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CLIMB TRAJECTORY PREDICTION ENHANCEMENT USING AIRLINE FLIGHT-PLANNING INFORMATION

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Abstract

Software decision support tools that assist controllers with the management of air traffic are dependent upon the ability to accurately predict future aircraft positions. Trajectory predictions in en route airspace rely upon the availability of aircraft state, aircraft performance, pilot intent, and atmospheric data. The use of real-time airline information for improving ground-based trajectory predictions has been a recent focus in the development of the Center-TRACON Automation System (CTAS) at NASA Ames. This paper studies the impact of airline flight-planning data on CTAS en route climb trajectory prediction accuracy. The climb trajectory synthesis process is first described along with existing input data. Flight–planning data parameters, available from a typical airline operations center, are then discussed along with their potential usefulness to CTAS. Results are then presented to show the significant impact of airline-provided takeoff weight, speed-profile, and thrust calibration data on CTAS climb trajectory prediction performance.

Introduction

In order to assist with Air-Traffic Management (ATM) under capacity-constrained conditions, the Center-TRACON Automation System (CTAS) has been developed at NASA Ames Research Center. CTAS includes a collection of software decision-support tools that enhance situational awareness and provide clearance advisories to assist controllers in separating, scheduling, sequencing, and spacing aircraft in en route and terminal airspace.

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The en route CTAS tools, which have been evaluated in the field, include the Traffic Management Advisor (TMA), the En route Descent Advisor (EDA), and Conflict Prediction and Trial Planner (CPTP). TMA generates schedules and sequences for aircraft transitioning from en route to terminal airspace, subject to airport capacity constraints. EDA assists controllers in developing efficient, conflict-free, descent advisories to deliver aircraft to the Center-TRACON boundary in accordance with TMA schedules[1]. CPTP assists with the identification and resolution of conflicts for all aircraft, whether in climb, cruise, or descent[2].

Together, the CTAS tools are designed to maximize airspace and airport capacity while improving the overall efficiency of flight operations. A central capability of CTAS, which provides the foundation for all CTAS tools, is the ability to accurately predict the future spatial and temporal position of each aircraft in the airspace over a range of look-ahead times. This capability is provided by the Trajectory Synthesizer (TS) module, often referred to as the CTAS "computational engine"[3].

The accuracy of trajectory predictions in en route (Center) airspace impacts ATM conflict predictions and Estimated Times of Arrival (ETAs) to control fixes[4]. Preliminary studies have shown that trajectory uncertainties can significantly effect the schedules and maneuver advisories that CTAS generates to manage traffic flows and resolve separation conflicts[5]. For the airspace user, inaccurate trajectory predictions may result in less-than-optimal maneuver advisories in response to a given traffic management problem. These include *missed advisories* and *false advisories.* Missed advisories refer to the lost opportunity of resolving a traffic management problem in a manner most efficient to the airspace user. An example of a missed advisory is the failure to resolve a conflict between two aircraft at the earliest opportunity, requiring the least amount of fuel-burn between them. False advisories refer to the suggestion of an unnecessary maneuver that may cause an aircraft to depart from its most efficient, or user-preferred, trajectory. An example of a false advisory occurs when an aircraft is vectored unnecessarily off its filed or preferred flight path in response to a false conflict alert. Although false and missed advisories can result in lost efficiency to user operations, they do not compromise safety. This is because ATM decision support tools involve long-range strategic trajectory predictions that are frequently updated and used by the service provider to continually reassess the traffic situation. Traffic management problems that are not resolved at the earliest, or most desirable, time can be expected to be resolved at a future time, but at the expense of user efficiency and controller workload. In addition to limiting user and ATM efficiency, inaccurate trajectory predictions also waste airspace capacity by forcing the controller to apply larger than required separation buffers in response to position uncertainties.

A limiting factor in the accurate prediction of aircraft trajectories is the difficulty in obtaining precise trajectory calibration and intent data for individual flights. Trajectory calibration data refers to aircraft state, aircraft performance, and atmospheric characteristics that influence the external forces acting on the aircraft. Trajectory intent information includes the anticipated route, speed profile, and maneuvering procedure of the aircraft over the trajectory prediction time horizon. The pilot, in concurrence with ATM clearance instructions, ultimately establishes the trajectory intent of a given flight.

The En route Data Exchange (EDX) research program at NASA Ames is addressing the exchange of trajectory information between the airspace user and the air traffic control system. The initial objective of EDX is to improve CTAS en route trajectory predictions by obtaining timely calibration and intent data from user systems. In an operational environment, user information can be acquired from either ground-based or airborne sources. Ground-based sources, which can readily provide pre-departure flight-planning data, include Airline Operational Control (AOC) centers and Flight Service Stations. Airborne data sources include the Flight Management System (FMS) and other avionics systems that can provide post-departure data through air-ground data link. In the interest of exploiting currently available technology and minimizing cost, EDX will consider obtaining trajectory data from ground-based resources, prior to focusing on aircraft systems and data link capabilities.

