

# **Evaluation of the En Route Automation Modernization Trajectory Modeler Performance Using an Experimental Adaptation for Unmanned Aircraft Systems**

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<b>16. Abstract</b> The number of military owned and operated Unmanned Aircraft Systems (UAS) operating in the en route portion of the National Airspace System (NAS) is increasing. In anticipation of further increases and of UAS being used for commercial and personal purposes as well, this study focuses on En Route Automation Modernization (ERAM) performance when modeling trajectories for UAS aircraft. The ERAM's Trajectory Modeler (TM) relies on empirically developed data in Aircraft Characteristics (ACChar) tables when modeling the climb or descent phases of aircraft. This study evaluates an update to these tables based on recorded track data from the Albuquerque (ZAB) and Los Angeles (ZLA) en route air traffic control centers between 2008 and 2015. The update applies to MQ1 Predators, RQ4B Global Hawks and MQ4 Tritons (virtually identical to the Global Hawk), and the MQ9 Reapers (Predator-B). Results of computer simulations allow for a comparison of the performance of the updated TM to the legacy TM. The updated ACChar tables provide some improvement to the modeling both in the vertical and along track dimension. However, the limited amount of data collected, the manner in which UAS fly in the NAS, and the way that the simulation was developed all lead to limitations on this study's recommendations. In addition, issues presented in [Schnitzer et al., 2015], such as inconsistent use of delay fixes or UAS that do not pass critical fixes, still hold true. The study concludes with a set of recommendations for future analysis and implementation.					
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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 Modeling and Simulation Branch (ANG-C55) 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."<sup>1</sup> One significant distinction is that UAS aircraft operate at quite different speeds and flight parameters as compared to typical commercial and general aviation aircraft. In light of this, one must update ERAM's aircraft characteristics tables (ACChar) 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 true airspeed (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. Currently, UAS are typically military owned and operated and fly in a manner that may be different from how commercially owned UAS fly in the future. However, this study attempts to proactively evaluate the treatment of UAS by the automation, and also to provide a methodology for updating ACChar tables and evaluating the performance of the TM in the future as the need arises, regardless of how UAS currently operate.

A large amount of empirical data is required in order to create the ACChar tables [Konyak, 2015]. Analysts collected track data from military operated UAS aircraft in two different Air Route Traffic Control Centers (ARTCCs) from 2008 to 2015, along with the corresponding wind data. ACZR, a program developed by Lockheed Martin [Torres 2013] in order to develop updated ACChar tables, processed this data. Simulations of the same flight data produced trajectories for analysis. The purpose of this study is to evaluate the effect of the updated ACChar tables on the performance of the TM for UAS flights. Trajectory data analysis revealed reductions in along track error by 0 to about 15 NM and reductions in vertical error by 0 to 200 ft. when compared to using legacy ACChar values. While the ACChar tables provided improvements, the analysts identified several important issues. Significant portions of flights' climb and descent were often missing from the collected data, flights were occasionally split across midnight UTC (Universal Time Coordinated), and some data was collected in special activity airspace in which trajectory reconformance does not occur.

In order to prepare for the increased frequency of UAS in the NAS, work needs to continue on the ACChar tables and other aspects of ERAM. Based on preliminary analysis of UAS flights in the 20 Contiguous United States (CONUS) ARTCCs from 2008-2015, only two ARTCCs were used for this study. The military owned and operated all of the observed flights, and it is unlikely that

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<sup>1</sup>Federal Aviation Administration, "Fact Sheet – Unmanned Aircraft Systems (UAS)" published Feb 15, 2015. <http://www.faa.gov/news>

the special missions in which these flights engaged will not be representative of future UAS operations. To ensure better population of the ACChar table in the future and to ensure that there is more data for evaluation, repetition of this study should occur in a manner guaranteeing that the data collected is better suited for simulation. Collection of data must be NAS-wide and over a variety of temperatures and altitudes. Identification and avoidance of SAAs will reduce unnecessary data collection. Maximization of the collected portion of each flight will produce more accurate *ACZR* analysis. Consideration of commercially operated UAS as opposed to military operated UAS, along with possible prototype enhancements for the automation tailored to the types of missions commonly flown by UAS, are also beneficial. Commercially operated UAS may need consideration separate from military-operated UAS. Additionally, perhaps consideration of automation prototype enhancements tailored to the types of missions commonly flown by UAS could be beneficial.

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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 Modeling and Simulation Branch (ANG-C55) 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. Implementation of an updated set of Aircraft Characteristics (ACChar) tables with values specific to UAS produces a set of trajectories suitable for comparison against legacy trajectories. Additionally, analysts examine potential problems or issues that are prevalent with UAS.

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 true airspeed (TAS) as well as climb and descent rates on a per aircraft basis, 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].

UAS entries in the ACChar table are a known deficiency in the current operational system, and updating the ACChar table using available flight data is one step in attenuating this deficiency. Since the presence of UAS flights in the NAS is increasing, and since these involve new aircraft types, it is important to update the ACChar tables in order to provide accurate 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 need to be identified and accounted for.

## 2. Methodology

This study is designed to evaluate whether updates to the ACChar table improve the ERAM TM performance. ANG-C55 created an experimental UAS aircraft adaptation by using the ACZR software developed by Lockheed Martin, using methods described in [Torres, 2013]. ACZR processes and analyzes wind, temperature and track data, determines vertical maneuver segments, and calculates derived TAS (true airspeed), CAS (calibrated airspeed), MACH (Mach speed), and ROCD (rate of climb or descent) for each aircraft at the altitude ranges and temperature bins available in the track and weather data.

### 2.1. Data Flow

This study utilized track and clearance data from NASQuest<sup>2</sup> and wind data collected from the National Oceanic and Atmospheric Administration (NOAA)<sup>3</sup>. Since the UAS under study do not commonly fly at present, analysts could not collect data from a single facility over the course of one day. This presents 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, analysts collected recorded data over the span of 7 years, from January 2008 to April of 2015, from the Albuquerque (ZAB) and Los Angeles (ZLA) ARTCCs. Analysts then combined this data into a single scenario for the aircraft in each center. Analysts set the ZAB scenario date to be March 28, 2014 and the ZLA simulation date to be January 3, 2014. Each flight received a unique ACID, determined by the actual recording date and the type of UAS, in order to maintain source information. The upside of this approach was that all of the data was simulated using a single VTL run; the downside was the simulated wind data was incorrect for the majority of the flights in both scenarios. Since the winds are incorrect, and winds normally play an important part in trajectory modeling, any inferences from flights that did not actually fly on the selected simulation dates should be limited. However, these UAS operate when winds and weather in general are fairly benign. While expectation is that only flights originally flown on the selected date for each simulation will match ground speeds well, the others will not deviate too significantly.

VTL performed simulations using wind data as well as merged track and clearances, producing two 14-hour-long scenarios for each center. One scenario for each ARTCC used the baseline ACChar tables and the other uses the updated ACChar table in the adaptation specially created for these runs by ANG-C55. These scenarios were used as inputs to the FAA Modeling and Simulation 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 subsequent analysis made use of this data. The focus of this study is on the performance of the TM and its resulting aircraft trajectory predictions, so no conflict prediction alert data is considered.

### 2.2. Analysis Methods

The goal of this analysis is to provide a quantitative evaluation of the ERAM TM when modeling UAS flights using the updated ACChar tables as compared to the baseline tables. This entails a

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<sup>2</sup> 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 ERAM or the legacy Host Computer System (HCS) if still in operation.

