

# AIRCRAFT PERFORMANCE MODELING FOR AIR TRAFFIC MANAGEMENT APPLICATIONS

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## Abstract

The future of the Air Traffic Management (ATM) system is based on a top-down and performance driven approach that sets quantifiable and measurable performance targets in the four ATM key performance areas: Safety, Capacity, Efficiency, and Environmental impact. Like in any other management system, the performance of the ATM system is directly related to the accuracy with which the future evolution of the traffic can be predicted.

The objective of this paper is to illustrate the important role of an accurate aircraft performance model in achieving this goal. Cooperation between the aircraft manufacturers that provides the reference performance data and the team that perform the modeling for ATM applications is essential. This paper describes the advances in aircraft performance modeling achieved and proposes direction for future development. The user requirements are identified that affect the choices to be made. The practical limitations that the potential providers of source data experience are discussed as well.

## Introduction

In legacy systems flight profile prediction functions most often require a simple aircraft performance model comprising average performance in given altitude bands. Different aircraft types are grouped into “classes” of similar performance. More complex performance models are often required in the flight simulation tools that drive the ATC simulation platforms.

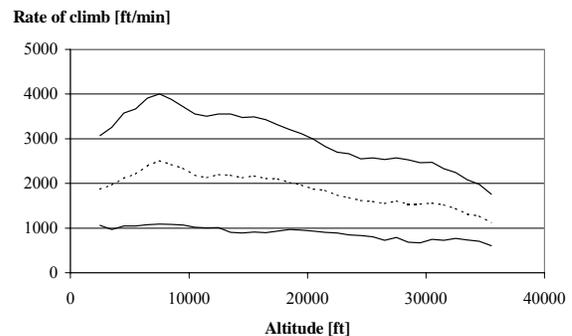
Efficient ATM requires the strategic, real-time planning of traffic flows and the capability of the aircraft to adhere to these plans. The introduction of accurate Decision Support Tools (DSTs) like Medium Term Conflict Detection functions (URET, MTCD, etc.) and Arrival and Departure Management

tools are essential. Such tools require a significantly higher quality for the predicted flight profiles than available in the Flight Data Processing Systems today. In this context, “quality” refers to both the accuracy and the time to compute a flight profile.

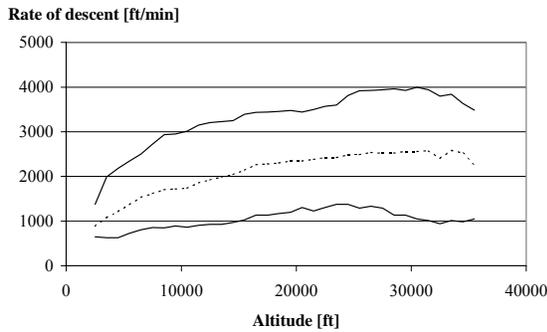
While accuracy of aircraft performance modeling is of significant importance in operational ATM applications, it is even more important to achieve it with a level higher in a simulated environment. The simulation tools can be based on mathematical model of an ATM environment or real-time simulation of existing or future systems.

## Aircraft Performance Data Impact in ATM Applications

Calculating the aircraft behavior in the vertical plane presents the greatest challenge. The accuracy of this calculation is very important because commercial flights often spend a significant amount of airborne time in climb and descent. Reference 1 reports on the variability of vertical speeds of commercial air traffic. Figures 1 and 2 depict the spread of vertical speeds observed from some 10,000 flights. The mean, 5<sup>th</sup> and 95<sup>th</sup> percentiles of the distribution of the vertical speeds for climbing and descending traffic are shown. The dotted line in the center of the graphs represents the mean values.



**Figure 1. Spread in Vertical Speed during climb**



**Figure 2. Spread in Vertical Speed during descent**

During climb, the vertical speed is closely related to the performance capabilities of an aircraft. Hence the spread gets smaller at higher altitudes. The vertical speed during descent is more related to aircraft operational conditions. Consequently the smallest spread is found at low altitude when the aircraft follows the glide slope.

The use of a reliable computer model of the aircraft characteristics, its performance capabilities and the operational flight envelope within which the aircraft can be safely operated should allow significant reduction of the spread.

### ***Sensitivity of Aircraft Performance to Variations in Take-Off Weight***

During the climb phase, for a given engine thrust setting, the mass of the aircraft has a major impact on the performance. In contrast, during descent, it is the aerodynamic drag that plays a dominant role.