This paper describes an initial EDX study to investigate the potential improvement that AOC flight-planning information offers to CTAS climb trajectory predictions. In support of current CTAS en route tools, accurate climb predictions are necessary in order to probe for conflicts and issue direct-route clearances that enhance user efficiency by shortening flight time. The algorithms and input data used in the current climb trajectory prediction process are first described, followed by a description of pertinent data elements that are either available or derivable from AOC flight-planning resources. Results are then presented which show the operational range of AOC trajectory parameters and their impact on the accuracy of CTAS climb predictions.

TS Algorithms and Existing Input Data

The CTAS TS uses a simplified set of point-mass aircraft equations of motion for generating four-dimensional (4D) trajectories consisting of aircraft position (x-y) and altitude over range of future times. In Center airspace, new predicted trajectories are generated for all aircraft in the airspace following each complete radar sweep (12 seconds). Trajectories are generated by integrating between predefined waypoints, defined by the current aircraft position, filed flight plan route, and airspace description data. The simplified equations of motion used by the TS, described fully in Reference 6, are given by

$$dh / dt = \gamma_a V_T = \gamma_i V_G \qquad (1)$$

$$V_G = U_W \cos(\delta_G - \delta_W) + V_T \cos(\sin^{-1}(U_W \sin(\delta_G - \delta_W) / V_T)) \qquad (2)$$

$$dV_T / dt = (T - D)/ m - g\gamma_a - g\gamma_i V_T \; dU_w / dt \qquad (3)$$

where h is geometric altitude; m is the aircraft mass; g is acceleration due to gravity; U_W is wind speed; V_G is ground speed; V_T is true airspeed; δ_W and δ_G are the wind direction and ground speed direction, respectively; γ_a and γ_i are the aerodynamic and inertial flight path angles, respectively; T is the aircraft thrust; and D and is the aircraft drag.

To simplify the prediction process, the horizontal and vertical components of the trajectory are de-coupled. First, an approximate vertical profile is computed in order to compute true airspeed as a function of path distance. This approximate speed profile is then used to calculate turn radii used in the synthesis of the horizontal trajectory, consisting of a series of straight-line segments connected by constant radius turns. This horizontal trajectory is then used as the basis for computing the actual vertical profile.

For computing undelayed trajectory positions and waypoint ETAs for en route climbs, the TS first checks to see if there is a company-preferred speed profile available from static files. Company-preferred profiles are typically defined for each aircraft type, but are not tailored specifically for individual flights. In absence of any known ATM constraints or clearances, these company speed profiles, together with the filed flight-plan, communicate trajectory intent. In general, climb speed profiles are defined in terms of a constant Calibrated Airspeed (CAS) segment and a constant Mach segment. In flying this profile, a pilot/FMS will hold a constant CAS and variable Mach until the specified profile Mach number is reached. At this point the pilot/FMS will transition to a constant Mach/ variable CAS profile to continue the climb. The altitude at which this transition takes place is typically near 27,000 ft for most jets, depending on the chosen CAS/Mach speed profile and atmospheric conditions. A typical CAS/Mach climb profile is illustrated in Figure 1.

The inputs to CTAS 4-D trajectory predictions can be characterized in terms of calibration, intent, and constraint data types. Specific data elements and data sources used in this process are summarized in Table 1.

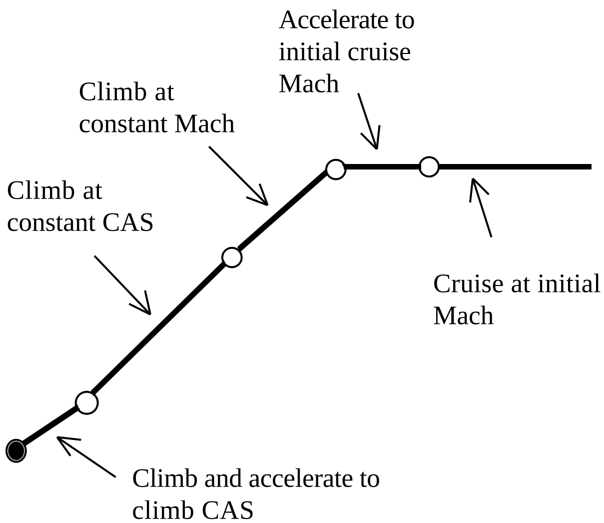


Figure 1: General CAS/Mach Climb Profile

Table 1. Current Climb TS Data Inputs and Sources

Data Classification	Data Input	Data Source
Calibration		
Aircraft state	Position, altitude	ATM Host computer
Aircraft performance	Drag , thrust	CTAS performance model
Atmospheric	Wind speed, temperature, pressure	NOAA RUC model
Intent		
Flight Plan	Route waypoints, cruise altitude, cruise speed	ATM Host computer
Company speed profile	Climb CAS/Mach	CTAS files
Constraint		
Procedural	ATM/airline speed, altitude, and route constraints	CTAS files
Performance	Aircraft speed and altitude envelope constraints	CTAS files
Traffic management	Route constraints due to conflict avoidance	CTAS advisories

Calibration Data

Calibration data includes current and predicted aircraft and atmospheric properties that effect the accuracy of trajectory predictions. This data, described in general in Reference 7, is crucial for calibrating ground-based trajectory predictions with those performed by an aircraft FMS using the latest airborne information. Calibration data includes current aircraft state and performance information along with atmospheric conditions along the flight path.