<sup>3</sup> NOAA provides RAP wind data in gridded binary (GRIB) format.

comparison of trajectory accuracy metrics between the operational trajectories produced by ERAM and the trajectories produced from the experimental scenario, as well as flight examples indicating differences in trajectories between the two conditions, problems with the scenarios, and other issues.

- Baseline scenario – These trajectories were produced using operational ACChar tables via simulation using VTL.
- Experimental scenario – These trajectories were produced using updated ACChar tables via simulation using VTL.

### 2.2.1. Preliminary Scenario Selection

Preliminary examination of the number of UAS flights in the NAS from 2008-2015 revealed that a sizable number of operations occurred in only a small number of ARTCCs (Figure 1). Centers like Atlanta (ZTL) and Cleveland (ZOB) centers had no UAS traffic during the selected timespan. Centers like Dallas-Ft. Worth (ZFW) and New York (ZNY) had very little UAS traffic. Only Albuquerque center (ZAB), Los Angeles center (ZLA), and Minneapolis center (ZMP) had enough UAS traffic to warrant consideration for study. As the result of this preliminary analysis, and in part due to the fact that a similar study was performed using UAS flights from ZMP [Schnitzer 2015], traffic was collected from the ZAB and ZLA ARTCCs for this study.



Figure 1 – UAS flight counts in 20 ARTCCs

## 2.2.2. Data Collection and Reduction

Analysts collected scenario information necessary for analysis 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*<sup>4</sup> Software. There were 470 UAS flights sampled and available for this analysis in the ZAB scenarios and 541 flights available in the ZLA scenario. For the quantitative analysis, analysts considered only the climb and descent portions of each flight for statistical comparisons. In order to ensure that measured trajectory differences between the Baseline and Experimental scenarios are due to the ACChar tables, only portions of track that involve aircraft either undergoing vertical transitions or accurately flying their routes (in adherence) are considered.

The majority of the quantitative analysis is 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. Climb and descent segments of flights were determined via SQL queries. Visual inspection of the track data verified that the data was appropriate for analysis. In all, only 3.5% of the track data for the ZAB scenario and 0.5% of the track data for the ZLA scenario were suitable for trajectory analysis after filtering. The start and end times of these segments were used as inputs for analysis of trajectory metrics due to the fact that many if not all of the UAS flights in the ZAB and ZLA scenarios are engaged in missions in a SAA (Special Activity Airspace). This behavior often includes sharp climbs and turns, deviation from assigned routes for extended periods of time, and completion of a route prior to landing (i.e. having a terminal route point that is not at a destination airport). The ERAM TM cannot accurately model aircraft when the intent is unknown, and since the goal of this analysis is specifically to identify any benefits of updated ACChar tables, only isolated segments of track and trajectories where the intent is known or where the flights are transitioning vertically are considered.

## 2.2.3. Metrics

Metrics for this study include a subset of the standard trajectory metrics used in many studies [Paglione and Oaks, 2007]. Analysts define *Vertical Error* as the vertical distance between a track point and its time coincident trajectory point, *Along Track Error* as the longitudinal distance between a track point and its time coincident trajectory point, and *Cross Track Error* as the lateral distance between a track point and its time coincident trajectory point. In the case where vertical transitions occur, only the vertical and along track error metrics are considered as the ACChar table primarily affects descent rate, and the path predicted by the TM is often poorly matched to the spiral-like climb and descent patterns common among UAS. This is a known limitation in ERAM's current modeling of UAS. However, the data is included in the tables for reference.

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<sup>4</sup>ANG-C55 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.

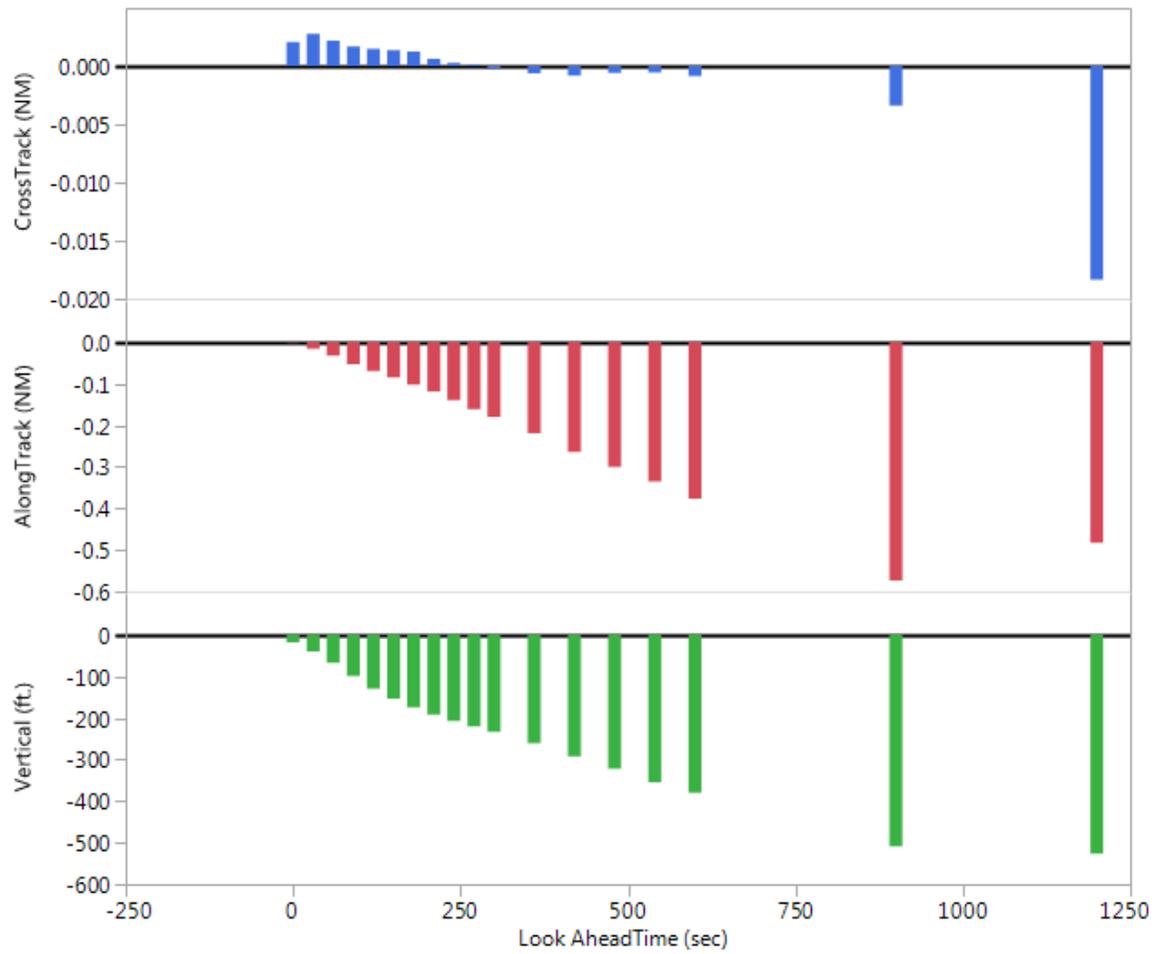
#### 3.1 Quantitative Analysis

Trajectory accuracy is a means of estimating how well the predictions of a flight path match the path a flight actually takes. Average metrics provide a general sense of how prediction accuracy differs between scenarios. In this case, Table 1 through Table 4 show the contrast between trajectory metrics in the Baseline and Experimental (updated ACChar) scenarios during the climb and descent portion of each flight. Brackets indicate the standard deviations of each metric.