Climb trajectory synthesis is extremely sensitive to errors in aircraft gross take-off weight (GTOW), especially at higher altitudes near top-of-climb (TOC). Without knowledge of take-off weight on per-flight basis, ATM DSTs has to apply an average (nominal) take-off weight to all aircraft of a given type leading to a crude approximation. There are uncertainties associated with fuel, passenger, and cargo weights. In addition, the operational empty weight (OEW) may change over time due to equipment installation or removal.

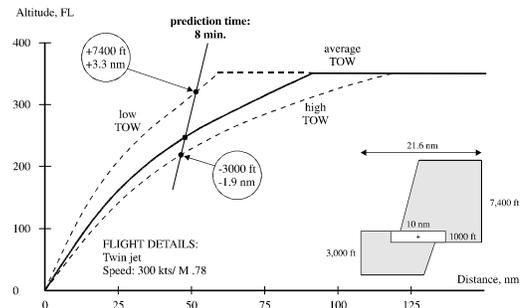
Based on data collected from Airline Operations Center (AOC) flight plans of two major airlines for operations departing from DFW and DEN (takeoff weight estimates for approximately 8,000 operations) for various aircraft types, it was demonstrated that same aircraft type (obviously depending on its final

destination) can show a variation of  $-27\%$  to  $+56\%$  of its mean GTOW. This in return could lead to variation of time to TOC (with target cruise altitude: FL310) from 390 to 2,390 sec and path distance to TOC from 42 to 270 nmi [2], [3].

Moreover, discussions with several airlines in The United States and Europe revealed that, at times, GTOW of the aircraft even recorded by AOC could be 5,000-6,000 lbs off the actual GTOW, which could lead to problems in rotation speed and achieving the altitude.

The capability to accurately estimate the aircraft weight is an important requirement for accurate trajectory prediction. Reference 4 reports on the practical problems to estimate the Take-Off Weight from flight plan data. Reference 5 provides some rules of thumb to make an educated guess based on the certified Maximum Landing Weight data. For on-line operation, more accurate estimates can be made available by the dispatching centers of the airlines and/or extracted from observed flight profile data through a “reverse engineering” process.

The impact of an uncertainty in take-off weight on the vertical climb performance is illustrated in Figure 3 from Reference 6 for a medium haul twinjet.

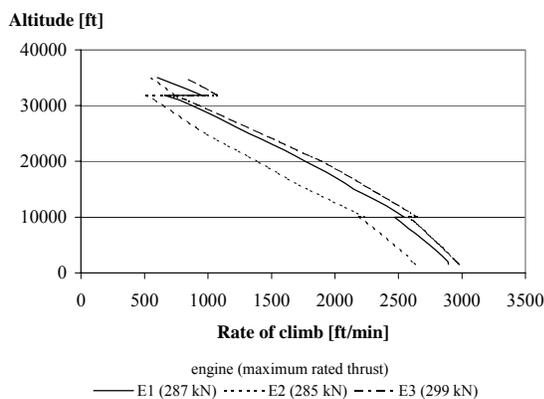


**Figure 3. Take-Off Weight Uncertainty Impact on the Climb Performance**

For the given conditions, the uncertainties in the flight profile can be summarized as 0.4 NM/minute-look-ahead-time in the horizontal plane and 900 ft/minute-look-ahead-time in the vertical plane. In particular, these results also illustrate how an uncertainty in the vertical plane directly affects the uncertainty in the horizontal plane.

## Aircraft Type Identifiers and Various Engine Types

ICAO maintains a list of aircraft type identifiers. Today almost 2000 different codes have been allocated. These type identifiers refer in the first place to the airframe. The same code may refer to different airframes if the variations are considered minor. However the same aircraft type can be delivered with different engines or engine versions. The resulting difference in performance can be significant. Figure 4 depicts the rate of climb of one airframe with different engine configurations. The difference in performance is sometimes greater than between different airframes in the same transport category.



**Figure 4. Performance of the Same Airframe with Different Engines**

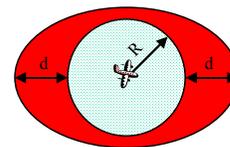
The introduction of the Mode S surveillance infrastructure provides the ATM world with the possibility to identify each individual airframe and, hence, the possibility to correlate this with the correct engine fit. Consequently, for the purpose of accurate flight profile prediction, it is required to apply a greater granularity in performance model identification than results from the ICAO type identifiers.

## The Volume of Protection

The uncertainty with which the future position of the aircraft can be computed by the Trajectory Predictor is characterized by two characteristics, namely the “Volume of Protection” (VoP) around the estimated position of the aircraft and the level of confidence that the aircraft will indeed be within this VoP. The VoP is the mathematical model with which most of the DSTs work. If no overlap of individual

VoP are found within the look-ahead time range, than it is concluded that no conflict exist.

