EMISSION SCATTERING SIMULATION FOR AIR-PORT REGION

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Abstract

The lecture deals with a new method developed for emission scattering simulation for airport region. The emissions are generated by time and flight technology dependent air transport and connected ground (road) transport. The applied method based on the Markov chain model describing the emission scattering as the diffusion process in airport zone. The transition coefficients of Markov chain are taking into consideration of the flight technology, aircraft and ground vehicle emissions depending on vehicle sizes, diffusion characteristics of air pollutants, air quality and behavior, weather (wind and air mixing) conditions, etc. The results are presented in 3D figures.

This method of emission scattering simulation can apply to investigation of the effects of air transportation system on the airport surroundings and to design of airports with ground transportation and flight technology reducing the air pollution in the airport zones.

1. Introduction

Nowadays the environment effective protection raises a lot of new tasks related to aviation, too. One of them is the emission scattering determination associated with air transportation system. The air pollution at the airport and in zone near the airport is generated by air and ground (road) transports.

This lecture deals with a new method developed for emission scattering simulation for airport region. The applied method based on the Markov chain model describing the emission scattering as the diffusion process in airport zone. The predefined space of airport region is divided into small boxes. The source of air pollutants calculated as time and space dependent function defined for the series of boxes determined by applied flight technology and designed ground transportation system. The transition coefficients of Markov chain are taking into consideration of the flight technology, aircraft and ground vehicle emissions depending on vehicle sizes, diffusion characteristics of air pollutants, air quality and behavior, weather (wind and air mixing) conditions, etc. The software is developed in MATLAB environment. The results are presented in 3D figures.

This method of emission scattering simulation can apply to investigation of the effects of air transportation system on the airport surroundings and to design of airports with ground transportation and flight technology reducing the air pollution in the airport zones.

The simulation method was developed for study the environment effects of air transport on the regions of airports under development and was applied to several new developed airports for environmental impact study with accordance the Hungarian rules and requirements [1, 2].

2. Some facts about the aircraft emissions

The environmental protectionists very often talk about the air transportation as the worst transport system. They deal with the old data. The true is that, every decade the aircraft emissions are reduced for 25 – 40 per cent. Today the modern aircraft (Fig. 1.) are operated by energy (fuel) related to one tkm less then fast train or good car [3]. For example, in 1998 the Lufthansa’s fleet of passenger aircraft required an average of 4.9 liters of fuel to carry one person over distance 100 km [4].

Another important fact, the land used by air transportation system (Fig. 2.) much more less then in any other cases [3]. So the air transport has direct impact on the environment near the airports, only, why the railway or road trans-

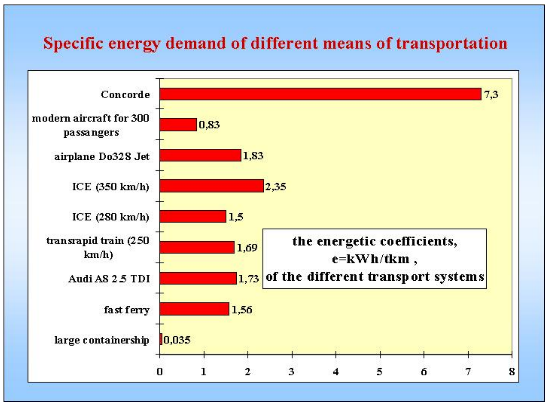

Fig. 1. Specific energy demand of different vehicles

transports have influence on air quality along the all transportation net.

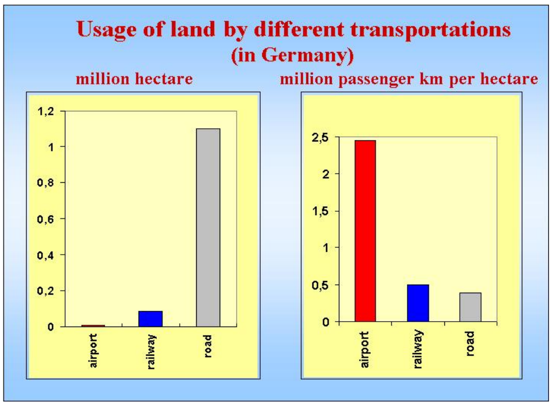

Fig. 2. Land use efficiency

The affectivity of aircraft development and relationship between the volume of passenger traffic and environmental impact can be demonstrated by Lufthansa's practice published in [4]. In period 1991 – 1998 passenger – kilometers performed by Lufthansa have increased by 73 per cent, however growth that was achieved with only 18 per cent more flights, while fuel consumption and carbon dioxide (CO_2) and nitrogen oxides (NO_x) have increased by only 37 per cent.

