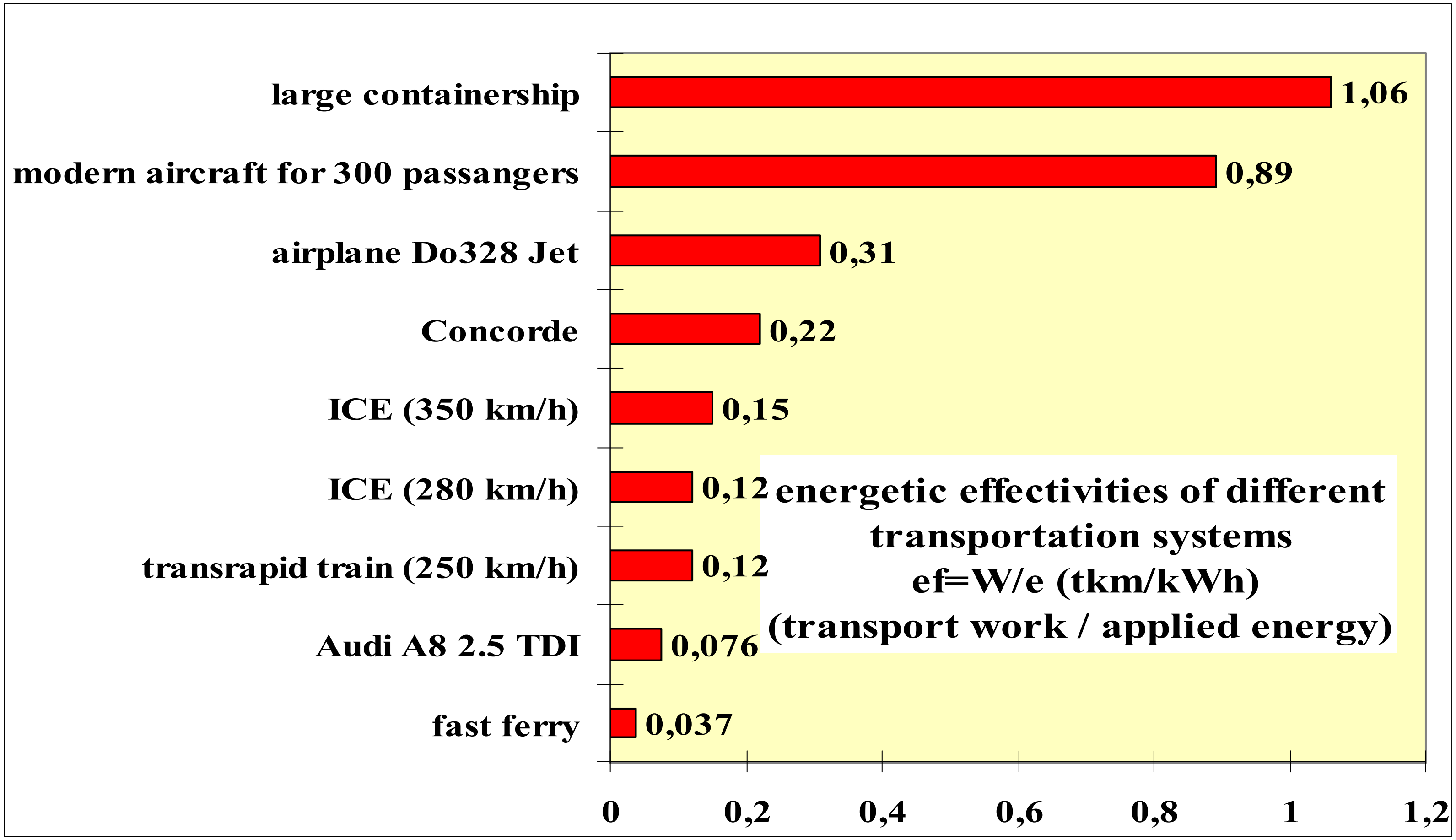
20 years ago …. and now



Air transport had better performance than most of the other transport, but electric /hybrid propulsion systems may change the game

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Effect of electric / hybrid aircraft operation on the environmental impact in airport areas

