable rise in missed alerts for operations not participating in 3D PAM operations (e.g., two over-flights in the same arrival/departure airspace).

Even though these parameters values had shown improvement in the environments studied in [4-5], it does not necessarily imply that the same results would be shown for this analysis because the 3D PAM operations environment has some distinct characteristics that significantly differentiate it from the operations previously assumed; main differences include a need to probe for arrival-to-arrival conflicts in arrival/departure airspace and an increased number of near-idle thrust descents. With that said, parameter changes utilized in the CRA study were followed most closely because the environment assumed in that study was most similar to the 3D PAM operations environment.

A total of six parameter changes were studied in this analysis. The parameter changes all have in common a goal of trying to lower false alerts while keeping missed alerts at the rates of today. Each parameter change is described next at a high level to explain why each was thought to help improve medium-term conflict detection performance in an environment with 3D PAM operations. A more detailed discussion of parameter changes is available in [4-8].

1) Conformance Box

The first parameter change evaluated involves the definition of conformance boxes or bounds. URET/ERAM uses conformance boxes or bounds for two reasons. The first reason is to determine when to rebuild the trajectory. If the aircraft surveillance position falls outside the conformance box, then a trajectory reconformance occurs (i.e., the trajectory is rebuilt). The second reason is to incorporate an error buffer around the trajectory prediction; URET/ERAM checks the distance between conformance boxes to detect conflicts.

It is important that the conformance box accurately represents prediction error to ensure that alerts are not missed due to prediction inaccuracy and that more false alerts than necessary are not caused. The more accurate the trajectory prediction, the smaller the conformance box (i.e., error buffer) can be. As aircraft navigation accuracy has increased, so has the lateral prediction accuracy of the trajectory modeler which, in turn, causes the longitudinal accuracy to increase as well. Therefore, the default JEDI conformance bounds (shown in blue in Figure 3) may be larger than needed. By reducing the conformance box to an appropriate size, false alerts can be reduced without increasing missed alerts. For this analysis the conformance box parameter was set equal to the values used in the CRA study; this parameter change will be referred to as "conformance box equal to CRA setting." When the conformance bounds equal the CRA setting (shown in red in Figure 3) the conformance box size shrinks with the aim of reducing false alerts while not increasing missed alerts. Missed alerts should not increase if the conformance box is still representative of the positions that aircraft could be at the given time.

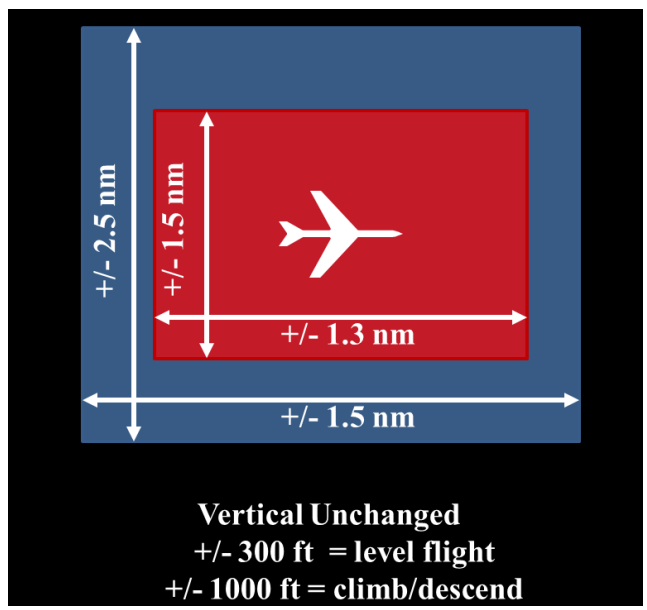

Figure 3. Default (blue) and CRA (red) Values for Conformance Boxes

2) Likelihood

The next parameter change to discuss involves the notification of a conflict based on the likelihood of that conflict occurring. Upon detecting that two aircraft's conformance boxes have come within a minimum distance of each other to result in a possible red or yellow alert, URET/ERAM assigns a probability that this conflict will actually occur. This probability is then used to determine if a notification should be displayed to the controller. The probability is compared to a likelihood curve (or function)

