



SOURDINE II

D5-1

Description of noise and emission

Modelling requirements

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1. INTRODUCTION

Work items of WP5 of the Sourdine II project will consist in developing advanced aircraft data, enhancing noise and emission modelling tools and analysing noise and emission exposure of the candidate noise abatement procedures (NAPs), both for approach and departure. The noise reduction potential of the NAPs will be evaluated both on single event level and airport scale. First, single event noise assessments will be performed for some specific aircraft types, in order to identify the procedures that will be evaluated at airport scale. This study will be described in a separate document. Secondly, the overall efficiency of these new NAPs when applied to any fleet mix under “real world” constraints will be assessed. This analysis performed mainly in WP4 will cover efficiency of these NAPs in terms of noise, fuel burn and emissions, in addition to capacity, safety and operational aspects.

The noise and emission evaluations at airport scale will be performed using the European Harmonised Aircraft Noise Modelling Environment (ENHANCE), the Integrated Noise Model (INM) and the Advanced Emission Model (AEM). The required input data of these tools (mainly the flight trajectories) will be taken, when available with a sufficient level of accuracy, from the fast-time (TAAM) and real-time simulations, which will be carried out at the three “test-bed” airports in order to evaluate the effects on capacity and safety of applying the new NAPs.

Nevertheless, these environmental models/tools need to be adapted and improved to fully meet the objectives of this work. In particular, their sensitivity to the different parameters that characterise the candidate NAPs and have a significant effect on the noise perceived on the ground, needs to be improved, in order to enable relevant comparisons between different procedures (especially NAPs against conventional procedures).

This document specifies the requirements for modifications and improvements to these environmental tools, including the need for aircraft data development. The ability or not of fast-time and real-time simulation tools to produce flight trajectories which correctly reflect the aircraft behaviour when flying according to the different NAPs under operational constraints, needs to be discussed in the context of WP4 and is not part of this document. However, modifications to ENHANCE and INM which might be required to possibly compensate unrealistic fast-time or real-time simulated trajectories are briefly presented here. The linkage of ENHANCE with TAAM mathematical simulator will be discussed in the context of WP4 and is not part of these requirements.

There are two distinct sections in this document:

Section 2 deals with modifications to ENHANCE and INM for noise modelling,

Section 3 deals with modifications to AEM for fuel burn and emissions modelling.



2. MODIFICATIONS & IMPROVEMENTS TO ENHANCE/INM

2.1. Use of ENHANCE/INM for airport noise modelling: requirements overview

INM will be used in combination with ENHANCE to evaluate the global and actual noise benefit of the candidate NAPs, both for approach and departure, when applied to the fleet mix of the three “test-bed” airports. As input data of these tools, it has been proposed to use the trajectories produced by the fast-time (TAAM) and real-time simulations performed at the “test-bed” airports, at the condition they are sufficiently realistic,...

2.1.1. Description of ENHANCE/INM in their current version

2.1.1.1. INM

To calculate aircraft noise exposure around airports, INM uses successive values of five basic parameters to describe the noise-source trajectory: (x, y) ground position, height, speed and thrust. INM usually takes the (x, y) values from nominal ground tracks. All the aircraft of a given studied fleet mix are assumed to follow these nominal tracks (with possibly a Gaussian dispersion around the backbone tracks to integrate more realism). For each aircraft type, values for height, speed and thrust corresponding to the successive ground positions are then obtained by INM in one of two different ways, depending on the available data in the INM aircraft databases:

- Fixed-points profiles: values for height, speed and thrust (as a function of ground distance along the track) are pre-defined in a standard fixed-points profile database.
- Procedural profiles: successive values for height, speed and thrust are calculated by INM from pre-defined take-off or approach procedures, using an aircraft performance model (based on methodology described in SAE AIR-1845[1] and an associated aircraft performance database (including jet coefficients, drag-over-lift coefficients, etc.).