State data, consisting of inertial position, altitude, speed, and heading, is used to initialize the trajectory prediction process for each aircraft. This data, currently obtained from the FAA Center Host computer, is derived from surveillance radar and Mode C altitude returns every 12 seconds.

Performance data is used in calculating the aerodynamic, propulsive, and gravitational forces acting on the aircraft. Aerodynamic drag forces are computed from drag coefficients stored in CTAS files for each aircraft type. In general, the total drag coefficient is calculated by summing the composite coefficients attributed to the clean airframe, flaps, speed brakes, and landing gear. Propulsive performance data, also stored in static CTAS files, allows for the calculation of thrust and fuel-flow as a function of airspeed, altitude, and engine control setting. In particular, the propulsive model data allows for the computation of maximum and idle thrust as a function of aircraft and atmospheric state for use in climb and descent trajectory predictions. The gravitational force is based on the estimated weight of the aircraft, stored in a static CTAS file. For climb predictions, CTAS currently uses a nominal estimated takeoff weight, which is identical for all aircraft of a given type. This is clearly a gross approximation since there is no accounting for real-world payload differences. The CTAS TS, however, does employ an adaptive algorithm that is capable of decrementing the nominal weight estimate in response to altitude envelope limitations.

Atmospheric information for CTAS en route trajectory predictions is obtained from the National Oceanic and Atmospheric Administration (NOAA). CTAS accesses 1-hour forecasts from the NOAA Rapid Update Cycle model to obtain horizontal wind speed, temperature, and pressure. This data is available in a 3-dimensional (3D) grid defined by a horizontal resolution of 40 km and a vertical resolution of 25 mb pressure altitude. The CTAS TS linearly interpolates between the RUC 3D grid points at each integration time step along the predicted trajectory[8].

Intent Data

Intent data consists of information associated with the intended flight path of an individual aircraft. This includes the originally filed flight plan amended by any ATM clearance instructions. Filed flight plan data includes the identification of horizontal waypoints that define the intended route of flight, along with the intended cruise speed. Intent data also includes company-preferred speed profiles for climb and descent. In the current CTAS, company-preferred speed profiles are represented by a desired climb/descent CAS. This CAS value is used to compute a companion Mach number for flights with an initial/terminal cruise altitude above 27,000 ft. Together, the CAS/Mach pair defines the nominal speed profile for undelayed climbs and descents.

Constraint Data

Constraints effecting the trajectory prediction process can be placed into three categories: performance, procedural, and traffic-management. Flight path constraints will override flight path intent/preference. Performance-related constraints, defined originally by the user and stored in CTAS files, establish the allowable speed and altitude envelop for each aircraft type. These speed and altitude constraints are used to limit the range of controller advisories generated by CTAS. Procedural constraints may include any combination of speed, altitude, or heading restrictions imposed by ATM regulations or airline company policy. Procedural constraints used by CTAS are stored within CTAS files and are specific to the airspace and airports to which CTAS has been adapted. Finally, traffic-management constraints are those generated internally within CTAS in response to scheduling advisories or conflict avoidance resolutions. For example, in the case of descent metering, TMA may generate a scheduling constraint for a given flight in the form of a meter fix crossing time. The iterative solution used in calculating a conflict-free trajectory that satisfies this scheduling constraint is managed by the EDA tool. EDA invokes the CTAS TS as needed to perform this function.

AOC Flight Plan Data

The primary limitation of current CTAS airline data is that it represents nominal performance and preference characteristics for all aircraft of a given type, without considering variations associated with specific flight operations or aircraft sub-types. Flight-specific pre-departure data, used by CTAS, is currently limited to flight plans available from the FAA Host computer. The ATM flight plan is limited to a broad description of aircraft type, expected route waypoints, and anticipated cruise altitude and airspeed. Detailed operational flight plans, available from AOC centers, can provide a rich source of calibration and intent data for improving ATM trajectory predictions, especially for en route climbs (above 10,000 ft). This data includes such items as aircraft weight, thrust and drag performance factors, and speed profile intent.

In addition to improving the accuracy of ground-based predictions, the receipt of AOC flight-planning data can allow the air traffic system to be more responsive to airline operational preferences. Pre-departure intent data provided by the AOC represents the preferred speed and routing for an individual flight, in absence of any unknown ATM, weather, or airspace restrictions. Airline trajectory preferences may be tailored to the fuel performance of an individual flight, or to the overall schedule efficiency of the airline as a whole. With better knowledge of the trajectory preferences associated with individual flights, ATM automation can more effectively accommodate airline operational considerations into traffic management advisories.

AOC calibration and intent data, useful for improving climb prediction performance, is presented in Table 2. These data items are known to be either directly available from existing AOC operational flight plans or thought to be derivable from the AOC flight-planning process[9]. The usefulness and availability of each parameter to CTAS is described as follows.

