ENHANCEMENT IN REALISM OF ATC SIMULATIONS BY IMPROVING AIRCRAFT BEHAVIOUR MODELS

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Abstract

This paper addresses the challenge to provide realistic aircraft behaviours in air traffic control simulations. Many simulation environments lack actual information on aircraft, airline or airspace-specific operational procedures: they resort to generic procedures to navigate the simulated aircraft, which may result in unsatisfying aircraft behaviours. A methodology has been developed by EURO-CONTROL to improve the aircraft behaviour model in its large-scale and real-time air traffic management simulation system, by identifying specific aircraft operation parameters from historical radar data. The simulator has been adapted to take these aircraft operation parameters into account, and the methodology was applied and tested during the last two simulations which took place at the EUROCONTROL Experimental Centre in 2010. The results of using operationally-tuned parameters during those simulations demonstrate that the analysis of flight recordings can bring valuable information about numerous flight behaviour parameters, and that the use of detailed flight behaviour models based on the parameters identified from the recordings can improve the accuracy of aircraft modeling enough that air traffic controllers liken the simulated traffic to a real traffic.

Introduction

To support research and development (R&D) activities, EUROCONTROL develops and manages a number of simulation tools ranging from mathematical models to fast-time and real-time simulation platforms. This paper concentrates on the EUROCONTROL Simulation Capability And Platform for Experimentation (ESCAPE). ESCAPE is widely used as an air traffic control (ATC) large-scale real-time simulator to assess new procedures, airspace design and operational concepts at EUROCONTROL Experimental Centre (EEC) in Brétigny, France, and EUROCONTROL Airspace Validation Unit in Budapest, Hungary. It is also used

as a training tool for air traffic controllers (ATCOs) at the Institute of Air Navigation Services (IANS) in Luxembourg, in Maastricht Upper Area Control Centre and in Portugal for military purposes, and by Italian and Spanish air navigation service providers (ANSP).

The air traffic management (ATM) is a dynamic and complex system whose functioning is influenced by a great number of factors, and as such is difficult to model. The success of the real-time simulation experiments and the validity of the obtained measurements are directly impacted by the quality of the simulation environment. This paper addresses the challenges in meeting the stringent requirements to provide a realistic real-time simulation environment, which enables the air traffic controllers who participate in the experiment to perform their operational tasks in the most realistic way.

This paper will first describe, through a top-down approach, the context of the presented work:

- The ESCAPE simulator, and more thoroughly its enhanced Air Traffic Generator (eATG) component,
- The Base of Aircraft Data (BADA), which is the underlying Aircraft Performance Model (APM) used by ESCAPE,
- The aircraft behaviour model, which aims at modeling the operational factors that may impact aircraft performances.

The second part will then report on the work performed by EUROCONTROL to improve aircraft behaviours in ATC simulations, by presenting:

- The Local Area Tuning, a process developed to increase the accuracy of the aircraft behaviour model,
- Two different use cases of the Local Area Tuning process,
- Several lessons learnt from the use cases and conclusions.

The ESCAPE Simulator

Real-time simulations performed at the EUROCONTROL Experimental Centre with the ESCAPE simulator were designed essentially to evaluate airspace organization and ATC procedures in en-route environments. Gradually, simulations' scope has been extended to cover TMA procedures and network design. In parallel, ESCAPE has been used intensively to support R&D projects to evaluate new concepts, new tools and their impact on air traffic controller roles and tasks, capacity and safety.

ESCAPE emulates an ATC/ATM environment with the air traffic controller as the key player. It works either in a completely simulated environment or in shadow-mode (connected to live data).
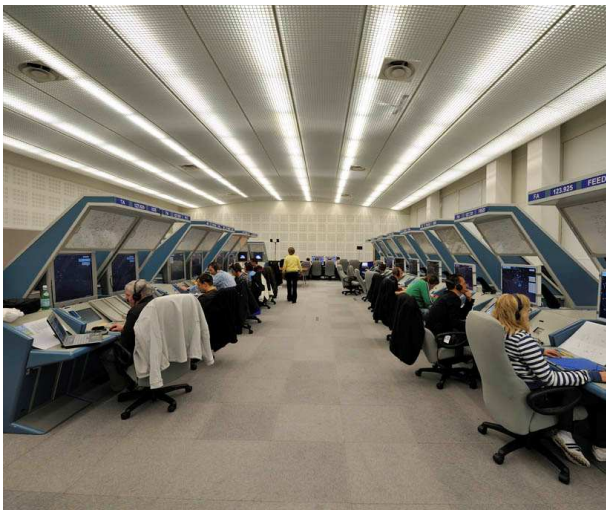
Figure 1. ESCAPE Platform Operational Room

EUROCONTROL has constantly allocated a significant effort to enhance the ESCAPE simulator in the following axes:

- Capabilities, by increasing the system capacities – it is now capable of simulating 45 Controller Working Positions (CWP), 50 Pilot Working Positions (PWP) and navigating up to 250 aircraft simultanously – and also widening the functionalities, including Data Link module (which enables pilot-controller communication over data networks) or Airborne Separation Assurance System (ASAS) functions,

- Area of operation, by extending the simulated airspace to several area control centers (ACC) or implementing inter-operability with other ATC simulators,

- Degree of realism, by designing the platform used for simulations like an ACC operational room (see Figure 1), and improving the components, such as the air traffic generator, whose quality contributes strongly to the realism achieved during a simulation.