which presents the probability of conflict as a function of the look-ahead time. If the probability of conflict for this pair at the look-ahead time is greater than the likelihood curve, then a notification is sent to the controller. If it is not greater than the likelihood curve, then URET/ERAM will withhold notification to the controller and continue to monitor the pair. If at any point the pair's probability of conflict for a given look-ahead time lies above the likelihood curve value, then a notification of conflict will be sent to the controller. If it is a low probability, then URET/ERAM will hold off on notification to the controller, waiting to gain more accurate information about the pair of aircraft in question. It may be the case that after waiting and gaining more information (i.e., better predictions), URET/ERAM will determine that the aircraft will no longer be predicted to be in conflict. To evaluate the effect of this parameter, the conflict likelihood curve used in the CRA study was adopted for this analysis. This parameter will be referred to as "likelihood equal to CRA setting."

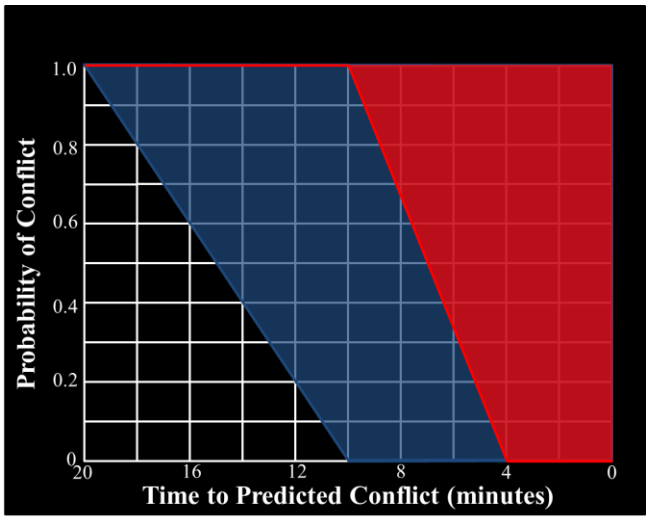

Figure 4. Likelihood Function Equal to Default (blue) and CRA (red) Settings

Figure 4 shows the URET/ERAM default likelihood curve and region of notification (shown in blue), as well as the likelihood equal to CRA settings curve and region of notification (shown in red). The red region is much smaller, causing automation to wait longer to notify the controller so that more information about the pair of aircraft in question can be gained. When the likelihood is set equal to CRA settings, automation trades alert notification look-ahead time for accuracy. A look-ahead time of three minutes or greater was considered a long enough time duration to support strategic resolution [4-5]. Given that look-ahead time value, false alerts can be reduced by gaining more accurate predictions and missed/late alerts (i.e., not providing enough notification lead time) will not increase because the controller still receives a notification for any chance of conflict identified 4 minutes and closer.

3)Tactical Check

Tactical Check is similar in principal to a parameter change already discussed, the conformance box equal to CRA setting, with respect to why it would be expected to produce a performance increase in conflict detection. With tactical check only the trajectory prediction buffer is addressed, which is only one of the roles addressed by the conformance box. For this case, the conformance bounds are set to the default JEDI conformance box. The automation first checks whether the conformance boxes are within a given distance to consider display of an alert to the controller. It then does a second check, essentially changing the trajectory prediction buffer to a set of boxes that grow as the look-ahead time increases. In Figure 5, the conformance bounds are shown in blue while the tactical check trajectory prediction buffer is shown in red. Conflicts predicted with less look-ahead time must have predicted trajectories located closer together in order for an alert to be provided to the controller. The trajectory prediction buffer was set to match the trajectory prediction accuracy for the different look-ahead times.