Table 2. Potential AOC Data for ATM Climb Trajectory Enhancement

Data Classification	Data Element
<u>Calibration</u>	· Specific airframe type · Specific engine type · Estimated takeoff weight · Engine thrust factors · Aircraft drag factors
<u>Intent</u>	· Intended/preferred climb speed profile (CAS/Mach) · Intended/preferred climb acceleration procedure · Intended/preferred takeoff throttle setting

<u>Airframe and Engine Type</u>

The explicit airframe and engine type specification are known by the AOC and incorporated in their flight planning. This information could be sent to CTAS to identify specific aircraft sub-types (e.g. B737-400 vs. B737-800) and engine fits (i.e. identical airframes fitted with different engine types). This information could then be used by CTAS to select more specific drag and propulsive models for use in the TS process.

<u>Estimated Takeoff Weight</u>

The estimated aircraft gross weight at takeoff is easily obtained from standard AOC operational flight plans. Climb trajectory synthesis is extremely sensitive to errors in takeoff weight, especially at higher altitudes near top-of-climb (TOC). Indeed, the absolute altitude ceiling for a given airframe/engine configuration will be determined solely by the aircraft gross weight. Without knowledge of takeoff weight on a per-flight basis, ATM decision-support tools are forced to apply an average takeoff weight to all aircraft of a given type. This is clearly a crude approximation due to the uncertainties associated with fuel, passenger, and cargo weights. In addition, the weight of the empty airframe may change over time due to equipment installation/removal.

For scheduled, non-chartered flights, the passenger and cargo weights are not typically well known by the AOC within the flight-planning time horizon prior to departure. The fuel weight, however, is usually well known by the AOC pre-departure, although last-minute adjustments can be made at the pilot’s discretion. Total planned fuel weight is a function of the anticipated duration of the flight as well as other factors that influence the amount of extra fuel carried for holding, alternative routing, and ferry transport. Ferried fuel is that to be used for future flight legs. Airlines often ferry fuel from locations where fuel prices are cheapest.

<u>Thrust and Drag Calibration Factors</u>

Certain AOC centers may take advantage of additional airframe-specific factors for computing thrust and drag performance. Thrust calibration factors, beyond the engine type specification previously discussed, can include an indication of how an airframe-specific engine is performing. In particular, knowledge of any degradation in thrust output or fuel consumption may be obtainable from AOC databases[9]. Similarly, drag performance factors may include any known changes in the drag characteristics associated with an individual airframe. It is likely that AOC centers will have knowledge of these characteristics from their analysis of in-flight performance data[10].

Climb Speed Profile

Climb speed profile, as described in the previous section, is fundamental to ATM climb trajectory predictions in en route airspace. In the current CTAS model, this parameter does not account for operational variations among individual flights. Although the pilot has the final authority in determining which CAS/Mach speed profile is flown, the AOC could provide a recommendation based upon operational considerations. For example, the importance of making up for lost time due a schedule slip will influence the decision to choose a profile that maximizes climb rate as opposed to maximizing fuel efficiency. For FMS-equipped flights, this recommendation is commonly issued by the AOC in the form of a cost index for climb power management.

Climb Throttle Setting and Acceleration Procedure

Climb throttle setting is a variable that determines aircraft thrust and is set at the discretion of the pilot in compliance with company procedures. For example, many airlines recommend reduced takeoff and climb thrust settings, when feasible, in order to prolong engine life and reduce maintenance costs. Other climb procedure data, potentially available from the AOC, includes the preferred procedure for accelerating from the TRACON speed, below 10,000 ft, to the initial en route climb speed, above 10,000 ft. The pilot may choose to perform this acceleration in level flight or during the climb, depending on operational objectives. Although secondary in importance to speed profile, these additional intent parameters, if well established by the AOC, could be sent to ATM to further improve climb prediction accuracy.

Results

The following results indicate the potential improvement that AOC flight-planning data has on CTAS climb trajectory predictions. In particular, the actual or anticipated impact of AOC takeoff weight, speed profile, and thrust calibration data on CTAS trajectory synthesis is examined.

Weight

Based on data collected from two major airlines, the observed operational range in takeoff weight among a variety of common aircraft types is shown in Table 3. This data was collected from AOC flight plans during the months of March and April 1999 for operations departing from Dallas/Ft. Worth Airport and Denver International Airport. Takeoff weight estimates for approximately 8,000 operations were obtained. The results in Table 3 show maximum variations of up to 50% of mean takeoff weight for certain aircraft types.

