Evaluation of the En Route Automation Modernization Trajectory Modeler Performance Using Preliminary Adaptation for Unmanned Aircraft Systems

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Technical Note

Separation Management, Trajectory Modeling, Trajectory Prediction, Adaptation, Aircraft Characteristics, En Route Automation Modernization, ERAM, Conflict Probe, Unmanned Aircraft System (UAS)

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Executive Summary

The Separation Management and Modern Procedures Project is an initiative of the Federal Aviation Administration (FAA) under the Next Generation Air Transportation System (NextGen) Program to implement improvements in the En-Route Automation Modernization (ERAM) system, which supports all en-route facilities in the United States. The FAA’s Air Traffic Organization En-Route Program Office (ATO-E) has tasked the FAA’s Concept Analysis Branch (ANG-C41) to execute several studies investigating the impacts from various proposed prototypes and parameter changes in ERAM’s Conflict Probe Tool (CPT) and/or Trajectory Modeler (TM). The overall objective is to improve the performance of ERAM’s CPT subsystem in preparation for integration of the CPT alert notification into the flight data block on the radar controller’s main display.

There is anticipation of major growth in the demand for flying unmanned aircraft systems (UAS) in the National Airspace System (NAS). In February 2015 the FAA noted that “because they are inherently different from manned aircraft, introducing UAS into the nation’s airspace is challenging.” One significant distinction is that UAS aircraft operate at quite different speeds and other flight parameters compared to typical commercial and general aviation aircraft. In light of this, ERAM’s aircraft characteristics tables (ACChar) need to be updated to allow the TM to properly predict UAS flight trajectories. The ACChar tables contain lookup values which provide rates of climb, rates of descent, and TAS for each aircraft type. This data is used by the TM in building trajectories which are the primary input to the CPT; the more accurate the trajectory the better the quality of the alerts generated by the CPT.

The purpose of this study is to evaluate the effect of an update to the ACChar tables on the performance of the TM, and to identify any potential issues in ERAM’s modeling of UAS due to their unique operating characteristics. Analysis of the UAS trajectory data revealed that both along track and vertical error were reduced by significant amounts as compared to the legacy ACChar values. Along track error was reduced by as high as 30 NM at the 20 minutes look ahead. Vertical error showed a similar trend, reaching more than 10,000 ft. improvement at the 20 minute look ahead. While the ACChar tables did provide improvements, several issues were also identified. The sampled UAS flights participated in specific missions that did not benefit from persistent trajectory modeling once the mission area was reached; an attempt to suspend TM was often performed using fix delays or route termination in the flight plan amendments. However, a software issue with ERAM occasionally prevented delays from being processed, leading to unnecessary trajectory builds and a potential increase in controller workload. In addition, sometimes routes were not filed in a manner conducive to suspension of TM, and sometimes the routes were simply not followed precisely enough to achieve TM suspension.

In order to prepare for the increased frequency of UAS in the NAS, continued work must be done on the ACChar tables and other aspects of ERAM. Only two UAS were considered for this study, and the observed flights were engaged in special missions which may not represent future UAS operations. A larger sample of UAS, both in terms of aircraft types and the number of flights per aircraft type, must be studied in order to ensure accurate modeling by the TM. In the future, flight plans may need to be tailored based on the type of mission flown. The ERAM system must process delays properly, and other features may need to be added in order to ensure that the inclusion of UAS in the NAS does not negatively impact functionality.

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1. Introduction

The Separation Management and Modern Procedures Project is an initiative of the Federal Aviation Administration (FAA) under the Next Generation Air Transportation System (NextGen) Program to implement improvements to the National Airspace System (NAS) in the United States. The FAA’s Air Traffic Organization En Route Program Office (ATO-E) has employed the FAA’s Concept Analysis Branch (ANG-C41) to execute several studies investigating the impacts from various proposed prototypes and parameter changes to the Trajectory Modeler (TM) and/or Conflict Probe Tool (CPT) of the En-Route Automation Modernization (ERAM) system. The overall objective is to improve the accuracy of trajectories built by the TM which will improve the performance of the CPT subsystem in ERAM in preparation for integration of the CP alert notification into the flight data block on the radar controller’s main display. This specific study evaluates how the ERAM system’s TM performs when Unmanned Aircraft System (UAS) flights travel through the NAS. An updated set of Aircraft Characteristic (ACChar) table values specific to UAS has been implemented, and characterization of potential problems or issues that are prevalent with UASs will be described.

