Real-Time Data Link of Aircraft Parameters to the Center-TRACON Automation System (CTAS)

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Abstract

Modern, strategic Air Traffic Control (ATC) decision-support tools are highly dependent upon accurate predictions of four-dimensional (4-D) aircraft trajectories. The accuracy of these trajectory predictions is a function of the availability of aircraft state, atmospheric state, and flight intent data. Research efforts in the U.S and Europe are exploring the feasibility of air-to-ground data link as a means for delivering flight-specific aircraft parameters to ATC decision-support tools. This paper describes the preliminary results from a field test involving the automatic data link of aircraft parameters to the Center-TRACON Automation System (CTAS) at NASA Ames Research Center. In support of this investigation, data were collected from over 1,000 United Airlines flights of Boeing-777 aircraft operating within the Denver Air-Route Traffic Control Center (ARTCC). The aircraft parameters and system for acquiring them are first described, followed by an assessment of the impact of these data on en-route CTAS trajectory predictions. Although this study exploits current-day infrastructure for generating, delivering, and processing air-to-ground data, it is intended to support the generation of requirements for future data link systems and services.

I. Introduction

Controller decisions within an Air Traffic Control (ATC) system, regardless of its complexity, are ultimately dependent upon the availability and accuracy of airborne traffic information. In today's system, the current and predicted traffic situation, as viewed by ATC, is derived from surveillance radar returns together with Instrument Flight Rules (IFR) flight plans. Radar-derived information includes horizontal track data (position and ground speed) along with transponded aircraft altitude reports. Flight plans are typically filed with ATC well in advance of a flight's departure, and are not normally updated by the airspace user once a flight is in progress. It is has been recognized for some time that the breadth and quality of data available to ATC for flight status and planning can be vastly improved by connecting ATC with data systems maintained by the airspace user, both on the ground and in the air[1].

Several ATC modernization efforts in both the U.S and Europe are exploring the benefits and feasibility of delivering data to ATC directly from airborne systems over air-to-ground data link[2,3]. Although these activities are concerned with a wide range of ground-based applications and data link architectures, they share a common need to access a subset of the parameters readily available from most modern aircraft equipped with a Flight Management System (FMS). Potential applications of aircraft parameters to air-traffic management fall into four general categories: 1) controller awareness, 2) enhanced surveillance, 3) monitoring and diagnostics, and 4) decision-support automation.

Applications of controller awareness involve displaying a common set of aircraft data to both the controller and flight crew (e.g., airspeed and heading) for use in verifying clearance delivery and conformance. Applications of enhanced surveillance involve supplementing current-day radar data with aircraft-reported position and velocity, together with additional parameters used to indicate the onset and magnitude of maneuvers. Applications of monitoring/diagnostics involve the potential use of aircraft data to improve awareness and shorten response time with regards to situations relating to safety and security. These applications could include the use of data link as a means of providing a non-destructible source of data for post-incident analysis (e.g., remote "black box").

The fourth category of ATC applications, and the subject of this research, involves the use of aircraft parameters for improving the performance of controller decision-support tools. These tools are characterized as software-based systems that assist controllers with separation assurance and traffic flow management tasks. Systems of these types, which typically employ strategic planning horizons ranging from 5 min to 30 min, are highly dependent upon accurate four-dimensional (4-D) trajectory predictions of individual flights. An example of a system of this type is the Center-TRACON Automation System (CTAS) that has been developed by NASA Ames Research Center and fielded, in part, under the FAA Free Flight Phase 1 initiative[4]. CTAS requires accurate trajectory predictions in order to generate controller advisories that will make efficient use of available capacity, while minimizing deviations from the speed and routing preferences expressed by airspace users. For example, more accurate long-range trajectory predictions can enable controllers to resolve separation conflicts earlier in time with smaller, more fuel-efficient maneuver advisories. Furthermore, the rate of missed alerts and false alarms associated with these advisories can be reduced[5].

This paper describes the system characteristics and preliminary findings from a field test involving the automatic data link of aircraft parameters to CTAS for the purpose of improving strategic trajectory prediction accuracy. This activity was conducted between January and August of 2001 under a NASA project referred to as En Route Data Exchange (EDX). EDX involved the real-time transfer of data to CTAS from operational, revenue aircraft. With cooperation from United Airlines, data was collected from over 1,000 flights of EDX-enabled Boeing 777 (B-777) aircraft operating within the Denver Air-Route Traffic Control Center (ARTCC). The paper begins by discussing the relevance of aircraft parameters to CTAS trajectory predictions, followed by a description of the system architecture and specific data parameters involved in the EDX evaluation. Results are then presented that illustrate the impact of real-time data link on CTAS trajectory prediction accuracy.