Table 3. Observed Variation in Takeoff Weight Among Common Aircraft Types

Aircraft type	Mean weight (1b)	Std. dev. (% of mean)	Min. weight (% from mean)	Max. weight (% from mean)
B727	159,700	6.8	-22.9	+14.3
B737	118,500	4.5	-8.8	+9.6
B747	567,700	3.9	-4.0	+6.8
B757	192,500	6.4	-23.8	+37.2
B767	341,800	15.0	-26.8	+19.3
B777	424,400	5.2	-9.3	+8.6
DC10	448,100	20.1	-29.3	+36.6
A319	126,000	6.5	-11.4	+15.1
F100	87,400	5.8	-20.6	+34.4
MD11	416,500	3.4	-3.5	+3.1
MD80	129,900	7.1	-27.0	+51.6

The potential impact of the observed weight deviations in Table 3 on CTAS climb performance was calculated using a stand-alone version of the CTAS TS. A single climb prediction, with a 40 minute look-ahead time, was performed as each aircraft passed through an altitude of 10,000 ft. The expected range of real-world climb performance due to weight variation was compared against the current nominal CTAS prediction. The nominal CTAS prediction was computed using a static weight estimate, thought to be representative of the general aircraft type. Figure 2 shows the climb performance of a B757 for the observed maximum and minimum AOC weight estimates. The altitude profile, altitude error, and path distance error time-histories in Figure 2 are show in

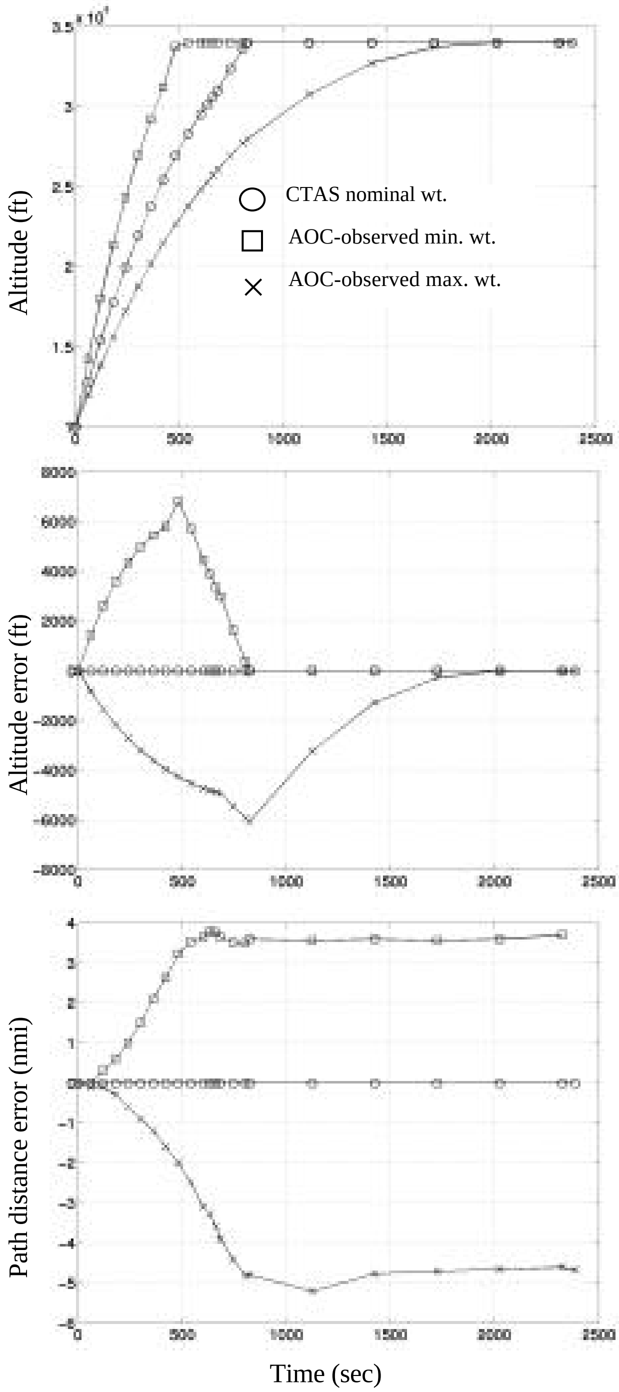


Figure 2: Potential Impact of Observed Weight Variation on B757 Climb Trajectory Synthesis

comparison with the nominal CTAS trajectory, using the generalized weight estimate.