With the second option, the resulting (calculated) flight profiles (in terms of height, speed and thrust as function of ground distance) vary with aircraft operational weight, meteorological conditions (temperature & pressure) and procedure parameters (e.g.: flap settings schedule, thrust cutback) which can be user input parameters.

From these input data describing the flight trajectories, the noise engine calculates the noise footprint produced by each single event, using a Noise Power Distance (NPD) database. This database provides for each aircraft type a set of curves specifying perceived noise levels as a function of source to receiver distance, for different thrust settings. These curves are developed for a single aerodynamic configuration and a reference (constant) true airspeed of 160kt, according to guidelines specified in SAE AIR-1845.

2.1.1.2. ENHANCE

ENHANCE is a tool aiming at improving the quality of the input data used by a noise model like INM. It allows to directly and easily import into INM full 4-D trajectories (3-D position + speed) taken from radar or ATC/ATM simulator data, each flight being modelled individually. In particular, through this approach, it is possible to better account for the “real” dispersion of trajectories resulting from a given procedure under operational conditions. Since thrust is generally not provided by fast-time and real-time simulators (or by radar data), one key feature of ENHANCE is to calculate in a reverse-engineering way the thrust profile (required by INM for noise calculations) associated to each flight trajectory. For that purpose, ENHANCE uses the thrust equations and the aircraft performance database of INM. The current version of



ENHANCE (V1.0) only works for departures, but the second release, currently being developed, will include the process for arrivals as well.

2.1.2. Overview of the required modifications and improvements for Sourdine II

The noise reduction potential of new noise abatement procedures is based on reduction of both noise produced by engines and airframe and the amount of noise energy transmitted to the observer on the ground. To properly evaluate the global noise benefit of new NAPs, it is required to ensure that all the parameters that characterise the NAPs and have an effect on the noise perceived on the ground, can be fully and accurately taken into account by ENHANCE and INM.

2.1.2.1. Need to better account for airframe noise during approach

For approach operations airframe noise may be the dominant component of the overall aircraft noise. For a given aircraft type, the magnitude of the airframe noise component depends on the aerodynamic configuration (configuration of high-lift devices and position landing gear) and airspeed. The noise assessment of new approach procedures requires a model that takes the variation of aircraft noise with these parameters into account.

With the current version of INM, it is not possible to model the effect that variation of configuration and speed has on the overall noise produced by aircraft. The ability to calculate noise on approach as function of aircraft configuration and, to the possible extent, airspeed should be therefore added. It should be mainly achieved by developing new types of NPD curves, as described in the sections below. Modifications to INM (and ENHANCE) to account for these new NPD curves are also required.

2.1.2.2. Thrust calculation process improvements

Even during approach, the overall produced aircraft noise remains strongly dependent on thrust settings (as explained in section 2.2. below). It is therefore fundamental to provide to the noise engine of INM, calculated thrust profiles that correctly reflect the power settings that aircraft would use when flying according to the different NAPs, under operational conditions.

For approach procedures, the second release of ENHANCE (currently under development) uses the thrust calculation process from INM, which does not correctly account for idle thrust settings. This thrust calculation process should be improved and validated. This might involve the development of more appropriate aircraft data than those currently available (drag-over-lift coefficients in particular), using manufacturer tools.

For departure procedures, engine noise is the dominant component of the overall produced aircraft noise. It is directly correlated to the thrust profile along the trajectory. Departure procedures using de-rated thrust should be logically one of the possibilities to look at within the project. At the moment, neither INM nor ENHANCE can properly calculate thrust profiles based on de-rated thrust procedures. The use of new types of jet coefficients (and a modified thrust equation) should be investigated.

Another aspect to look at is the effect of turns on thrust settings: indeed, the aircraft bank angle during turns naturally involves an altitude and/or speed loss tendency. The only way to compensate this energy loss is to increase thrust (if such compensation is required by a given NA procedure). At the moment, neither INM nor ENHANCE can easily model this potential thrust increase during turns. Investigations have to be made for that purpose.