II. Overview of CTAS Trajectory Prediction

The CTAS Trajectory Synthesizer (TS) uses a simplified set of point-mass aircraft equations of motion for generating 4-D trajectories consisting of aircraft position and altitude as a function of look-ahead time. In Center airspace, new predicted trajectories are generated by TS approximately every 12 seconds. The simplified equations of motion, numerically integrated by TS, are described fully in Ref. 6. Within CTAS, a separate process known as the Route Analyzer (RA) provides the routes upon which predictions are based. The RA provides the TS with a set of waypoint locations that represent the expected course of flight in en route airspace. These waypoints are defined by flight plan information, normally provided by the airspace user prior to departure, in conjunction with detailed airspace data stored within CTAS. To simplify the prediction process, the horizontal and vertical components of the trajectory are de-coupled. First, an approximate vertical profile is constructed in order to calculate airspeed as a function of path distance. Using this approximate airspeed profile, the horizontal trajectory is computed as a series of straight-line path segments connected by constant radius turns. This horizontal trajectory is then used as the basis for computing the actual vertical trajectory. Measures are taken within the TS/RA to ensure that the final 4-D prediction is in conformance with all relevant constraints on the trajectory, imposed by aircraft performance, pilot/ATC procedures, and airspace capacity limitations.

The basic input data required by the TS/RA process is shown in Fig. 1. These data fall into three general categories: 1) aircraft state, 2) atmospheric state, and 3) flight intent. For the purpose of trajectory prediction, aircraft state data are defined by those parameters relating to the kinetic and dynamic properties of the aircraft. Kinetic parameters - used by the TS to initialize the trajectory prediction process - consist of inertial position, altitude, speed, and heading. Within baseline CTAS - i.e., the system without data link

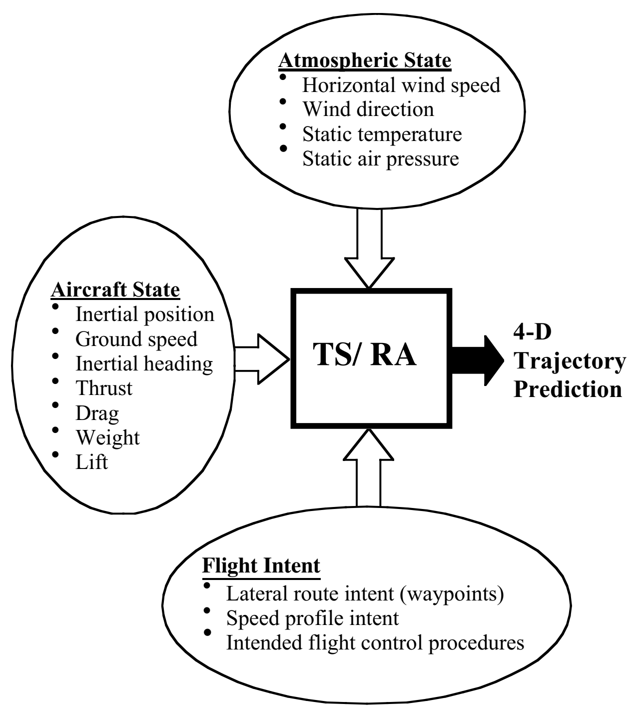


Fig. 1 Inputs to CTAS Trajectory Prediction Process

augmentation - kinetic data is provided entirely by the FAA Center Host computer based on processed radar position and Mode C altitude returns.

Dynamic state parameters are those that define the thrust, drag, weight, and lift forces acting on the aircraft. Thrust and drag forces are computed from aircraft-specific performance models maintained within CTAS. In baseline CTAS, aircraft weight is derived from stored, static values representative of the general aircraft type (e.g., Boeing 777-200). This is a clearly an approximation, however, since it does not account for actual, flight-specific, fuel and payload weight variations[2].

Atmospheric state data employed by the TS includes horizontal wind speed, wind direction, static pressure, and static temperature. These data - used to obtain accurate airspeed estimates along the predicted trajectory - are provided by the National Oceanic and Atmospheric Administration (NOAA) Rapid Update Cycle 2 (RUC2) model. The CTAS TS obtains atmospheric state at each time step along the predicted trajectory by linearly interpolating between 3-dimensional grid points within the RUC2 database. The RUC2 database is updated with 1-hour forecasts and stores data using a horizontal grid resolution of 40 km, and a vertical grid resolution of 25 mb pressure altitude[7].

