ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF ELECTRIC TAXI BY MEANS OF FAST-TIME SIMULATION

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Abstract

The contribution of air transportation to pollution is significant, constantly growing and has a great impact on the climate change. According to SESAR D1 forecast, the number of IFR flights in Europe in the period of 2005 to 2025 is expected to increase by approximately 150% under the most optimistic conditions. Along with this enormous growth of traffic, people become increasingly aware of the environmental issues. Although the share of aircraft emissions (2-3%) is very small compared to total man-made emissions, it affects and contributes to pollution in the atmosphere. Seeking for a solution, the European Commission has launched the “Clean Sky” Joint Technology Initiative (JTI) which aims at solving these environmental issues. It is made up of six Integrated Technology Demonstrators (ITD) which main goal is to develop technologies that will bring into life ACARE’s 2020 platform:

- 50% reduction of CO_2 emissions through reduction of fuel consumption
- 80% reduction of NO_x emissions
- 50% reduction of external noise

The aim of work package “Smart Operations on Ground”, which is part of the “System for Green Operations” ITD, is the development of an electric motor for autonomous pushback and taxi. By taxiing with the help of an electric motor, which is installed at the main landing gear and supplied by the APU, a reduction of fuel consumption and emissions is expected, since the main engines can remain switched off during taxi. DLR’s goal as partner in this project is to demonstrate by means of fast-time simulations (FTS) the impact of this new technology regarding capacity, delay, emissions and noise.

1. INTRODUCTION

Global pollution, so as aviation transportation is increasing constantly. European Union environmental policy has strengthened lately. People became more and more aware on the consequences from pollution. Studies have shown that in certain period, the earth experiences climate change, but the Kyoto Protocol points out to the fact that lately the climate change is greatly caused by human activities. Aviation transportation is part of those activities. Although the aviation environmental impact is very small, the emissions produced do harm the environment and therefore should be reduced.

There is no doubt that the air transportation notes precipitous increment. Predictions show that the percentage of aircraft movements will be doubled and in some cases even tripled all over the world. Looking into the economical benefit of the aviation community, this is a very positive sign and is very important source of employment and growth in many regions. On the other hand it affects the pollution and increases its part in creating greenhouse gases which greatly affect or more precise reduce the absorption level of the ozone [5].

Aircraft engines produce emissions which affect the temperature of the atmosphere, no matter if they were produced on ground or in the air. They produce Carbon dioxide (CO_2), Nitrogen oxides (NO_x), and different particles of sulphur. Carbon dioxide (CO_2) is the most common gas among the list of pollutants that come as a result of burning fuel in the aircraft engines. It is produced during the combustion of kerosene in direct proportion to the consumption of kerosene. It is considered to be one of the most common greenhouse gasses and used as a base when calculating environment pollution. Once again, the human activities had a main role in increasing the amounts of this gas in the atmosphere. The combustion of fossil fuels and deforestation has caused the atmospheric of CO_2 to increase up to 35% since the beginning of industrial age. When produced, it stays in the atmosphere for 100 years. According to [8] nitrogen oxides (NO_x) are produced in the aircraft engine at high temperatures and pressures by the reaction between oxygen and atmospheric nitrogen. NO_x refers to NO and NO_2. The production of this gas greatly depends on the engine load. It is estimated that approximately 8-15 grams nitrogen oxides are produced per kilogram kerosene consumed in passenger jet engines when cruising. Water, soot and sulfur are important starting materials for creating particles. Ambient air saturated with moisture can condense on particles, resulting in condensation trails and high, hazy ice clouds (cirrus clouds). These clouds act like a glass roof over the earth and thus contribute to climate warming [1].

According to statistics, the aviation greenhouse gas emissions in the period 1990-2006 are increased by 100%. The situation in Europe is alarming as well. In order to decrease the climate impacts of aviation, European Union has introduced legislation to include aviation in the EU emissions trading scheme (EU ETS).

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 established a scheme for greenhouse gas emission allowance trading within the Community in order to promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner. The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC), which was approved on behalf of the European Community by Council Decision 94/69/EC (5), is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system [4].

Noise pollution is also very important parameter in the calculations, especially in the airport vicinity. Therefore, the airports have established noise charges. They are computed per landing and per takeoff and charged with fixed amounts per noise category. As a first step in this procedure, aircraft types must be allocated according to their ICAO classification. All turbo-jet aircraft are obliged to take into account the conditions of ICAO Annex 16, Chapter 2, 3 and 4. The certification can be comprehended by the aircraft manufacturer or a certifying authority, stating that the noise values allowed by Chapter 2, 3 and 4 are not exceeded. Airports have designated charges for landing and takeoff for each 1,000 kg MTOW.