The typical shape of the VoP in the horizontal plane is depicted in Figure 5. In a typical multi-radar environment the minimum size of the VoP is a circle with a radius of 2.5 NM around the observed aircraft position. The ultimate shape is an oval because the impact of the uncertainties in the along-track and across-track directions are different. The across-track error is limited by the accuracy of the navigation system of the aircraft that keeps the aircraft close to the route centerline. The along-track uncertainty increases linearly with the look-ahead time.



$R = 0.5 * \text{minimum separation distance}$   
 $d = \text{increase in Volume of Protection due to prediction uncertainty:}$   
 $d = \text{uncertainty} * \text{look-ahead time}$

**Figure 5. Dimensions of Volume of Protection**

In certain systems with inefficient trajectory prediction algorithms, Monitoring Aids are introduced to reduce the number of trajectory calculations required in real time. In that case the dimensions of the “monitoring window” need to be added to those of the VoP. In addition a Level of Confidence can be attributed to the VoP. This value identifies the level of confidence that the aircraft will indeed remain within the computed VoP

## Impact on System Capacity

Radar controllers constantly monitor the evolution of the traffic. When they discover a potential problem, the specific situation will receive special attention. When there is a reasonable certainty that minimum separation standard might become violated in the near future, then a tactical resolution is implemented.

DSTs work at a look-ahead-time, e.g. 20 minutes, which is significantly longer than that applied by a busy executive controller. Due to this extended time range, the dimensions of the Volume of Protection with which these tools work are significantly larger than those applied by Air Traffic Controllers. This results in the generation of warnings for problems that may not materialize at all:

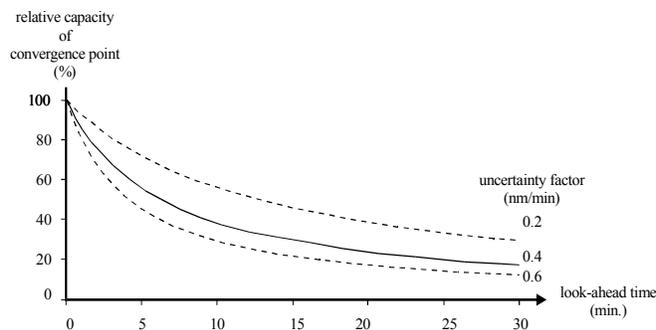
“false alerts”. The level of false alerts is critical for the operational acceptance of the Tool.

Reference 7 reports on the results of a series of fast time simulations. The simulations assumed a high quality of predicted trajectories based on an uncertainty in the horizontal speed of 0.13 NM/minute-look-ahead-time and 5 % uncertainty in the vertical speed. The requirement for the Confidence level was that, at the maximum look-ahead time of 20 min., 95 % of the conflicts must be detected. The results are shown in Table 1.

**Table 1. Frequency of False Alerts**

Look-Ahead Time (min)	False-Alert Rate (% of true conflicts)
5	70
10	125
15	160
20	200

For trajectory predictors that provide less accurate performance data the situation is even significantly worse. The planning process of the ATM tool has to consider the dimensions of the VoP around an aircraft rather than the minimum radar separation requirements at a give look-ahead time. In Figure 6 from Reference 6 the “loss of capacity” is illustrated for traffic that crosses at 90 degrees.



**Figure 6. Capacity Reduction due to Prediction Uncertainties**

For crossing situations at angles less than 90 degrees, the loss in capacity increases significantly. This is unfortunate, because the number of such traffic crossing situations in a “free route” environment increases compared to the fixed route situation. In practice, for DSTs, a compromise is

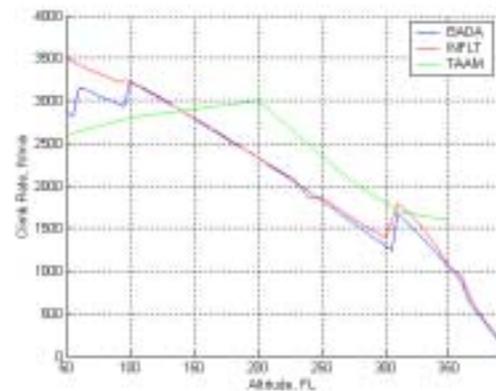
sought between the level of confidence that all potential problems will be detected within the target time horizon, the false alert rate that is acceptable by the controllers and the acceptable loss in ATM efficiency.

From the above, it is clear that the accuracy with which the future flight paths can be computed is paramount to the successful introduction of advanced DSTs in operational systems.