2.2. Airframe and engine noise during approach: theoretical background

The basic components of aircraft noise are engine and airframe noise. For departure operations engine noise is known to be the dominant component of overall aircraft noise. On approach the airframe noise accounts for a significant, in some cases dominating, part of the overall aircraft noise.

Different studies, both theoretical and empirical [2,3], have shown that noise generated aerodynamically is the main source of the airframe noise (vibrations of parts of the airframe structure may be another, less important source). Experiments in wind tunnels [3,4] have demonstrated that among other effects, the creation of a vortex system both on slats and flaps is a significant source of airframe noise. Another contributor of the aerodynamic noise is the noise generated by the boundary layer. The perceived airframe noise strongly depends on aircraft configuration setting. It also depends on aircraft speed (as explained below) and distance (effect of geometrical and atmospheric attenuation).

The spectral content of airframe noise differs from the spectral content of engine noise. The different contributors each produce noise in their own, characteristic frequency range. The amount of sound energy attenuated during propagation from source to observer depends not only on the source-observer geometry and atmospheric conditions, but also on the frequency of the sound signal. Atmospheric absorption attenuates especially the high-frequency part of the spectrum. This causes airframe noise and engine noise to propagate differently over equal far field distances. In case the sound pressure level of one of the two components is much higher for each of the one-third octave bands in which the other signal is present the observer will only perceive the dominant noise component. This is known as masking. The impact of a change in airframe noise due to a change of configuration on overall perceived noise depends therefore on the magnitude and spectral shape of the engine noise component.

This means that, to calculate perceived overall aircraft sound levels for different aerodynamic configurations and different engine settings, the observed noise spectra of both components need to be determined separately before being summed up logarithmically.

Airspeed has influence on both airframe and engine noise. The influence of speed on airframe noise is explained by its influence on boundary layers and wake turbulence. The influence of speed on engine noise is explained by the interaction between the airflow and exhaust jet; the difference in speed between these two flows determines the magnitude of jet noise. In addition, airspeed has effects on noise propagation: it determines of course the amount of sound energy perceived on the ground, and also the magnitude of the Doppler effect (frequency shift).

All these considerations are essential to determine how the current INM program and database could be modified, within the limited timeframe of the project, to better account for changes in airframe noise due to changes in aircraft configuration and speed, as explained in 2.4.1.

2.3. NPD data development in current situation

In the current situation NPD curves for approach are calculated for one single landing configuration (for Airbus aircraft this is for example the approach/landing configuration CONF3 with extended landing gear). These curves are calculated for two or more specific approach thrust values.

The Airbus NPD data are calculated using a computerised method for the certification of derivative aircraft. This tool enables the calculation of NPD data according to the SAE AIR-1845



guidelines. It calculates aircraft noise at an observer position for a given aircraft type, flight trajectory and source-observer geometry. Engine and airframe sound pressure level spectra are calculated separately and added logarithmically, to obtain the overall aircraft noise spectrum perceived at the observer position. The observed noise spectra are calculated as function of time, on basis of which maximum and exposure based noise metrics are calculated.

The engine noise spectra are calculated by projection of noise data obtained from static engine tests into flight conditions. The method and data are adjusted using noise data obtained from certification flight tests. Airframe noise spectra are calculated using a semi-empirical method that has been calibrated on basis of results of airframe noise flight tests.

The development of approach NPD data is more complicated than the development of departure NPD data, for several reasons. The low thrust levels require usage of data at the lower limit of the static engine noise database. Moreover, for exposure-based NPDs (such as SEL, EPNL), the emitted sound pressure levels being relatively low, the 10dB-down periods¹ may be extremely long, requiring a significant amount of extrapolation, especially for the lower thrust levels combined with zero/intermediate flap settings and retracted landing gears. The flight trajectories used to calculate NPD data differ significantly from the certification and airframe noise flight trajectories meaning that part of the methodology to calculate source noise and propagation effects is used outside its domain of validity.