Figure 2 presents the main sub-systems of the ESCAPE simulator:

- IPAS (Integrated Data Preparation and Analysis System) enables the preparation of scenarios and analysis of data for all types of simulations,

- GROUND centralises the flight plan and surveillance data processing with advanced ATM features,

- eATG (enhanced Air Traffic Generator) generates simulated aircraft data (both radar tracks and predicted trajectory) based on flight plans and responding to pilot intructions given via a PWP (Pilot Working Position),

- MCS (Multi aircraft Cockpit Simulator) is a fixed-base cockpit simulator developed for the EEC,

- CWP (Controller Working Position) is the controller workstation, built on technologies used by major industrial suppliers of ATM systems,

- STORIA is an on-line data recording and analysis tool whose results are the main source for assessing the experiments made during the simulation.

Figure 2. ESCAPE Simulator Main Sub-Systems

On top of that, the Supervision component is in charge of the launch/stop and monitoring of the whole ESCAPE system, and communications are provided through two architectures:

- AudioLan, which enables voice communication between pilots and controllers,
- Open Architecture for Simulation Systems (OASIS), the underlying middleware of the global ESCAPE platform.

The work presented in this paper relates to the eATG component, whose main function is the real-time navigation of the simulated aircraft in the airspace. The navigated trajectory computed by eATG depends on several factors:

- Flight plan information, which contains mandatory data such as departure time, initial altitude, flight path description and cruising level,
- Aircraft information, such as the aircraft type and the take-off weight,
- Flight instructions given by the ATCOs and entered via the PWP, for example speed reductions or rerouting orders,
- Environmental information, comprising meteorogical data (wind, temperature) and airspace data.

Figure 3 presents an overview of the eATG architecture through an analogy between the real world operation of an aircraft and the way eATG emulates it. eATG merges flight plan and aircraft information, together with flight instructions, into a trajectory description which is then input to a trajectory computation engine to generate, according to an aircraft performance model and an environmental model, the computed trajectory.
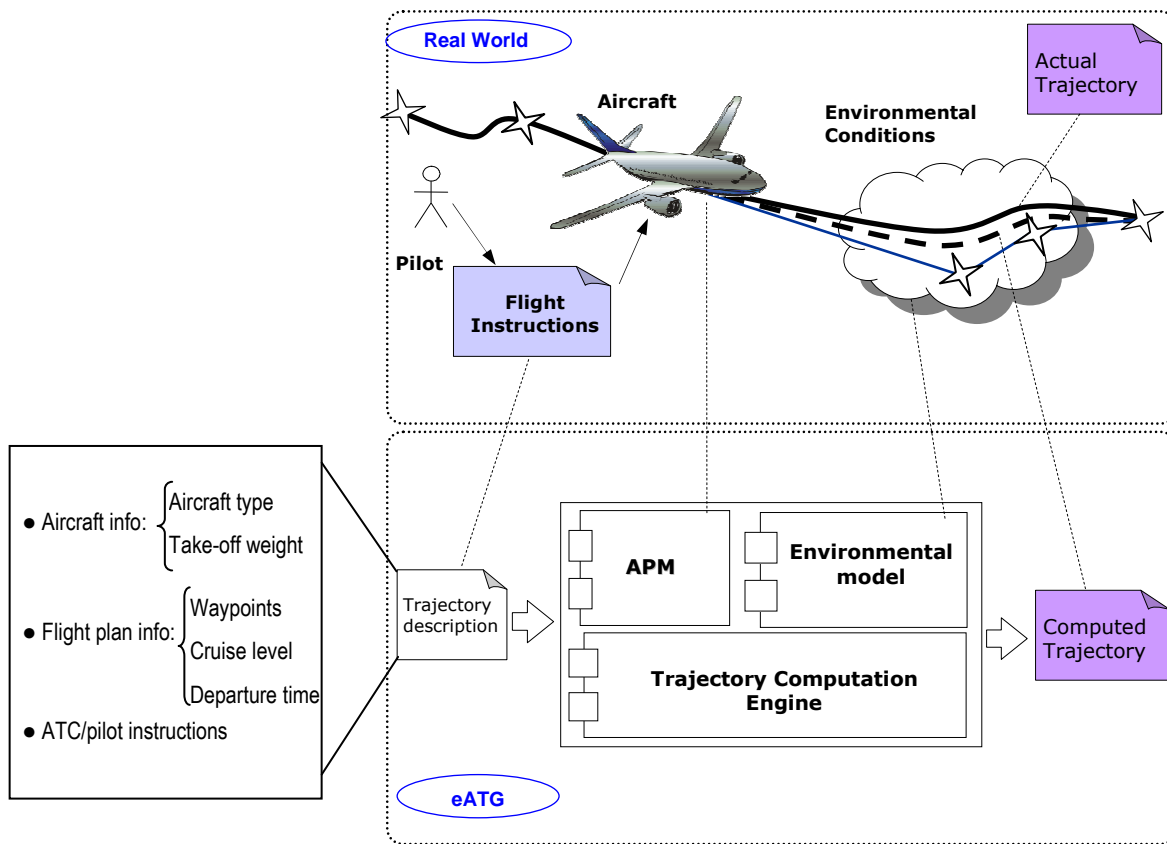
Figure 3. Overview of the eATG Architecture

BADA Aircraft Performance Model

ATM research and development activities and simulation environments that require information on aircraft performances often have to rely on a substitute for the real aircraft. This is the role that an Aircraft Performance Model (APM) takes on board.