There are many ongoing environmental projects both in Europe and USA. One of the largest European research projects ever, with a budget estimated over 1.6 billion Euros is the project of the European Commission called Clean Sky JTI.

2. CLEAN SKY JTI AND SGO

The awareness about the environmental issues of air pollution, noise and climate change is in constant rise among the aviation industry. Although today air transport only produces 2% of man-made CO_2 emissions, this is expected to increase to 3% by 2050. Clean Sky is a “Joint Technology Initiative” that will develop breakthrough technologies to reduce environmental impact. The idea of this European Commission environmental project is to speed up technological breakthrough developments and shorten the time to produce the new solutions tested on Full Scale Demonstrators. The Clean Sky JTI is made up of six Integrated Technology Demonstrators (ITD). Each ITD focuses on achieving the main ACARE goals: reduction of fuel consumption, emissions and noise and economic life cycle. Clean Sky project has started in 2008 and it will run for seven years as part of the European Commission’s Seventh Research Framework Programme [3].

Clean Sky takes into account the EU economy as well. Since air transport is one of the most important sectors in the EU economy, it should be kept in mind that the implementation of the ACARE goals should not affect the global GDP.

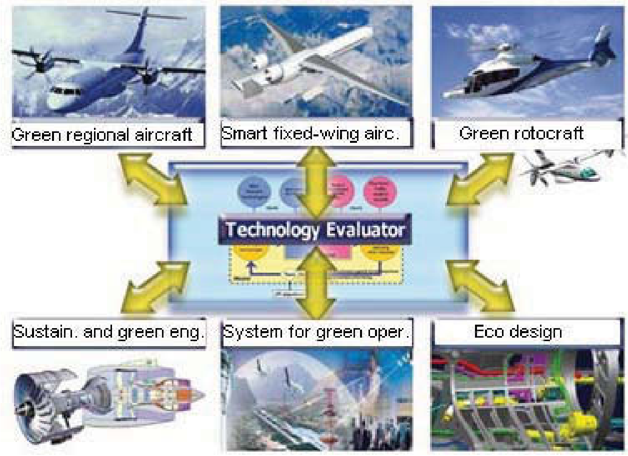

FIGURE 1. Summarised content of Clean Sky [3]

FIGURE 1 shows the six Integrated Technology Demonstrators. Each ITD is connected to a simulation network called Technology Evaluator which wills asses the technologies developed in the ITD’s. One of the focuses of the Systems for Green Operations (SGO) is creating new architectures for electrical aircraft equipment. This ITD will create improved aircraft operation reducing the fuel consumption and emissions. It is consisted of four work packages:

– The Management of Aircraft Energy
– Green Trajectories
– Smart Operations on Ground (SOG)
– Green Missions

SOG focuses on the airfield itself. Uses new technologies, system solutions and procedures to allow airplane engines to reduce fuel consumption and offer additional environmental benefits. The aim of this work package is to develop electric motor for autonomous pushback and taxi and to evaluate the impact that this new technology will have on the overall traffic at the airport. DLR’s goal as partner in this project is to demonstrate by means of fast-time simulations (FTS) the impact of this new technology regarding capacity, delay, emissions and noise. To assess the benefit of autonomous pushback and taxi FTS of Frankfurt Airport and Berlin Brandenburg International Airport are conducted. With the help of Simmod PRO!, a fast-time simulation tool which allows the user to define the aircraft behaviour by a set of instructions, the ground movements are simulated within two cycles.

3. FAST-TIME SIMULATION

To assess the impact of the electric taxi on the operations of an airport, fast-time simulations will be conducted, which allow simulating the movements and the interdependencies of aircraft with each other at a high level of reality in very short time. Depending on the simulation program it takes just a few minutes to calculate the movements of one day with hundreds of flights. As an output from the simulation the user gets detailed information on each of the movements such as taxi and flight times, delays including their reasons and the location of the aircraft at any point in time. This output can be processed for use with other programs for example to calculate emissions and noise.

For this study Simmod PRO! was chosen since it offers the most flexibility among the available fast-time simulation tools at DLR. Its greatest advantage is the ability to allow the user to define the aircraft's behaviour by creating sets of conditions and instructions. Instead of executing standard procedures, the aircraft performs any detailed activities which results in a greatly increased level of detail and accuracy. On the other hand the selection of Simmod PRO! also revealed some disadvantages. Since SIMMOD is a discrete simulation, that is to say that simulation clock does not advance at constant time increments rather than jumping to the next point in time when the state of an aircraft changes or a new location is reached, basic effects such as smooth acceleration and breaking cannot be simulated in detail. Another issue is the fact that SIMMOD is not able to take decisions based on the simulation state in future, in other words the user cannot define rules which require SIMMOD to know what will happen in the simulation in the next minutes or hours. It is up to the user to find solutions for these restrictions.