Flight intent inputs to the TS/RA consist of data pertaining to the intended actions of the flight crew in controlling the future path of the aircraft, in compliance with any known airspace or ATC constraints. An important component of flight intent data is the expected routing and speed profile over future flight segments. For baseline CTAS, routing information is obtained from the FAA Center Host computer, which updates the originally filed IFR flight plan with any ATC flight plan amendments entered by the controller. The intended speed profile during the cruise portion of the flight is based on either the filed or detected cruise airspeed, depending on whether the aircraft is in steady-state cruise at the time the prediction is initiated. For climbs and descents, the vertical speed profile of the flight is based upon a CTAS estimate of the most likely climb/descent procedure to be executed by the pilot in light of ATC constraints, such as crossing restrictions and known clearance instructions. Vertical speed profiles are modeled as constant airspeed segments, defined by either a constant Calibrated Airspeed (CAS) or constant Mach number during the climb or descent. For jets, this constant airspeed assumption together with a known thrust setting is sufficient for the TS to define the vertical profile. For turboprop aircraft, the vertical profile is typically defined by a constant airspeed together with constant vertical rate (or flight path angle) assumption. In absence of any specific climb or descent CTAS advisories, such as those provided by the En Route Descent Advisor (EDA) tool, the vertical airspeed profile used by baseline CTAS is obtained from stored company preference information[8]. This company preference is represented by static values of climb and descent CAS, obtained from published procedures designed to maximize fuel efficiency for a given aircraft type.

At high altitudes (typically above Flight Level 280), CTAS models the vertical profile with a constant Mach number instead of constant CAS. This is consistent with pilot and ATC procedures that recognize that typical aircraft performance is limited more by maximum Mach number than maximum CAS at higher altitudes[9].

III. EDX System Architecture

Airborne System

The system used to support EDX is shown schematically in Fig. 2. Parameters, described fully in section IV, were down-linked from UAL B-777 aircraft operating with Denver ARTCC airspace. The B-777 was chosen due to its non-intrusive, integrated FMS-ACARS capability. The aircraft comes equipped with a Honeywell Airplane Information Management System (AIMS) architecture that ties together numerous avionics systems, including the FMS, Airplane Condition Monitoring System (ACMS), and VHF data link. Data are shared between these systems over the AIMS back-plane bus. Furthermore, data can be readily extracted from the ACMS through a configurable/loadable software module known as an Airline Modifiable Interface (AMI) file. Because the ACMS/AMI is partitioned off from safety-critical components, modifications needed to support EDX were made to the AMI without requiring additional FAA certification. This was a key consideration in identifying airframe/avionics that minimized the lead time for the data collection activity.

The EDX AMI contained instructions for extracting the appropriate data parameters from avionics systems and automatically triggering their down-link. In addition, the AMI was designed so that parameters controlling down-link performance could be modified via up-link messages. For example, data link trigger conditions based on geographic boundaries and altitude constraints could be modified by up-link commands sent from the EDX lab at NASA Ames. Up-link

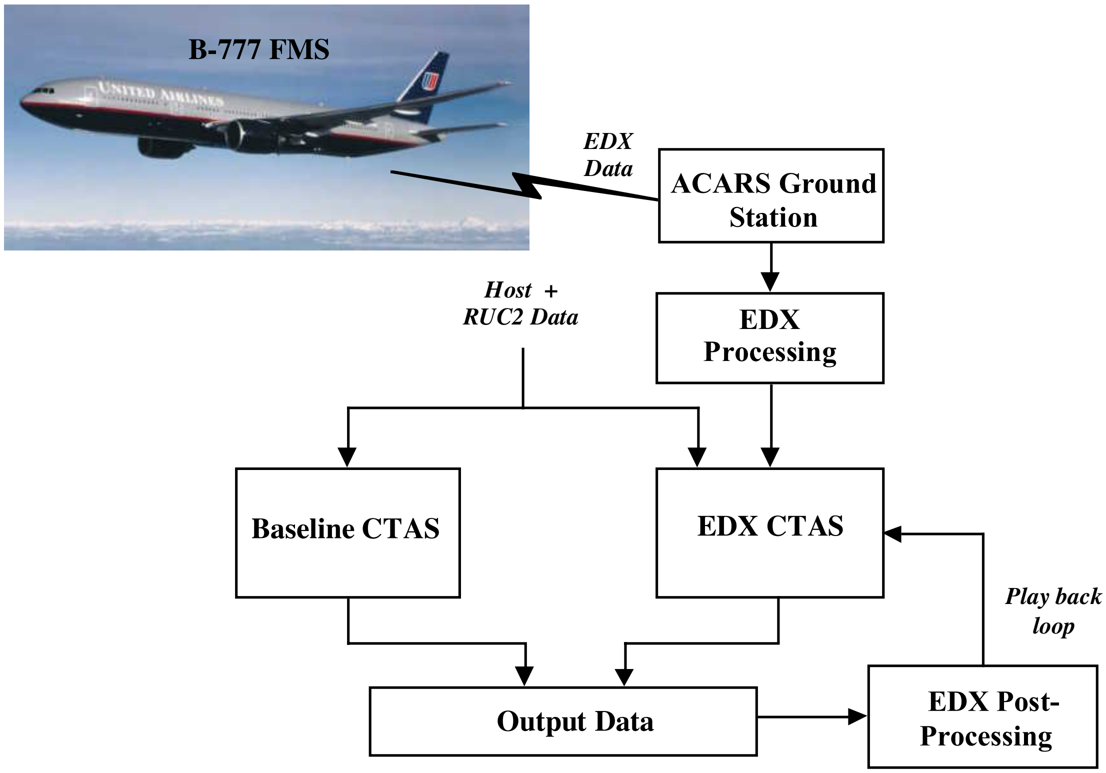


Fig. 2 EDX System Architecture

commands could be sent to enable/disable EDX data link and specify the data link rate. These controls enabled the EDX researchers to maximize data collection within the designated airspace while minimizing the communication load on the ACARS system. A total of forty-eight B-777 aircraft were equipped with the EDX AMI. This equipage was performed by UAL as part of a routine avionics software upgrade cycle.