The TM in ERAM currently uses a set of lookup tables, referred to as Aircraft Characteristics (ACChar) tables, when building the climb and descent portions of trajectories for flights in the NAS. These tables contain TAS as well as climb and descent rates on a per aircraft basis, and are binned by altitude and by temperature deviation from the standard day. Cruise modeling is based on the assigned speed for a given flight, and so the ACChar tables are not referenced during cruise [Konyak, 2015]. Since the presence of UAS flights in the NAS is increasing, and since these involve new aircraft types, it’s important that the ACChar tables be updated in order to provide proper lookup values for these types of aircraft. In addition, it is hypothesized that UAS are flown quite differently compared to the typical commercial or general aviation traffic ERAM models today, and any issues that the ERAM TM has in modeling these flights needs to be identified and accounted for.


2. Methodology

This study is designed to evaluate how the ERAM TM models UAS traffic in the NAS today. The first objective is to determine whether ERAM is able to build acceptable trajectories for UAS flights by updating the ACChar table with a preliminary UAS aircraft adaptation provided by Lockheed Martin \cite{Torres2014}. UAS entries in the ACChar table are a known deficiency in the current operational system. The second objective is to examine ERAM TM’s performance with UAS flights under current real world conditions by utilizing recent UAS flights in the NAS.

2.1. Data Flow

This study used track and clearance data from NASQuest\footnote{NASQuest is the FAA’s data repository for the Common Message Set (CMS) from all 20 en route centers. It collects CMS data from either the legacy Host Computer System (HCS) if still in operation or ERAM.} and wind data collected from Lockheed Martin’s Sarbot\footnote{Sarbot is a tool developed by Lockheed Martin as part of the ERAM deployment that records and allows robust searches of CMS data and other ERAM output data such as aircraft trajectories.} tool. Since the UAS aircraft under study, the Global Hawk (RQ4B) and Reaper (MQ9), are not commonly flown at present, data could not be collected from a single facility over the course of one day, presenting a unique issue when using Lockheed’s laboratory version of ERAM, (referred to as the Virtual Test Laboratory or VTL). In order to address this issue, data from 52 different days spanning October 22, 2013 to April 29, 2014 was recorded from the Minneapolis (ZMP) ARTCC and were combined into a single scenario with the date March 19th, 2014. Unique ACIDs were applied to each flight on a given day, determined by the actual recording date and the type of UAS, in order to maintain source information. For example, an RQ4B collected on December 5, 2013 was assigned the ACID R131205. The upside of this approach was that all of the data was simulated using a single VTL run; the downside was that only two flights, M140319 and R140319, were simulated using the wind data for the specific scenario date chosen. This limits any inferences that can be made about trajectory accuracy for the flights that were not originally collected from March 19, 2014 since the winds are incorrect, and winds normally play an important part in trajectory modeling. However, these UAS operate when winds and weather in general are fairly benign. Thus, only the two flights flown from the same date can be expected to match ground speeds well, yet the other are not expected to deviate too significantly due to this factor.

To supplement the analysis, an additional set of trajectory predictions produced by operational ERAM were collected from Sarbot, and were combined with the merged NASQuest scenario in order to produce a baseline scenario in an attempt to see how the TM performs without updated ACChar tables.