The simulation part of this study splits up into two cycles: First, the present situation on two airports is reproduced and simulated in order to gain reference values for noise and emissions. In the second cycle all commercial aircraft with a MTOW of 78 tonnes or less are equipped with the electric motor and perform autonomous pushback and engine-out taxi. After simulating the altered scenario and calculation of the new values for emissions and noise, a comparison can be made and evaluated.

3.1. Airports and Flight Schedules

In order to be able to choose two representative airports for this study, a categorisation regarding various characteristics such as movements per day, traffic mix, ground layout etc. was done. According to the approach of [7] the focus was put on primary hubs (more than 20 million passengers per year) and secondary hubs (10-20 million passengers per year). Regional feeder airports were not taken into account since their limited traffic does not allow a comprehensive assessment of the electric taxi. To assure the best availability of data for the fast-time simulation activities, the following two German airports were chosen: Frankfurt/Main (FRA) and Berlin Brandenburg International (BER), which is currently under construction and will begin operations in 2011.

With a total of more than 54.1 million passengers in 2007 [1] Frankfurt Airport is the third busiest airport in Europe and serves according to the aforementioned categorisation as primary hub in Germany. Its aerodrome layout with three dependent runways can be considered as complex and allows assessing the impact of electric taxi in dense traffic. The traffic mix comprises roughly a 26% of heavy aircraft (MTOW greater than 136 tonnes), 72% medium jets and 2% medium props and a negligible share of light aircraft (MTOW below 7 tonnes). The airport authority provided a flight schedule of 4 April 2010 which consists of 1,263 flights. For each of them detailed information on arrival/departure time, gate, runway, route etc. is contained such that the simulation can be calibrated against a real life scenario.

FIGURE 2 shows the flow at the runways throughout the day (rolling hour). It can be noticed that a relatively constant high level of 80 movements is handled between 8 a.m. and 8 p.m. Only around 11 o'clock in the morning a maximum of 92 movements is reached, while there is a decline to 60 at 6 o'clock in the afternoon. During night only a couple of flights are operated due to a night curfew.

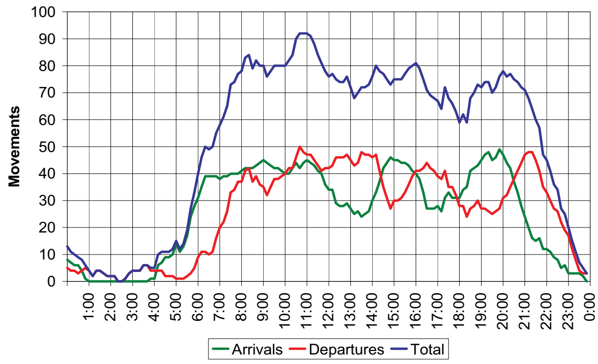

FIGURE 2. Traffic Flow in FRA (rolling hour)

Berlin Brandenburg International, the new capital airport, will substitute the remaining two Berlin airports Tegel and Schönefeld on its opening in November 2011. Two independent parallel runways and a midfield terminal outline the simplicity of the aerodrome layout and lead one to assume that this is an almost completely new construction. Based on the traffic figures of 2007 the formerly three airports registered roughly 20 million passengers [1]. With a share of more than 84% of the total traffic medium jets dominate operations at BER. In contrast to FRA the share of heavy aircraft is only 2%, indicating the role of Berlin Brandenburg International as secondary hub airport. The share of light aircraft is comparatively high (7%) and might have a negative effect on the traffic throughput. The rest 7% is medium props. As there was no forecast flight schedule contained in the plan approval order, a new one was created with the help of traffic statistics on the Berlin airports. It consists of approximately 1,000 flights which are mostly operated between 4 a.m. and 10 p.m.