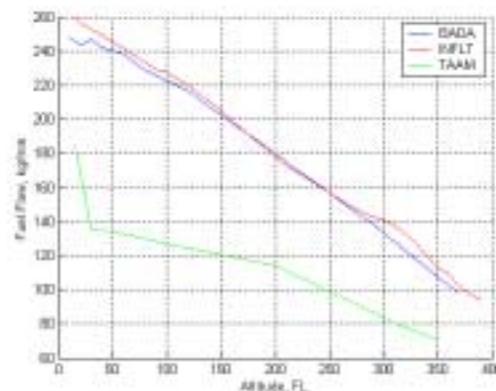
### ***Real and Fast-Time Simulations***

Fast-time simulations use techniques where all the elements of the ATM activities are modeled. The main output of an ATM fast-time simulation is the workload measurement of the controller, together with the metrics and indicators to assess the efficiency and safety. An example of it is TAAM.

Figures 7 and 8 illustrate Climb Rate and Fuel Flow of a medium-haul aircraft using TAAM data, BADA and INFLT (Boeing aircraft performance program).



**Figure 7. Rate of Climb Comparison**



**Figure 8. Fuel Flow in Climb Comparison**

Real time simulations are used for development and validation of new ATM concepts, ATC procedures, advanced controller decision support tools and equipment before they are introduced into operational service. Traffic simulations are also used for researching new control strategies for use in future Air Traffic Control Systems.

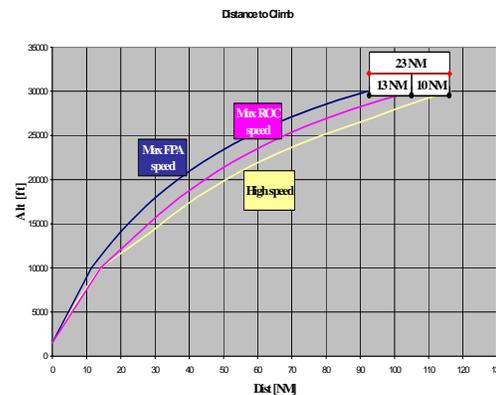
In general, the purpose of real time simulation is to: provide experimental data required for development of new ATM concepts; support the validation of the concept and provide information on the impact of change; assess safety, controller workload and acceptability of new system; estimate the economic and environmental impact.

Supported by an aircraft performance model, real time simulation is very important means to obtain acceptability, safety and workload measurements of the system under investigation. The conclusions based on the obtained measurements and responses from the controllers can only be as good as the realism of the simulation environment. Controllers participating in the experiment are asked to perform their operational task in the most realistic way in order to ensure the safe, orderly, and expeditious flow of (simulated) traffic through the managed sector. Identification of the problems, i.e. detection of potential losses of separation between aircraft; determination of a solution when a problem has been detected; decision making of which aircraft has to maneuver and the type of maneuver to be executed; implementation of the solution and monitoring of the implementation; are the main tasks that an ATCo performs. All of these tasks are closely related to the aircraft performance. Accurate aircraft performance model, capable of reacting to precise pilot actions and representing accurately the controller-pilot-aircraft loop is necessary for success of the experiment.

Within the experimental environment controller actions, responses and decisions are analyzed and results used to draw conclusions for future development. Final results of simulation are highly dependent on the accurate and operationally realistic simulation of aircraft movements.

To ensure operationally realistic behavior of aircraft in the simulation environment, another set of inputs has to be provided to the aircraft performance model in use. Namely, airline operational procedures defining how an aircraft type is operated by different airlines (speed schedules) and an accurate estimation

of initial aircraft weight (at brake release or at entry point of a simulated area). Both parameters significantly effect aircraft trajectory and can highly influence realism of the aircraft performances in the simulated environment. The importance of these aspects have been frequently reported by controllers during the past real-time simulation held at Eurocontrol Experimental Center (EEC) [8]. The impact of uncertainty in GTOW has already been shown. An example of how difference in speed can impact climb trajectory, in particular 3D position of TOC, for a medium haul jet aircraft at the same GTOW is presented in Figure 9. In this case, the difference in climb speed schedule (CAS/Mach) may lead to 10 to 23 NM difference in distance to climb from 1,500 ft to FL300.



**Figure 9. Climb Trajectory for Different Climb Speeds**

To avoid erroneous conclusions and move for operational implementation of a system based on real and/or fast time simulation without risking incurring losses instead of projected benefits, it is absolutely essential that we address aircraft performance modeling with much more significant level of detail than has been accomplished in the past.

## Aircraft Performance Models for ATM Applications

For ATM applications it may be assumed that the pilot controls the motion of the aircraft around the center of gravity and ensures the overall stability of the aircraft. Accordingly it is reasonable to consider the three dimensional motion of the aircraft, the mass being concentrated at the center of gravity.