The principal objectives of an APM are to provide realistic, accurate and complete aircraft performance models:

- Capable of supporting accurate computation of the geometric, kinematic and kinetic aspects of the aircraft behaviour,

- Applicable to a wide set of aircraft types, over the entire operation flight envelope, and in all phases of flight,

- With reasonable complexity, maintainability and computing requirements.

eATG uses the Base of Aircraft Data (BADA) [1], an APM developed and maintained by EUROCONTROL. BADA is based on a mass-varying, kinetic approach that models an aircraft as a point and requires the modeling of underlying forces that cause aircraft motion [2]. eATG implements the BADA model algorithms based on the Total Energy Model (TEM), which provides the relation between thrust, speed and rate of climb/descent used to compute the aircraft performances depending on the aircraft control law. BADA also provides a limitation model which defines the flight envelope in terms of speed and altitude.

The current version of BADA provides 111 aircraft type models developed from manufacturer aircraft reference data and referred to as original models. Another 207 aircraft types may be simulated by using an equivalent to an original BADA model. Together, BADA original and equivalent models cover more than 98% of the European air traffic,

according to data provided by the EUROCONTROL Central Flow Management Unity (CFMU) [3].

Aircraft manufacturers are the principal source of aircraft performance reference data for BADA, which confers a high degree of trustworthiness on this model. Consequently, BADA is not only used in simulation environments like ESCAPE, but also widely employed by the ATM systems supply industry.

Aircraft Behaviour Model

BADA Airline Procedure Model

Alongside the aircraft performance model, which focuses on the aircraft itself, BADA also provides a generic aircraft behaviour model, called AiRline Procedure Model (ARPM), which focuses on how the aircraft is operated. The definition of the standard airline procedures in BADA is driven by a requirement to provide information on nominal aircraft operations to different simulation and modeling tools for various ATM applications. The way an aircraft is operated, however, varies significantly in function of specific airspace procedures and operating policies of locally dominant airlines: the speed schedules provided by the BADA standard airline procedure model may thus differ from specific aircraft operations in a particular geographical location or airspace.
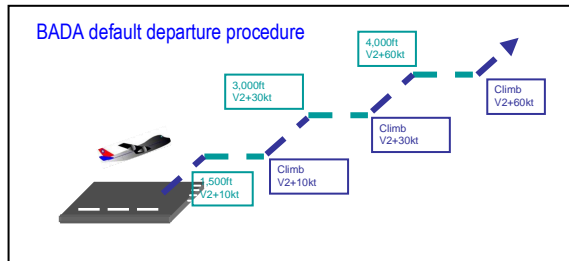
Figure 4. BADA ARPM Structure

The BADA ARPM structure, illustrated on Figure 4, has been inspired by standard operational procedures published in aircraft flight manuals and Aeronautical Information Publications (AIP). It provides nominal aircraft operating speeds in function of altitude, through a set of formulas and coefficients [1]. To fit the general behaviour of

different aircraft, the formulas depend on the flight phase (climb, cruise or descent) and the engine type (jet, turboprop or piston). To account for the particular behaviour of each aircraft, the values of the coefficients depend on the aircraft type (A320, B736, CRJ2, etc.) and the aircraft mass. Figure 5, where the calibrated airspeed (CAS) is plotted against the pressure altitude, provides an example of nominal climb speed schedule provided for one jet in BADA (the three coloured lines correspond to three different takeoff weights).
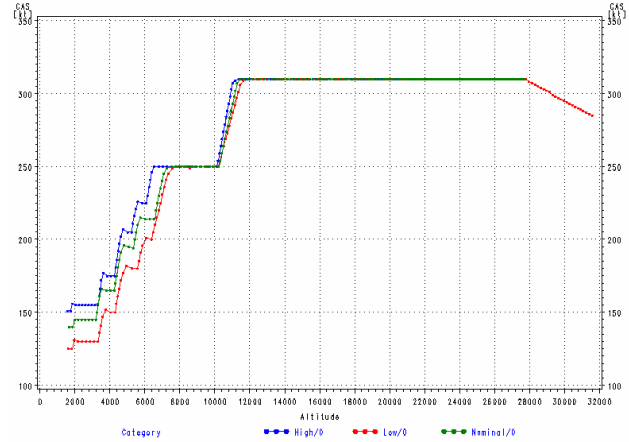
Figure 5. Nominal Climb Speed for a Jet Aircraft in BADA

Energy Share Factor
Definition

The Total-Energy Model used in BADA equates the rate of work done by forces acting on the aircraft to the rate of increase in potential and kinetic energy (see details in [1]):

$$(\text{Thr} - D) \, V_{TAS} \; = \; mg_0 \, \frac{dh}{dt} + m V_{TAS} \, \frac{dV_{TAS}}{dt} \qquad (1)$$

Where:

Thr : thrust acting parallel to the aircraft velocity vector   [N]

D   : aerodynamic drag [N]

m   : aircraft mass [kg]

h   : geodetic altitude [m]

g_0 : gravitational acceleration [9.80665 m/s^2]

V_{TAS}: true airspeed [m/s]

As shown in [5], equation (1) can be rewritten by introducing an energy share factor (ESF) as a function of Mach number, f{M}:

$$\frac{dh}{dt} = \left[\frac{(Thr - D)V_{TAS}}{mg_0} \right] f\{M\} \qquad (2)$$

where:

$$f\{M\} = \left[1 + \left(\frac{V_{TAS}}{g_0} \right) \cdot \left(\frac{dV_{TAS}}{dh} \right) \right]^{-1} \qquad (3)$$