Figure 2 through Figure 5 illustrate the difference in error between the Baseline and Experimental scenarios. Note that the available data for ZLA was much less than the data available in ZAB, and so the data is significantly noisier. In addition, examination of metrics at look ahead times of over 600 seconds should be coupled with the consideration that the number of available data points is often quite low at that range. Even considering that, cross track error should be virtually identical for the “in adherence” segments in the two scenarios, with differences being primarily limited trajectory builds at different times. Table 1/Figure 2 and Table 2/Figure 3 suggest that this is the case as the difference in cross track error is below 0.02 NM for ZAB and ZLA. Along track error decreases with increasing look ahead time in the ZAB scenario for the “in adherence” segments, suggesting that updates to the ACChar tables provide a slight but systematic improvement in trajectory modeling in this dimension. Along track error shows almost no change in the ZLA “in adherence” dataset. Vertical error improves by several hundred feet as look ahead time increases in the ZAB “in adherence” data and is virtually unchanged in the ZLA “in adherence” data. The transition data (Table 3/Figure 4 and Table 4/Figure 5) shows a similar pattern wherein ZAB shows improvement of several hundred up to 1500 ft. and ZLA shows an improvement as look ahead time increases.

**Table 1. Average aggregate trajectory metrics for in adherence segments in ZAB Baseline and Experimental scenarios. Standard deviations are in brackets.**

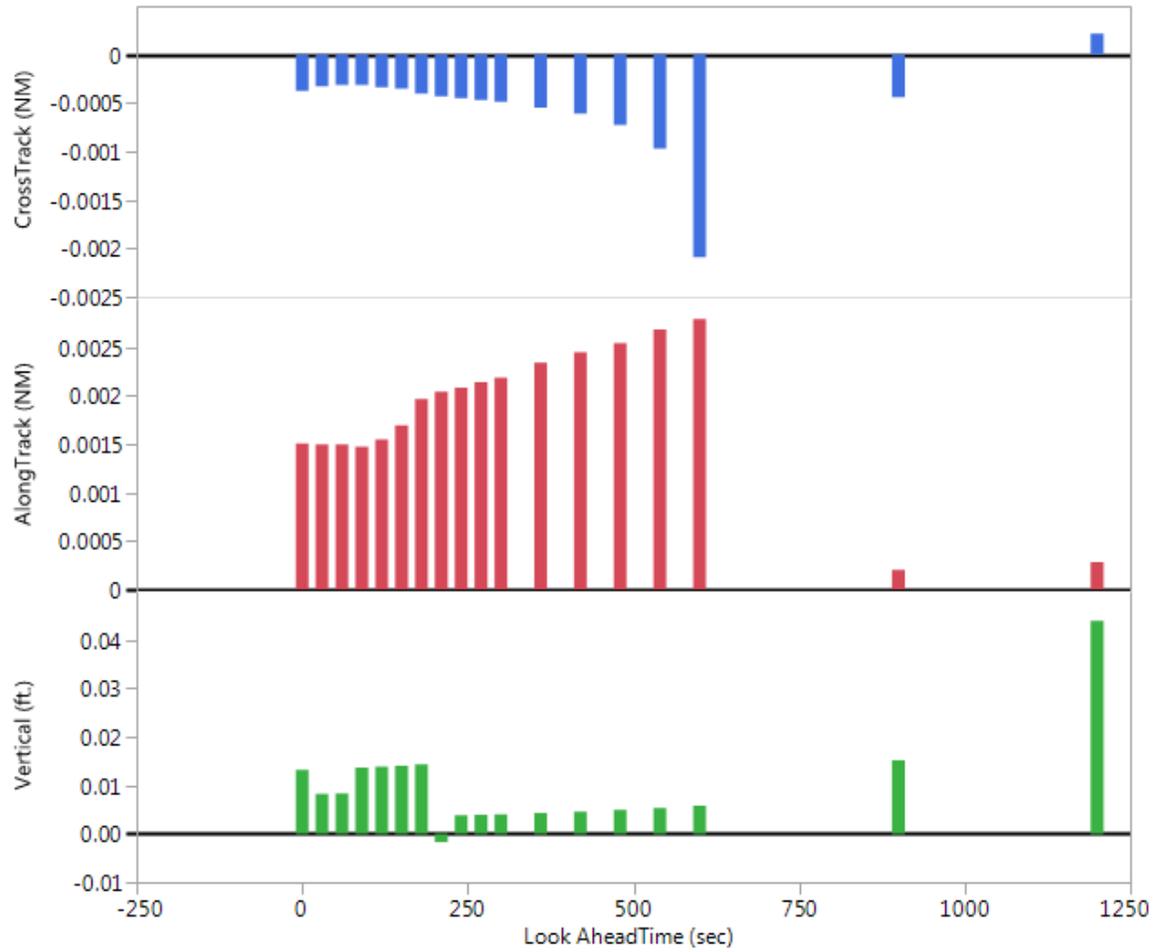
ZAB – In adherence segments								
	Baseline				Experimental			
Look Ahead (sec)	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N flights	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N
0	0.64 [0.31]	0.59 [0.17]	68 [71]	44	0.64 [0.31]	0.59 [0.17]	51 [60]	44
60	0.69 [0.39]	0.86 [0.33]	154 [173]	44	0.69 [0.39]	0.83 [0.33]	87 [107]	44
120	0.74 [0.48]	1.17 [0.57]	269 [380]	44	0.74 [0.48]	1.10 [0.57]	140 [246]	44
180	0.78 [0.56]	1.49 [0.82]	358 [546]	44	0.78 [0.56]	1.39 [0.83]	185 [384]	44
240	0.81 [0.65]	1.83 [1.08]	436 [701]	44	0.81 [0.65]	1.69 [1.10]	229 [534]	44
300	0.85 [0.74]	2.17 [1.35]	499 [841]	44	0.85 [0.74]	1.99 [1.38]	265 [651]	44
600	0.95 [0.98]	4.01 [2.83]	785 [1571]	44	0.95 [0.98]	3.64 [2.89]	406 [1168]	44
900	1.05 [1.22]	6.08 [4.38]	1036 [2254]	44	1.05 [1.20]	5.50 [4.39]	527 [1630]	44
1200	1.08 [1.29]	8.01 [5.67]	873 [1301]	41	1.06 [1.26]	7.53 [5.84]	347 [686]	41



**Figure 2. Difference in mean error between ZAB Baseline and Experimental scenarios for in adherence segments. Negative differences indicate a reduction in error for the Experimental scenario.**

**Table 2. Average trajectory metrics for in adherence segments in ZLA Baseline and Experimental scenarios. Standard deviations are in brackets.**