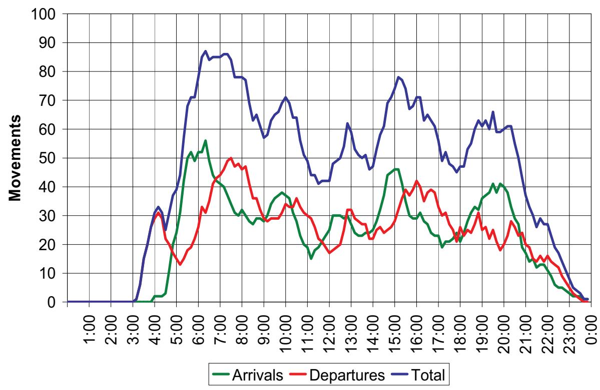

FIGURE 3. Demand in BER (rolling hour)

FIGURE 3 shows the demand based on on/off-block times throughout the day (rolling hour). After a distinct peak in the morning with a number of 85 movements the demand drops to a minimum of 41 at noon and swings up to another peak in the afternoon of almost 80. It is remarkable that the demand greatly varies in the course of the day whereas in FRA it remains almost stable at high level. Finally there is also a night curfew in Berlin during which no flights are operated.

3.2. General Setup of the fast-time simulation

Before dealing with the details about how to simulate the electric taxi in SIMMOD, some general information on the setup of the fast-time simulations have to be presented which refer to both scenarios. First, the ground network of the airport was created by importing a background image of the respective layout, which was either provided by the airport authority of FRA or in case of BER downloaded from the website of the regulatory authority. Special afford was spend to split long taxiways into links with a length of approximately 100 meters to be able to locate the aircraft as precisely as possible within the network, which will be of special importance for the subsequent noise calculation. All links are set to a capacity of one aircraft and configured as required (no overtaking, single direction, standard taxi speed, etc.). All aircraft types that operate at the airports were defined and sorted into two types of groups: When operating on ground, the common behaviour of the different aircraft types is defined by the ground groups which in this simulation depend on the ICAO landing speed category and decide on takeoff and landing distances and taxi speeds. When being airborne, the aircraft types are grouped by their wake turbulence category and their type of engine in order to assure appropriate airspeeds and separations. Though being a copy of the real world structure, the airspace is reduced to the final approach and the initial departure routes since this study focuses on the operations on ground.

To control the separations on the runways, SIMMOD offers different sets of procedures which define runway occupancy time (ROT), departure-departure separation and blocking distance (departure-arrival separation). Since in this study the ROT is controlled by probability distributions that are defined in the runway exit selection logic, it is not required to create procedures for this purpose. It turned out that values for these procedures are required nevertheless since they also define when a departing aircraft may line up on the runway after an arrival has landed. Therefore the procedure for ROT contains times which are needed for an arrival to pass a runway exit, where the next departure waits for its line up clearance. The most complex and time-consuming part is the calculation and setup of departure-departure separations. With the help of rather simple equations of motion time values for the following cases are calculated and entered:

– Departures from the same or dependent parallel runways: In general, if the combination of both departures requires wake turbulence separation none of the other rules can be applied. If both aircraft take the same departure route or travel for more than 3 NM on the same track an initial enroute separation of 4 NM is established. If both flights depart on diverging routes, it is sufficient that the leading aircraft has crossed the threshold before the trailing one begins its takeoff roll.
– Departures from independent parallel runways in BER: As one would expect no separations have to be applied.
– Departures from runway 18 and 25 in FRA: In general, crossings have to be avoided by holding a departure on runway 18 until the departure from 25 has crossed the intersection point or vice versa. Additionally, if the leading departure on runway 25L is of higher wake turbulence category than the trailing departure on runway 18 appropriate separation has to be established.

The blocking distance defines how close an arrival may approach the runway before a departure must have started its takeoff roll. Taking into account the landing speed and required time for a departure to accelerate lift off and cross the end of the runway, a time value for all runway/aircraft type combinations was calculated. This applies to arrivals and departures on the same runway (BER) and on dependent parallel runways (FRA). Exceptions are arrivals on runway 25L and departures on runway 18 in FRA where wake turbulence separation has to be taken into account.

3.3. Implementation of the electric taxi

Beside the general setup of the fast-time simulation some specific configurations are required in order to carry out highly detailed simulations for the purpose of this study. The aim of these configurations is to improve the simulated behaviour of the aircraft on ground by replacing SIMMOD's standard routines with tailor-made procedures which comply with the project specifications.

3.3.1. Pushback procedure

Depending on the gate type a pushback is usually required before the aircraft can begin its taxi to the runway. In this study the complete pushback procedure is internally handled like a set of taxi instructions. At the scheduled off-block time the aircraft will begin its push back at a constant speed of 3 kts, which was found to be the best average for the considered airports. Simultaneously the start-up sequence of the main engines is initiated which takes one minute for each of the engines to start and to stabilise at idle conditions. For each of the gates an individual location is defined where the pushback ends and the push back vehicle is unhooked which takes one minute. When all engines are running, one additional minute is provided to complete the After Start Checklist and to request the taxi clearance. When simultaneous activities, pushback and engine start sequence, are finished the taxi-out begins.