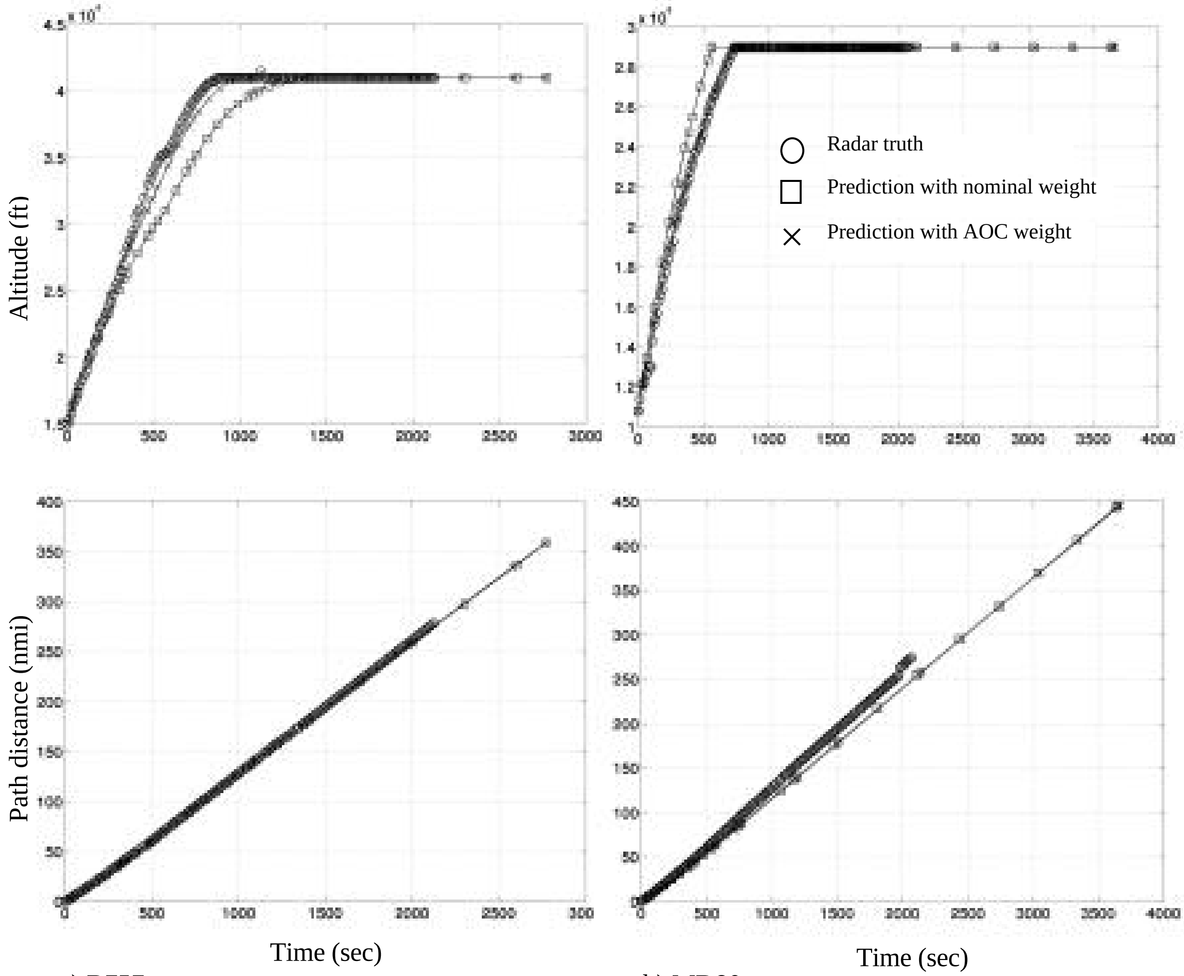
Table 4 summarizes the effect of observed takeoff weight variation on climb performance among the aircraft types for which data was obtained from the AOC centers. In Table 4, the metrics chosen to represent climb performance in comparison with nominal CTAS trajectories are: 1) maximum altitude error over the prediction time horizon, 2) maximum longitudinal path distance error over the prediction time horizon, 3) time required to reach TOC, and 4) longitudinal path distance required to reach TOC. The purpose of Table 4 is to show "worst case" scenarios, not typical CTAS errors, in comparing trajectory predictions with and without AOC data exchange. For this purpose, the extreme minimum and maximum weight observations from the AOC data were used. In generating Table 4, terminal altitudes were chosen as representative operational cruise altitudes for each aircraft type. In the event that the cruise altitude was beyond the operational ceiling for the heaviest aircraft using the current CTAS performance model, the target altitude was lowered accordingly. It should be noted that in the case of the B737, B747, and A319 aircraft types, the CTAS nominal weight estimates did not fall within the range of operational weight estimates obtained from AOC data over the recording period. This indicates the existence of obvious modeling inaccuracies that could be corrected with the data from this experiment.

The results in Table 4 show significant potential errors in CTAS climb predictions due to observed variations in takeoff weight. Potential peak altitude errors of nearly 10,000 ft are shown for the B747 and B767 aircraft. Peak longitudinal errors in the climb of 15 nmi. or more are shown for the B747, DC10, and MD80 aircraft. Table 4 also indicates a dramatic potential variation in time and distance to TOC for these aircraft types – up to 35 minutes and 230 nmi.

In order to show improvement in climb trajectory prediction accuracy with the inclusion of AOC weight estimates, predicted climb profiles were compared against actual radar track data. This was accomplished by extracting radar track data from CTAS archives and matching it with flights for which AOC takeoff weight data was obtained. In order to make the trajectory predictions valid, wind and temperature data files, relevant to the flights of interest, were also retrieved from CTAS archives. Finally, care was taken to ensure that flights selected for this analysis did not get their