During the same period, the emission of carbon monoxide (CO) and unburned hydrocarbons (HC) have fallen in absolute terms, by 8 per cent and 42 per cent respectively.

Principally, the air transportation system effecting on the ground air quality is greener then any others.

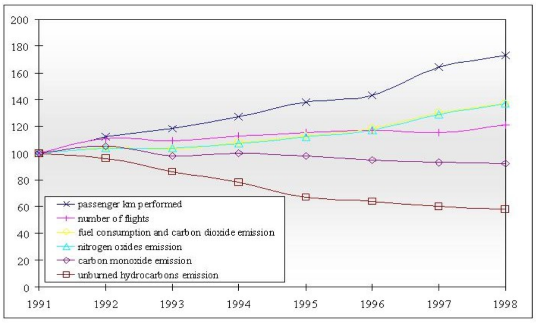

Fig. 3. Changes in airlines productivity and environmental impact

3. Basic characteristics

On the basis of regarding instructions [5, 6] and practical experiences, of the pollutants emitted by aircraft engines, it was considered that the following should be controlled:

- unburned hydrocarbons (H_xC_y or HC), including vented fuel,
- carbon monoxide (CO),
- oxides of nitrogen (NO_x), including a nitric oxide (NO) and nitrogen dioxide (NO_2),
- smoke (or soot).

The environment-biological deleterious effects of these pollutants are the same as effects of car engines' pollution.

In the latest references and research reports the nitric oxide and the nitrogen dioxide as well as carbon oxide are investigated independently.

According to 16th Annex [5] of International Civil Aviation Organization (ICAO) the Aircraft Engine Emissions should be given by emission index (EI) and smoke number converted into ISA (International Standard Atmosphere) sea-level condition form. The mass of pollutant present in the exhaust gas sample divided by the mass of fuel used by the engine during the time of taking the sample expressed in terms of g/kg called as an emission index. However the smoke number is the dimensionless term quantifying smoke emission level, based upon the staining of a filter by reference mass of exhaust gas sample, and rated on a scale of 0 to 100. The smoke number should be measured by using the instruments and technology prescribed by ICAO.

Addition to emission index and smoke number the mass of pollutant, D_p emitted during the reference emissions landing and take-off cycle (LTC), in g, or its value related to the engine ISA, sea-level take-off static thrust, D_p/F_{oo}, in g/kN, is used often, too. The reference emissions LTC (Fig. 4.) is a cycle of engine operation [7] with times at different operating phases prescribed by ICAO Annex, too.

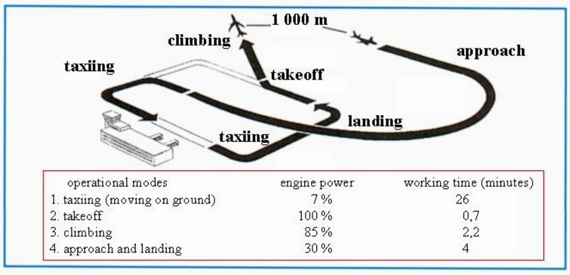

Fig. 4. Landing and takeoff cycle defined by ICAO Annex 16.

Most important emission indexes defined by ICAO Annex [5]:

hydrocarbons (H_xC_y – HC): $D_p/F_{oo} = 9.6$,

carbon monoxide (CO): $D_p/F_{oo} = 118$,

nitrogen oxides (NO_x): $D_p/F_{oo} = 40 + 2\pi_{oo}$,

where π_{oo} is the engine pressure ratio.

The smoke can be given in form similar to the emission index as the mass of unburned carbon present in the exhaust gas sample divided by the mass of fuel used by engine.

Some interesting emission indexes published by [8] are given in table 1.