Commercial flights are operated at relatively small flight path angles. This assumption facilitates a significant simplification of the set of equations of

motion that govern the movement of the aircraft in the vertical and horizontal plane. The vertical speed depends on the balance between the various forces acting on the center of gravity, namely thrust, drag, lift and weight. During the climb phase, for a given engine thrust setting, the mass of the aircraft has a major impact on the performance. During descent it is the aerodynamic drag that plays a dominant role.

### ***Manufacturers Reference Data***

The basis source data for the generation of aircraft performance models for ATM applications are the aircraft performance manuals produced by the aircraft manufacturers and/or the computer programs and databases that were used to generate these. An example of such program is INFLT/REPORT, Boeing Performance Software.

INFLT and REPORT were developed for operational in-flight data production. Data from these programs are used for the production of Operations Manuals, Flight Planning Performance Manuals and tabular data to support flight planning dispatch systems. INFLT and REPORT can be used to generate climb, cruise, holding, drift down, descent, optimum altitude, and simple flight planning data in a variety of formats ranging from Operations Manual formats to computerized formats suitable for follow-on analysis with customers' flight planning systems. Designed to be used in sequence, INFLT is the computational module while REPORT is the output listing module.

Depending upon the option selected, two or three general types of optional output reports are available. They include:

- Detailed, engineering output report suitable for in-depth study and evaluation;
- Tabular output report which replicates that typically contained in the Boeing Operations Manual;
- Computer sensible report compatible with that provided in the past to airlines-customers via magnetic tape.

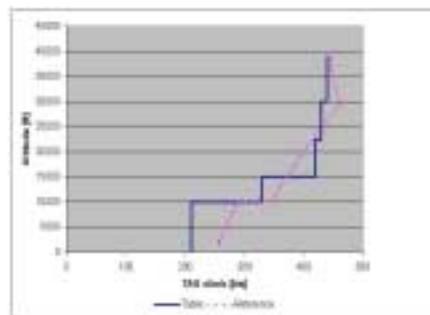
It is not practical at this stage to use the manufacturers models directly in ATM applications because of the dimensions of the database, the speed with which the flight profiles can be computed using these data, Intellectual Property (IP) Rights and other legal issues.

In effect, the aircraft performance models designed for ATM applications intend to compress the extent of the source data of the manufacturers (approximately 1 MB/aircraft) whilst providing a sufficiently accurate approximation of the aircraft performance within the normal operating envelope of the aircraft and facilitating fast flight profile calculations.

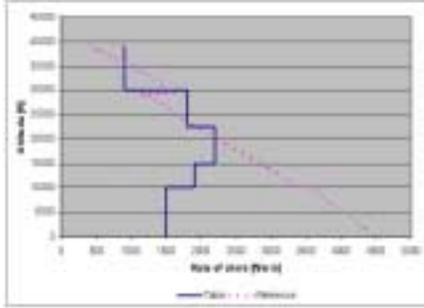
We will discuss three typical examples of ATM performance models: the BADA model, which is based on the kinetic method, and the GAME model and look-up-table models, which are both kinematic methods

### ***Look-Up Tables***

The look-up table approach is the oldest aircraft performance model developed for ATM applications. It is a kinematic model that is widely used in Flight Data processing Systems and the Flight Profile Prediction function that drive Flow Management applications. For example, the tables used in Flow Management applications at Eurocontrol provide for up to seven altitude bands, for each altitude range the average horizontal speed for climb, cruise and descent and the vertical speeds for climb and descent. Figures 10 and 11 depict the table data for a typical short haul aircraft. Average horizontal and vertical speed data are available for five altitude bands. The thick line shows the values in the tables and the selected altitude bands. The dotted line depicts the aircraft performance estimated by the aircraft performance program of the manufacturer for an average operational take-off mass.



**Figure 10. Look-Up Table for TAS vs. Altitude**



**Figure 11. Look-Up Table for ROC vs. Altitude**

The flight profile calculation algorithms used in this application compute the horizontal flight path on the basis the sequence of waypoints defined in the flight plan. Detailed Standard Instrument Departure (SIDs) or Arrival procedures (STARs) are not considered. Consequently there is a significant uncertainty in the path length at lower altitudes. For this application, the potential problems associated with this uncertainty are mitigated through a significantly lower estimate of horizontal and vertical speeds in the table.