Data Link System

The data link system used by EDX was the Aircraft Communications Addressing and Reporting System (ACARS)[10]. ACARS, owned and operated by ARINC Inc., is the most prevalent data link system employed in the U.S at this time. ACARS consists of VHF transceivers connected to a nationwide network. All terminal nodes on the network, including both ground stations and aircraft, have a unique address to which messages are routed. In support of EDX, an ACARS ground station was established at NASA Ames with access to the network over a dedicated line. For down-link, the ground station collected aircraft messages for transfer to CTAS. For up-link, the ground station allowed for messages to be composed by the EDX team and sent to aircraft destinations, designated by their ACARS network address.

Although ACARS was not designed to support mission-critical ATC applications, it did provide an excellent platform for conducting the EDX data collection activity. The purpose of EDX was not to critique current data link infrastructure, but rather to validate requirements for next-generation data link systems and services.

CTAS

On the ground side, CTAS was run in a passive/shadow mode (i.e., without controllers) from the EDX lab at NASA Ames. Aircraft state, atmospheric state, and flight intent data were delivered to CTAS at a nominal rate of once per minute. CTAS was adapted to incorporate EDX aircraft parameters directly into the TS/RA process.

The EDX evaluation involved substantial modifications to CTAS in order to introduce aircraft parameters into the TS and RA processes. In support of EDX demonstrations and future analyses, CTAS was configured to run the following en-route decision-support tools while incorporating aircraft parameters into TS/RA: Traffic Management Advisor (TMA), En Route Descent Advisor (EDA), and Direct-To (D2)[4]. As shown in Fig. 2, the impact of aircraft data on CTAS performance was assessed by comparing baseline CTAS with EDX CTAS (i.e., the version with data link augmentation). EDX CTAS was also designed to support the processing of aircraft data post flight, using a play back interface. This interface supported post flight EDX research by allowing aircraft parameters to be time-blended with archived radar track, flight plan, and weather data.

IV. EDX Data Content

EDX aircraft down linked the parameters shown in Table 1 and 2 at a nominal rate of once per minute. During occasional periods where few active EDX aircraft were present in the airspace, data link was increased up to a rate of once every 12 seconds in order to mirror the update rate of data from the FAA Center Host computer. The entire set of 40 parameters was packaged together into a single ACARS digital message totaling 192 bytes in length. As shown by Table 1 and 2, parameters were characterized as either primary or secondary. Primary parameters were those used to support the analysis presented later in this paper; secondary parameters were collected to support future research activities.

	Aircraft Parameter	Baseline CTAS Data Source
Aircraft State	UTC time stamp	CTAS clock
	Gross weight	Stored files
	Longitude -x	Radar data
	Latitude - y	Radar data
	Altitude - z	Mode-C transponder
	True track heading	Radar data
	Ground speed	Radar data
	Calibrated airspeed (CAS)	CTAS-computed
	True airspeed (TAS)	CTAS-computed
	Mach number	CTAS-computed
	Altitude rate	Radar data
	LNAV on/off	N/A
	VNAV on/off	N/A
Atmospheric State	Static air temperature	RUC2 model
	Static air pressure	RUC2 model
	Wind speed	RUC2 model
	Wind direction	RUC2 model
Flight Intent	Next (active) waypoint	ATC flight plan
	Next + 1 waypoint	ATC flight plan
	Target climb/descent CAS	Stored files
	Target climb/descent Mach	Stored files

Table 1 Primary EDX Parameters

	Aircraft Parameter	Baseline CTAS Data Source
Aircraft State	Aircraft true body heading	N/A
	LNAV cross track deviation	N/A
	VNAV vertical path deviation	N/A
	Engine pressure ratio (EPR)	CTAS engine model
	VNAV mode	N/A
	Autopilot mode	N/A
	Flight phase (e.g., climb, cruise)	CTAS-deduced
	Position certainty (ANP)	N/A
Flight Intent	Cost Index	N/A
	Target altitude for cruise	ATC flight plan
	Target altitude at next constraint	N/A
	Target track heading	N/A
	Estimated Time to TOD	CTAS TS
	Intended approach CAS	Stored files
	Vertical speed target TAS for	N/A
	VNAV	CTAS TS
	Estimated time to destination	N/A
	Target EPR for VNAV	N/A
	Target EPR for level flight	N/A
	Destination airport	ATC flight plan

Table 2 Secondary EDX Parameters

V. Results

Data Collection and Delay Characteristics

Over an eight-month period, data were collected for over 1,000 operations within Denver ARTCC airspace, consisting of 288 departures, 372 over-flights, and 341 arrivals. Data link messages containing the EDX parameters were transmitted automatically for aircraft operating within 250 nmi of Denver International Airport. Because each EDX message was stamped with Coordinated Universal Time (UTC) aboard the aircraft, it was possible to measure the total delay associated with data transmission. For 60 randomly selected flights, involving an equal number of departures, over-flights, and arrivals, the average message delay was found to be 9 sec with a standard deviation of 12 sec.