2.4. Proposed enhancements on noise modelling during approach

Modifications are proposed both to the INM noise database format (and content) and the program. Minor modifications shall be also required on the ENHANCE program.

The main modification consists in the addition of NPD curves for multiple aerodynamic configurations, which shall also include to the possible extent the effect of actual aircraft speed on the overall perceived noise (both airframe and engine noise). This will require an adaptation of the INM source code to account for these new NPD curves.

Another modification is the reduction of the maximum altitude for which NPD data is developed from 25000ft to 10000ft.

These proposals need to be evaluated on their feasibility by the INM developer, the data developer and Sourdine II WP5 partners. They are described in the following paragraphs. Configuration indicators used in this section are aircraft and manufacturer specific and given as example.

2.4.1. Addition of NPD curves for multiple aerodynamic configurations to the existing single-configuration NPD data.

During approach operations the aircraft configuration changes from clean to landing configuration. Subsequent flap/slats settings are CONF 0, 1, 2, 3 and FULL (Airbus configuration identifiers serve as example in this section). CONF 1 through 3 are intermediate configurations and CONF 3 and CONF FULL are landing configurations.

¹ The period during which the instantaneous perceived sound pressure level is higher than the maximum perceived noise level ("L_{max}") minus 10dB. Practically, integrating instantaneous sound pressure level over such a defined period accurately represents the sound energy level produced by a single flight event.



The time at which the landing gear is extended is operator dependent. For INM standard approaches it is assumed that the landing gear is extended when the aircraft is in CONF 2. The landing gear position is denoted as U(p)/D(own).

This results in six aerodynamic configurations, CONF 0-U, 1-U, 2-U, 2-D, 3-D and FULL-D, for which NPD curves may be required. In case the noise differences between subsequent configurations appear to be negligible, one or more can be left out to reduce amount of data and development time.

The use of multiple-configurations NPD data in the form of curves that represent overall aircraft noise levels as a function of source-observer distance for different thrust values is compatible with current practice and requires relatively minor modifications to the INM source code. The modified INM version shall be able to use both multiple configuration and conventional NPD type data. It allows the manufacturer, as data developer, to add similar data in a similar format as provided in the current situation for additional parameter values (i.e. aircraft configuration). An alternative method, in which engine and airframe components are delivered in separate tables and added up to overall noise in INM, would require additional information on spectral content for correct summation of the different components. This would require a too significant adaptation of INM source code and data requirements to handle within the timeframe of the Sourdine II project.

In addition to modelling multiple configurations, a better way to account for speed effects on noise is sought. A large amount of noise emission and propagation phenomena (summarised in 2.2.) depend on speed. It is unlikely that an independent speed correction that provides significant accuracy improvement can be developed and validated within the Sourdine II time frame. A simple modification that is expected to deliver improvement without need for additional noise data, is the replacement of the single reference speed of 160kt TAS by several configuration-specific reference airspeeds, each of these airspeed values being the average operational airspeed which is generally associated to a specific configuration.

In addition to the implications for the INM, the technical feasibility of developing multiple-configurations NPD data, including the required adaptations of manufacturer tools for that purpose, needs evaluation. For the approach noise data that is currently developed for INM, the manufacturer tools are used at the limits of their domain of application (as explained in 2.3.). The development of data for cleaner approach configurations and flight idle engine settings will require adaptations to manufacturer tools.

If these adaptations are possible and effective, the generation of multiple-configurations NPD data is expected to require a relatively small amount of additional development time per aircraft.

2.4.2. Reduction of the maximum altitude for which NPD data is developed from 25000ft to 10000ft.

The reduction of the maximum altitude for which approach NPD data is developed is proposed for several reasons. The calculation of noise levels for large source to receiver distances for approach thrust settings requires usage of noise tools beyond the domain for which underlying methodology was developed, as explained above. No guarantee can be given on the precision of noise levels calculated for these long distances. Noise levels for these distances are often lower than ambient noise levels hence impossible to validate by measurement. On the development side, these cases require roughly 60% of the actual NPD development time due to program aborts, manual parameter adjustment and extrapolation.