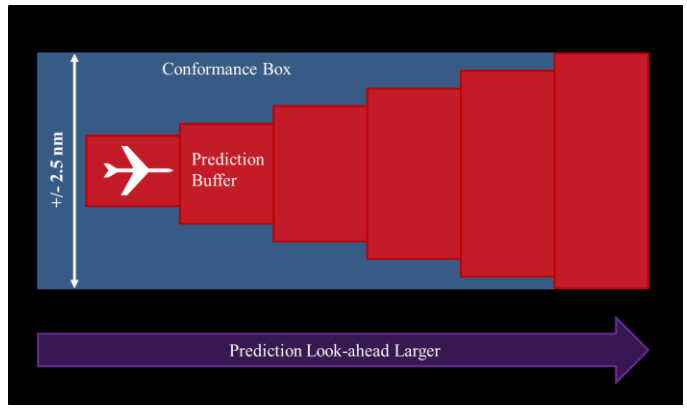

Figure 5. Default (blue) and CRA (red) Values for Conflict Detection Trajectory Prediction Buffer

Figure 5 illustrates how this change would reduce false alerts since the red region is smaller than the blue region and two red regions would have to come within a minimum separation threshold rather than the two blue regions. An increase in missed alerts would not be expected because the buffer accurately represents the true prediction error. Therefore, enabling tactical check such that it matched the settings used in the CRA study was another parameter selected to be evaluated.

The previous three parameter changes were expected to improve conflict detection performance because of their direct impact on the detection function. Additionally some changes may have indirectly resulted in increased trajectory prediction accuracy (e.g., CRA conformance boxes may cause the trajectory to be rebuilt sooner as the aircraft is drifting away from its prediction). The next three parameter changes described are directly related to increasing trajectory prediction accuracy by changing parameters that influence the trajectory modeler.

4)Adherence Logic

Adherence logic is referred to in this document as a parameter change, but it is more about updating the logic and rules for ways trajectories are rebuilt given flights have or have-not been "adhering" to the lateral predicted trajectory. The changes required to rebuild the trajectory are only in terms of logic/rules; therefore, it does not require extensive reworks of the trajectory modeler. As a result, the magnitude of effort to implement the change may be higher than a simple parameter change but still less extensive than other changes such as incorporating the use of descent speeds into the predicted trajectory. Logic changes for rebuilding a trajectory are summarized in [5]. By themselves, the amount of impact to conflict detection performance that these logic changes would provide for an environment with 3D PAM operations was unclear, but these logic changes seemed to have benefit in allowing the reduction of conformance bounds.

The next two parameter changes that will be described are not directly correlated to previous analyses completed for the CRA or Separation Management studies. These changes were instead identified as potential solutions based on a previous analysis completed to evaluate conflict detection compatibility in an environment with 3D PAM operations [9].

5) Reweighting Inputs To Determine Predicted Speed

The predicted trajectory speed profile calculated by ERAM/URET trajectory modeler is a weighted average of the following three inputs: 1) the advisory/planned speed, 2) the current observed tracker speed, and 3) smoothed tracker speed based on the last several tracker observations. Details about the weighting applied to these inputs can be found in [11].

In an environment with 3D PAM operations, aircraft will utilize the FMS to execute and fly the advisory speed profile. Additionally, the advisory provided by the 3D PAM DST enables an easy update of speed information (to automation) by the controller. Therefore, the advisory/planned speed can be trusted and there is no longer a need to rely on a "wait and observe" approach to determine speed from the tracker. Since this parameter change relies on having good wind prediction, it is susceptible to noise (e.g., wind error). Still, this parameter change was used because the speeds of some aircraft were previously observed to be influenced too much by local speed variation and would be better predicted if the advisory/planned speed was used [9].