The wind data and merged track and clearances were run through VTL, producing a 14 hour scenario. The scenario, as well as the operational scenario collected via Sarbot, was used as an input to the FAA Concept Analysis Branch’s analysis suite, called CpatTools. These tools are comprised of a set of customized software that converts and filters input traffic files into a linked set of relational database tables including smoothed track data, calculated trajectory metrics, clearances, and routes for each flight in the scenario. All resulting analyses were performed using this data. The focus of this study was on the performance of the TM and its resulting aircraft trajectory predictions, so no conflict prediction alert data was examined.
2.2. Analysis Methods

The goal of this analysis was to provide a qualitative evaluation of the ERAM TM when UAS flights are modeled. In addition, a brief comparison of trajectory accuracy metrics between the operational trajectories produced by ERAM and the trajectories produced from the experimental scenario were considered.

- Baseline scenario – Trajectories were produced using operational ACChar tables and were collected using Sarbot. As a result, these aircraft trajectories were built using the matching wind and temperature data in which the aircraft actually flew.
- Experimental scenario – Trajectories were produced using an updated ACChar tables and were created through simulation using VTL. Only the 2 aforementioned flights had trajectories built with the matching wind and temperature data. This was explained in detail in Section 2.1.

2.2.1. Data Collection and Reduction

Scenario information necessary for analysis was collected from the set of relational database tables described in Section 2.1. All data was collected via custom SQL queries and was imported into JMP Statistical Discovery Software. There were 65 UAS flights sampled and available for this analysis. For the quantitative analysis, only the climb portion of each flight was considered. It should be noted that a comparison between the Baseline and Experimental scenario trajectories is confounded by incorrect wind used when modeling 63 of the 65 flights in the Experimental scenario. For this reason, a precise matched pair analysis was not performed in favor of a more descriptive statistical comparison.

The majority of the qualitative analysis was supported by illustrated examples and the results are indicative of potential issues when modeling UAS flights in ERAM. SQL Oracle queries were developed in order to gather various pieces of information useful for picking out qualitative examples and for trajectory metrics analysis. Top of Climb (TOC) was determined by visual inspection of the track for each of the flights, and was used as the cutoff time for analysis of trajectory metrics due to the fact that all of the UAS flights in the ZMP scenario are engaged in missions in a SAA (Special Activity Airspace) and exhibit behavior inconsistent with commercial traffic, as demonstrated via flight examples in Section 3.2. This behavior includes sharp climbs and turns, deviation from assigned routes, and completion of a route prior to landing (i.e. having a terminal route point that is not at a destination airport).

Of the 65 flights available for trajectory accuracy analysis, one was removed from consideration because the climb portion of the flight was not captured in the Experimental scenario and another was removed as it had no trajectories available during the Experimental scenario.

2.2.2. Metrics

Metrics for this study include a subset of the standard trajectory metrics used in many studies [Paglione and Oaks, 2007]. Vertical Error is defined as the vertical distance between a track point and its time coincident trajectory point, Along Track Error is defined as the longitudinal distance between a track point and its time coincident trajectory point, and Cross Track Error is defined as the lateral distance between a track point and its time coincident trajectory point. In addition, a metric expressing the rate at which trajectories are built per hour of flight time is presented.

ANG-C41 frequently uses JMP®, a commercially available software tool that provides the user with the capability to perform simple and complex statistical analyses. See http://www.jmp.com
3 Analysis and Flight Examples

This section presents the quantitative results and qualitative flight examples for the data and analysis described in Section 2.

3.1 Quantitative Analysis

Trajectory accuracy is a means of estimating how well the predictions of a flight path match the path a flight actually takes. Aggregate metrics provide a general sense of how prediction accuracy differs between scenarios. In this case, the contrast between trajectory metrics in the Baseline and Experimental (updated ACChar) scenarios during the climb portion of each flight are shown in Table 1, with standard deviations of each metric in brackets. Cross track error is comparable per look ahead bin, which is expected given the fact that updates to the ACChar tables should not affect the routing. Any differences in cross track error are likely due to differences in the timing of trajectory rebuilds and/or slight differences between the routing in the Baseline and Experimental scenarios, as the source of route date (VTL, Sarbot) methods in parsing said route data were necessarily different. Along track error and vertical error, on the other hand, differ greatly. Along track error is typically twice as large in the Experimental scenario as it is in the Baseline scenario. Vertical error is similar across the two scenarios at the 0 look ahead time but the vertical accuracy decreases in the Experimental scenario as look ahead time increases, becoming about 300% smaller than Baseline at 1200 sec LAT.