In support of the analyses presented in this paper, a perfect data link was emulated by removing message delay in post processing using the play back capability previously described. The was done since transit delay can potentially cause highly-dynamic parameters such as position, speed and heading to become invalid for stringent real-time applications. It should be noted, however, that the transit delays observed with the ACARS system were much lower than expected, and might have been lowered further by providing a higher priority to message delivery (EDX messages were purposely given a low priority so as not to interfere with routine airline operational messaging).

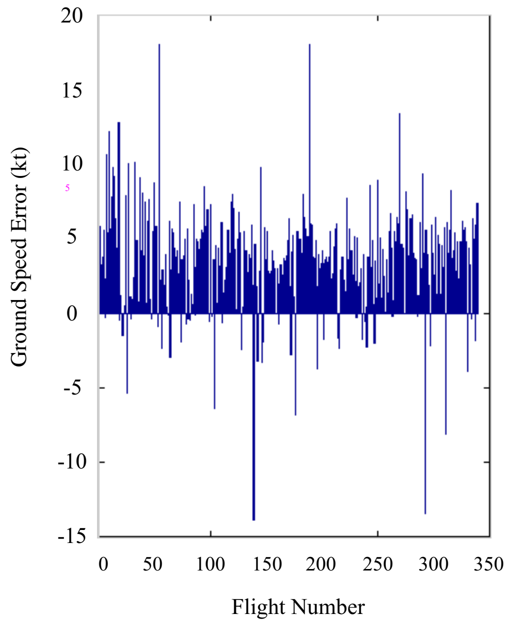


Fig. 3 Signed Error in Mean Ground Speed

	Parameter	Departures		Over-flights		Arrivals	
		Mean	*Std. Dev*	*Mean*	*Std. Dev*	*Mean*	*Std. Dev*
Aircraft State	Weight ($x10^3$lb)	53.9	20.3	53.8	47.7	18.9	13.4
	Gnd. speed (kt)	21	17.4	17	15.5	15	14.5
	CAS (kt)	19	13	25	26	20	16
	TAS (kt)	26	19	37	42	30	25
	Mach	.048	.03	.068	.069	.050	.041
	Alt. rate (ft/min)	345	495	85	124	390	487
	Track hdg. (deg)	3	3.23	2	3.73	6	15.7
Atmospheric State	Pressure (lb/ft^2)	7.6	12.1	1.1	0.6	10.1	10.5
	Wind speed (kt)	20	15	22	14	-	-
Flight Intent	Tgt. CAS (kt)	10	9	-	-	50	15
	Tgt. Mach	.047	.01	-	-	-	-
	LRIE (nmi)	1.12	1.16	.81	1.03	1.92	6.60

Table 3 Absolute Error in Trajectory Prediction Input Parameters Across all Flights

Comparison of Trajectory Prediction Input Data

The primary EDX parameters, shown in Table 1, were compared against their corresponding baseline-CTAS values. This was done in order to examine errors - defined as the difference between existing ATC trajectory-prediction input data and corresponding aircraft-derived values (considered as truth). For example, Fig. 3 shows the mean ground speed error detected over each departure operation. Table 3 provides a summary of these types of results for all primary parameters over every flight for which data was available. The results in Table 3 point to significant errors in the trajectory prediction data used today by ATC automation without the benefit of data link.

<u>Flight Intent Error</u>

The calculation of speed and routing intent errors in Table 3 was more complex than that for other trajectory prediction input parameters. For departures, speed intent error was represented by the difference between EDX and baseline-CTAS values for CAS and Mach speed targets, used to define climb profiles as previously described. For arrivals, only CAS targets were compared since CTAS does not store target Mach numbers explicitly for trajectory prediction, but instead assumes that the aircraft will descend at the cruise Mach number until reaching an altitude where the target CAS is captured.

Lateral route intent error, shown in the last row of Table 3, was defined as the difference in the planned horizontal route constructed with and without the incorporation of EDX waypoint information originating from the aircraft FMS. As illustrated in Fig. 4, horizontal route intent was defined, at any given time, by connecting a path through all known downstream waypoints. Additional complexity was introduced by the intrinsically dynamic nature of route intent; route intent employed by baseline CTAS was affected by flight path amendments entered by the controller, while EDX route intent was affected by pilot inputs into the FMS.