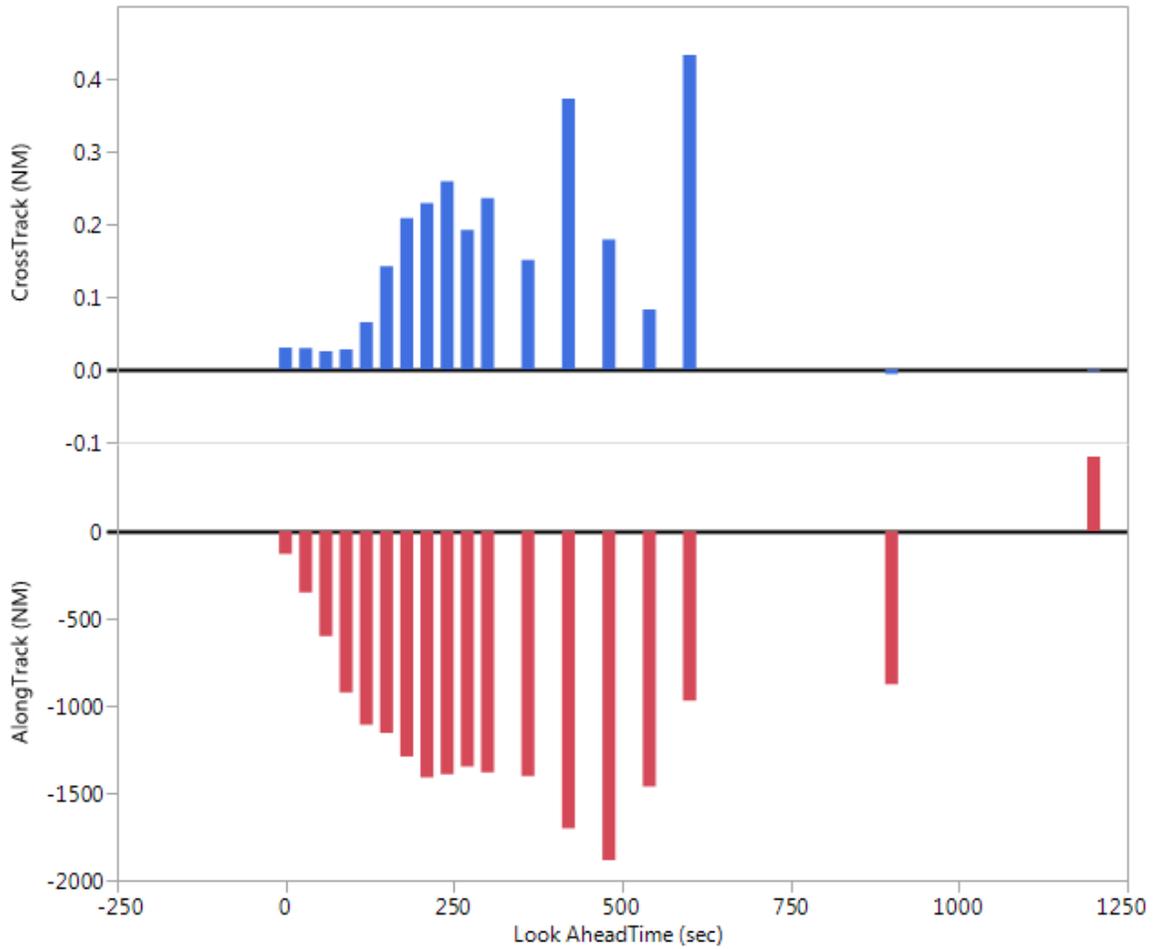
ZLA – In adherence segments								
Look Ahead (sec)	Baseline				Experimental			
	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N flights	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N
0	0.53 [0.45]	3.44 [9.24]	175 [406]	11	0.53 [0.45]	3.65 [9.93]	175 [406]	11
60	0.54 [0.46]	3.77 [9.78]	228 [580]	11	0.54 [0.46]	3.77 [9.78]	228 [580]	11
120	0.57 [0.49]	3.70 [8.98]	270 [713]	11	0.57 [0.49]	3.93 [9.73]	270 [713]	11
180	0.59 [0.53]	3.66 [8.27]	299 [808]	11	0.59 [0.53]	3.90 [9.09]	299 [808]	11
240	0.61 [0.58]	3.64 [7.59]	325 [896]	11	0.61 [0.58]	3.91 [8.48]	325 [896]	11
300	0.67 [0.62]	3.60 [6.77]	349 [978]	11	0.67 [0.62]	3.90 [7.75]	349 [978]	11
600	0.65 [0.74]	4.61 [6.09]	303 [826]	11	0.65 [0.74]	4.61 [6.09]	303 [826]	11
900	0.71 [0.74]	6.63 [4.73]	61 [69]	6	0.71 [0.74]	6.63 [4.73]	61 [69]	6
1200	0.84 [0.59]	5.09 [4.25]	141 [116]	4	0.84 [0.59]	5.09 [4.26]	141 [116]	4



**Figure 3. Difference in mean error between ZLA Baseline and Experimental scenarios for in adherence segments. Negative differences indicate a reduction in error for the Experimental scenario.**

**Table 3. Average trajectory metrics for transition segments in ZAB Baseline and Experimental scenarios. Standard deviations are in brackets.**

ZAB – Transition segments								
Look Ahead (sec)	Baseline				Experimental			
	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N flights	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N
0	1.25 [0.36]	1.38 [2.76]	384 [215]	60	1.28 [0.35]	0.74 [0.61]	254 [153]	60
60	2.13 [0.83]	3.65 [4.35]	1136 [620]	60	2.15 [0.85]	1.99 [2.08]	535 [414]	60
120	2.69 [1.33]	6.44 [5.59]	1832 [1096]	60	2.76 [1.41]	3.14 [2.56]	724 [633]	60
180	3.08 [1.87]	9.83 [7.47]	2297 [1976]	57	3.29 [2.07]	4.38 [3.72]	1007 [1143]	57
240	3.40 [2.42]	12.97 [9.24]	2510 [2420]	52	3.66 [2.66]	6.23 [6.00]	1118 [1494]	52
300	3.60 [2.98]	16.31 [10.5]	2388 [2914]	46	3.83 [3.16]	7.60 [6.44]	1007 [1541]	46
600	4.86 [5.98]	22.27 [11.9]	1562 [1852]	14	5.29 [6.14]	7.59 [6.97]	591 [686]	14
900	5.16 [8.25]	17.21 [15.0]	1468 [1845]	4	5.15 [8.23]	6.98 [3.44]	591 [793]	4
1200	0.65 [N/A]	11.63 [N/A]	1131 [N/A]	1	0.64 [N/A]	8.88 [N/A]	1560 [N/A]	1



**Figure 4. Difference in mean error between ZAB Baseline and Experimental scenarios for transition segments. Negative differences indicate a reduction in error for the Experimental scenario.**

**Table 4. Average trajectory metrics for transition segments in ZLA Baseline and Experimental scenarios. Standard deviations are in brackets.**

ZLA – Transition segments								
	Baseline				Experimental			
Look Ahead (sec)	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N flights	Avg. Cross Track Error (NM)	Avg. Along Track Error (NM)	Avg. Vertical Error (ft.)	N
0	1.81 [1.55]	1.24 [1.06]	521 [381]	6	1.85 [1.54]	1.25 [1.07]	567 [380]	6
60	2.26 [1.85]	2.59 [1.30]	1008 [349]	6	2.27 [1.85]	2.58 [1.37]	1016 [375]	6
120	2.50 [2.15]	4.09 [1.89]	1476 [336]	6	2.51 [2.16]	4.04 [1.90]	1415 [318]	6
180	2.58 [2.24]	5.12 [2.28]	2076 [344]	6	2.57 [2.25]	5.06 [2.30]	1947 [258]	6
240	1.74 [0.69]	5.42 [3.10]	2582 [596]	5	1.73 [0.69]	5.19 [3.14]	2333 [391]	5
300	1.68 [0.84]	5.83 [3.59]	3409 [1122]	5	1.66 [0.85]	5.69 [3.79]	3118 [1091]	5
600	1.58 [1.69]	11.8 [11.40]	3270 [3192]	2	1.65 [1.59]	10.8 [12.8]	2874 [2632]	2
900	1.32 [N/A]	1.14 [N/A]	7919 [N/A]	1	1.23 [N/A]	2.53 [N/A]	2234 [N/A]	1