6) Turn Parameter

Because each aircraft that receives a 3D PAM path stretch advisory would produce a route amendment, the effect of turn parameter changes on conflict detection performance was also evaluated. When the route amendment is received, the trajectory modeler evaluates the new route to determine how the lateral path will be modeled. One piece of information used to define the lateral path is the first fix's distance to the current state of the aircraft. The trajectory modeler compares this distance to a parameter distance and, based on this comparison along with other inputs (e.g., current heading of aircraft), it may choose to bypass the first amendment waypoint to a waypoint downstream. The case described above, along with the old and new parameter, is shown in Figure 6 which presents the boundaries of the ZDV arrival airspace corridor selected for this analysis. In this figure the solid white line is the amended route. If the aircraft is within the turn parameter distance (2 nm (new, shown in red) or 20 nm (old, shown in blue)) of the first waypoint (YANKI), the current URET/ERAM system may choose to model the lateral path instead as the dotted white line to join the amended route. The more accurate assumption would be to model the lateral path based on the amendment (shown by the solid white line).

In the 3D PAM operations environment, the amendment route information is more reliable since the advisory is well-defined (e.g., at waypoint A, fly to Place/Bearing/Distance, and then proceed to waypoint B). There is less of a need to try to guess how the aircraft is going to execute the lateral path (as compared with the open-loop clearances (i.e., vectoring) used today). This is a benefit enabled both by the pilot's use of the FMS to execute and fly the advisory and the controller's ability to easily keep the flight plan up to date by accepting the 3D PAM advisory.

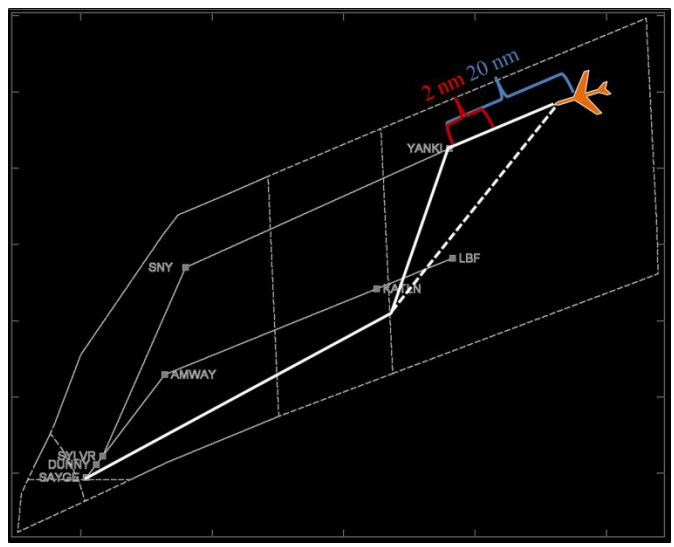

Figure 6. Default (blue) and New (red) Turn Parameter

D. Metrics

The measurement of conflict detection performance was based on high level DST performance metrics which consisted of classifying alerts as True Alerts, False Alerts, and Missed/Late Alerts. These alert classifications were made by evaluating a pair(s) of aircraft with at least one aircraft in the pair being an arrival to Denver International Airport (DEN). Because the 3D PAM concept will change the flight profiles of arrivals but not over-flights, alert events were defined as requiring at least one DEN arrival. Over-flight to over-flight conflict detection performance is expected to be unchanged in a 3D PAM operations environment.

Alerts were filtered to only consider those that occurred after appropriate (i.e., arrival) aircraft in the pair had received all of their 3D PAM advisories. This was so that URET/ERAM was not mistakenly faulted or credited when the

future state predicted was not observed in practice. For example, an alert is given for a conflict, but then an aircraft receives a 3D PAM advisory that it starts to execute which changes the trajectory of the aircraft. In this example, URET/ERAM should not be faulted for providing a false alert, but also it should not be given credit for detecting a true conflict. Not enough information is available to make an alert classification since the true trajectory had changed. The rules for classifying an alert will be discussed next.

Figure 7 provides a graphical representation of each alert classification. A true alert is defined as when URET/ERAM conflict detection provides the controller a conflict alert notification for a pair of aircraft, with the alert notification (shown as a red box in Figure 7) provided at least 3 minutes before the start of the true conflict (shown as a cyan box in Figure 7 with a cyan bracket to represent 3 minutes before start of conflict) and did not disappear, and that pair of aircraft actually had a conflict (i.e., were less than the minimum separation distance of 5 nm). The terms *true tracks* and *true conflict* apply to events that occurred with regards to the output of the 3D PAM operations simulation platform.