1. Introduction
2. Preliminary consideration
3. Practical aspects
4. Simulation model
5. Developed simulation program
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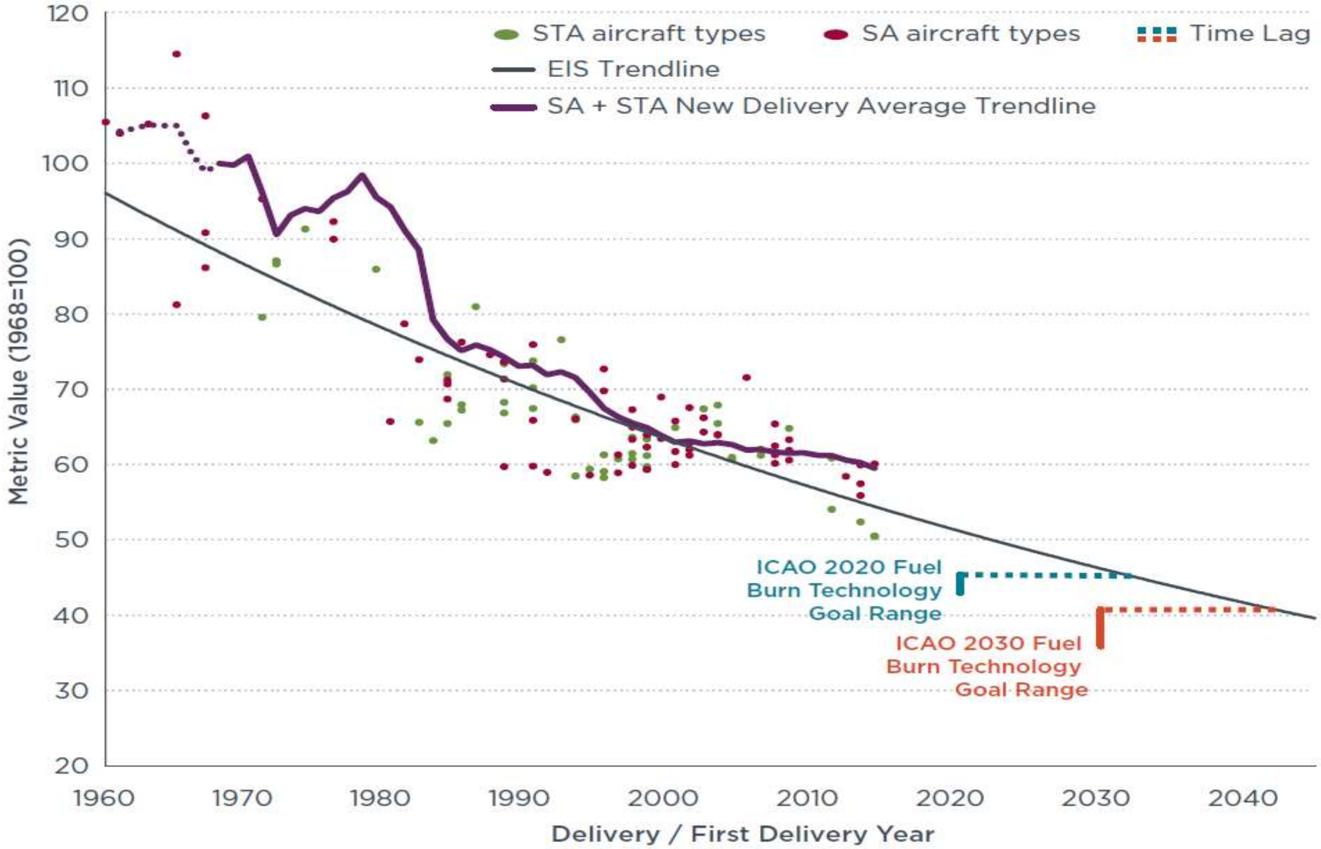
1. Introduction



New single-aisle (SA) and small twin-aisle (STA) jet aircraft metric value depending on their enter into service (EIS) vs. ICAO fuel burn technology goals

1. Introduction

- The aircraft with electric / hybrid propulsion systems are most promising future cleaner technologies.
- Their entering into service, the chemical emissions in airport region will be changed, reduces radically.
- Influence and evaluation of this influence of electric / hybrid aircraft on environmental impact at airport regions is one of the important task.
- Idea estimating the effect with avoided impact (reduction in environmental impact).
- Required model for emission and its scattering estimation.