This energy share factor f{M} specifies how much of the available power is allocated to the vertical evolution as opposed to acceleration while following a selected speed profile during climb or descent. When the aircraft is flying at constant Mach or CAS, the ESF can be calculated: the necessary expressions are provided in [1]. When neither constant Mach nor constant CAS is maintained, the value of the ESF determines how fast the change in speed takes place, and its value has to be chosen accordingly. In real operations, the choice of ESF during speed changes can be handled by either the flight management system (FMS) or the pilot. The following values are proposed by the BADA model, based on standard settings commonly used in aircraft FMS [1]:

- Acceleration in climb or deceleration in descent: f{M} = 0.3

- Deceleration in climb or acceleration in descent: f{M} = 1.7

Applications

Since the power available to the aircraft is limited, climb performance is reduced during accelerations. For example, during an acceleration in the climb phase using an ESF of 0.3, 70% of the power goes into the acceleration, leaving only 30% for the climb. When the BADA ARPM is used, several accelerations occur in the course of a typical climb (ex: 6 accelerations for a jet), and the aircraft consequently spends a non-negligible part of the first minutes of flight in this "reduced performance" state. Accurate modeling of this behaviour may thus be needed in simulations, and the default ESF values provided by BADA for the speed changes may need some adjustments depending on the simulated environment (ex: terminal maneuvring area (TMA)

environments, where accurate aircraft behaviour in departure and approach phases may be required).

Figure 6 illustrates the impact of the choice of ESF for accelerations, by comparing the simulated vertical and horizontal speeds of a jet aircraft during the first 6 minutes of flight using an ESF value, from top to bottom, of 0 (maximum acceleration), 0.3 (BADA proposed value) and 0.6 (slower accelerations).
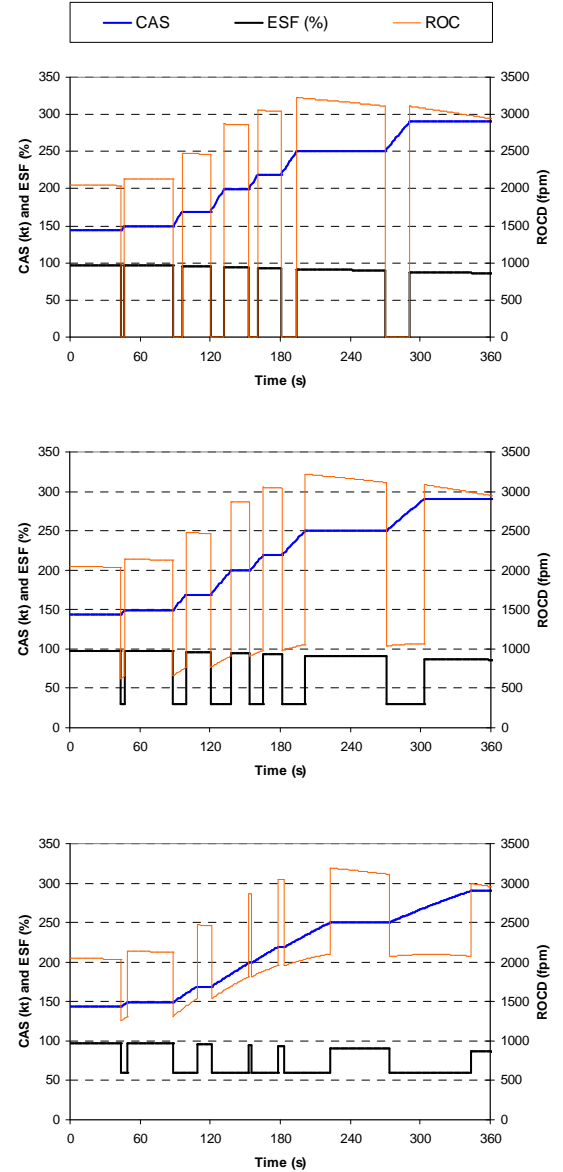
Figure 6. Impact of ESF on Accelerations

On each graphic, the black line plots the value of the ESF, the blue line plots the aircraft calibrated airspeed, and the orange line plots the aircraft rate of climb, all three parameters in function of time. It can be seen that the higher the ESF is, the longer the accelerations take, and the less the rate of climb decreases during those accelerations.

Aircraft Behaviour Model in eATG

In eATG, the aircraft behaviour model from BADA is used to determine the nominal operation of the aircraft. The nominal behaviour can then be superseded by pilot orders, input via a PWP which gives access to all instructions a pilot can be given by the controller (CFL, heading, etc.). Each PWP is operated by one person (Figure 7), called pseudo-pilot, who plays the role of the pilot not only for one aircraft, but for up to 32 aircraft within an airspace sector (usually a pseudo-pilot manages simultaneously a maximum of 8 aircraft).

Figure 7. ESCAPE Platform Pilots Room

Contrary to real world pilots, and because of their simultaneous handling of multiple aircraft, pseudo-pilots are confined to the input of orders given by controllers, and they do not know about the standard procedures in place in the simulated area, such as:

- ATC procedures locally applied (noise abatement, speed limits),
- Airline operating policy, en-route or on the airports,
- Specific piloting of particular aircraft types.

Air traffic controllers operating in the simulated area, however, are used to aircraft following those procedures, and they expect the simulated aircraft to behave similarly. For example, if the simulation concentrates on arrival flows on Geneva airport, a Geneva TMA controller may complain about the behaviour of an Airbus A320 coming from Dubai and landing at Geneva because according to him, the simulated aircraft does not descend at the same rate as the real one he is used to controlling every Monday. Such discrepancies are expected since the simulator uses both a generic behaviour model and a pseudo-pilot for the navigation of the aircraft, neither of which knows about the detailed airline policies and aircraft handling characteristics applicable to each particular flight.