The source data requirements for the table contents depend on the final application. Only “average” performance is modeled without considering meteorological conditions. The basic source data can be extracted from climb and descent tables as used by the aircraft operators. These data are often “tuned” for the specific application, e.g. in this example, the actual speed values at low altitude are significantly lower than the operational speeds, but this adjustment compensates for flight path length uncertainties. On the one hand, the accuracy that will be obtained is relatively low. On the other hand, the data processing requirements for flight profile calculation are extremely low due to the simplicity of the model.

## **BADA**

The vertical speed of an aircraft in flight depends on the balance between the various forces acting on the center of gravity, namely thrust, drag, lift and weight. The movement of the aircraft in the vertical and horizontal plane is governed by a complex set of differential equations. Commercial flights are operated at relatively small flight path angles. This assumption facilitates a significant simplification of the set of equations of motion. The methodology that is based on the independent modeling of thrust and drag is often referred to as the

“kinetic” approach. An example is BADA (Base of Aircraft Data) described in further detail later in this paper.

BADA is an aircraft performance database. It provides a set of ASCII files, which specify aircraft Operations Performance Model, Airline Procedure Model and performance summary tables for various aircraft types [9], [10]. The information provided in BADA is designed for use in trajectory simulation and prediction algorithms within the domain of ATM. All files are maintained within a configuration management system at EEC in Brétigny-sur-Orge, France.

Currently at 3.4 version, BADA covers nearly 90% of the European air traffic and provides operations and procedures data for a total of 252 aircraft types, including 3 generic models for military aircraft. For 80 of these aircraft types, data is provided directly in BADA files. These aircraft types are referred to as being directly supported. For the other 172 aircraft types, the data is specified to be the same as one of the directly supported 80 aircraft types. This second set of aircraft types is referred to as being supported through equivalence.

With exceptions for military aircraft, each supported aircraft type is identified by a 4-character designation code assigned by the International Civil Aviation Organization (ICAO).

The aircraft model behind BADA is a so-called Total Energy Model or TEM. It can be considered as being a reduced point-mass model. TEM equates the rate of work done by forces acting on the aircraft to the rate of increase in potential and kinetic energy, that is:

$$(T - D) V_{TAS} = mg \frac{dh}{dt} + m V_{TAS} \frac{dV_{TAS}}{dt}$$

Without considering the use of devices such as spoilers, leading-edge slats or trailing-edge flaps, there are two independent control inputs available for affecting the aircraft trajectory in the vertical plane. These are the throttle and the elevator. These inputs allow any two of the three variables of thrust, speed, or vertical speed to be controlled.

Besides TEM, the Operations Performance Model of BADA defines: the aircraft type, mass, flight envelope, aerodynamics, engine thrust, fuel consumption and ground movements. In total, fifty operations performance parameters (called BADA

coefficients) describe one, BADA aircraft performance model.

The Airline Procedure Model defines the speeds that are to be used during the climb, cruise and descent flight phases.

Reference aircraft performance and airline operating procedure data, required for modeling of an aircraft, is obtained from various aircraft documents provided by aircraft manufactures or aircraft operators. A number of reference climb and descent profiles, which specify, in either tabular or graphical form, the climb and descent performance of the aircraft at various mass, speed and temperature conditions are used. This integrated aircraft performance data specifying time, distance and fuel to climb or to descend is used to determine the values of thrust, drag and fuel flow coefficients in BADA.

In order to obtain coefficients that can robustly represent the aircraft behavior over a variety of conditions the following number of profiles is required:

- 3 descent profiles at ISA conditions for a nominal aircraft weight and minimum, nominal, and maximum descent speed;
- 9 climb profiles at ISA conditions for the low, nominal and high climb speed and representing minimum, nominal, and maximum aircraft weight;
- 3 climb profiles at ISA+10 conditions for the nominal speed and representing minimum, nominal and maximum aircraft weight;
- 1 climb profile at ISA+20 conditions for the nominal speed and aircraft weight;
- 1 cruise profile at ISA conditions for the nominal speed and aircraft weight.

A figure-of-merit,  $F_M$ , is defined in BADA to measure the accuracy of a BADA aircraft model.  $F_M$  includes measures of accuracy in both distance (X) and altitude (h). It is defined as:

$$F_M = \frac{[(\Delta X)_{\max} + (\Delta X)_{\text{rms}} + (\Delta h)_{\max} + (\Delta h)_{\text{rms}}]}{4}$$