NPD data is developed for a range of aircraft altitudes and not distances. The way in which INM uses NPD data to calculate noise levels perceived at observer position actually enables noise data developed for a flyover altitude of 25000ft to be used for noise calculation at 25000ft lateral distance for an aircraft near the runway. It is obvious that the engine state and flight conditions change significantly with altitude as well as the characteristics of the atmospheric layer through which the sound reaches the observer. The error in the modelling of emitted noise and propagation effects increases with the source-observer distance.

2.4.3. Resulting modifications to the INM and ENHANCE programs

An adaptation of the INM source code to account for these new NPD curves will be required:

- In addition to the successive values of the five parameters currently used to calculate noise (x, y, height, speed and thrust), information about the aircraft configuration along the trajectory will have also to be specified, in order to access the corresponding NPD curves. Through the INM segmentation process, the aircraft configuration to be assigned to each segment of the trajectory will be determined as a function of the user-specified aircraft configuration schedule along the trajectory.
- Another modification will deal with the INM speed correction formula for exposure-based metrics. In the current version, the correction uses the single 160 knots reference speed value. With the new NPD curves, the speed correction formula will have to replace this value by the different configuration-specific reference speed values.

Modifications to ENHANCE will be also required, in order to provide to INM the aircraft configuration setting associated to each point of the fast-time (and further, real-time) simulated trajectories. In its current version, ENHANCE uses a default configuration schedule (as a function of altitude), which is used to calculate thrust profiles. But the user can not modify it. It will be therefore required to modify the program:

- to allow the user to easily specify the configuration settings schedule associated to a given NAP,
- to import into INM the configuration information required to access the new NPDs, in terms of aircraft configuration setting at each point of the trajectories resulting from this NAP.

2.5. Required enhancements on the thrust calculation process

2.5.1. Thrust calculation for approach

For approach procedures, the second release of ENHANCE (currently under development) uses the INM thrust calculation process. The corrected net thrust is calculated using a total zero force balance equation (i.e. without any acceleration/deceleration term). In this equation, thrust depends on aircraft weight, descent angle and configuration settings (through drag-over-lift coefficients). The modification of ENHANCE allowing the user to easily specify the configuration settings schedule associated to a given NAP (as specified in 2.4.3) is therefore also required to calculate the thrust profiles associated to the fast-time (and further, real time) simulated trajectories which result from the NAPs.

Nevertheless, neither ENHANCE nor INM (when using procedural profiles) correctly account for idle thrust settings by using this calculation process. In particular, for a level segment, the use of the current thrust equation results in a systematic increase of thrust, which does not reflect "real" practice. The thrust settings depend on changes in aircraft speed as well. For that reason, the INM aircraft data which have been recently provided by some of the manufacturers for new



aircraft types have been delivered in the form of fixed-points profiles (which can not be easily modified) and not procedural-profiles.

A relatively “low cost” improvement could be to modify the ENHANCE thrust calculation process by adding algorithms which look at speed profiles (ex: no thrust increase during deceleration segments). But the calculated thrust profiles using this modified thrust calculation process will need to be validated against thrust profiles generated by the manufacturer tools. Moreover, this proposed improvement will be effective only if the fast-time and real-time simulated trajectories can provide speed profiles that reflect the aircraft behaviour when flying according to the NAPs. If this is not the case, alternative solutions will have to be found, as explained in section 2.7. In addition, the development of more appropriate aircraft data than those currently available (drag-over-lift coefficients for approach-specific aircraft configuration settings in particular), using manufacturer tools, will be required.