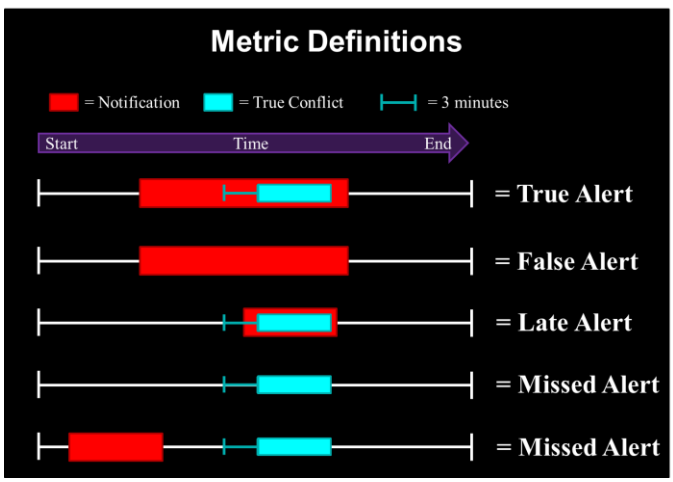

Figure 7. Rules for Classification of Alerts

A false alert is when URET/ERAM provides the controller a conflict alert notification for a pair of aircraft that never had a true conflict. To be classified as a missed/late alert one of three conditions must be met:

a) A conflict alert notification was provided to the controller for a pair of aircraft but was provided less than 3 minutes in advance of the true conflict start time (i.e., alert was late)

b) No conflict alert notification was provided to the controller for a pair of aircraft that had a true conflict

c) A conflict alert notification was provided to the controller for a pair of aircraft but was removed (i.e., rescinded) more than 3 minutes prior to the start of the true conflict and a new notification was never provided to the controller prior to 3 minutes in advance of the true conflict start

A criterion of 3 minutes before the start of a true conflict was applied because the active conflict detection function is intended to enable strategic resolution of the conflict. A look-ahead time of 3 minutes or greater was considered a long enough time duration to support strategic resolution [4-5]. Most missed/late alerts were expected to be due to condition *a* rather than either of the other two conditions.

IV. Results

MITRE/CAASD defined and implemented various parameter changes in a URET simulation platform to assess the effectiveness of medium-term conflict detection during simulated 3D PAM operations. MITRE/CAASD designed and executed closed-loop simulations to analyze the accuracy of URET conflict detection given the various parameter changes. The following section describes the results.

A. *Results by Alert Clasification*

MITRE/CAASD assessed conflict detection performance by classifying each eligible alert (or pair) that was notified to the controller as false, missed/late, or true. Table 1 presents the number of False, Missed/Late, and True Alerts for the same scenario but with different parameter changes (or combination of parameter changes) applied, noted by the scenario test condition column. Each row reflects the number of alert classifications observed. The first row presents results of a baseline test condition which represents the conflict detection performance provided by URET/ERAM as-is, without any parameter changes applied. The last row of Table 1 reflects a combination of parameter changes applied simultaneously; in this case the first four parameter changes, those directly traceable to the CRA study, were enacted (Likelihood, Conformance Box, Tactical Check, and Adherence Logic). This was done to determine whether a collective application of parameter changes provided benefits; a testing of the whole to determine if it was greater than the sum of its parts.