Table 1. Average aggregate trajectory metrics for climb portions of flights in Experimental and Baseline scenarios. Standard deviations are in brackets.

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<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.94 [1.0]</td>
<td>2.60 [7.8]</td>
<td>294.9 [371]</td>
<td>2517</td>
<td>0.81 [0.90]</td>
<td>5.47 [15.0]</td>
<td>305.9 [327]</td>
<td>2449</td>
</tr>
<tr>
<td>1200</td>
<td>0.64 [1.8]</td>
<td>18.02 [10.9]</td>
<td>7020.8 [3306]</td>
<td>221</td>
<td>0.52 [2.3]</td>
<td>46.72 [23.6]</td>
<td>19705.9 [5811]</td>
<td>158</td>
</tr>
</tbody>
</table>

As previously indicated, the majority of the flights analyzed in the Experimental scenario were simulated with weather that differs from the date that the flight originally occurred. However, two flights were simulated with matching weather: R140319 and M140319. Differences in the routing between the simulated M140319 and the Sarbot recording of M140319 prevent direct comparisons for that flight, leaving R140319 as the only viable candidate for direct comparison. A snapshot of the flight at the time the flight enters the Experimental scenario (65570 sec), showing a look ahead of 600 seconds, is presented in Figure 1 and Figure 2. In Figure 1, the routing of the flight extends from the lower right to the upper node. The Baseline scenario is represented by blue coloration and the Experimental scenario by red coloration. The series of overlapping blue/red dots represent the track, which are virtually identical in the two scenarios. The wireframe boxes/strips are the associated trajectories active at the time shown. It can be seen in Figure 2 that the Experimental (red) trajectory predicts a much greater rate of climb than in the Baseline scenario, reaching a predicted altitude of about 29,000 ft. while still over the initial portion of the route. The Baseline trajectory predicts that the flight will begin traveling along the route much sooner than in the Experimental scenario leading to a large difference in along track
error, depicted by the blue cylinder being significantly ahead of the red cylinder in Figure 1.

Figure 1. Top-down view of R140319 at 65570 sec, look ahead at 600 seconds.
The average aggregate trajectory metrics for the climb portion of R140319 is presented in Table 2, which illustrates that the along track error is higher in the Experimental scenario, especially at the 600 sec. look ahead time when the difference is over 10 NM, illustrated in Figure 2. The difference in cross track error is low for the two scenarios, as is expected when the routes are identical. The vertical error is significantly improved in the Experimental scenario as compared to the Baseline scenario, especially at the higher look ahead times, suggesting that the updated ACCChar values are a better estimate of climb rate than the values currently used by the ERAM system. It is invalid to make generalizations using a single flight, however; this specific flight has received attention solely as an example of how the TM handles UAS.
Table 2. Average aggregate trajectory metrics for climb portion of R140319 in Experimental and Baseline scenarios. Standard deviation is in brackets.

<table>
<thead>
<tr>
<th>Look Ahead (sec)</th>
<th>Experimental</th>
<th>Baseline</th>
</tr>
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Another aspect of trajectory performance that can be quantified is the number of trajectories built during the duration of a flight. A larger proportion of trajectory rebuilds in a given time suggests that a flight is either deviating from the assigned flight plan for some reason (voice clearances) or that the flight is modeled poorly (e.g. poor AC Characteristics, flight plan not parsed properly by ERAM). On average, there should be a consistent pattern of more trajectories built as duration of the flight increases. However, this is not always the case. One of the reasons that deviation from this trend could occur is that UAS flights engaging in the type of flights plans prevalent in the scenario used for this study use delays, which is not something that is typically seen when considering commercial aviation. In ERAM, delays are meant to suspend modeling of a flight that reaches a specified target location for a parameter-defined amount of time. For example, a route string comprised of the following:

RDR..RDR318020..RDR310044..HML257059..MOT070060/D1+00..RDR specifies a delay of 1 hour when the aircraft reaches the location of MOT070600 (MOT070060/D1+00). Trajectory modeling should be suspended for 1 hour when the flight reaches that location on the route.