If the aircraft is equipped with an electric motor, it autonomously pushes back at a speed of 2 kts to the pushback location without starting the main engines. The rest of the procedure remains unchanged. If the parking position can be left without a pushback, the engine start sequence as described is performed at the stand.

3.3.2. Acceleration during taxi

As mentioned before SIMMOD is not able to simulate smooth acceleration, therefore a work-around was required to fix this deficiency. Scientists at the RWTH Aachen University created a simple method to solve the problem by calculating a time supplement which represents the acceleration phase [6]. In other words, an aircraft after a full stop will wait for a specific time before continuing its taxi at constant speed.

According to this approach the goal is to calculate the time difference between an object that is travelling a given distance d_{tot} at constant speed v_{taxi} and an object that accelerates to the same speed before continuing at constant speed to the given distance.

The time difference Δt is the time for an object to accelerate t_{accel} plus the time to travel the remaining distance at constant speed $t_{v,const}$ minus the time for an object to travel the complete distance at constant speed without acceleration $t_{s,v,const}$:

(1) $$\Delta t = \left[t_{accel} + t_{v,const} \right] - t_{s,v,const}$$

The time for travelling at constant speed can be expressed as distance d (with d_{tot} being the total distance and d_{accel} being the distance for acceleration to v_{taxi}) devided by speed v_{taxi}:

(2) $$\Delta t = t_{accel} + \frac{d_{tot} - d_{accel}}{v_{taxi}} - \frac{d_{tot}}{v_{taxi}}$$

Assuming constant acceleration, the acceleration distance d_{accel} is the acceleration value a double integrated over time t_{accel}.

(3) $$\Delta t = t_{accel} + \frac{\left(d_{tot} - \frac{1}{2} a\, t_{accel}^2 \right)}{v_{taxi}} - \frac{d_{tot}}{v_{taxi}}$$

Subtracting both fractions gives

(4) $$\Delta t = t_{accel} - \frac{a\, t_{accel}^2}{2\, v_{taxi}}.$$

With the acceleration time $t_{accel} = \frac{v_{taxi}}{a}$ follows

(5) $$\Delta t = t_{accel} - \frac{t_{accel}}{2} = \frac{v_{taxi}}{2a}.$$

This shows that the increased time for the acceleration phase of an object can be considered as a time supplement provided the target speed is reached within the travelled distance and the acceleration can be assumed as constant. In order to be able to calculate the time difference, which will be entered into SIMMOD as “spool up delay”, both the taxi speed and the acceleration have to be known.

According to a study of the airport operator the average taxi speed in FRA is 12.4 kts [10]. This value refers to the taxi distance and the required time to taxi from the pushback position to the runway or vice versa from the runway to the gate.

With regard to the variety of aircraft with their different weights and dimensions that operate at hub airports, the critical information is less speed rather than acceleration. The Airport Cooperative Research Program has carried out an examination of flight data recorder information from a major European airline to obtain general conclusions about the taxi behaviour of commercial aircraft [8]. Statistical analysis revealed that acceleration events can be divided into two distinct types: “Burst” events with longitudinal acceleration of up to 0.35 g for less than 15 seconds and “gentle” events with longer duration but less than 0.1 g longitudinal acceleration. However there were a lot of events which did not belong to any of these groups and it could not be explained whether they are a matter of outlier or erroneous data. Because of licensing restrictions the authors were not able to conduct further investigations to figure out the conditions under which the outliers were measured. It is assumed that certain manoeuvres like rolling takeoffs could not be eliminated in all cases. Another problem arises from the fact that the handling of the aircraft greatly varies among the pilots and also depends on the aircraft type (e.g. Airbus A319 vs. A380) and the individual circumstances (on time vs. rushing). Consequently a general prediction about the acceleration value during taxi cannot be made. The findings of [8] are used nonetheless as they are expected to be precise enough for the purpose of this study.

In the fast-time simulations acceleration values can be specified for two situations: after a full stop during taxi or after waiting at a runway crossing. As crossing of an active runway is a critical situation pilots usually apply more thrust after a full stop in order to quickly get clear of the runway than when beginning the taxi to the runway prior to takeoff. Therefore the “burst” acceleration values are used for the runway crossing logic and a combination of “burst” and “gentle” for the acceleration on taxiways since it can be assumed that both procedures occur in reality.