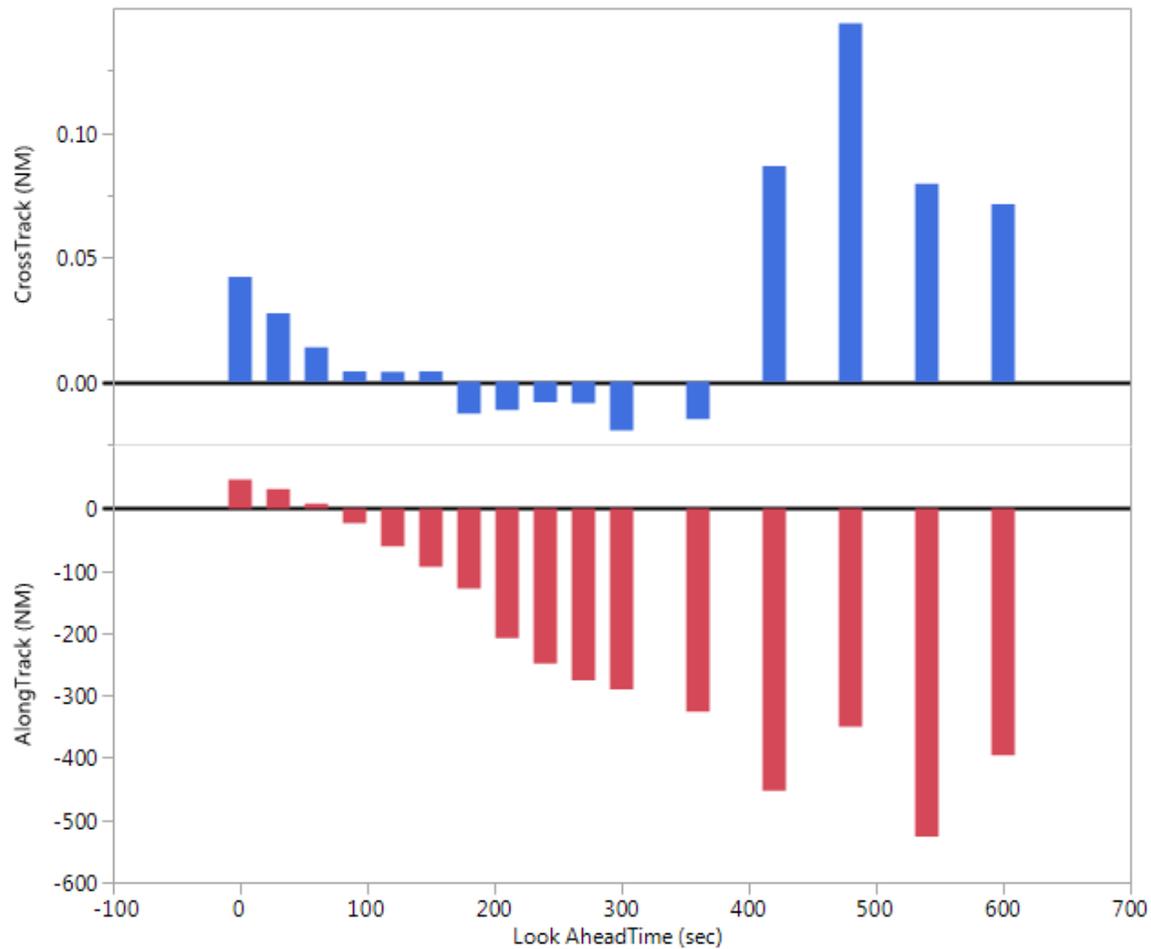


Figure 5. Difference in mean error between ZLA Baseline and Experimental scenarios for transition segments. Negative differences indicate a reduction in error for the Experimental scenario.

### 3.2 Qualitative Analysis and Flight Examples

In the following examples, dotted lines represent the track of each flight. 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. Examples demonstrate both benefits of an updated ACChar table as well as simulation issues.

#### 3.2.1 Flight Example 1: Improvement

Example 1 depicts an MQ9 Reaper (Predator B) that is returning to KFHU (Sierra Vista Municipal Libby Army Air Field Airport) after flying a mission (Figure 6). At the time shown, MQ90074 has begun its descent. The red (Experimental) trajectory is based on lookup values that predict a shallower, slower descent to the destination airport than does the blue (Baseline) trajectory. As a result, an improvement is indicated in the prediction of vertical position (6800 ft. to 1200 ft. error) and along track position (3 NM to 0.01 NM error). The arrow indicates the position of the aircraft at a time of 300 sec from the current position.

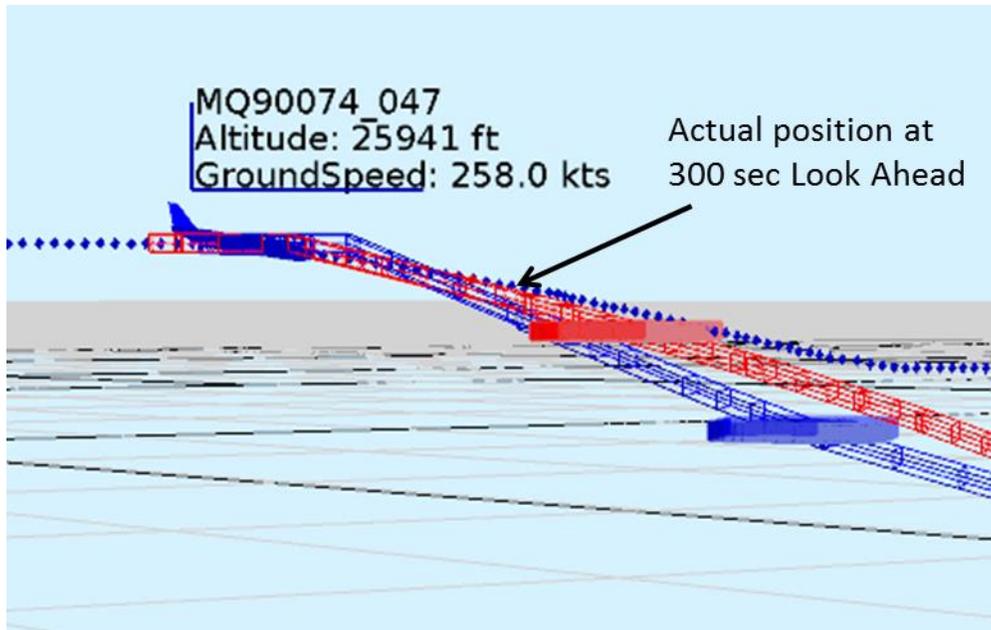


Figure 6. Improvement in vertical and along track prediction due to ACChar tables.

### 3.2.2 Flight Example 2: Improvement

Example 2 depicts an MQ9 (Predator B) that is returning to KFHU (Sierra Vista Municipal Libby Army Air Field Airport) after flying a mission (Figure 7). At the time shown, MQ10020 is more than 25 minutes from its top of descent. The red (Experimental) trajectory is based on lookup values that predict a steeper descent to the destination airport than does the blue (Baseline) trajectory. Results indicate an improvement in the prediction of top of descent location, and thus vertical position. The arrow indicates the position of the aircraft at a time of 1200 sec from the current position.