2.5.2. Thrust calculation for departures

To calculate thrust for departures, ENHANCE uses the regression equation of INM. This equation defines the corrected net thrust as a function of speed, altitude (and also pressure ratio and temperature), using constant (regression) coefficients which are derived from manufacturer data. These so-called jet coefficients are available for two power states: max-takeoff and max-climb. Depending on the phase of the flight, ENHANCE (and INM) use one of the two states to calculate thrust values.

This process is however not appropriate to calculate thrust profiles for de-rated thrust departure procedures (or any other procedure with a specific management of thrust settings), which should be yet evaluated as potentially efficient NAPs. It is therefore necessary to investigate into an alternative way to produce/calculate thrust profiles which correctly reflect that kind of procedures. One possibility could be to use a generic thrust equation form, which defines corrected net thrust as a function of engine pressure ratio (EPR) or low-pressure rotor speed (N1), in addition to the other parameters (altitude and speed). This equation uses general (regression) coefficients, which are already available in the INM database for some aircraft types.

The calculated thrust profiles using this generic thrust equation will need to be validated against thrust profiles generated by the manufacturer tools. Moreover, the use of this generic form requires specifying the EPR or N1 profiles resulting from the different departure procedures to be studied. If these EPR or N1 profiles are also aircraft-dependent, it will be necessary to specify them for each aircraft type of the fleet mix that will be used at the three airports. In that case, it might be more suitable to directly produce corrected net thrust (plus altitude and speed) profiles, using manufacturer tools, for the different aircraft types when using procedures with a specific thrust management. In addition, the use of the generic thrust equation form by ENHANCE to calculate those particular thrust profiles will be useful only if the fast-time and real-time simulated trajectories can provide altitude and speed profiles which reflect the aircraft behaviour when flying according to those procedures. Once again, if that was not the case, alternative solutions will have to be found.

For thrust evaluation during turns, the required improvements will depend on the results of the manufacturer single event assessments (e.g. effect of turns on thrust increase for procedures requiring a maintained climb rate and/or speed).



2.6. List of aircraft types for which data need to be produced

The new INM databases, including multi-configuration NPD curves (and possibly additional aircraft approach performance coefficients) will have to be produced for a list of aircraft types which needs to be defined. With the evaluation of candidate NAPs proposed for implementation between 2005 and 2015, the global noise impact assessments will have to be carried out using the predicted fleet mix for that timeframe at the three airports. The list of aircraft types for which data have to be produced using manufacturer tools, will cover as far as possible the predicted fleet mixes at the three airports. That point needs to be discussed within WP4.

2.7. Potential limitations of fast-time and real-time simulated trajectories

The ability or not of fast-time (and further, real-time) simulation tools to produce flight trajectories which correctly reflect the aircraft behaviour when flying according to the different NAPs under operational conditions is a key issue, which needs to be discussed in the context of WP4. In particular, the aptness of trajectories calculated by fast-time and real-time simulators to be used as input for INM noise studies for the candidate NAPs should be evaluated prior to the airport noise studies. This evaluation could be performed by comparison of these trajectories against trajectories calculated in a detailed manner with manufacturer performance tools for a series of test procedures.

This section specifies modifications to ENHANCE (and INM) which might be required to possibly compensate unrealistic fast-time and real-time simulated trajectories.

For arrivals, ENHANCE should be easily modified to re-calculate unrealistic height profiles. But it seems much more difficult to do the same with speed profiles. In the case of unrealistic speed profiles, INM procedural profiles should be used instead. But that would require additional work to modify – and validate – the performance model used by INM, in particular to better account for idle thrust mode.

For departures, the flight profiles (in terms of speed and altitude) are highly aircraft performance-dependent. The risk that fast-time and real-time simulators produce flight profiles that do not properly reflect the aircraft behaviour when applying departure NAPs is very high. It seems particularly difficult to modify ENHANCE to correct unrealistic speed and altitude profiles. Direct use of the INM procedural profiles instead is an option that should be considered in case fast-time simulators provide unrealistic trajectories (the required improvements on the INM thrust calculation process for departure procedures with “unconventional” thrust management is described in 2.5.2).