To obtain realistic values for the fast-time simulation, the data from [8] was related to the ICAO landing speed categories and supplemented since the selection of aircraft in the study was rather limited. The calculated acceleration values are presented in TABLE 1 for the runway crossing logic and in table TABLE 2 for normal taxi and refer to conventional taxi using the main engines. Since the performance of the electric motor has not been defined yet, acceleration values for this case cannot be presented.

Landing Speed Category	Acceleration (m/s²)
ICAO A	2.0
ICAO B	2.0
ICAO C	1.8
ICAO D	1.5
ICAO E	2.0

TABLE 1. Acceleration of aircraft at runway crossings

Landing Speed Category	Acceleration (m/s²)
ICAO A	1.1
ICAO B	1.1
ICAO C	1.0
ICAO D	0.9
ICAO E	1.1

TABLE 2. Acceleration of aircraft during Taxi

With the average taxi speed of FRA and the values from the table above time supplements were calculated and entered into the simulation. To address the fact that an aircraft does not immediately start to move after releasing the brakes and applying thrust as required, a uniformly distributed delay of 1-3 seconds, depending on the aircraft size, will be added by the simulation. The different performance of electric and conventional taxi will be controlled by individual ground groups for either case.

3.3.3. Taxi speed and main engine warm-up

Two other items which have to be solved when implementing the electric taxi into the fast-time simulation are the taxi speeds, which most likely are slower than for the conventional case, and the necessity to warm-up the main engines before takeoff.

Normally the taxi speed in SIMMOD is controlled by the properties of the respective airfield links and can be considered as a default value. If an aircraft type is not able to comply with these speeds, it can be added to the “AF link speed types” logic which allows defining different speeds for certain aircraft on the airfield links. Although the aircraft with electric motor are gathered to separate ground groups, the logic requires explicitly adding every aircraft type to the respective table.

A new problem arises from the fact that aircraft which taxi with the help of the electric motor have to start their engines in good time before takeoff. In reality the pilot would have to anticipate the remaining time until takeoff by taking into account the distance to the runway holding point, his number in the departure sequence and the situation of arrivals to his assigned runway and therefore even with the help of ATC it is a difficult task. The task is still more difficult in SIMMOD since it is not able to take decisions based on a future simulation state as mentioned before. Therefore an equivalent rule has to be created that only refers to the current simulation state but that is good enough to make useable predictions. At present it is unclear whether this problem can be adequately solved in Simmod PRO! as it is impossible to check any conditions as long as the aircraft is executing a command like taxiing to a certain location.

3.3.4. Runway exit selection

On the other hand, aircraft arrivals are handled in different way. The choice of the runway exit is another complex topic as it depends on various factors such as aircraft type, runway condition, location and geometry of the runway exits, preferences of pilot and company and even location of the arrival gate. This shows that precise predictions are almost impossible. For an adequate simulation it is sufficient however to reproduce the situation at a general degree that is to say that the cumulated exit events should approximately match the real distribution. To achieve these aim, probabilities were calculated for each of the ICAO landing speed categories to specify the choice of the available exits for every runway.

When an aircraft with electric motor arrives at the airport, it is supposed to land, decelerate and vacate the runway before switching to the electric motor for the taxi-in. To be able to change the characteristics of the aircraft in Simmod PRO!, it is necessary to begin a new taxi command at the runway exit. If the runway exit selection is controlled by a probability distribution, SIMMOD chooses the exit during runtime thus it is not known in advance. To solve this problem, the runway exit is randomly chosen by a switch command (but according to the specified distribution) such that it is known at least where the execution jumps to within the code. To force SIMMOD to use the selected exit, an entry in the runway exit gates table was created and a gate placed on the taxiway that leads off the runway. Additionally the probability value in the runway exits distribution table was set to 100%. After adapting the properties of the “virtual gate”, it will act like an ordinary ground node but it now is possible to issue a new taxi command to the aircraft and to change its characteristics for taxi.

4. POSTPROCESSING

In order to evaluate the results from the simulations in both cycles, a post processing tool called Extensible Workflow Management for Simulations (EWMS) is used. The main objectives of EWMS concept are a consistent data backup strategy, transparent post processing and standardised, well documented and peer-reviewed algorithms and methods for analysis and reporting. EWMS is a post processing tool which at the current stage includes three different environments: SIMMOD, Simtool and TOWSIM. In this study, the Simmod PRO! Environment is used. When uploading the project in EWMS, it collects the simulation data for aircraft’s airspace and ground movements, as well as some important simulation information and processes it. EWMS offers the ability to set up filters for more controlled and precise calculations [9].