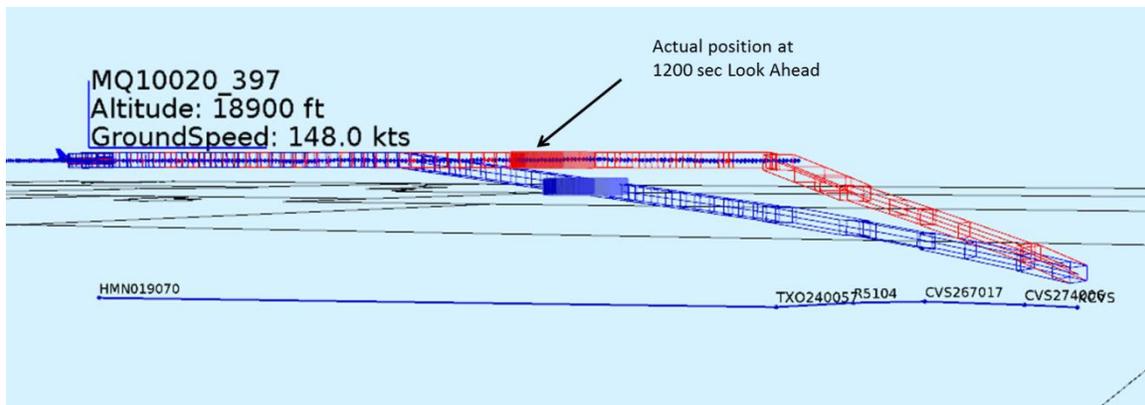


Figure 7. Improvement in top of descent prediction.

### 3.2.3 Flight Example 3: Follows filed route

Example 3 depicts an MQ-1 Predator that has just begun flying from KINS (Creech Air Force Base Airport) on a mission to a fix inside Utah and then back again (Figure 8). The thick solid

line indicates the route, which is very similar in quality to the kind of route used in commercial flight plans. The dots represent a subsampled set of track data with one point occurring every 100 seconds. Trajectories are not shown in the figure as the accuracy is extremely good for this flight in both the Baseline and Experimental scenarios. The MQ1 follows its filed flight plan well, consistently adhering to the route. At present, however, the number of UAS that fly a route similar to those found in commercial traffic is low compared to the number of flights that engage in missions in Special Activities Airspace (SAA) or utilize fix delays, which present problems in modeling and simulation if not used correctly [Schnitzer et al., 2015].

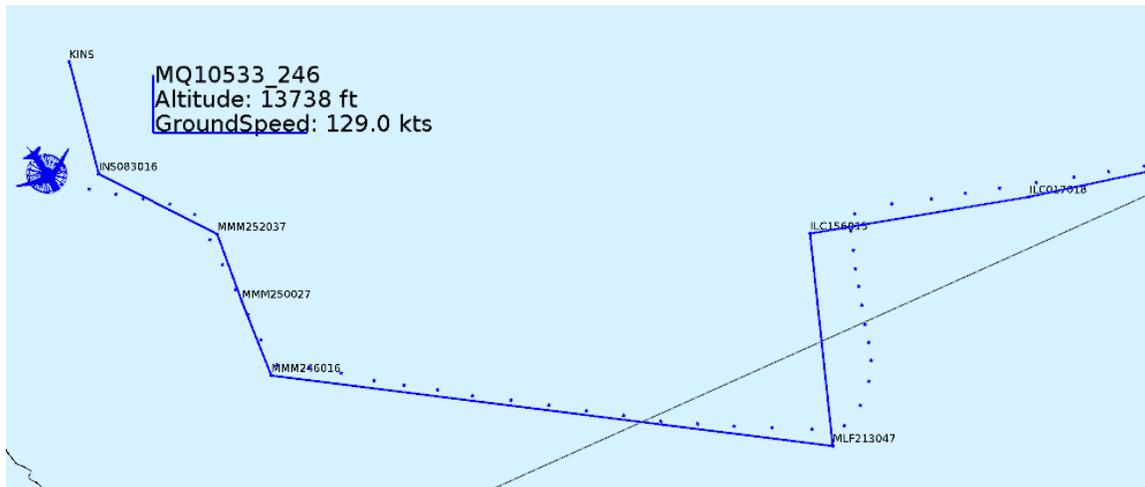


Figure 8. MQ-1 following route as filed.

### 3.2.4 Flight Example: Simulation Issue - Tactical Airspace

Example 4 depicts an MQ-1 Predator flying from KINS (Creech Air Force Base Airport) on a mission to a fix inside Nevada and then back again (Figure 9). Part of the area around KINS is tactical airspace, and not rebuilding trajectories when out of conformance in tactical airspace represents purposeful decisions in the configuration of ERAM. In Figure 9 and Figure 10 the initial climb and mission area are all out of conformance yet the trajectory shown remains fixed for the entire portion of the recorded track. While this behavior may be undesirable for prediction and conflict probing, it is currently appropriate given the configuration of operational ERAM.

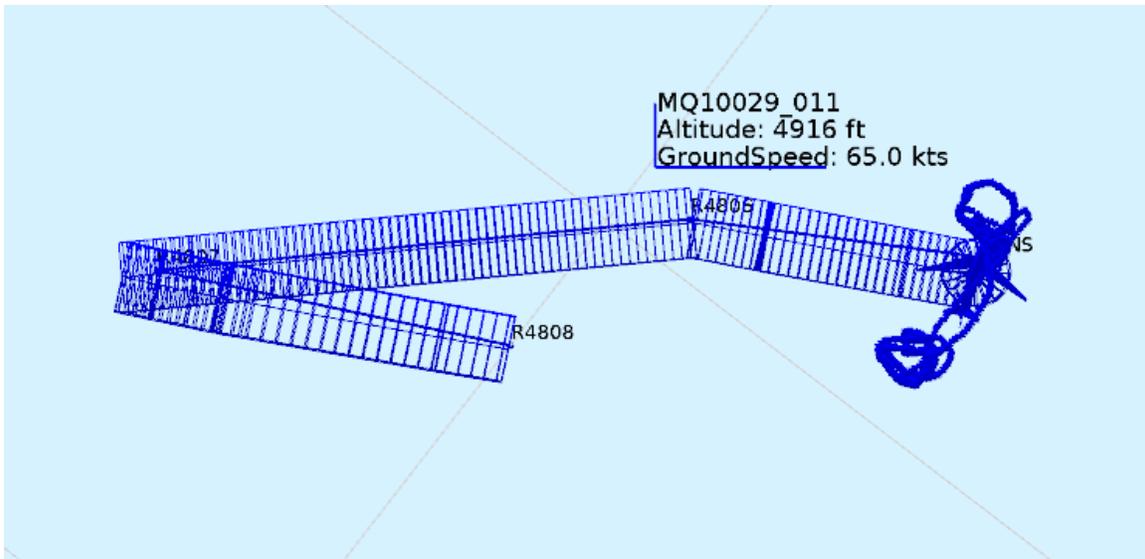


Figure 9. Lack of reconformance in tactical airspace, top-down view.