Sometimes these delays are extremely large as the UAS engages in mission specific maneuvers; delays of 6 hours or more have been observed. It is expected that flights with delay maneuvers should have fewer trajectories built per hour than analogous flights without delays. In addition, when flights reach the end of their routes modeling is suspended until a new route is assigned. This is expected behavior in ERAM, and allows for automatic suspension of modeling when flights reach a specified location; modeling can be reestablished at any time by assigning a new route, which is something that allows for a more precise ‘delay’ than declaring a specific delay time in advance.

Figure 3 illustrates the number of trajectories built versus flight time. Each marker in Figure 3 represents a single UAS; green dots denote flights with delays of various times in their routes and red plusses denote flights that do not have delays. Two subsets of data are evident; the group of data that shows a positive correlation between number of trajectories built and flight duration and the group of data along the abscissa that shows no correlation between number of trajectories built and flight duration. It is expected that the group of flights along the abscissa either have delays in the route strings (green dots) or reach the end of their route and then continuing flying after completion of the route (green dots or red plusses). Only one flight, represented by the red plus by itself in the middle-right side of the figure, does not follow this pattern. That flight, R140414 (see Flight Example 3.2.2) never completes its route and no delay is assigned in the last fix reached, which means that the flight is modeled over the next 11 hours while the flight is effectively deviating from its flight plan the entire time. Had the route been designed so that the flight reached the last fix or had a lengthy delay (11 hours) been added to the last fix reached, modeling would have been suspended and the number of trajectories built would have been 22 (based on trajectory modeling ending at the time that the effective end of route is reached, about 48500 sec) instead of 366.
In addition, there are flights that received delays in their routes but the delays were never modeled by ERAM (see Flight Example in 3.2.1). Route conversion logic in ERAM dictates that when two identical fixes are presented back to back, the duplicates are removed. When flight plan messages contain routes with delays, and the delays occur between two identical fixes as in “RDR..RDR184023/D5+30..RDR184023..RDR”, the fix with the associated delay may be removed and the delay will not be processed. This is the case for several of the flights in the scenario developed for this experiment. The example detailed here corresponds to the flight plan for M131024, an MQ9. Had the route been filed as “RDR..RDR184023/D5+30..RDR”, the delay would have been modeled and the intent would have been the same. As flown, the number of trajectories built was 314; were the delay processed only 22 trajectories would have been created, assuming that the estimated start time for the delay is about 54270 sec.

The majority of the flights that are in the uncorrelated subset of data along the abscissa have few if any modeling issues as pertains to the suspension of modeling. In contrast, the vast majority of the flights in the subset of positively correlated data in Figure 3 have reason as to why trajectory modeling hasn’t been suspended; typically, these reasons are either unprocessed delays, routes in
which the final is a return to the origin airport, or the final fix isn’t reached prior to entering the mission phase of the flight.

### 3.2 Qualitative Analysis and Flight Examples

In the following examples, the track of each flight is represented by dotted lines. Blue wireframes represent the Baseline trajectories and red wireframes represent trajectories from the Experimental scenario. Routes are solid lines snapped to the ground, with each node labeled. Cylinders of the same colors represent the current position of each flight. Issues prevalent in UAS engaging in missions are detailed in these examples. Note that slight differences between route fixes and track data occur between the simulated (Experimental) and live (Baseline) scenarios.