In order to fulfill controllers' need for realism, it was first attempted to gain knowledge about the specific airline procedures, that could then be tentatively reproduced in the simulator. Experience showed however that it is difficult to obtain this information, because the airline procedures are often confidential. A methodology, called the Local Area Tuning process, was then defined to:

- Analyse real flight data to find out the parameters which influence the behaviour of the aircraft,
- Input the parameters which were identified during the analysis phase into eATG to mimic the real behaviour with the simulated aircraft,
- Validate the improvements in the context of the simulation.

Local Area Tuning Process

Data Collection

The main set of data required to perform the analysis consists of recordings of real flights operated in the environment to be simulated. Three differents types of recordings are necessary:

- Flight plan information, providing for each flight the aircraft type, operating airline, departure and arrival airports, and flight path,

- Radar track data, providing information on the actual position (including altitude) of the aircraft at regular time intervals,

- Meteo data – usually forecasts updated every 6 hours, providing wind and temperature information, at regular altitude and latitude/longitude intervals, for the considered airspace at the time of the recordings.

The timeframe to be covered by the recordings has to be determined so that the number of flights is sufficient to provide meaningful statistical results. Depending on how busy the considered airspace is, one day of recordings can contain up to several hundreds of flights.

Data Processing

From the collected recordings, a number of parameters can be measured or computed for each flight, at a frequency equal to the radar data frequency (typically every 5 seconds):

- Rate of climb/descent (ROCD), determined from radar data either directly (if present in the radar information fields) or by computation from altitude and time information,

- True airspeed (TAS), by applying the wind triangle formula to the ground speed (from radar data) and wind speed (from weather forecast),

- Calibrated airspeed (CAS) or Mach number, using the TAS to CAS/Mach conversion formulas from [1] with the computed TAS value, the altitude (from radar data) and the temperature (from weather forecast).

Statistical processings can then be applied to the individual measurements to analyse the flight behaviours according to different criteria such as the aircraft type, operating airline, destination airport or cruise flight level. For this purpose, the experiments presented in this paper used EUROCONTROL's Radar Data Analysis and Processing (RDAP) tool, which is designed to store the recordings (flight plan, radar and weather data), process them to calculate additional flight data, filter the flights according to user defined criteria, perform measurements on the selected flights and produce a set of statistical metrics. Several statistical plots can be output by the tool for quick analyses, such as average flight vertical profile as a function of time, or average airspeed as a function of altitude. Figure 8 presents an overview of a typical workflow using RDAP.

Identification of Operational Parameters Values

Common criteria that can be used in combination to define flight categories for which similar flight behaviour can be expected include aircraft type, operating airline, airport and flight range. For each such category, several operational parameters can then be identified from the statistical analysis: average climb, cruise and descent speeds, altitudes where changes in speed – acceleration or deceleration – occur, time taken to perform those speed changes, average rate of climb during initial and final climb segments among others. Several examples of operational parameters identification are provided in Figure 9 to 11, based on radar recordings.
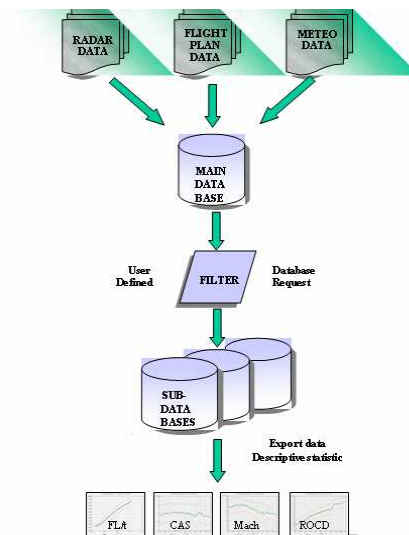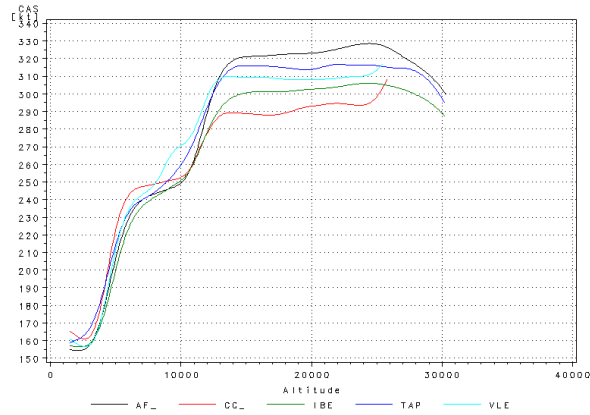

Figure 8. RDAP Typical Workflow

Figure 9 illustrates the differences in climb speeds between several airlines operating the Airbus A320 aircraft from Paris-Orly airport. We can see that all of those airlines first maintain a similar CAS (about 160 kt) up to 3,000 ft, then accelerate to 250 kt and maintain that speed below 10,000 ft. Above

10,000 ft, however, they accelerate to a final climb speed which is here different for each airline, ranging from 290 to 320 kt.