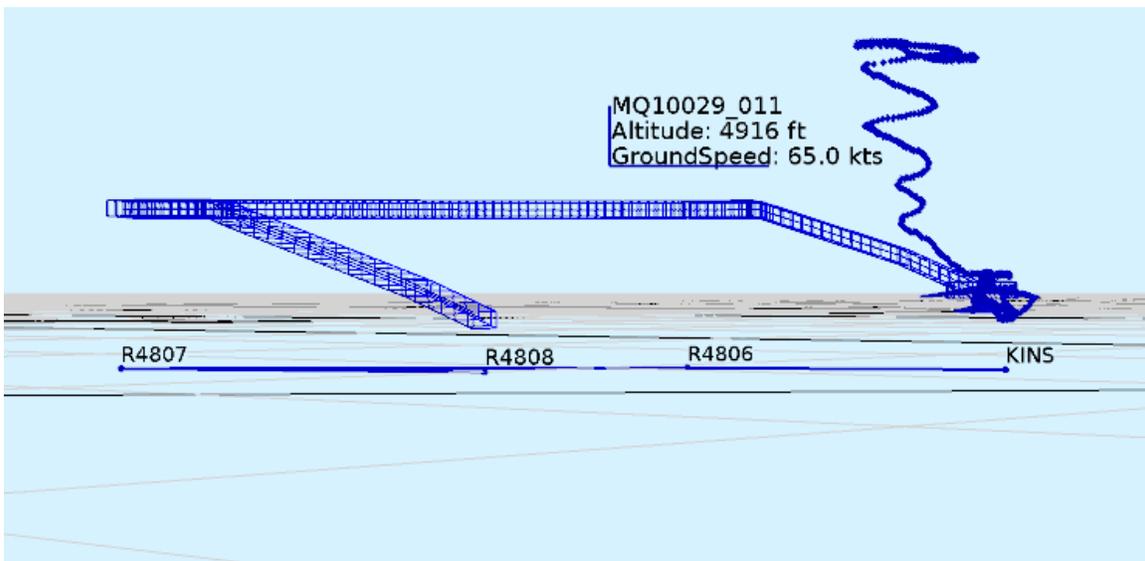


Figure 10. Lack of reconformance in tactical airspace, side view.

### 3.2.5 Flight Example: Simulation Issue - 00:00 UTC

Example 5 (Figure 11 and Figure 12) presents an issue that is atypical when developing simulations for commercial and general aviation traffic, resulting from the fact that UAS aircraft on missions are commonly in the air for extended periods of time within a single ARTCC, and they frequently fly at night. Therefore, they often span the crossover (00:00 UTC, Universal Time Coordinated) from one day to another. Essentially, the issue is that timestamps are stored as part of each CMS message. In this case, the flight leaves from and returns to KFHU (Sierra Vista Municipal Libby Army Air Field Airport), the rightmost fix in Figure 11 and in Figure 12. Also, note that the filed route contains a 13 hour delay for the route node at OLS270020, the leftmost fix.

Commercial and general aviation flights typically do not spend large amounts of time in the air in a given ARTCC. Sometimes flights will remain in an ARTCC for training or testing for several hours, but these flights are few and far between and thus don't affect experiments and simulations that evaluate prototypes. In addition, the flight durations are typically short and so only a few aircraft per day are flying during the crossover between one day and another. ANG-C55 hasn't had to reconcile this problem previously, and this issue was not observed in time to allow for correction in the timeshifting process used to create the ZAB and ZLA scenarios. The result of this is that a flight may be broken into two separate flight objects: one before 00:00 UTC on the first day (7.5 hours of track data) and one after 00:00 UTC on the second day (3.5 hours of track data). The internal tools used for scenario generation and analysis treat these objects as independent flights. This leads to a missing "end of track" in one object (Figure 11) and a missing "beginning of track" in the other object (Figure 12). In this example, the delay fix OLS270020 is not reached in the simulation of flight MQ90586 as the first segment of the flight (MQ90586\_PART1) is considered to be a separate flight - MQ90585. The real concern is that in a simulation such as the one performed by ANG-C55, VTL has no concept of 'what came before' in the second half of the flight (Figure 12) and thus is not aware of track history, which fixes have been passed, delay fixes that may or may not be valid, etc. Note that this is an artifact of data collection and simulation and is not something that affects operational ERAM.



Figure 11. Track before 00:00 UTC on day 1.

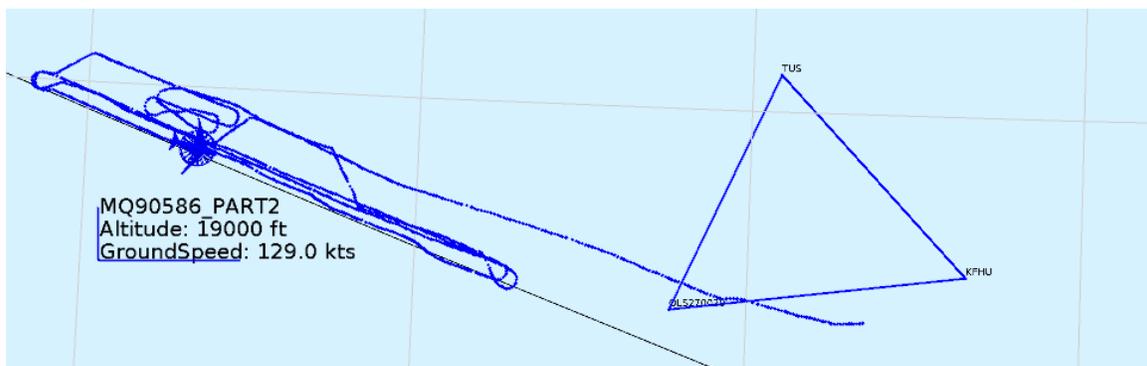


Figure 12. Track after 00:00 UTC on day 2.

### 3.2.6 Flight Example: Simulation Issue – Track not available

Example 6 presents a situation where the entire track of the UAS is not available. Since an update to the ACChar tables should primarily affect the ERAM TM during climbs and descents,

maximizing the amount of climb and descent track data is imperative. Figure 13 presents the side view of one such flight, for which the entirety of the track is at cruise altitude. However, the interest is in climbs and descents. The top-down view in Figure 14 reveals that data collection did not include the climb or the descent portion of the flight, in spite of the entirety of the track occurring during a single day. This is an issue distinct from the one observed in Section 3.2.5.

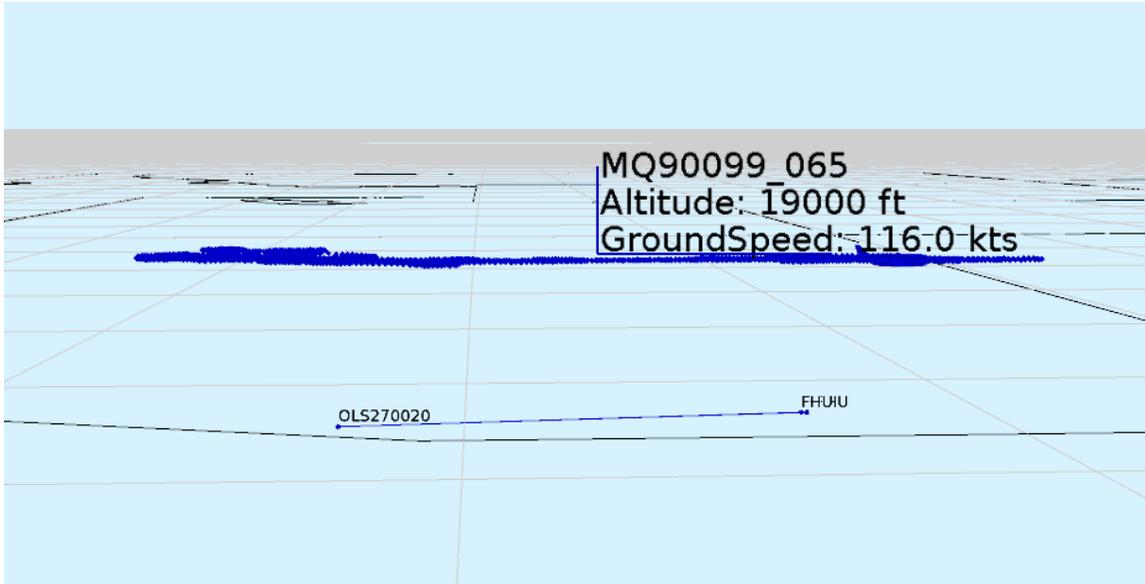


Figure 13. Side view, climb and descent track not collected.