For each trajectory, the goodness-of-fit between the calculation and the reference trajectory is measured. Maximum error terms are included since these are generally the main specification for a trajectory prediction efficiency. Root-mean-square error terms are included because it is believed that this improves the robustness of the selected

coefficients for prediction trajectories at conditions other than the reference conditions used. The modeling optimization criterion is that the average  $F_M$  over the different profiles be a minimum. A target value of 2.0 is set for nominal profiles, while maximum of 3.0 is generally acceptable for alternative speed, temperature and aircraft weight conditions. Most of the BADA aircraft models, in particular ones for which the requested number of reference flight profiles is made available by the aircraft manufacturers (e.g. INFLT/REPORT), result with  $F_M$  per reference profile lower than the target value (2.0 or 3.0). An example of the BADA aircraft model accuracy is given in Table 2. The table contains average error values (max and rms for distance and altitude) and resulting  $F_M$ 's over 13 climb and 3 descent profiles covering different speed, mass and temperature conditions for a long haul aircraft model in BADA 3.4.

**Table 2. Average Max and Rms Errors and  $F_M$  for the reference climb and descent flight profiles**

$(\Delta X)_{\max}$ %	$(\Delta X)_{\text{rms}}$ %	$(\Delta h)_{\max}$ %	$(\Delta h)_{\text{rms}}$ %	$F_M$
2.1	1.0	1.3	0.8	1.3

### GAME

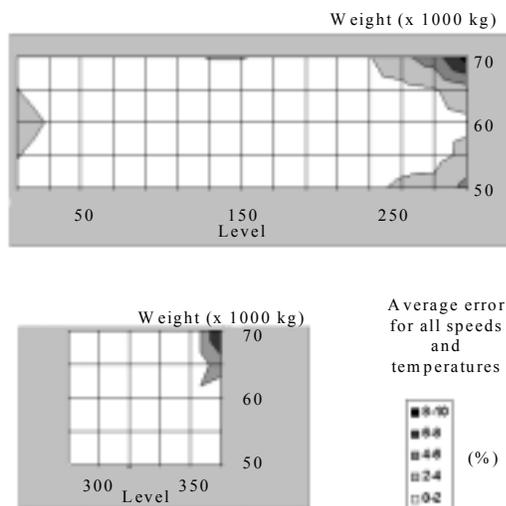
The GAME-model [11] is a kinematic model based on a purely parametric approach. In effect, the GAME approach is an upgrading and extension of the original EROCOA/PARZOC-model developed in the 70s.

The GAME method provides a direct model of the path characteristics of the aircraft without attempting to model the underlying physics. The functions for the approximation of the aircraft performance depend on the mode of flight, e.g. the polynomials that approximate the vertical speed during climb at constant CAS or MACH number are different, but both estimate the vertical speed considering engine thrust setting, aircraft weight, outside air temperature and pressure altitude. The mathematical functions will be the same for all aircraft types, but the coefficients used by these functions are specific for a given airframe/engine combination.

In the GAME method the “primary” flight path characteristics like vertical speeds and fuel flow in the various phases of flight and for different aircraft configurations are modelled and validated directly

from the reference flight profile data provided by the aircraft manufacturers. The “secondary” flight path characteristics, like estimates for acceleration and deceleration, are computed from the “primary” approximations. From the vertical speed data, the “performance term”, i.e.  $(\text{Thrust}-\text{Drag})/(\text{Weight})$ , can be readily computed. Subsequently the acceleration/deceleration performance can be easily computed. This approach provides accurate model of the aircraft behaviour without requiring additional validation steps.

An example of the average climb speed errors for the complete practical range of take-off mass, climb speeds and temperature profiles from ISA-15 until ISA+15 for a typical short haul aircraft is presented in Figure 12. The comparison is presented between the GAME functions to compute the vertical speed for the flight modes climb at “Constant CAS” and “Constant Mach” and the manufacturers performance program.



**Figure 12. Error Summary for Climb over the Entire Flight Envelope**

The validation of the GAME model is performed in two steps: In the first step an error analysis is made against the reference performance data provided by the manufacturers. The results cover the entire flight envelope. In a second step the integrated flight profiles computed with the GAME model are compared against the manufacturers profiles. In this process validation against observed flight profiles or those extracted from on-board recordings are also feasible.

Due to the simplicity of the kinematic method, the actual modeling process can be highly automated. Moreover, the kinematic approach applied in GAME provides implicit extensibility to include new aircraft operating methods in the future without compromising the obtained accuracy. Presently GAME system comprises some 100-approximation functions. A total of 28 aircraft types have been modelled so far, including most Boeing and Airbus aircraft, a military fighter and a helicopter.

The complexity of an accurate aircraft performance model like GAME is managed through the provision of an Application Program Interface (API) library, available for different programming environments. The source code of the library is generated by the GAME modeling software. Its application is fully integrated in the GAME validation process. Hence, for the client applications, an upgrade of the GAME performance database is limited to re-linking with the new library. No further validation by the client is required.