The emission index depends on

- the condition of the surrounding air (temperature, pressure, humidity),
- the characteristics (H/C ratio) of fuel used by engine,
- the characteristics (type, thrust, pressure ratio, rpm, temperature before turbine) of engine.

ICAO Annex 16 Volume II entitled 'Aircraft Engine Emission' [5] gives the control levels for the emission index and smoke number that are the maximum permissible values depending on the type and power of engines. These values will apply by us to following emission simulation.

Table 1. Emission indexes characterized the aircraft operation in 1990 – 1993

Aircraft	**Engines**	**nitrogen oxides** kg/LTC	**Carbon oxide** kg/LTC	**hydro-carbons** kg/LTC
Small range				
B727	JT8D-17	11.47	13.49	3.04
B737	JT8D-17	7.65	9.00	2.03
B737-300	CFM56-3	6.63	6.50	0.36
Bae146	ALF502R5	3.39	5.81	0.70
DC9-30	JT8D-17	7.65	9.00	2.03
DC9-80	JT8D-217	10.47	3.73	1.13
average		**7.88**	**7.92**	**1.55**
middle range				
B707	JT3D-7	10.28	74.28	59.33
DC8-63	JT3D-7	16.28	74.28	59.33
DC8-70	CFM56-2		13.93	0.63
B757-200	PW 2037	15.86	6.64	0.65
average		**13.17**	**42.28**	**29.99**
Large range				
A300	GE CF6-50	25.69	23.13	8.88
B747-100	GE CF6-56	51.39	46.25	17.77
B747-200	JT9D-7	35.02	75.75	27.70
B747-SP	RB211-524	53.78	19.66	2.93
B767-200	GE CF6-80	22.91	9.73	1.01
DC10-10	GE CF6-6	2.77	26.50	9.10
DC10-30	GE CF6-50	38.54	34.69	13.33
DC10-40	JT9D-7	26.26	56.81	20.77
L1011-1	RB211-22	27.15	59.95	40.57
L1011-5	RB211-524	40.79	14.74	40.79
Average		**34.87**	**36.72**	**18.24**

4. Difficulties of the simulation problem

The mean problem is the scattering simulation of aircraft pollutants for evaluation of environmental impact of air transportation system in airport region and the design of optimal flight technology namely motion of the aircraft on the ground and in the air for environment sparing.

The solving of this problem is a difficult task [1, 2] because

- number of previous measurements and calculations is very limited,
- the methods specified by Hungarian standards and as usually used for calculation of air pollutant scattering can not give the required accuracy in case of individual air pollutant source like aircraft moving in the space with the relatively large velocity,
- the actual emissions of individual engines are unknown,
- a lack of information about the characteristics representing the air pollutant diffusion and precipitation,
- the airport air traffic in respect of aircraft weight, engine types and aircraft operations

(taxiing, takeoff, climbing, descent, landing) is a stochastic process,

- there is a lack of modeling the processes in atmosphere and the influences of air motions, gusts, microburts, and winds on the air pollutant scattering.

With taking into consideration of these difficulties the new method should be developed for solving of task air pollutant scattering modeling based on approximation with a well-known stochastic process and the random generation of the airport air traffic and atmospheric relations.

5. The task solving possibilities

The task, determining of air pollution caused by aircraft moving on the ground and flying in the air at airport zone and modeling of air pollutant scattering claims the solving of following part-tasks:

a./ description of the reference emission cycle i.e. take-off, climb, descent, landing and taxing operation,
b./ giving the quantities and concentrations of aircraft engine air pollutants,
c./ describing the air behavior,
d./ determining the scattering of the emitted air pollutants,
e./ design the flying technology recommended for environment sparing and adequate to geographic meteorological conditions.

The first and the second part-tasks can be solved easy on the basis of emission quantities given in the ICAO Annex or on the basis of real engine emission taken from the engine type emission certification.

The air behavior can be described by methods of air quality standards (i.e. air inversion, air mixing) or by giving the velocity field of air motion.

To solving the fourth part-task two different methods can be applied. At first the scattering of the air pollutants can be modeled by using the statistics and probability theory like written in the air pollution determining standards. Unfortunately these methods are developed for distribution of air pollutants emitted by point or line sources on the large-scale zone. They cannot give accuracy results on an accepted level in the case emission of aircraft moved stochastically in the space and time.