For the particular case of the SIMMOD (fast-time) simulation at Naples airport, it is already anticipated that the produced data will not be exploitable, because of their well-known lack of realism. For that specific case, INM will be used standalone, with its improved performance model/database. A question remains however about the ground track dispersion to apply.

2.8. Cost

Four separate actors are involved in this work: EEC, FAA (with Volpe Labs.), Airbus and Boeing.

EEC and Airbus are main consortium members in WP5. Their activities in WP5 and the budget allocated to these activities are described in the Description of Work.



Work to be performed by FAA and Boeing will form part of an FAA Statement of Work (SoW) for 2002. It is estimated that Boeing will be able to produce full sets of NPDs, under the new definitions given here, for six or seven aircraft in 2002.

Volpe Labs. (developers of INM) will make the modifications necessary to INM in order to take configuration changes into account by accessing the correct NPDs. This is estimated as being a fairly simple task. Further contractual details of work to be performed both by Boeing and Volpe should become available soon after the SoWs are finalised.

EEC will pass a contract with ISA Software (developers of ENHANCE) for work on ENHANCE modifications. This is estimated at n man-months work.

2.9. References

- [1] SAE AIR 1845, Aerospace Information Report, "Procedure for the calculation of airplane noise in the vicinity of airports", prepared by SAE committee A-21, aircraft noise.
- [2] AIAA 98-0628, "Numerical Simulation of Fluctuations leading to Noise in a Flap-Edge Flowfield", C.L. Streett (NASA Langley Research Center, Hampton).
- [3] AIAA 2000-1975, "Flap Edge Aeroacoustic Measurements and Predictions", Thomas F. Brooks and William M. Humphereys, Jr. (NASA Langley Research Center, Hampton).
- [4] AIAA 2001-2155, "Time-Accurate Simulations and Acoustic Analysis of Slat Free-Shear Layer", Mehedi R. Khorrami, Bart A. Singer (NASA Langley Research Center, Hampton).



3. DEVELOPMENTS NECESSARY FOR EMISSION MODELLING

3.1. Objectives:

The Sourdine II Emission Modelling System will be based on the Advanced Emissions Model (AEM)² developed over the last few years at the EEC to evaluate fuel burn and emissions. This tool enables to calculate fuel burn and aircraft emissions (specifically Hydrocarbons (HC), Carbon Monoxide (CO), Oxides of Nitrogen (NO_x); Sulphur Dioxide (SO₂); Carbon Dioxide (CO₂), Water Vapour and Benzene) based on engine thrust settings for different arrival and departure profiles. It perfectly supports the analysis needs after fast-time simulation studies concerning environmental issues. The system will use the ENHANCE/INM flight profiles (used for the noise calculations) as input data and the International Civil Aviation Organisation (ICAO) Engine Exhaust Emissions Data Bank to quantify emission levels.

3.2. Description of Work/Tasks:

3.2.1. *Development and implementation of an Aircraft/Engine/Emission database.*

A database has to be developed which links aircraft/profile information from the ENHANCE/INM system to the engine exhaust information from the ICAO Exhaust Emissions Data Bank. The ENHANCE/INM profile data are text files which provide a description of arrival and departure profiles along a series of 'legs' or data points, including altitude, speed and thrust for each flight (and aircraft type).

The ICAO Engine Exhaust Emissions Data Bank is an Excel file covering a large series of aircraft/engines. It contains the fuel flow (kg/s) and emission indices (g/kg fuel flow) for Hydrocarbons (HC), Carbon Monoxide (CO) and Oxides of Nitrogen (NO_x) at four different thrust setting levels - Take-Off, Climb-Out, Approach and Idle.

3.2.2. *Development and implementation of algorithms for the calculation of fuel burn and pollutants using the ICAO databases.*

The system is required to calculate fuel burn and emission levels of each of the pollutants, at each leg of a given flight profile, using all possible engines available for the particular aircraft type. At each leg point a linear interpolation method, using the actual thrust setting from the ENHANCE/INM profile data, shall be used in order to improve the estimation of the actual fuel flow and emission indices. In addition, the system shall use emission coefficients to calculate CO₂, SO₂, H₂O and Benzene levels based on Fuel burn.