### Source Data

The source data for the look-up table model are minimal. The level of detail required is such that the information can be readily extracted from radar track recordings. Data defining the operational flight envelope can be extracted from sources like Janes Aircraft of the World.

The BADA and GAME models have identical data requirements. The ATM tool requirements for gate-to-gate applications require the calculation of all phases of flight, including ground movements. Accordingly, the source data required comprises flight data in clean and non-clean configurations. For current aircraft types these data are in principle available from the aircraft manufacturers. The conditions under which these will or can be made available are being negotiated. It is in the direct commercial interest of the aircraft manufacturers that the capacity of the ATM system be increased. Therefore a well-organized flow of basic aircraft performance data from the aircraft manufacturers to the ATM Aircraft Performance modelers is essential to ensure the quality of the computed flight profiles.

### Conclusions

In the future, the DSTs will make more efficient use of the operational flight capabilities of the aircraft. A good estimation of the locus of the operational flight envelope and a complete validation

of the approximated aircraft performance within this flight envelope is paramount. The availability of the correct range of reference data, e.g. as can be provided by the aircraft manufacturers performance programs is essential to perform the validation.

Already today there are several ATM applications that depend on the knowledge of the future flight paths of the aircraft considered. The ATC system is a distributed system. From a safety and efficiency point of view, it is paramount that in all applications, the same basic input data will result in identical computed flight profiles and the same estimate of the operational flight envelope. The aircraft performance model is the basis for these calculations.

The collection of the source data for the modeling process is a major work. IP Rights issues, confidential data and other commercial interests complicate the collection process significantly.

## Acknowledgments

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## References

- [1] Magill, S.A.N., January 1996, *On the Vertical Speeds of Airways Traffic*, Journal of Navigation, vol 49 no. 1
- [2] Coppenbarger, R., 1999, *Climb Trajectory Enhancement Using Airline Flight Planning Information*, AIAA-99-4147
- [3] Suchkov, A., 2001, *Refined Benefits Assessment of Expedite Departure Path (EDP)*, CSSI, Inc. Report to NASA
- [4] Hoffman, E., *TOM Estimation*, Eurocontrol Experimental Center Report
- [5] Gerretsen, A., et al., January 2003, *Sensitivity of Aircraft Performance to Variability of Input Data*, Eurocontrol Report
- [6] Benoit, A., et al., May 2003, *Decision Making Aids in On-Line ATC Systems*, AGARD GCP Symposium on "Machine Intelligence in ATM, Berlin
- [7] Magill, S.A.N., October 1997, *Trajectory Predictability and Frequency of Conflict Avoidance*

*Action*, CEAS 10<sup>th</sup> European Aerospace Conference, Amsterdam

[8] <http://www.eurocontrol.fr/public/reports/eecreports/>

[9] Eurocontrol, June 2002, *User Manual for the Base of Aircraft Data (BADA)*, Revision 3.4, EEC Note No. 08/20

[10] <http://www.eurocontrol.fr/projects/bada/>

[11] Calders, P., December 2000, *GAME-Model Conventions*, Eurocontrol Document

## Key Words

Aircraft Performance, Decision Support Tools, Modeling, Simulation

## Biographies

**Alex Suchkov** is responsible for External Engineering Relations at Boeing ATM. In this capacity he is working closely with International ATM R&D community to enable a better cooperation and harmonization of the efforts requiring manufacturer's participation. Mr. Suchkov holds degrees of MS in Aircraft Engineering, MS in Aerospace Engineering, and MS in Civil Engineering (Aviation Transportation). Prior to joining Boeing, Mr. Suchkov worked as a consultant for FAA and NASA with CSSI, Inc. in Washington, DC.

**Sip Swierstra** is responsible for the Center of Expertise for Trajectory Prediction at Eurocontrol Head Quarters in Brussels, Belgium. After graduating as an electronics engineer he joined Eurocontrol in 1973. He has been working aircraft performance modeling, trajectory prediction and the application of these techniques in advanced ATM tools, in particular the Arrivals Management concept "Zone of Convergence".

**Angela Nuic** is responsible for management of the BADA at EEC in Brétigny-sur-Orge, France. After graduating as an aerospace engineer in 1993, she started her professional career within an European aircraft operator, working as an aircraft performance engineer in Flight Operation Department. In 2000 she joined EEC where she took a lead of a BADA project. She also participates in INTENT project, which addresses ATM en-route concepts based on the communication of information about intended aircraft trajectories calculated by the aircraft Flight Management System (FMS) to other aircraft and the ground ATM system.