#### 3.2.1 Flight Example 1: Failure to Process Delay

Example 1 depicts an MQ9 Reaper (Predator B) that leaves KRDR (Grand Forks Air Force Base) to fly a mission (Figure 4 and Figure 5). Track data begins at 53000 sec. As can be seen in the two figures, M131024 engages in a spiral-like climb typical of UAS flying out of KRDR. The flight climbs to its assigned altitude block of FL190 to FL210 (actual cruise altitude of 19,900 ft.) and remains in the NAS until 71430 sec (5.1 hours). M131024 has an assigned route of “RDR..RDR184023/D5+30..RDR184023..RDR” and reaches the fix RDR184023 at about 54270 sec. However, as previously detailed in Section 3.1, the delay at this fix is not observed, and nothing disables trajectory modeling for remainder of the flight (4.8 hours), as there are no additional route amendments and the end of the route (KRDR) is never reached, resulting in poor trajectory modeling. Current trajectories (at 58590 sec) are shown in Figure 6 and Figure 7.

![Figure 4. Example 1, topdown view, no trajectory data shown.](image-url)
Figure 5. Example 1, side view, no trajectory data shown.

Figure 6. Example 1, poor trajectory modeling resulting from failure to process delay, top down view.
3.2.2 Flight Example 2: Failure to reach end of route

Example 2 depicts an RQ4B (Global Hawk) that leaves KRDR (Grand Forks Air Force Base) with the intention of flying a mission (Figure 8 and Figure 9). Track data begins at 46530 sec. As can be seen in the two figures, R140414 engages in a spiral-like climb typical of UAS flying out of KRDR. The flight climbs to FL 290 and then begins to step climb up to its assigned altitude block of FL500 to FL590 (actual cruise altitude of begins at 51,000 ft.) and remains in the NAS until the scenario ends at 86400 sec (11.1 hours). R140414 has an assigned route of “RDR..RDR355009..RDR268009..RDR..RDR318020..RDR310044..HML257059..RDR297005” and reaches the fix HML257059 at about 48430 sec, though the flight is shown in Figure 10 at 48530 sec for the purposes of clear visualization. However, this is the second to last route fix and no delay is indicated, which means that inaccurate trajectory modeling (Figure 11, 62260 sec) continues until 84240 sec, 6.2 hours later. At this point an updated route amendment (AH message) directing the flight to return to KRDR is provided by a controller, restoring reasonable trajectory modeling. Using a delay at HML257059 or using the route “RDR..RDR355009..RDR268009..RDR..RDR318020..RDR310044..HML257059” would have suspended trajectory modeling during the interval from 48530 to 84240, preventing 9.9 hours of unnecessary and inaccurate trajectory builds and reducing the total number of trajectories built for the flight from 366 to 43.
Figure 8. Example 2, top down view, no trajectory data shown.

Figure 9. Example 2, side view, no trajectory data shown.
Figure 10. Example 2, flight reaches penultimate route fix.
3.2.3 Flight Example 3: Proper suspension of trajectory modeling

Example 3 depicts an RQ4B (Global Hawk) that leaves KRDR (Grand Forks Air Force Base) with the intention of flying a mission (Figure 12, Figure 13). Track data begins at 56200 sec. As can be seen in the two figures, R140402 engages in a spiral-like climb typical of UAS flying out of KRDR. The flight climbs to its assigned altitude block of FL500 to FL590 (actual cruise altitude of 50,000 ft., then 52,700) and remains in the NAS until 86400 sec (8.4 hours). R140402 has an assigned route of “RDR..RDR355009..RDR268009..RDR..RDR318020..RDR310044..HML257059..RDR297055”.

Trajectories are modeled while the flight proceeds to the location shown in Figure 14 (58750 sec). At about time 59500 sec R140402 reaches fix RDR297055 (Figure 15) and trajectory modeling is suspended until flight modeling ends at 86400 (7.5 hours). 36 trajectories were built for the flight, and had the TM not been suspended approximately 300 more trajectories would have been built over the remaining 7.5 hours. In spite of the flight deviating from the route, circling around toward the upper left and then meeting the final route point, this is an example of how intentionally suspending TM through use of delays and routes should work in the ERAM system.
Figure 12. Example 3, top down view, no trajectory data shown.
Figure 13. Example 3, side view, no trajectory data shown.
Figure 14. Example 3, trajectory modeling shown at time 58750 sec.
Figure 15. Example 3, suspension of trajectory modeling at 59500 sec shown.