3.2.3. *Development and implementation of Graphics routines.*

The system will allow the calculated emissions to be viewed graphically.

² Advanced Emission Model (AEM) is a stand-alone data analysis capability. It uses flight profile information to calculate information about fuel consumption and emissions produced. It perfectly supports the analysis needs after fast-time simulation studies concerning environmental issues. AEM is able to analyse fast-time simulation output from any simulation tool. It only requires the data to be formatted in the AEM input formats. AEM provides as result of its calculation, information about the estimated fuel consumption of the traffic scenario under analysis.



3.3. Functionality

The required functionality of the modelling system shall be divided into three main sections: Data, Graphics, and System Defaults.

3.3.1. Data

The Data Section will contain three main parts:

- Import ENHANCE/INM Profile TEXT Data

The User will be able to select the location of the ENHANCE/INM profile data to be imported.

- Calculate Emissions

If the user decides to change the input profile data and/or to make adjustments to the system data (such as adding new engine types or changing the emission rates), the output emission data will need to be re-calculated. In addition, the emissions will be automatically re-calculated after the user adds a new ENHANCE/INM profile to the database.

- Export Emissions results

The user will be able to output the emissions data to Microsoft Excel by indicating a name and location for the output data file. The Excel files can then be used for further analysis and/or for including the calculated emission results into reports.

The Data Section will further contain HMI elements to select specific profiles and related data as Aircraft Types, Engines, Profiles and Profile type.

3.3.2. Data Viewer

The data viewer is required to be able to view ENHANCE/INM Profile Data Input and the Emission Data Output.

- ENHANCE/INM Profile Data Input:

The ENHANCE/INM Profile Data Input part will show the profile data for a specific profile selected. The user will be able to edit the data and then re-calculate the emissions using the Calculate Emission feature.

- Emission Data Output:

The emission data output part shall show the emission output results calculated by the model. The user will be able to display output data sets such as:

- Thrust levels per leg;
- Fuel burn total or per leg;
- NO_x total or per leg;
- CO total or per leg;
- HC total or per leg;
- SO₂ total or per leg;
- CO₂ total or per leg;
- H₂O total or per leg;
- Benzene total or per leg;
- etc.



3.3.3. Graphics

The Graphics section is required to allow the user to graphically view the emissions both on a 'per time' basis and on a 'per leg' basis.

- Total Emissions per Profile (Graphs):

The user will be able to view any of the following: Profile (Altitude); Total fuel burn; and pollutant total emissions (NO_x, CO, HC, SO₂, CO₂, H₂O and Benzene).

- Emissions per Leg (Bar Charts):

The user will be able to view any of the following: Thrust levels per leg; Fuel burn per leg; and Pollutant levels per leg (NO_x, CO, HC, SO₂, CO₂, H₂O and Benzene).

3.3.4. System Defaults

The purpose of this section is required to allow the user to change various system data sets. There seem to be four required main areas for system data: Aircraft data; Aircraft Engines; Engine Mode Emission Rates and System Constants.

- Aircraft Data

These will be the aircraft data that are currently used by INM. The system will need to use the following fields: Aircraft Name; Number of Engines; Static Thrust.

- Aircraft Engines

These data relate the aircraft name to the engine type. It will be permissible to allow several engine types to be entered for each aircraft name.

- Engine Mode Emission Rates

These data will be entered in the system directly from the ICAO Exhaust emission database.

- System Constants

The system constants will keep data like emission coefficients etc. The emission coefficients are factors for calculating Carbon Dioxide (CO₂), Sulphur Dioxide (SO₂), Benzene and water levels emitted from an engine in kg/kg fuel flow (g/kg fuel flow for SO₂).