On the other hand, the scattering of air pollutant as stochastic diffusion process can be approximated by well-known stochastic processes.

A new method based on the stochastic approximation was applied by us with aim of determining the flight technology for environment sparing.

6. Pollutant scattering simulation

The pollutant scattering depends on the following factors:

- chemical reaction (chemical transformation),
- diffusion (mixing, distribution),
- setting (fall-out of the pollutants on the boundary of investigated field),
- natural air mixing (depending mostly on the vertical temperature gradient, but the inside heat emission, the air pressure, the air specific heat transfer coefficient, etc. have the influences on it, too),
- air motion (air turbulence having influence on the diffusion and chemical reaction and the wind does the diffusion process directed, carries along the air pollutants).

The practical experiences show that the flights only under than one km have influences on air pollutant emission in zone of the airports. So, the investigation of the air pollutant scattering can be focused on air boundary layer at the ground.

The change in the concentrations of the air pollutants, $\mathbf{x}$ at given point of air can be determined by following equation:

$$\dot{\mathbf{x}}(t) = \mathbf{F}(\mathbf{x},\mathbf{p},t) + \mathbf{R}(\mathbf{x},t) + \mathbf{q}(t) \qquad (1)$$

where $\mathbf{p}$ is the parameter vector having influence on change in the air pollutant concentrations (these parameters represents all the deterministic effects like diffusions, chemical reactions, effects of winds, air inversion, etc.), $\mathbf{R}$ is the part-function taking into account of the stochastic effects i.e. air turbulence, $\mathbf{q}$ is the change in air pollutants concentrations caused by any sources like aircraft engine emission or road transport emissions in given point, t is the time.

In sufficiently big zone the effects caused by air turbulence can be neglected (rather they would be taken into account in diffusion of the air pollutants).

If the changes in the concentrations can be described by exponential distribution and the investigated field can be divided into part-spaces in which the air pollutants can transmitted only from one part-space to next, then the scattering process of air pollutant type (1) can be approximated by well-known Markov chain of discrete time and discrete space.

$$\mathbf{x}[k+1]=\mathbf{A}[k]+\mathbf{x}[k] \qquad (2)$$

where $\mathbf{A}$ is a transfer matrix, its elements show the probability of transmitting the air pollutants from given part-space elements to nearest sub-spaces.

For example the concentrations in sub-space element of q-th layer i-th row and j-th column at the k+1 time-step can be calculated by the following equation

$$\begin{aligned}
&\mathbf{x}_{q,i,j}[k+1]=\mathbf{x}_{q,i,j}[k]a_{q,i,j}[k]+\\
&+\mathbf{x}_{q-1,i,j}[k]a_{q-1,i,j}[k]+\mathbf{x}_{q+1,i,j}[k]a_{q+1,i,j}[k]+\\
&+\mathbf{x}_{q,i-1,j}[k]a_{q,i-1,j}[k]+\mathbf{x}_{q,i+1,j}[k]a_{q,i+1,j}[k]+\\
&+\mathbf{x}_{q,i,j-1}[k]a_{q,i,j-1}[k]+\mathbf{x}_{q,i,j+1}[k]a_{q,i,j+1}[k]
\end{aligned} \qquad (3)$$

There was developed a new program based on MATLAB for simulation of the aircraft emission scattering.

The main point of this software is that the space around the airport is divided into subspace of dimensions n x n x m (in our simple simulation for 600 x 600 x 250 m). The space completed from 5 layers with 55 x 55 elements. So, the modeled space is a 33 x 33 x 1.25 km flat prism. The runway axis is parallel to one edge of prism.

The initial data should be defined are the following:

- the elements of transform matrix or matrix functions (taking into account the diffusion processes, chemical reactions, setting of air pollutants, and wind velocity profiles),
- prescribed flight technology (the methods of using the air: takeoff direction, turning points, approach, etc.),
- motion of aircraft (the random series of aircraft motion on the ground and in the air depending on the dimensions and types of aircraft),
- the measure characteristics of the road transport (road and railway system, traffic description, vehicle emissions, etc.).