4 Conclusion and Discussion

Trajectories are created by the ERAM system as a means of supporting controllers by predicting aircraft position and hence conflicts that may occur up to 20 minutes in the future. The accuracy of these predicted conflicts is affected by many factors. Fundamentally, however, the conflict probe’s accuracy is directly dependent on the accuracy of the underlying 4-D trajectories used to make the conflict predictions. It has been shown previously that inaccurate trajectories can lead to degradation of performance in the ERAM Conflict Probe and an increase in alerts that may not be beneficial to the controller [Paglione and Oaks, 2009].

This study evaluates an initial update to the Aircraft Characteristics tables in preparation of UAS being flown through the NAS by comparing the performance of the ERAM Trajectory Modeler in the presence of these updates. The TM relies on the ACChar tables when building the climb and descent portions of trajectories for flights in the NAS. As the frequency of UAS traveling through the NAS is expected to increase in the future, continued work needs to be done to ensure that these tables contain accurate information in order to support UAS operations.

An examination of UAS in the ZMP region revealed that the updates made to the ACChar table did improve the climb rate. When comparing a specific flight, R140319, in the Experimental
scenario (with updated ACChar tables) to the Baseline scenario, vertical error during the climb improved about 1000 ft. at 300 sec. look ahead and over 10,000 ft. at 1200 sec. look ahead.

However, there are other issues with modeling UAS flights that need to be considered in the future. The TM has difficulty in accurately modeling the horizontal aspects of a UAS during the climb phase of flight. This is due to the spiral-like pattern of climb and the associated prevalence of route fixes with sharp angle turns that the flights in this study perform. These flights climb rapidly and with relatively little movement in the horizontal direction while doing so, something that is uncommon among commercial and general aviation flights, and something which causes a significant number of trajectory rebuilds when the routes are not followed precisely.

In addition, the UAS flights in this scenario engage in missions that involve complex paths that may or may not be known ahead of time. This behavior may be specific to the types of missions that are flown out of Grand Forks Air Force Base and may be atypical of UAS that will be flown in NAS in the future, but lessons can still be learned from analysis of how these UAS are modeled. Flight plans need to be designed in a way that allows for suspension of the TM in mission areas if desired. This includes ensuring that delay fixes are reached and that the delays are processed by ERAM, and making sure that the final fix of a given route is reached. These both require that the routes filed are the routes followed by the UAS, at least up until the mission area. TM resumes when the given delay expires, or it can be resumed manually at any time by having a controller issue a new flight plan (FP) clearance for the flight in question. Furthermore, the length of time over which UAS operate exacerbates the problem further. If the TM continues to model during relatively long missions, as illustrated in this study, ERAM produces several hundred anomalous trajectories that are likely to produce inaccurate conflict notifications. The poor trajectories and alerts can add unnecessary workload to air traffic controllers while consuming valuable automation resources such as CPU cycles and disk space.

In conclusion, climb rates for the UAS in this study are improved over the baseline. Future work should involve fine tuning the information in the ACChar tables to enhance the accuracy of the climb/descent rates for UAS. This work needs to be performed as new types of UAS become prevalent in the NAS, using similar aircraft as placeholders for the climb/descent rate as necessary. The current issue in ERAM that prevents delays from being properly modeled in some flight plans needs to be corrected. Procedurally, accurate flight plans need to be filed and UAS need to fly these routes at least until reaching a delay fix or the end of route, at which point TM will be suspended. If TM is not suspended during a mission, the number of inaccurate trajectories that are built becomes large and, depending on the location and altitude of the UAS, could cause a significant number of conflict alerts to be generated, interfering with the controller’s ability to manage air traffic.
5 References