Table 1. Number of Alert Classifications for Each Parameter Change

Scenario Test Condition	**False Alerts**	**Missed/Late Alerts**	**True Alerts**
Baseline	35	0	7
Conformance Box = CRA	**33**	**0**	**7**
Likelihood = CRA	35	0	7
Tactical check	35	0	7
Adherence logic	35	0	7
Speed Weighting	35	0	7
Turn parameter	35	0	7
Likelihood = CRA, conformance box = CRA, Tactical Check, Adherence Logic	**33**	**0**	**7**

The only individual parameter change that showed improvement from the baseline condition was when the conformance box equaled the CRA setting (Table 1 row 3, highlighted in yellow). The last row (also highlighted in yellow), where all parameters were equal to CRA settings showed no improvement over the individual conformance box parameter change. The scenario evaluated was about 90 minutes long and contained 80 aircraft; 36 arrivals and 44 over-flights. The false alert results observed equate to one false alert every 2.5 to 3 minutes on average, which may be even a low estimate for particular periods of the scenario when traffic is denser. Overall it appears that only changing the conformance box size leads to a decrease in false alerts.

B. Detailed False Alert Examination

MITRE/CAASD then further analyzed the false alerts by identifying common characteristics among them. To do this, the baseline case was evaluated since it reflected current settings in today's conflict detection system. Understanding why false alerts are occurring can inform ways to implement improvements.

The first characteristic examined was the contribution of aircraft interactions to the false alert results. Understanding whether arrival-to-arrival conflicts contribute to a higher number of false alerts than arrival to over-flight conflicts is desirable especially for concepts of operation that may not require removal of the arrival stream filter (i.e., it is operationally acceptable to inhibit arrival-to-arrival medium-term conflict detection in arrival/departure airspace). Results show that approximately 45% of the false alerts consist of arrival to over-flight conflicts. This means that even if a TBO concept did not have a conflict detection need for all operations, which is closer to today's conflict detection performance requirement, 16 false alerts would still exist for the scenario analyzed.

It should be pointed out that the synthetic design of the scenario evaluated directly influences the frequency of alerts. In order to provide continuity between the ATC validation activities and this analysis, a decision was made to use a traffic scenario that had been previously verified by controllers via a HITL simulation; however, we recognize that the scenario was designed to challenge controllers and the 3D PAM DST (automation). To do that, over-flights were placed in closer proximity to arrivals than may be the case in real life. In any case, the fact that these arrival to over-flight conflicts appear underscores the potential for a high number of false alerts in arrival/departure airspace with large amounts of over-flight interactions. It also foreshadows a particular reason why a false alert occurs, which is due to the inaccurate prediction of Top of Descent (ToD) location. While this effect is ultimately due to a trajectory modeler deficiency with respect to arrivals, it also affects the arrival-to-over-flight conflict prediction. Arrival-to-arrival conflicts comprise a higher percentage (55%) of false alerts, but not at the high magnitude expected.

The next characteristic examined was whether most of the false alerts occurred because of a deficiency in the way the trajectory modeler predicted the descent portion of the predicted trajectory. A good proxy for determining this is to examine muted alerts[2]. It should be noted that in this setting muted alerts take on a different meaning than one most people may be accustomed to. In the 3D PAM operations environment the controller is essentially telling the pilot to descend where the FMS indicates, but there is no way for the controller to explicitly communicate this intent to automation using the current flight plan; therefore, no altitude amendments are entered into the system. If the controller were to actually enter an altitude amendment, the trajectory modeler would start modeling an immediate descent which would lead to inaccuracies in the predicted trajectory because the aircraft's intent is to wait to descend where the FMS indicates. This is another case (similar to the descent speed) where today's flight plan is unable to capture and pass particular information to automation. Automation is never told that the flight has been given clearance (by the controller) to a lower altitude. Automation still models the descent of the aircraft because of an altitude constraint at the meter fix that needs to be adhered to. The outcome is that any conflict predicted after ToD location, according to the predicted trajectory, would be labeled a muted alert.