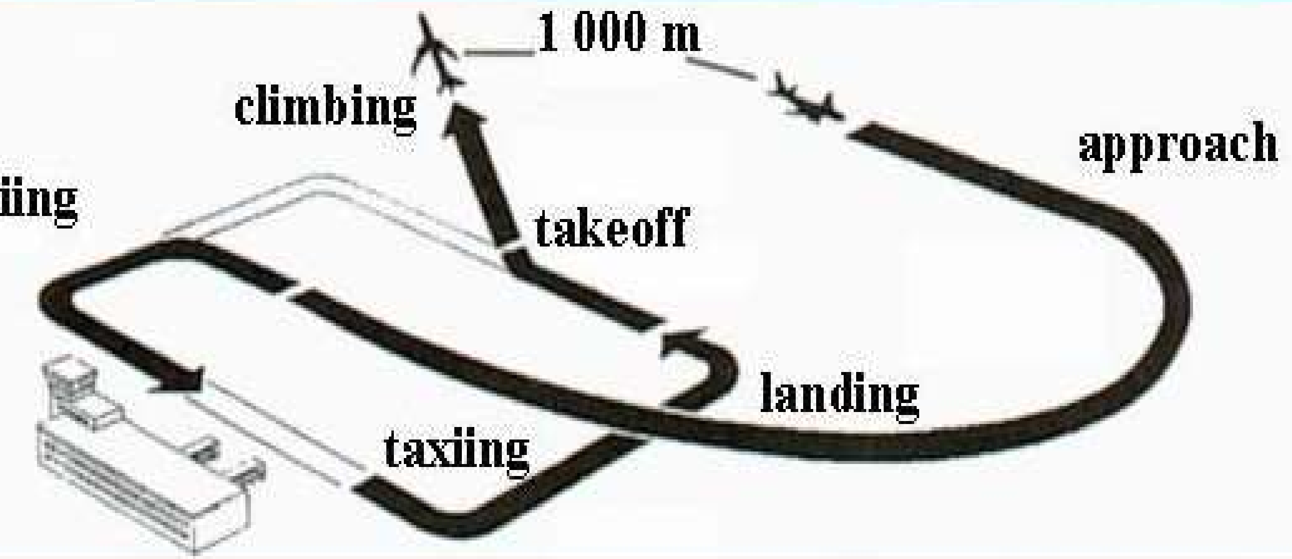
2. Preliminary consideration

- **chemical emission (must be investigated):**
  - unburned hydrocarbons (HxCy), including vented fuel,
  - carbon monoxide (CO),
  - oxides of nitrogen (NOx), including a nitric oxide (NO) and nitrogen dioxide (NO2),
  - smoke (or soot)

ICAO Annex 16., Volume II. Aircraft Engine Emission, 1981.

hydrocarbons (HxCy)	Dp/Foo = 9.6 (g/kN),
carbon monoxide (CO)	Dp/Foo = 118 (g/kN),
nitrogen oxides (NOx)	Dp/Foo = 40 + 2 πoo (g/kN),
smoke number	83.6 x (Foo)-0.274 or 50

2. Preliminary consideration



operational modes	engine power	working time (minutes)
1. taxiing (moving on ground)	7 %	26
2. takeoff	100 %	0,7
3. climbing	85 %	2,2
4. approach and landing	30 %	4

3. Practical aspects

- **Real LTO measured**

  (piston engine,

  max 70 l / h

  fuel consumption

Flight mode	time (minutes)	% of maximum fuel flow	fuel flow (kg/s)	fuel used (kg)
take-off	0.3	100.00	0.02	0.33
climb out	2.5	85.00	0.02	2.70
approach/landing	3	45.00	0.01	1.76
taxi	12	AFM	0.00	2.74
total for LTO	17.8			7.53

Flight mode	emission (g/kg flow)			Emission (g/LTO flight mode part)		
	CO (g/kg)	H_xC_y (g/kg)	NO_x (g/kg)	CO (g/LTO)	H_xC_y (g/LTO)	NO_x (g/LTO)
take-off	818.00	12.70	6.00	267.98	4.16	1.97
climb out	787.00	12.30	6.00	2124.90	33.21	16.20
approach / landing	1055.00	11.50	2.00	1861.02	20.29	3.53
taxi	1123.00	42.60	0.00	3072.53	116.55	0.00
total for LTO				7326.42	174.21	21.69

3. Practical aspects

Effect of material characteristics on the emission scattering:

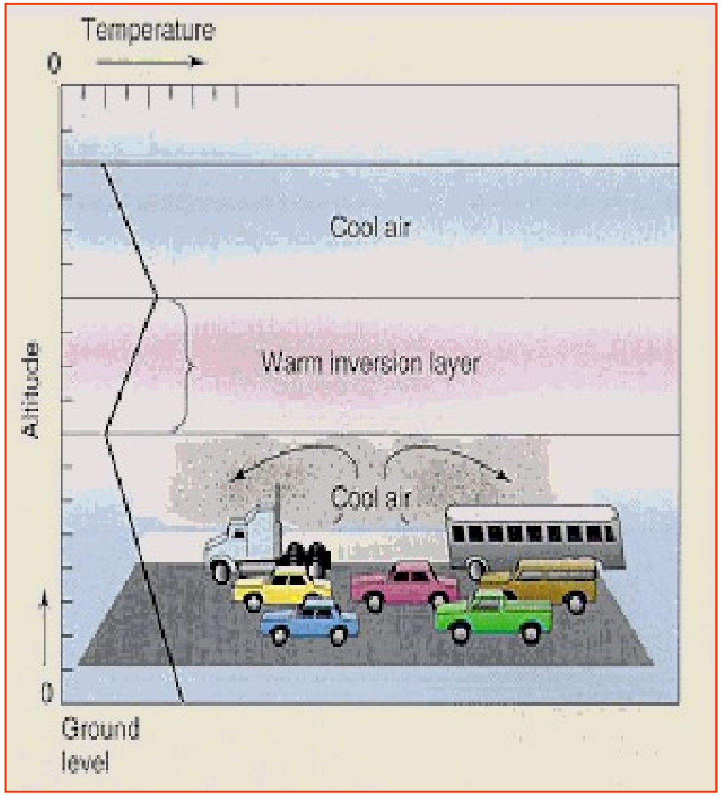
- **diffusion**
- **recombination**
- **setting off**

material	time of setting off from air
CH_4	about 7 years
C_xH_y	from several hours to several days
CO	about 60 days
NO	3 – 30 hours
CO_2	2 - 4 years
NO_2	1 - 2 days
N_2O	100 - 200 years
NH_3	2 - 14 days
H_2S	0.5 - 2 days
SO_2	About 5 days
O_3	35 days in clear air, in other case only several hours

3. Practical aspects

Weather effects on air quality:

- wind
- air turbulence
- inversion



Smoke trapped by an inversion layer

At night, the ground level temperature cools faster than the air above it. Pollutants become trapped under the layer of warm air.
As the sun rises in the morning, the ground level temperature warms up faster than the air above it, pushing the air upwards, which breaks up the warm air layer, allowing the pollutants to escape.
However, if there is no wind, the air can become stagnant.

4. Simulation model

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.

⇦ LTO description ICAO , JAA

⇦ air quality weather condition

⇦ stochastic model

⇦ simulation

4. Simulation model

The pollutant scattering depends on the following factors:

- chemical reaction (chemical transformation),

- diffusion (mixing, distribution),

- setting (fall-out of the pollutants on the boundary 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).

4. Simulation model

Pollutant scattering is a typical diffusion process.

$$\dot{x} = f(x,t) + \sigma(x,t)\eta(t)$$

It is a Markov process.

$$p(x_2, t_2 | X_1, t_1), \quad (t_2 \succ t_1)$$

The transition probability density function of which can be described by application of the Fokker - Planck - Kolmogorov equations like:

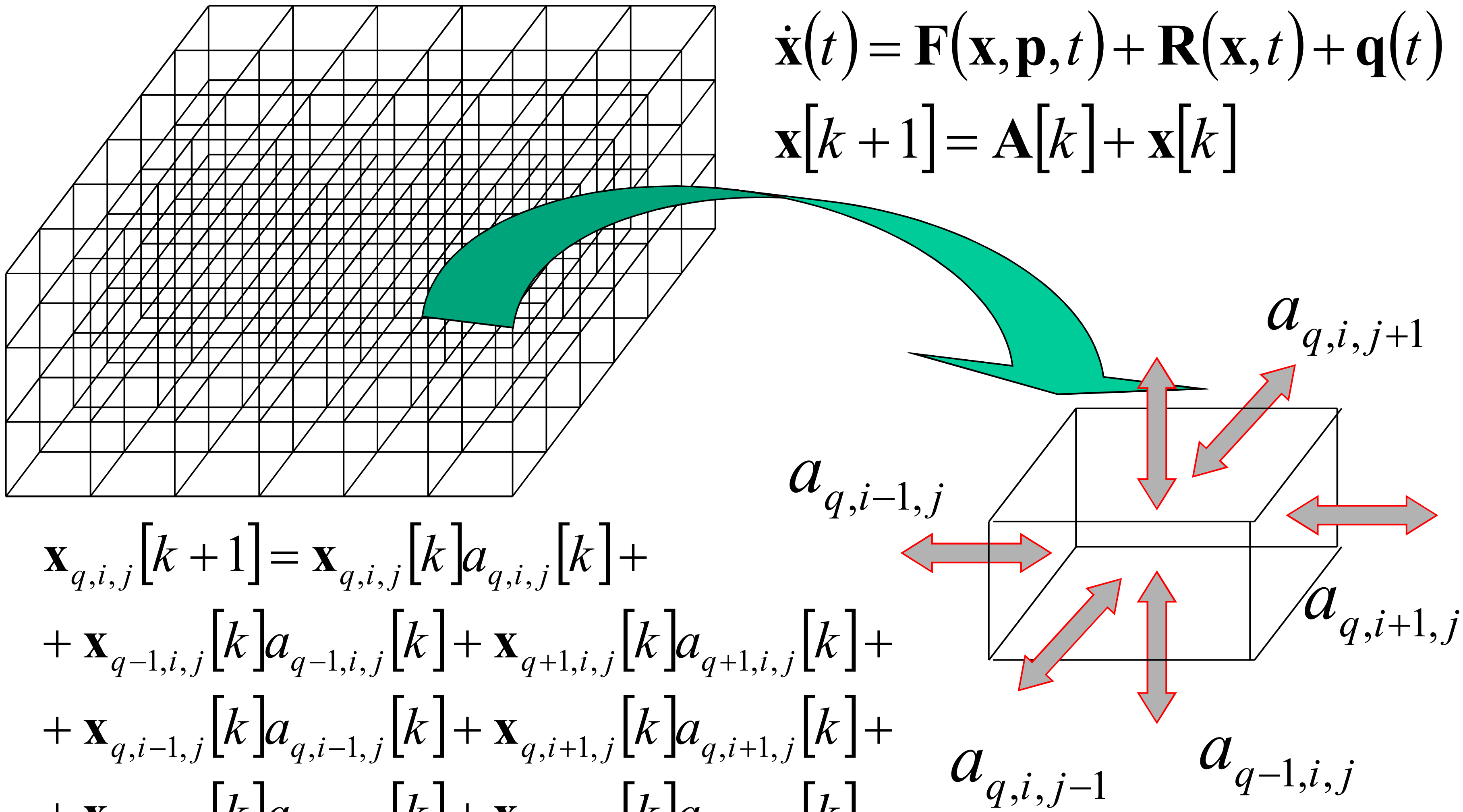
$$\frac{\partial p(x_2, t_2 | X_1, t_1)}{\partial t_2} = -\frac{\partial}{\partial x_2}\left[f(x_2, t_2) p(x_2, t_2 | X_1, t_1)\right] +$$

$$+\frac{1}{2}\frac{\partial^2}{\partial x_2^2}\left[\sigma^2(x_2, t_2) p(x_2, t_2 | X_1, t_1)\right]$$