Table 4. Potential Effect of Weight Variation on Climb Trajectory Prediction

Aircraft type, target cruise altitude (10^2 ft), and min/max observed takeoff weights (lb.)	Max altitude error from nominal CTAS climb trajectory (ft)	Max path distance error from nominal CTAS climb trajectory (nmi)	Time to TOC (sec)	Path distance to TOC (nmi)
B727				
Target cruise alt: 330				
Min wt. (123,240)	4,830	3	650	76
Max wt. (182,500)	-1,620	-1	1,220	145
B737				
Target cruise alt: 290				
Min wt. (108,100)	-760	-0.7	890	95
Max wt. (129,900)	-4,360	-6	1,540	168
B747				
Target cruise alt: 270				
Min wt. (544,800)	-6,860	-7	1,320	139
Max wt. (606,100)	-9,160	-16	3,060	332
B757				
Target cruise alt: 340				
Min wt. (146,780)	6,830	3.8	490	57
Max wt. (264,140)	-6,030	-5	1,880	230
B767				
Target cruise alt: 350				
Min wt. (250,250)	9,770	5	460	54
Max wt. (407,850)	-1,070	-0.7	1,160	139
B777				
Target cruise alt: 340				
Min wt. (385,100)	800	0.9	950	106
Max wt. (461,000)	-4,430	-7	1,980	230
DC10				
Target cruise alt: 320				
Min wt. (316,860)	3,600	2	350	36
Max wt. (612,100)	-8,880	-14	2,440	259
A319				
Target cruise alt: 350				
Min wt. (111,600)	6,590	4	480	53
Max wt. (145,000)	1,530	0.9	700	78
F100				
Target cruise alt: 310				
Min wt. (69,480)	5,530	5	540	59
Max wt. (117,511)	-3,690	-7	1,820	204
MD11				
Target cruise alt: 320				
Min wt. (401,788)	-380	-0.5	890	98
Max wt. (429,473)	-2,150	-3	1,070	118
MD80				
Target cruise alt: 310				
Min wt. (94,800)	5,440	4	390	42
Max wt. (196,931)	-8,630	-15	2,390	270



a) B757 b) MD80

Figure 3: Example of Improvement in CTAS Climb Prediction with AOC Weight Estimate for B757 and MD80

climb profiles interrupted in any way by unexpected ATM clearance instructions. Figure 3 shows an example of corroborated climb trajectory enhancement with AOC weight data, for specific flights of a B757 and MD80.

Although most of the TS predictions showed improvements similar to those in Figure 3, a few predictions proved to be less accurate with the inclusion of AOC weight estimates. This is likely due to inaccuracies in current CTAS engine models. This points to an important requirement of matching accurate weight estimates with more precise aircraft thrust performance modeling.

<u>Speed Profile</u>

In order to show the impact of speed-profile variation on CTAS trajectory synthesis, climb profiles are shown in Figure 4 for a ±10% variation in CAS/Mach. This off-nominal value was chosen only to show TS sensitivity to speed profile error. A more precise measurement of actual speed-profile variation for real-world operations remains a subject for further study.

The altitude and path distance error profiles in Figure 4 shows peak errors of 2,700 ft and 25 nmi, over the duration of the climb. This shows that longitudinal error is highly sensitive and grows with time due to CAS/Mach variation. This analysis points to the importance of obtaining flight-specific