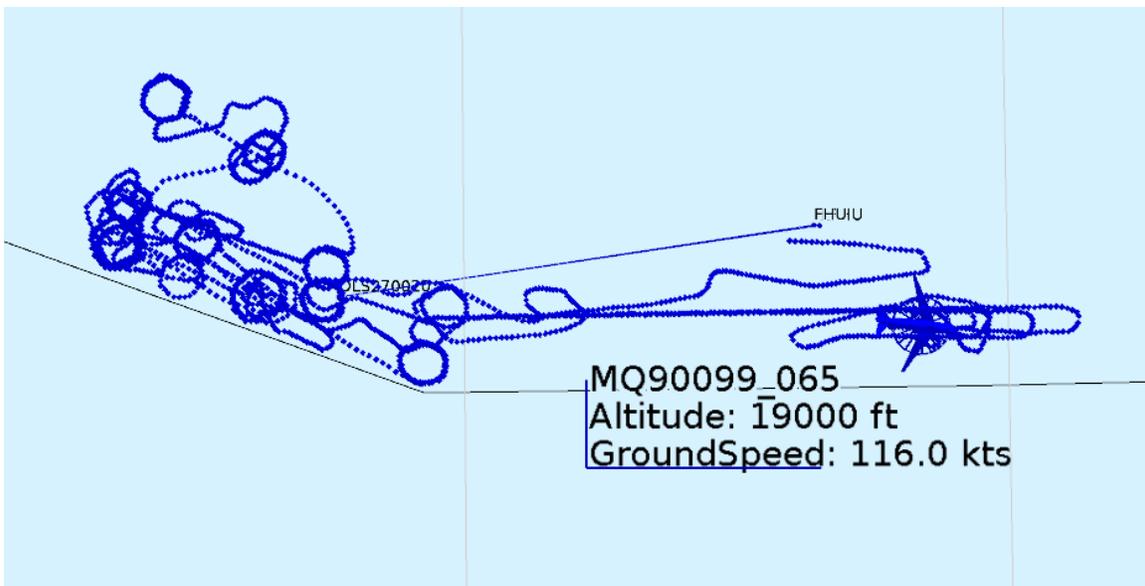


Figure 14. Top-down view, climb and descent track not collected.

## 4 Conclusions and Future Considerations

The ERAM system creates trajectories as a means of supporting controllers by predicting aircraft position and hence conflicts that may occur up to 20 minutes in the future. Many factors affect the accuracy of these predicted conflicts. Fundamentally, however, the conflict probe's accuracy is dependent on the accuracy of the underlying 4-D trajectories used to make the conflict predictions. 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, as shown previously [Paglione and Oaks, 2009].

This study evaluates an update to the Aircraft Characteristics tables, based on recorded track data, in preparation of UAS being flown through the NAS, by comparing the performance of the ERAM Trajectory Modeler with and without the update. The TM relies on the ACChar tables when building the climb and descent portions of trajectories for UAS flights in the NAS. As an increase in the frequency of UAS traveling through the NAS is expected, continued work will ensure that these tables contain accurate information in order to support UAS operations.

An examination of military UAS in the ZAB and ZLA ARTCCs revealed that the updates made to the ACChar table did improve the accuracy when predicting the vertical transitions considered for analysis. Average vertical error typically improved by at several hundred feet near look ahead times. Typically, this improvement increases as look ahead times increase, with a maximum benefit of about 2000 ft. for the ZAB transition segments. Analysis reveals modest improvements in along track error in most cases, though improvements of up to 15 NM are noted.

Analysis of TM performance across the two centers considered in this study revealed some differences. However, the UAS operations captured in the data reflect a very small number of airports in each center. The operations from the sample of airports were extremely limited in scope and were often quite similar from day to day. In addition, the flights observed in ZLA are predominantly on missions of limited complexity. In ZAB, observed flights are of mixed complexity. These missions include patrolling the border between the United States and Mexico, and involve flying complex flight plans that closely follow international boundary lines. Thus it is the difference in mission types and underlying track data that leads to dichotomous results rather than any difference in the TM.

However, of more interest at this level of concept maturity is the qualitative analysis. Analysts identified several issues that limited this particular study and several others that would limit *any* study. First off, there are simply not many UAS flying through the NAS in any given en route center, even as recently as 2015. When developing ACChar tables for commercially used aircraft, a large amount of data is required; 1000 – 1500 total flights is recommended for each aircraft type, NAS-wide [Konyak, 2015]. This study only considers 2 ARTCCs and obtained quality data for far less than 1000 flights per aircraft type. In addition, proper analysis requires the entirety of the vertical profile (ground to top of climb and top of descent to ground) to build a reasonable set of lookup values for entry into the ACChar table. Typically, ANG-C55 collects track data from NASQuest for en route studies, and only climb/descent information collected by HOST or ERAM (depending on the age of the data) at the time is captured in this manner. However, for many of the UAS under study sizable portions of the climb and descent track data were not available in NASQuest. In the future, collection of data should make use of multiple sources in order to ensure that analysts obtain a greater percentage of each flight's track. Merging data from multiple sources in proper fashion should yield more robust flight tracks.

Second, many of the UAS currently observed do not operate in a manner that is conducive to reasonable trajectory prediction in the NAS. When a UAS follows its filed intent information, even for a portion of its flight, the automation can perform prediction as intended. However, as discussed in [Schnitzer et al., 2015], when an aircraft does not follow the intent information that is accessible to the automation, proper trajectory modeling cannot be expected to occur. An example of this is when controllers enter fix delays into freeform text and not into the route string itself. The automation has no access to intent data specified in freeform text and will not suspend trajectory modeling in these cases. Even if a delay appears in a route string, if the flight does not approach within a threshold distance of that fix the automation cannot determine whether the fix has been reached or passed and will not suspend trajectory modeling. In fact, logic in the automation may conclude that the fix was skipped and begin building trajectories using other downstream fixes. Another example includes filing a route with an end point that occurs at the start of a mission area; if the flight does not pass near that fix the automation may continue to build trajectories toward the final fix until the flight reaches the fix or until filing of a route amendment occurs. Additional situations during which the automation may not perform as desired are track that enters an SAA or track that occurs in any situation in which the automation rebuilds trajectories due to 'out of conformance' states. All of these situations occur much more frequently when UAS fly missions in the NAS than when commercial aircraft are following standard routes and they can severely impact the predictive capabilities of the automation, potentially causing more work for operational personnel. In the future, if UAS fly in a manner more similar to that of commercial flights, predictions will tend to be more accurate. If not, then this will continue to be an issue that will require future considerations such as protecting a large amount of airspace near a UAS, performing short term trajectory prediction based solely on recent track speed and heading, or other approaches.

Third, the military own and operate the vast majority of UAS that currently fly in the NAS. These military-operated flights often engage in special missions. It is likely that when integration of UAS into the NAS occurs in the future, commercial owners will operate many of these UAS. In addition the commercially operate UAS will likely have different mission and flight parameters. The current study provides an initial update to the ACChar. Adaptation teams must continue to make updates to the ACChar tables as driven by changes in traffic types, patterns, and operational need.

The final concern stems from issues with the current capabilities of the tools used by ANG-C55. Essentially, the tools cannot currently take into account scenario data that spans 0000 UTC, something which frequently occurs with long-duration UAS flights. Analysts can work around this issue by putting simple processes in place. Future work in this area will need to address the majority of the issues mentioned above.

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