4. Simulation model

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

$$\mathbf{x}[k+1] = \mathbf{A}[k] + \mathbf{x}[k]$$



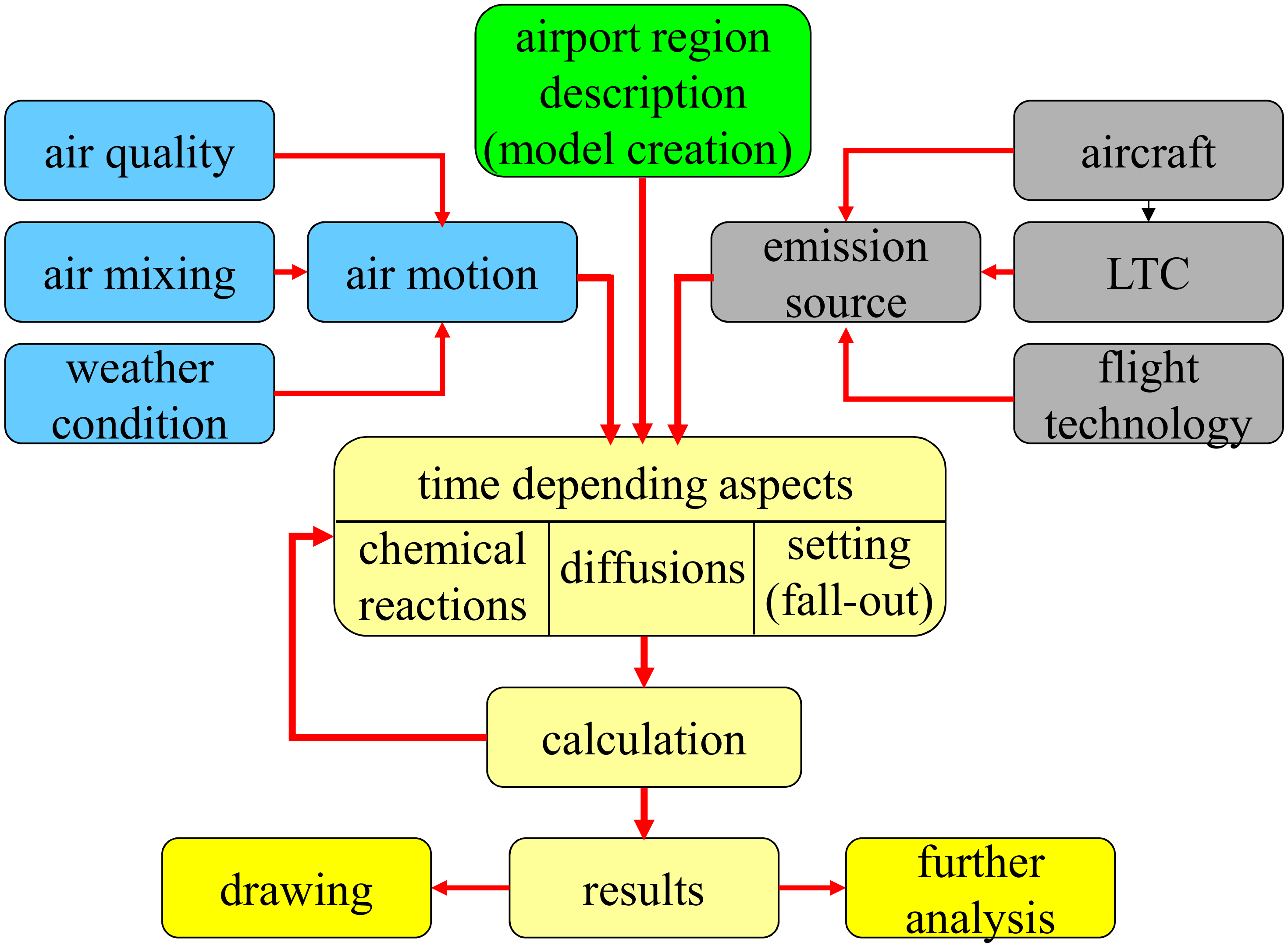
$$\begin{aligned}
\mathbf{x}_{q,i,j}[k+1] &= \mathbf{x}_{q,i,j}[k]a_{q,i,j}[k] + \\
&+ \mathbf{x}_{q-1,i,j}[k]a_{q-1,i,j}[k] + \mathbf{x}_{q+1,i,j}[k]a_{q+1,i,j}[k] + \\
&+ \mathbf{x}_{q,i-1,j}[k]a_{q,i-1,j}[k] + \mathbf{x}_{q,i+1,j}[k]a_{q,i+1,j}[k] + \\
&+ \mathbf{x}_{q,i,j-1}[k]a_{q,i,j-1}[k] + \mathbf{x}_{q,i,j+1}[k]a_{q,i,j+1}[k]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

5. Developed simulation program

The initial data should be defined are the following:

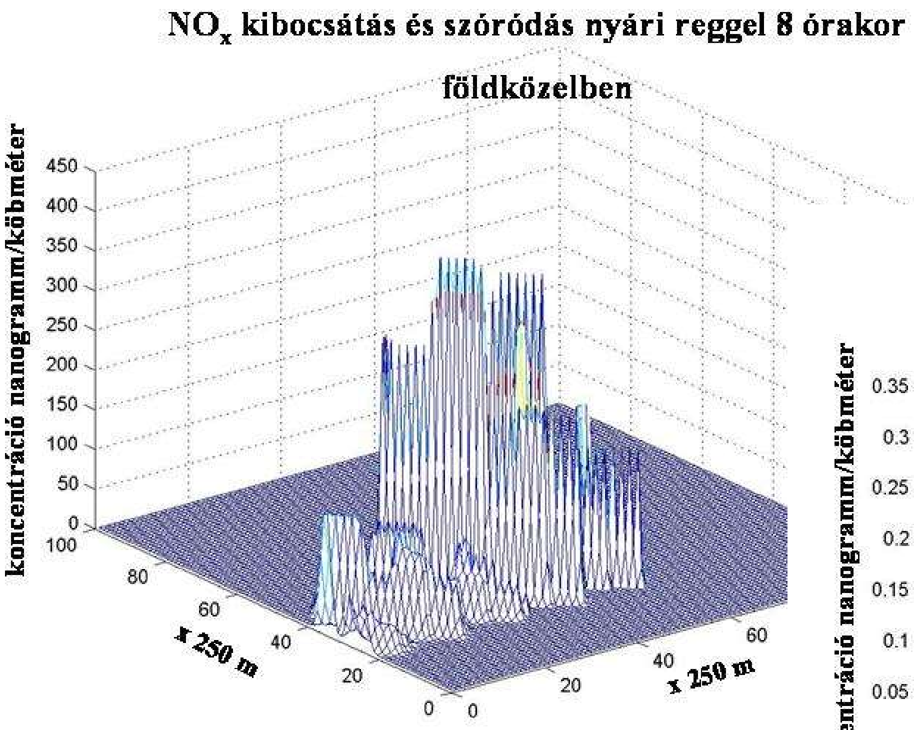
- **the elements of transform matrix or matrix functions (taking into account the diffusion processes, chemical reactions, setting of air pollutants, and wind velocity profiles),**
- **prescribed flight technology (the methods of using the air: take - off direction, turning points, approach, etc.),**
- **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.).**