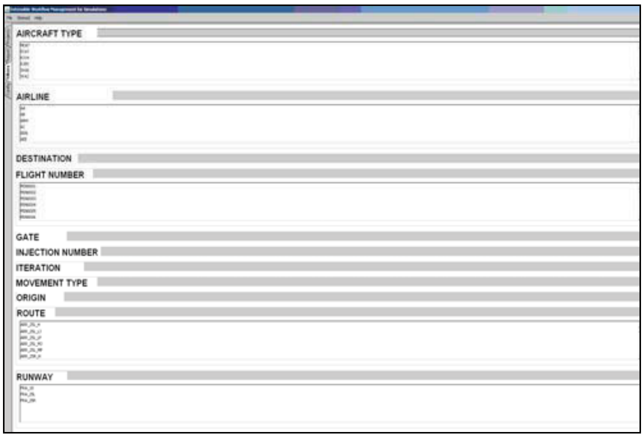

FIGURE 4. EWMS filters

FIGURE 4 shows the different filters within EWMS. Among the filters which are used belong the following groups:

- Aircraft type – The user can narrow the scope of the results and concentrate to only one or few aircraft types that are used in the simulation.
- Airline – The user can choose whether to use all the airlines which are contained in the scenario or choose only the ones that are important for observation.
- Destination
- Flight number – The user can choose between different flight numbers from the flight plan in order to evaluate them more precisely if needed.
- Gate
- Injection number
- Iteration
- Movement type – This is a very important filter, as one can distinguish between arrival, departure or ground movements.
- Origin – With this filter the user can choose the origin of the flight or flights that are of interest for the study.

– Route – This filter shows all the routes that exist in the simulation.
– Runway – When a multiple runway system is used, the user can choose which runway is of interest for the study.
– Time range

The parameters that can be calculated within EWMS are the following: average emission values, total emission, fuel burn, flight phases, traffic flow etc.

The approach which is taken for calculating the impact on reduction of emissions and noise is performed in few stages. In the first cycle a fast-time simulation with a present situation at the airports is simulated and therefore the results from this simulation are generated into EWMS. When processing the data in the post processing tool, representative values for the emissions, fuel consumption and noise at FRA and BER are received. After the second cycle of simulations is done, where part of the aircrafts is equipped with electric motor, the same post processing of the results will be initiated. The object of this is to compare the results obtained from both simulations.

The draft version of the results from the first cycle of FTS for Frankfurt Airport were imported in EWMS and the results will be demonstrated in the examples below. It is important to mention that in the current version of EWMS, no engine data is available for specific engine types. Thus it is foreseen that the engine database table will be updated in the following releases of EWMS.

FIGURE 5 below, shows the example for total emission chart at Frankfurt Airport. EWMS takes into account the following phases: departure queue delay, landing roll, spool up, takeoff run, taxi and taxi delay. The distribution of the greenhouse gasses in the departure queue delay phase are in the following order: 0.03% HC, 0.41% CO, 0.12% NO_x, 71% CO_2, 0.02% SO_x, 28% H_2O and a negligible procent of PM. In the landing roll phase 0.04% HC, 0.41% CO, 0.12% NO_x, 71.38% CO_2, 0.02% SO_x, 28.03% H_2O and a negligible procent of PM were calculated. In the spool up phase the following values were obtained: 0.03% HC, 0.41% CO, 0.12% NO_x, 71.38% CO_2, 0.02% SO_x, 28.03% H_2O and a negligible percent of PM. In the takeoff run, slightly different values were received: 0.00% HC, 0.00% CO, 0.88% NO_x, 71% CO_2, 0.02% SO_x, 28% H_2O and a negligible percent of PM. In the next two phases, taxi and taxi delay, almost all the gasses are coming out with the same percentage values, except for CO, HC and CO_2. In the taxi phase the percentage of produced HC is 0.04% and in the taxi delay it is 0.03%. There is a slight difference in the percentages between the CO and CO_2 in these two phases. In the taxi phase it is noticed value of 71.37% CO_2 and 0.42% CO, while in the taxi delay phase the same gasses were registered with the following values: 0.36% of CO and 71.42% of CO_2.

In 24 hours of traffic simulation, the following results were obtained for different green house gasses: 0.02% HC, 0.28% CO, 0.37% NO_x, 71% CO_2, 0.02% SO_x, 28% H_2O and negligible percent of PM.

One of the parameters that EWMS can calculate from a simulation is the fuel burn. In the next example, the fuel used in this simulation by flight phases will be presented.