For this reason, the results in Table 3 were found by examining the route intent error present each time a trajectory prediction was made. At each time interval, the intent error was found by marching the aircraft along the intended routes - defined separately by baseline-CTAS and EDX waypoints – and measuring the distance variation between them. As indicated in Fig. 4, the Lateral Route Intent Error (LRIE) at time *t* was defined as the mean distance error between baseline and EDX predicted routes at that instant. The mean LRIE was then computed over the entire flight segment for which EDX data was available. Finally the

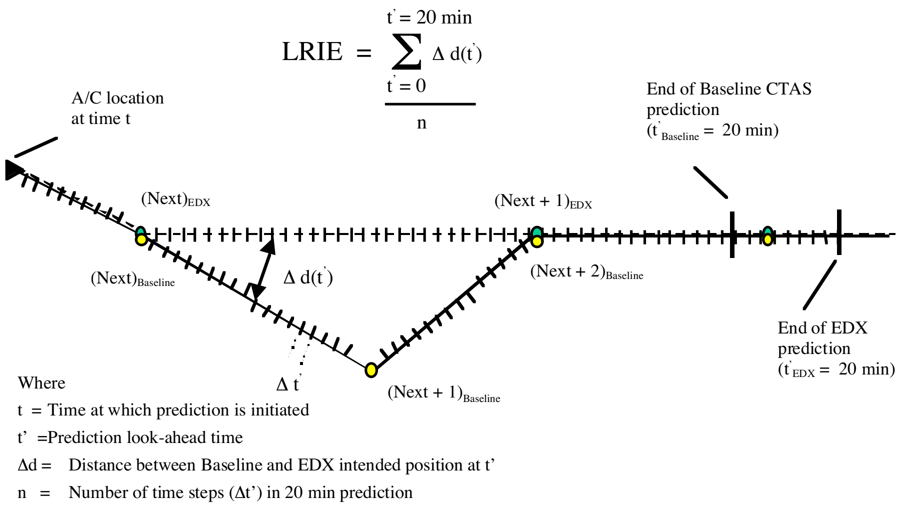


Fig. 4 Definition of Lateral Route Intent Error (LRIE)

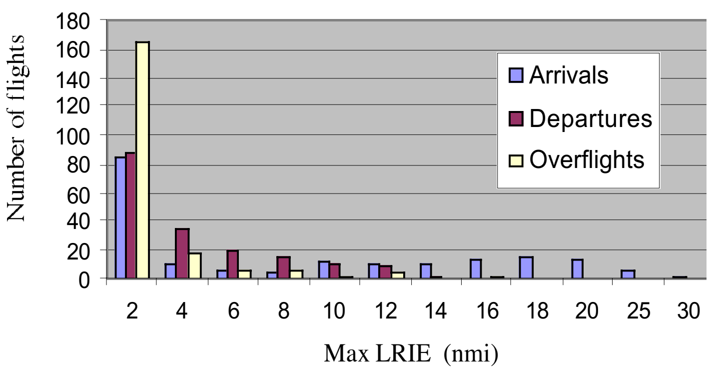


Fig. 5 Histogram of Maximum LRIE Across all Flight Phases

Parameter(s)	Mean Altitude Error (ft)		Mean Lateral Error (nmi)	
	Baseline	*EDX*	*Baseline*	*EDX*
Weight	1,346	980	12.0	10.5
Speed Intent	1,360	1,160	12.3	10.0
Weight + Speed Intent	1,360	644	12.3	9.3
Lateral Route Intent	-	-	2.42	0.98

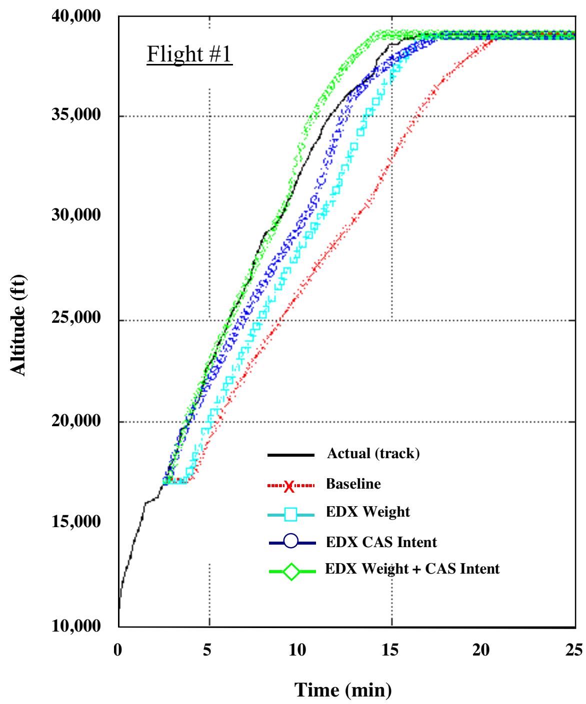
Table 4 Summary of the Impact of EDX Parameters on CTAS Trajectory Prediction Accuracy

overall mean LRIE, as presented in Table 3, was found by further averaging LRIE over all flights.