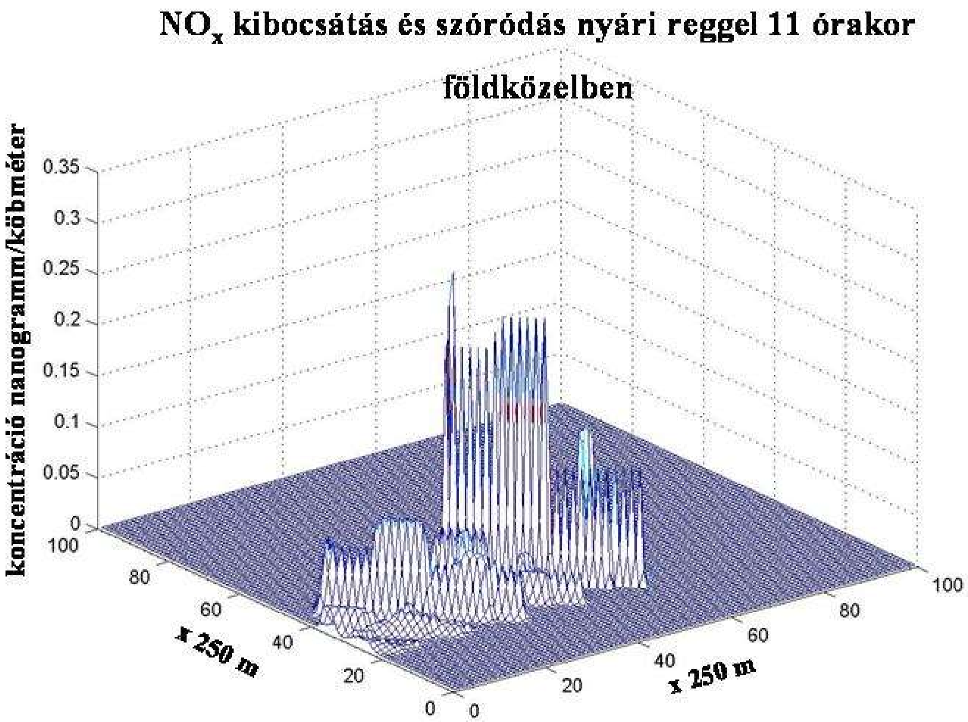
5. Developed simulation program



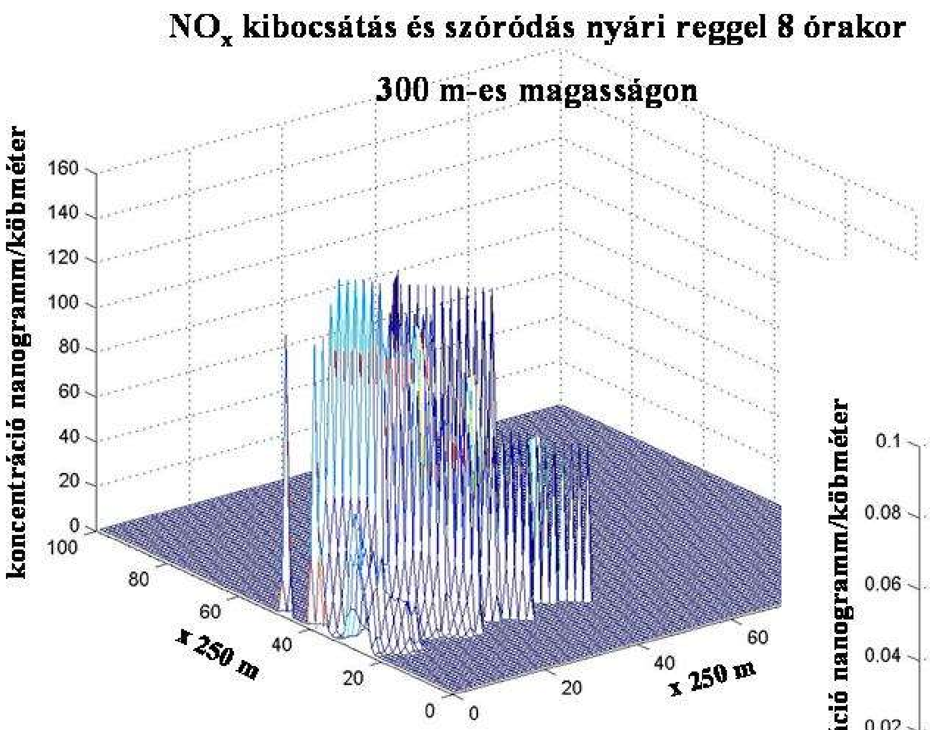
6. Results and discussions

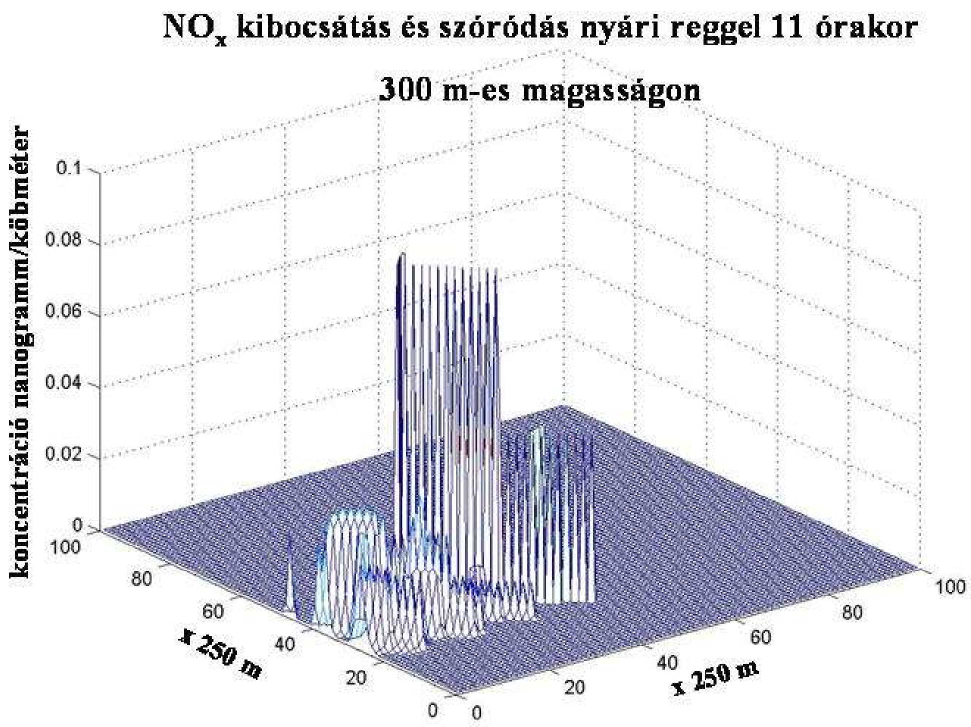
- 37 movements pro day
- 1/3 – 1/3 small, regional and medium size aircraft
- small aircraft will be replaced first





6. Results and discussions





7. Conclusions

- The electric / hybrid aircraft will be entered into operation after 2020 (small aircraft) and 2030
- Estimation of their effect on the environmental impact at airport region is an important, actual task.
- The problem is rather complex (because the real emission, diffusion, chemical reaction, air motion, etc.)
- A special simulation model and program was developed.
- The results shows that deployment of the electric / hybrid aircraft might be the most promising cleaner technology emerging.

8. Acknowledgement

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