Based on the analysis results, if false alerts after ToD were ignored (i.e., muted alerts) then false alerts would be reduced by approximately 85%. This seems advantageous, but removing muted alerts means that the controller would not get any medium-term conflict detection support for interactions beyond the predicted trajectory ToD location. Under these conditions the controller would not be notified of true conflicts after ToD either. The large percentage of all false alerts after TOD implies that cruise phase modeling and parameter settings may be doing an acceptable job. This has important implications to other TBO concepts of operations; if controllers do not require conflict detection support after a flight's ToD location, then the current URET/ERAM system may provide a sufficient level of conflict detection performance. Given the high number of false alerts found to be caused by inaccuracies of descent modeling, the most gain for adapting existing automation systems to an environment with 3D PAM operations appears to be by increasing the modeling accuracy of the predicted trajectory descent.

V. Summary of Findings and Discussion

MITRE/CAASD was asked by the FAA to determine if parameter changes alone would improve medium-term conflict detection performance so that it would be acceptable for managing operations in a 3D PAM environment. The results of this analysis show that parameter changes alone will not produce acceptable medium-term conflict detection performance as measured by operational suitability. This analysis represents only a partial step in trying to understand and improve conflict detection performance in an environment with 3D PAM operations. While little improvement was

[2] A muted alert occurs when the loss of separation occurs only on the portion of the trajectory for which an altitude clearance has not yet been issued [5].

shown for the parameter changes, it did yield results about where to focus efforts for improvement. Results indicate that additional analysis toward changing aircraft performance data and/or the trajectory modeler to produce acceptable conflict detection performance is needed.

Because of TBFM enhancements in the NAS, speed advisories will be available to controllers in order to assist them in meeting a meter fix schedule. If the speed advisories are issued in a manner that allows for idle-thrust descents to the meter fix (i.e., the only altitude constraint is at the meter fix) then conflict detection for arrival-to-over-flight operations would be a concern. The more constrained the vertical path, the less opportunity for idle-thrust descents since it will remove some of the uncertainty present in the prediction of the vertical profile, particularly the ToD location. With the ToD location more well-known (i.e., less difficult to predict), one would expect the medium-term conflict detection accuracy with speed advisories to be similar to today's environment and with conflict alerts only displayed for arrival-to-over-flight conflicts and not arrival-to-arrival conflicts. Arrival-to-arrival conflict detection may not be needed in a speed advisory-only environment, because the controller is still manually (i.e., tactically) determining the lateral path modifications needed; however, this needs to be better understood. The increased reliance on automation-provided path stretches was the main driver for the requirement of arrival-to-arrival medium-term conflict detection in the 3D PAM environment, but more research should be conducted about whether the introduction of speed advisories would cause a new requirement of arrival-to-arrival conflict detection in busy arrival/departure airspace. Controller acceptance of automation speed advisories, rather than producing the speed advisories manually, may create a similar conflict detection need to help support their mental model of operations.

The addition of speed advisories to the environment provides the opportunity to have knowledge about the descent speed much earlier than today; knowing the descent speed ahead of time provides the potential to increase the accuracy of medium-term conflict detection. The improvement of conflict detection performance is only realized if the conflict detection automation is able to properly utilize that descent speed information ahead of time. Current fielded en route medium-term conflict detection automation is not equipped to properly utilize information about a descent speed ahead of time. The descent speed would allow the longitudinal path of the aircraft to be better predicted resulting in better medium-term conflict detection accuracy with respect to arrival-to-arrival conflicts. Medium-term conflict detection of arrival-to-arrival conflicts in arrival/departure airspace has long been a difficult and inaccurate task for current conflict detection; therefore, most busy arrival/departure sectors inhibit the notification of arrival-to-arrival conflict alerts. But with speed advisories providing increased knowledge of descent speeds ahead of time, there may no longer be the need to inhibit notification of arrival-to-arrival conflict alerts.

The introduction of speed advisories into the NAS provides an opportunity to improve medium-term conflict detection and that opportunity should be capitalized upon. The initial implementation of speed advisories needs to be better understood to determine whether there is any impact to medium-term conflict detection performance like that shown in this analysis. Certainly, as TBO concepts assume less constrained vertical profiles and automation advised lateral paths are introduced, as described in NextGen, the issues raised in this paper about medium-term conflict detection performance impact will become more realized.

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