Figure 9. Differences in Final Climb Speeds between Operating Airlines

Figure 10 illustrates the differences in initial climb acceleration and final climb speed between several airlines operating the Airbus A321 aircraft from Geneva airport. We can see that two airlines (represented by the black and green lines) maintain a similar CAS (about 160 kt) up to 4,000 ft, and use a final climb CAS of about 315 kt, whereas another airline (represented by the red line) accelerates much sooner, as early as 1,500 ft, and use a lower final climb CAS of about 300 kt.
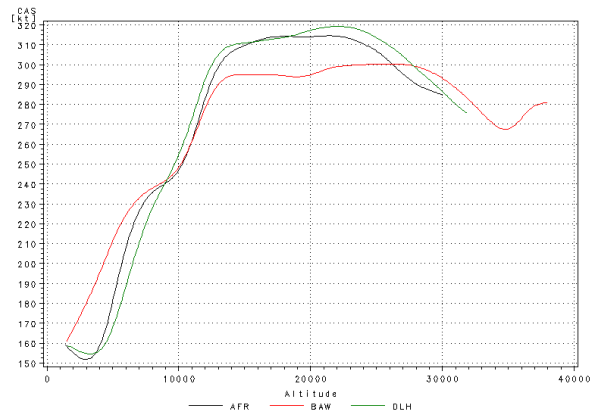
Figure 10. Differences in Initial Climb Acceleration and Final Climb Speed between Operating Airlines

Figure 11 illustrates the differences in acceleration times than can result from the simulated and real aircraft using different energy share factors. The red, green and blue lines represent, in function of altitude, the BADA climb speed profile of an A320 for three different takeoff masses (low, nominal and high), whereas the black line represents the average climb speed profile of the A320 departing from Paris-Charles de Gaulle (grey lines represent average profile +/- one standard deviation), computed with RDAP from a set of recordings. We can see that the sequence of climb speeds used by the real aircraft match the BADA climb speeds at nominal or high weight, but the accelerations between those speeds are longer for the real aircraft, indicating that an ESF higher than the BADA default value should be used to properly model the accelerations of the A320 in that environment.
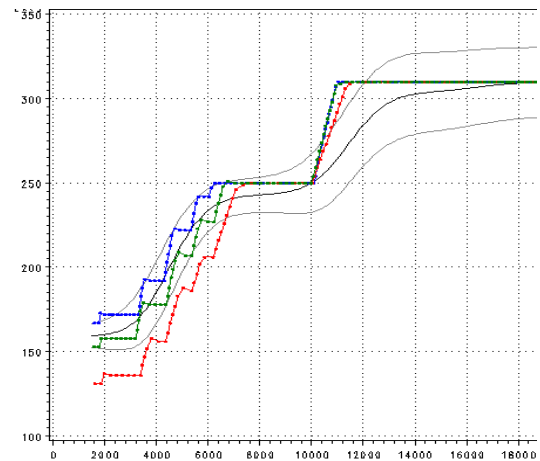
Figure 11. Differences in ESF between Simulated and Real Aircraft

According to the operational parameters that have been identified from the recordings, a custom flight behaviour model can then be established for each considered flight category.

Integration of the Findings in the Simulation Environment

The eATG component of the ESCAPE platform has been enhanced to use more advanced aircraft behaviour models than the default one described in BADA. eATG is now capable of handling particularized flight behaviour models – including

custom speed profiles and energy share factors as functions of altitude – according to the operated airport, aircraft type, operating airline, flight phase and flight range. This enables a highly detailed reproduction of the simulated environment: aircraft can accelerate to their climb speed at different altitudes depending on their departing airport, different cruise speeds can be used according to the flight range, and different final speeds can be used in the landing phase for different operating airlines, among other possible uses of this flexibility. Figure 12 provides an example of the eATG input file used to define flight behaviour models differentiated by operating airline (second column) and flight phase (here: climb and descent).

| #		Climbing phase					Descending phase					
#Level (FL)	AO	short range	med range	long range	TC	ESF	short range	med range	long range	TC	DC	ESF
035	AFR						130	130	130			0.70
040	AFR	150	150	150								0.70
090	AFR	240	240	240		0.65						0.70
120	AFR					0.6	170	170	170			0.70
250	AFR					0.6	270	270	270			0.75
310	AFR					0.6					0.30	
999	AFR	310/310/77	310/310/77	310/310/77		0.6	285/285/78	285/285/78	285/285/78			
015	BAW	150	150	150								0.70
035	BAW					0.7	130	130	130			0.70
090	BAW	240	240	240		0.7						0.70
120	BAW					0.65	170	170	170			0.70
250	BAW					0.65	270	270	270			0.75
310	BAW					0.65					0.30	
999	BAW	290/290/77	290/290/77	290/290/77		0.65	285/285/78	285/285/78	285/285/78			

Figure 12. Example of eATG Flight Behaviour Model

Validation of the Improvements Against the Recordings

Once the custom flight behaviour models have been integrated in the simulation environment, simulated flight profiles can be generated for the considered flight categories and compared to the average real profiles determined from the recordings for the same flight categories. A dedicated functionality is present in RDAP to superimpose the simulated data over the recorded data and allow an easy validation of the custom flight behaviour models. Figure 13 presents an example of such a validation exercise, where two simulated flights are compared to the average recorded flight of the same category: one that uses the default flight behaviour model of the simulator (left plot), and one that uses a custom flight behaviour model established from the analysis of the recordings (right plot).