At the end of simulation the developed software automatically draws the three dimensional distributions of the air pollutants and their counter lines for each layers of investigated space. The program user has a possibility for drawing the distribution of air pollutant concentration of any section of three dimensional pictures.

The typical results of simulation are demonstrated by figures 5 and 6.

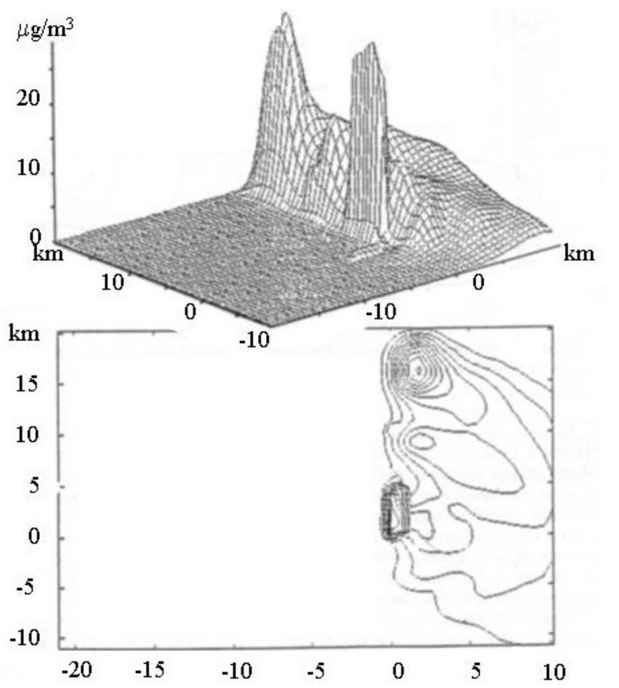

Fig. 5. Results of 3D image and contours of carbon oxide (CO) distribution at summer late morning simulated for Hungarian Kiskunlachaza Airport region

(the road transport effect is neglected, runway zero point is the origin of the reference system, small town is situated on the left side of the runway, at point -3, 3 km from runway is a corner of the national park)

The simulation was performed for the Kiskunlachaza Airport during the preliminary environmental protection study [9] for airport planned to develop as the second airport of Budapest. This airport is about 45 km South from the Budapest and very closed to one national park. Actually the corner of the national park is only 3 km far from the beginning of the runway. Plus to them, the dominant wind is directed to the national park. The simulation was realized for worst case, late morning, after morning peak at hot summer day.

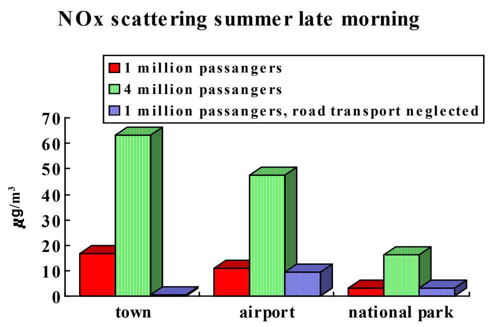

Fig. 6. Air and ground transport impact on the environment

Figure 6. shows that even in worst case the realized pollutant concentrations are 2 – 3 times less then allowed by Hungarian standards.

Summary

Nowadays the environmental protection is a very important task. New airport can be developed after accurate investigation of effects of air and road transport on the airport region. The methods described in the Hungarian standards and generally applied for emission scattering can not results to the acceptable accuracy. The effects on the environment associated with air transport are much more complex. Therefore a new method was developed for emission scattering simulation.

A new method is based on the approximation of the emission scattering process by Markov chain process. The simulation takes into consideration the road transport effects, random motion of aircraft, diffusion characteristics of the air pollutants and air peculiarities. The simulation deals with the maximum allowed emissions defined by ICAO for different size of aircraft equipped by different types of engines.

The results of simulation demonstrated the possibilities of aircraft engine air pollutant scattering simulation through the approximation of stochastic emission and scattering process by Markov chain and give the possibilities for determining the flight technology with environment sparing depending on the geographic and atmospheric conditions.

Up today, this method was applied in seven different airport development projects for making preliminary examination of effects of air transportation on the airport region environment. The results were accepted by different regional offices of Hungarian environment protection centers.

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