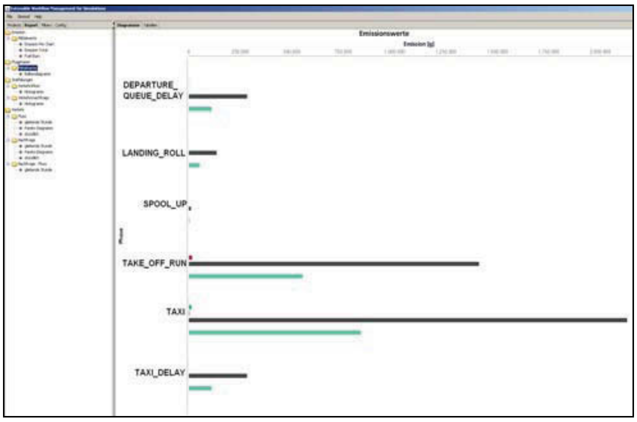

FIGURE 5. Total emission chart

The fuel burn is calculated in the same phases as the total emission chart. In the example for Frankfurt Airport the draft results (FIGURE 6) show the following results: around 6.35% of the fuel used belongs to the departure queue delay, 3% to landing roll, 0.26% to spool up, 33% to takeoff run, 51% to taxi and 6% to taxi delay.

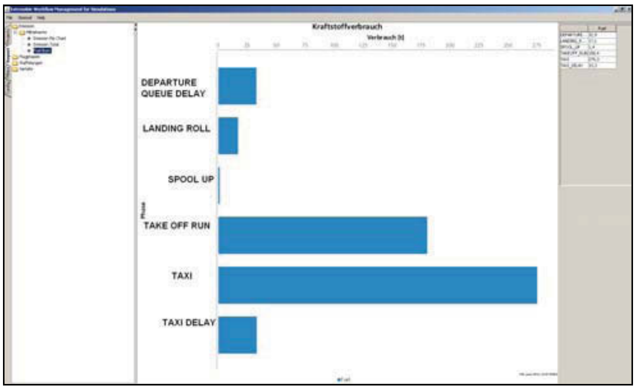

FIGURE 6. Fuel burn

On the other hand, for the process of calculating the noise pollution, a tool named Integrated Noise Model (INM) is used. INM is a computer model produced by the FAA, which calculates and evaluates the noise impact within the airport area. The INM can calculate the noise impact on an area or the noise level in different locations. For this study, the INM is also used in the two cycles. In the first cycle, using the base simulation scenario, INM will evaluate the noise level in the approach, takeoff and taxi phase. In this cycle the aircraft use normal engine power supply in the taxi phase and therefore the preliminary results show greater values of noise level. In the second phase, the engines of the aircraft within INM will be replaced with APU. This approach is used since the main goal is to reduce the emissions during the taxi phase using electric motors. The electric motors will be supplied with energy from the APU's. That means that in the taxi phase in the second cycle of simulations the only source of noise and emissions will be the APU.

5. SUMMARY

In the scope of the Joint Technology Initiative "Clean Sky", Systems for Green Operations ITD, work package "Smart Operations on Ground" fast-time simulations are conducted to assess the benefit of an electric motor that allows aircraft to autonomously push back and taxi without using the main engines.

Simmod PRO! was chosen as fast-time simulation tool as it provides the required flexibility to create tailor-made procedures which allow to simulate the activities during pushback, engine-start and taxi in great detail. Some of these procedures and their implementation into the simulation tool were described to show how new technologies can be integrated and which difficulties were met. The calculation of fuel burn and emissions from the simulation results was done with the help of EWMS, a post-processing program for various simulation tools, which was created by the Institute of Flight Guidance of the German Aerospace Centre. The goal is to evaluate and calculate the emissions and fuel burn. Draft results were presented in this paper. Finally the noise calculation will be carried out by using the Integrated Noise Model. An approach how to calculate ground noise and how to set up INM for calculation of the new electric taxi was presented.

As the second simulation cycle which includes the electric taxi has not been finished yet only assumptions can be made on the results but it can be expected that the use of the electric motor instead of the main engines will lead to significant savings on fuel and exhaust emissions. A reduction of noise may also be achieved but is considered to only have an effect within the airport ground. However the positive effects might be impaired by a slight increase of delay on the airports due to the lower performance of the electric motor compared to the main engines regarding acceleration and speed.

Objectives of the future work will be in the direction of implementing the new aircraft technology in the fast-time simulation. Further on, when obtaining the results from the simulation, detailed analyses on the noise, emissions and fuel burn will be carried on.

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