Depending on the quality of the matching between the simulated flights and the average real flights, the flight behaviour models can then be refined and the process iterated to reach the desired level of accuracy.
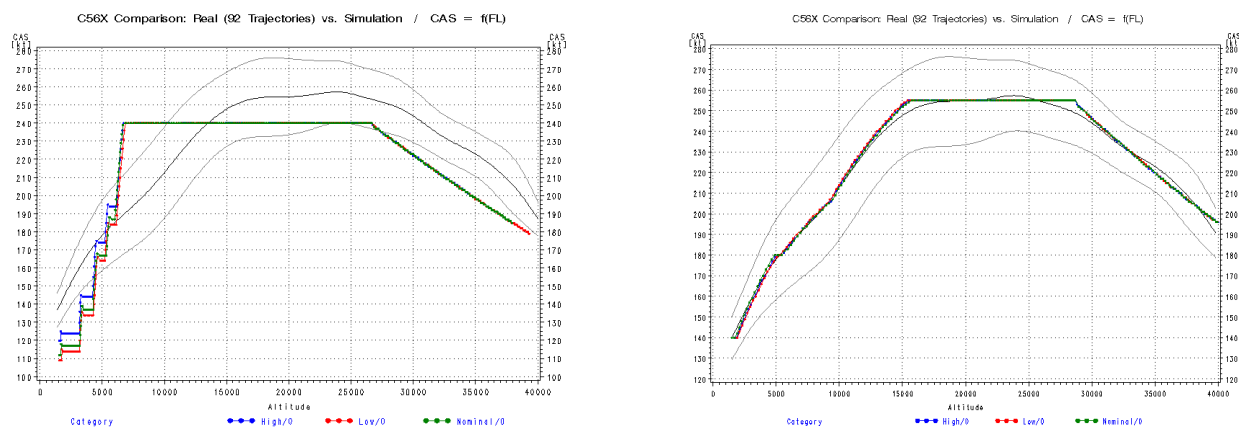
Figure 13. Validation of a Flight Behaviour Model

Validation of the Improvements Against ATCOs' Feedback

The use of radar data as reference data for the development of flight behaviour models has limitations inherent to the nature of the radar data: they describe each flight as it actually flew, taking into account the clearances issued by the ATCOs, which does not necessarily represent how the pilot intended to fly. If the nature of the simulation requires ATCOs to be part of the environment (human-in-the-loop), then a decoupling must be performed in the identified flight behaviour model between what comes from actual aircraft intents and what comes from ATC decisions and constraints, in order to model only the behaviour of the aircraft and pilot. If, however, the simulation takes place in a fast-time environment with no ATCO, then the implicit integration of usual ATC constraints directly into the flight behaviour model may provide desirable accuracy benefits, and should then be considered.

When the Local Area Tuning process is targeted at real-time simulations operated by ATCOs, their input about ATC procedures in place in the simulated environment is valuable to properly decouple the aircraft and pilot intents from the ATC interventions in the first iterations of the process.

Again, depending on the quality of the matching between the simulated flights and the aircraft behaviours expected by the ATCOs, the flight behaviour models can then be refined and the process iterated to reach the desired level of accuracy.

Application to Real-Time Simulations

SWAP Simulation

The methodology was first applied and tested in the context of SWAP, one of the Functional Airspace Blocks for Europe Central (FABEC) simulations, which took place in EUROCONTROL Experimental Centre in April 2010 and covered en-route operations across Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland [6]. The aircraft performance analysis focused on the departure and arrival flights to/from the Geneva airport (ICAO code: LSGG).

To perform the data collection initiating the Local Area Tuning process, the following data sources were used:

- Radar: Correlated Position Report (CPR), the official radar data recorded by EUROCONTROL CFMU, covering the ECAC (European Civil Aviation Conference) area,

- Flight plan: All_FT data (from CFMU),

- Weather: wind and temperature forecasts updated every 6 hours (from Meteo-France).

The chosen flight sample covered 15 summer days and 15 winter days, that together provided recordings for over 5000 flights to/from Geneva. Operational parameters — climb and descent speeds, as well as energy share factors for acceleration phases — were identified from those data and custom aircraft behaviour models were created for 36 aircraft types, each one containing up to 5 airline-specific models. 2 to 4 iterations of the tuning process were required to bring each custom model to the desired level of accuracy, using a rule that a maximum difference of 5 knots was allowed over the complete climb and descent phases between the simulated speed profile and the average speed profile computed from the radar recordings.

Because of planning constraints in the preparation of that simulation, the ATCOs could not be involved early in the process and could only give their feedback after several iterations.

The first observation from the ATCOs was that the simulated aircraft were not representative of the real ones: they tended to comply with usual ATC rate of climb/descent constraints or speed constraints before the ATCOs had even issued the corresponding clearances, which artificially lightened controllers workload. This was a direct consequence of the missing decoupling between ATC procedures and aircraft intent at this stage of the process, and it was corrected by removing from the aircraft behaviour models the information linked to ATC-related behaviours.

The second observation was related to the custom ESF values used to control the accelerations/decelerations and fit the simulated speed profile to the radar one (Figure 13). Although the graphical fit was perfect, this solution

demonstrated a drawback. When a tactical order was given to an aircraft by ATC to change its speed, the aircraft response was sometimes degraded: several simulated aircraft were taking too long to reach the assigned speed compared to real aircraft. The explanation is that the ESF used during accelerations and decelerations had been increased from 0.3 to 0.6-0.8 in some tuned aircraft behaviour models, in order to replicate the slow changes in speed observed in the radar data. These high ESF values were indeed adequate for aircraft following their nominal speed profile, but they also prevented quick accelerations upon tactical speed orders, which was an unforeseen and undesirable side effect. A compromise solution was to limit the values of ESF to 0.5 in the aircraft behaviour models: this intermediate value provided an acceptable compromise between smooth nominal accelerations and fast response to ATC speed orders. A long-term solution to this problem would be to use different ESF values whether the aircraft is following its nominal speed schedule or responding to a speed order.