The potential magnitude of lateral intent error is illustrated in Fig. 5, which shows a histogram of maximum LRIE for all flights, organized by flight phase. Fig. 5 provides statistical insight into how much ATC and FMS route intent can differ at any instance in time. The results in Fig. 5 show that approximately 40% of all flights experienced mean route intent differences over the prediction window of between 4 nmi and 8 nmi at some instance.

Trajectory Prediction Accuracy Analysis

Based upon the observed variation of trajectory prediction input data, analysis was carried out to examine the accuracy of resulting CTAS trajectory predictions. For select flights, twenty-minute predictions, both with and without EDX data, were compared against truth - as established by the final track of the aircraft. A total of 50 flights with large observed errors between baseline-CTAS and EDX input data were processed. Twenty departures were processed based on weight error; 10 departures were processed based on speed intent error; and 20 over-flights were processed based on route intent error. In addition, the cumulative impact of weight and speed intent error was evaluated for the ten departures examined for speed intent alone. For each flight, single 20-minute trajectory predictions were calculated with baseline-CTAS and EDX input parameters. In order to isolate the effect of the parameter in question, all other input parameters were set equal to baseline-CTAS values. A comparison of the accuracy of EDX and baseline-CTAS trajectory predictions for the 50 flights is summarized in Table 4.



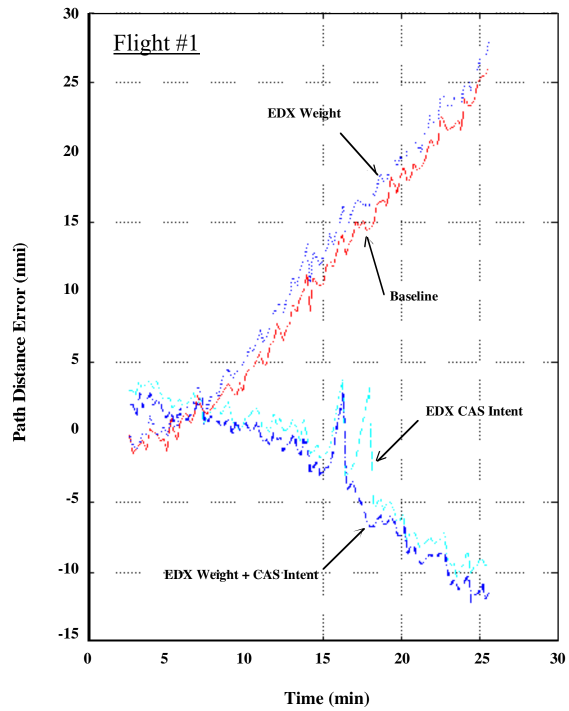
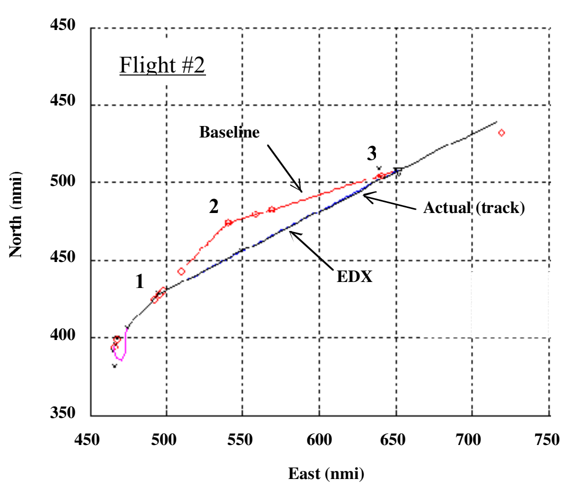


Fig. 6 Effect of EDX Data on Predicted Altitude Profile Accuracy

Fig. 7 Effect of EDX Data on Predicted Path Distance Accuracy



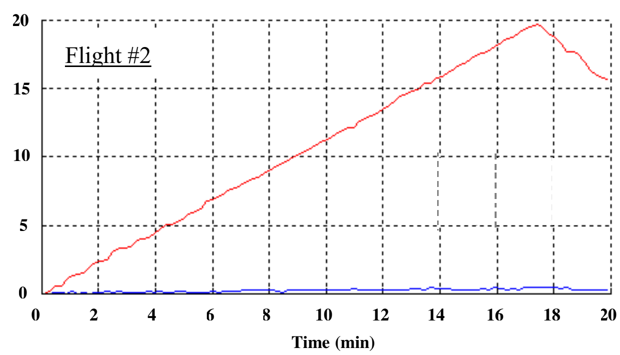


Fig. 8 Impact of EDX Lateral-Route-Intent Data on Course Prediction Accuracy

Fig. 9 Impact of EDX Lateral-Route-Intent Data on Absolute Horizontal Prediction Error

The results in Table 4 show that EDX weight data alone improved the accuracy of predicted altitude by an average of nearly 30%. The incorporation of EDX speed intent improved the accuracy of predicted path distance by an average of 20%. Furthermore, the use of both EDX weight and speed intent improved altitude and path distance predictions by an average of 53% and 24%, respectively. Perhaps most significant of all, the results in Table 4 show an improvement in lateral path prediction accuracy of 80% with the use of EDX route intent data, provided in the form of FMS waypoints.