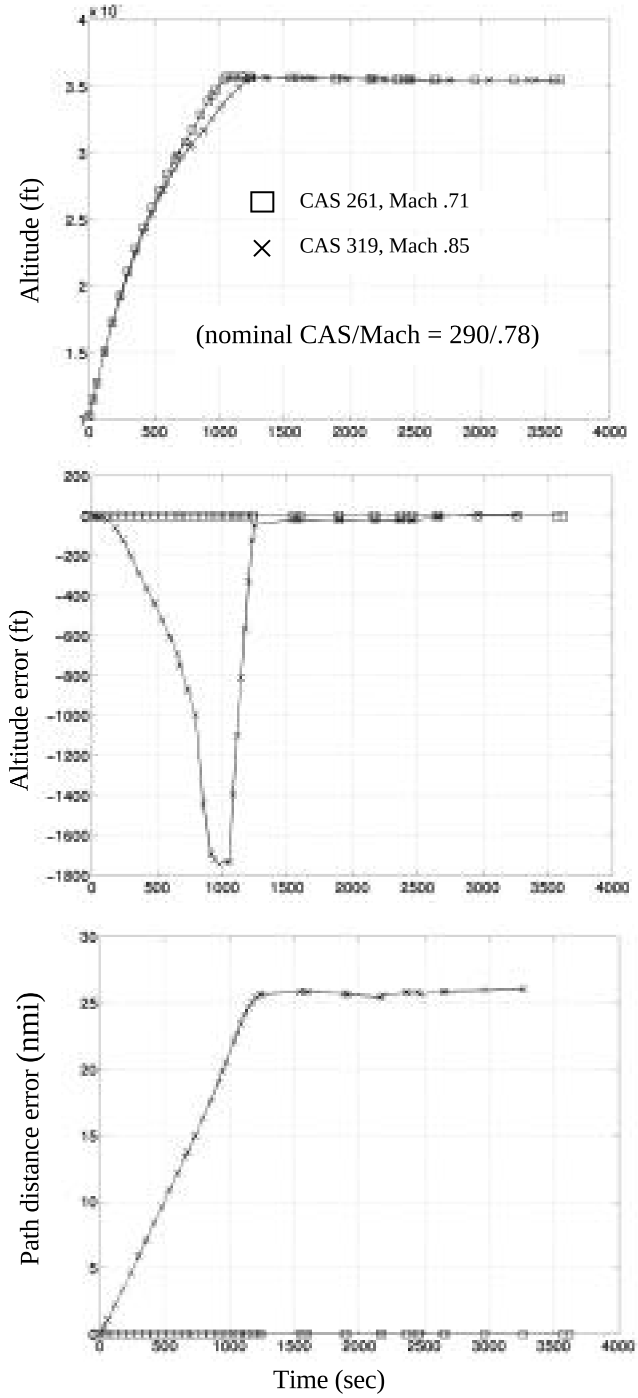


Figure 4: Potential Impact of ±10% CAS/Mach Variation on B767 Climb Trajectory Synthesis

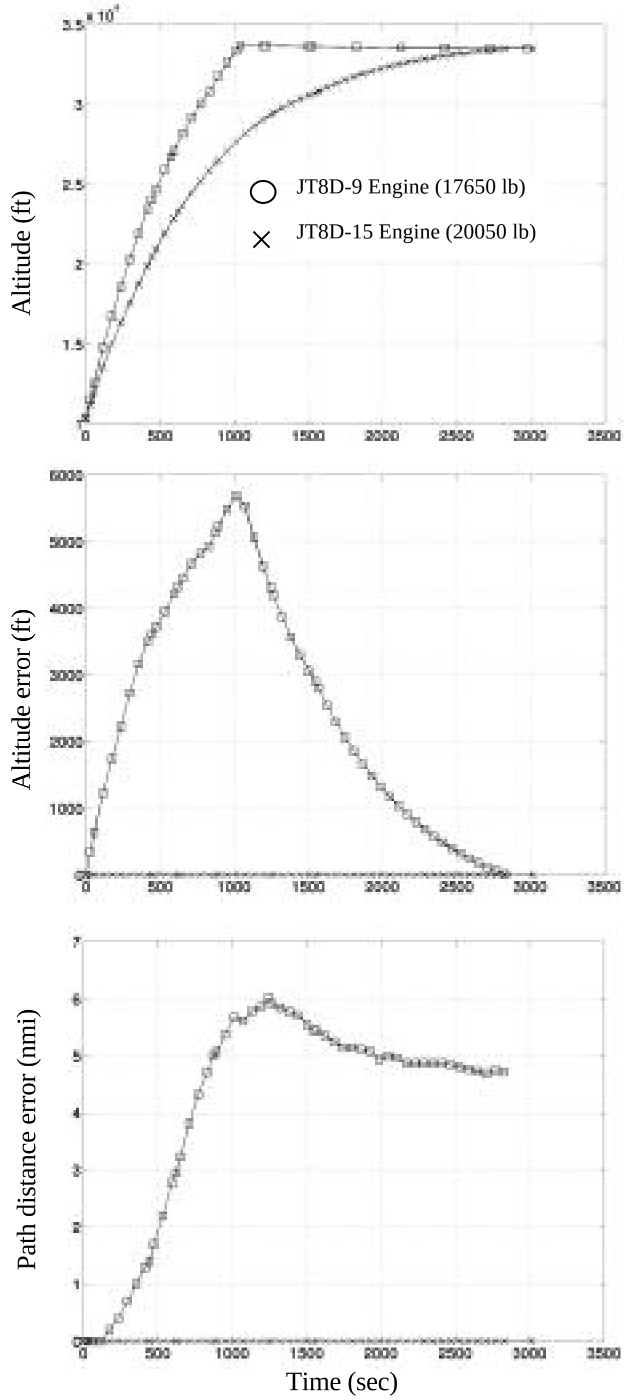


Figure 5: Potential Impact of Engine Fit on B727 Climb Trajectory Synthesis

CAS/Mach speed profiles from the AOC or aircraft systems in order to significantly improve ATM climb prediction accuracy.

Climb Thrust

The potential influence of engine fit on ATM climb prediction is shown in Figure 5, based upon an AOC-reported average climb thrust variation of approximately 12% for two different engine types for the B727. The results in Figure 5 were generated for identical weights and climb speed profiles. The altitude and path distance error profiles show peak errors of 5,700 ft and 6 nmi, respectively, for a 12% variation in climb thrust

Conclusion

The CTAS climb trajectory prediction process has been described along with current input data for establishing trajectory calibration and pilot intent. Current input data has been shown to be broadly defined for generic aircraft types and nominal airline preference, without taking into account the operational considerations of specific flights or performance variations among individual aircraft of a given type. Flight-planning data from AOC centers offers substantial improvement in en route climb prediction accuracy, promising capacity and efficiency benefits for the airspace user. In particular, AOC-provided takeoff weight, speed profile, and engine type specification can significantly reduce climb trajectory uncertainty. Although the results of this analysis indicate dramatic potential benefits of including AOC performance and intent data in the ATM trajectory prediction process, aircraft performance models must be of sufficient fidelity in order to appropriately benefit from airline information.

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