TA10 Simulation

The methodology was then applied to the TA10 simulation, which took place in EUROCONTROL Experimental Centre in June 2010 and covered all operations in a 100 NM radius around Paris, France. The aircraft performance analysis focused on the departure and arrival flights to/from five airports: Paris-Charles de Gaulle (LFPG), Paris-Orly (LFPO), Paris-Le Bourget (LFPB), Toussus-Le-Noble (LFPN) and Villacoublay-Vélizy (LFPV). These airports present different characteristics when it comes to aircraft performance analysis: Charles de Gaulle and Orly operate mainly airliners, Le Bourget operates mainly business jets, Toussus-Le-Noble operates many small piston aircraft, and Villacoublay is a military airport.

To perform the data collection initiating the Local Area Tuning process, we had access to the following data sources:

- Radar: ATM surveillance Tracker And Server (ARTAS) data provided by the French ANSP Direction des Services de la Navigation Aérienne (DSNA)
- Flight plan: data provided by DNSA

- Weather: wind and temperature forecasts updated every 6 hours (from MeteoFrance)

The chosen flight sample covered 14 summer days that provided recordings for the following amounts of flights:

- LFPG: over 5000 flights
- LFPO: over 2000 flights
- LFPB: over 700 flights

Operational parameters — climb and descent speeds, as well as energy share factors — were identified from those data and 76 custom aircraft behaviour models were created. Taking into account the lessons learnt from the SWAP simulation and the different operational conditions between the SWAP and TA10 simulations, the process was applied with a different set of objectives:

- Whereas the SWAP simulation focused on en-route operations, the Paris TMA was an important part of the TA10 simulation, which required additional in-depth validation of the aircraft performances at low altitudes, such as initial climb and approach/landing performances.

- ATCOs informed us that most aircraft receive tactical speed orders during their descent in that environment: the scope of the speed tuning in descent could then be limited to final approach speeds.

- The maximum number of iterations for the validation of speed profiles against radar data was limited to 2 in order to decrease the time spent on tuning.

- ESF values could no longer exceed 0.5 (following the SWAP findings).

- ATCOs did not identify major differences in operations between airlines for any aircraft type but one (a particular airline requires its RJ85 aircraft to reach their final speed much earlier than other airlines), so no airline-specific analysis was performed.

- ATCOs requested that some variability be present in the speed profiles to match real conditions and avoid excessive predictability, so in each custom behaviour model, 3 sets of climb speeds were defined according to the flight range.

Whereas, during the previous simulations using ESCAPE, aircraft performances proved to be very difficult to model in a way that meets the ATCOs' expectations, the feedback from the ATCOs regarding the TA10 simulation was mostly positive: they characterized the observed aircraft behaviour as "correct" for aircraft types whose behaviour model had been tuned, likening it to "real traffic with accomodating pilots". Because of time constraints, some aircraft types did not have a custom behaviour model identified, and ATCOs were easily able to distinguish between aircraft with and without a custom behaviour model thanks to the added realism of aircraft using such a model, thus validating the added value of the Local Area Tuning process.

Conclusion

This paper showed that the analysis of flight recordings can bring valuable information about numerous flight behaviour parameters – such as operating speeds (whether in climb, cruise or descent), altitudes where accelerations and decelerations take place, and energy share factors used during those speed changes – as well as the way these parameters differ according to operational factors – such as departure and arrival airport, operating airline or aircraft type. Moreover, the use of detailed flight behaviour models based on the parameters identified from the recordings can improve the accuracy of aircraft modeling enough that air traffic controllers liken the simulated traffic to a real traffic.

When a flight behaviour model is identified from recordings, the choice of flight behaviour parameters included in the model may differ depending on the nature of the simulation:

- If the simulation requires ATCOs to be part of the environment, then a decoupling must be performed between what comes from actual aircraft intents and what comes from ATC decisions and constraints, in order to model only the behaviour of the aircraft and pilot.
- If, however, the simulation takes place in an environment with no ATCO, then the implicit integration of usual ATC constraints directly into the flight behaviour model may provide desirable

accuracy benefits, and should then be considered.

The methodology described in this paper was developed to compensate for the absence, in the ATM modeling and simulation facilities, of actual information on aircraft, airline or airspace-specific operational procedures and operational data. There is an expectation that, through initiatives such as the System-Wide Information Management (SWIM), the sharing of information between different actors in the ATM as envisioned by the Single European Sky ATM Research (SESAR) and NextGen programs shall make this kind of data available in the future, and thus improve the realism of the simulation tools.

References

[1] EUROCONTROL, 2010, User Manual for the Base of Aircraft Data (BADA) Revision 3.8, EEC Technical Report 2010-003

[2] Nuic, Angela, C. Poinsot, M. Iagaru, E. Gallo, F. Navarro, C. Querejeta, 2005, "Advanced Aircraft Performance Modeling for ATM: Enhancements to the BADA Model", 24th Digital Avionics Systems Conference, Washington D.C., USA

[3] Sheehan, Carol, 2010, Coverage of 2009 European Air Traffic for the Base of Aircraft Data (BADA) Revision 3.8, EEC Technical Report 2010-008

[4] Nuic, Angela, D. Poles, V. Mouillet, 2010, BADA: An advanced aircraft performance model for present and future ATM systems, International Journal of Adaptive Control and Signal Processing, John Wiley & Sons, Ltd, p. 15

[5] Renteux, Jean-Louis, 1987, Aircraft Modelling Standards for Future ATC Systems, EUROCONTROL Division E1 Document No. 872003

[6] Trzmiel, Aymeric, L. Rognin, K. Harvey, 2010, FABEC NTM/DIK – SWAP Validation report, EUROCONTROL

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