As an illustrative example, Fig. 6 shows the improvement in altitude profile prediction accuracy with the use of EDX data. Along with the baseline-CTAS prediction and actual track (truth), Fig. 6 shows separate predictions based on the incorporation of 1) EDX weight, 2) EDX speed intent, and 3) EDX weight + speed intent. Fig.7 shows the corresponding path distance error measured for the same set of EDX and baseline predictions shown in Fig. 6. It can be seen in Fig. 7 that path-distance error was largely unaffected by aircraft weight. This observation is backed up by the equations of motion (Ref. 6) which show that weight primarily influences the altitude dynamics, not path distance. Path distance error, however, was impacted by EDX speed intent, as expected.

For this example flight (Flight #1), the maximum altitude error over a 20-minute prediction window was reduced by 73% with the incorporation of EDX weight and speed intent data. Similarly, the maximum path distance error was reduced by 60% with the incorporation of speed intent. It should be noted that the magnitude of the error reduction in both altitude and path are well beyond the separation standards of low altitude en route airspace (1,000 ft and 5 nmi in altitude and path, respectively). This leads to the conclusion that EDX data could significantly influence ATC automation advisories and controller decisions relating to conflict avoidance and traffic flow management.

Fig. 8 shows an example of the improvement in lateral routing intent possible with the receipt of aircraft FMS waypoint information. In this example, the FMS data indicated that a direct route was to be flown from fix 1 to fix 3, thereby bypassing a dog-leg introduced by fix 2 in the filed flight plan. As shown in Fig. 8, truth data, gathered post-flight, was used to validate FMS route intent. Fig. 9 shows the total horizontal error corresponding to the predictions in Fig. 8. Fig.9 indicates a reduction in maximum horizontal prediction error of over 95% with the use of EDX aircraft data, for this particular 20-minute prediction example.

VI. Conclusions

The results of this study suggest substantial benefits associated with the delivery of aircraft parameters to ATC over real-time data link. In particular, the EDX project has explored the use of aircraft data for improving ATC trajectory prediction accuracy in en route and transition airspace. Accurate trajectory predictions are crucial for maximizing the performance, benefits, and controller acceptance of ATC decision-support tools such as CTAS. Based on the collection of real-world operational data, the results of this study showed 1) sizable errors associated with existing ATC data sources, and 2) significant improvement in CTAS trajectory prediction accuracy with the incorporation of aircraft data. Finally, as an important engineering achievement, this study proved that a wealth of aircraft data could be extracted with minimal avionics intrusion, and transferred to ATC over existing ACARS with minimal transit delay.

The results of this work are intended to support on-going efforts aimed at developing data requirements and establishing benefits for next-generation data link systems and services. Future EDX work at NASA Ames is intended to explore concepts that further integrate CTAS with flight deck information systems, for the benefit of controllers and airspace users alike.

VII. Acknowledgement

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Biographies

Richard A. Coppenbarger

Rich Coppenbarger, has been employed with NASA Ames Research Center at Moffett Field, California since 1989. During his tenure at Ames, Mr. Coppenbarger acquired a Masters degree in Aerospace Engineering from Stanford University. Mr. Coppenbarger has been involved with ATC automation research for the past three years. During this time, he has focused on data link research and en route decision-support-tool development under the AATT/CTAS project. His prior research activities at Ames included microburst wind shear accident investigation, and helicopter obstacle-avoidance guidance and control.

Gerd Kanning

Gerd Kanning has been employed at the NASA Ames Research Center for 38 years. He received his Masters Degree in Electrical Engineering from the University of Santa Clara. He has worked on a variety of projects from mathematical modeling of gravity-stabilized satellites to modeling of helicopter rotor dynamics. He developed parameter identification techniques for V/STOL aircraft and applied Kalman filter theory to the automatic landing of V/STOL aircraft. He helped develop the automation system for landing of aircraft using the Global Positioning Satellite network. His most recent work has been in the development of a data link between aircraft and ground for the Center-TRACON Automation System (CTAS).

Rey Salcido

Rey Salcido earned a B.S. in chemical engineering from Stanford University and has worked in software development since 1995. Mr. Salcido joined Raytheon ITSS in 1998 and has since been involved with software development and analysis in support of the EDX research project.