IMPROVEMENT OF AIRPORT LOCAL AIR QUALITY ASSESSMENT

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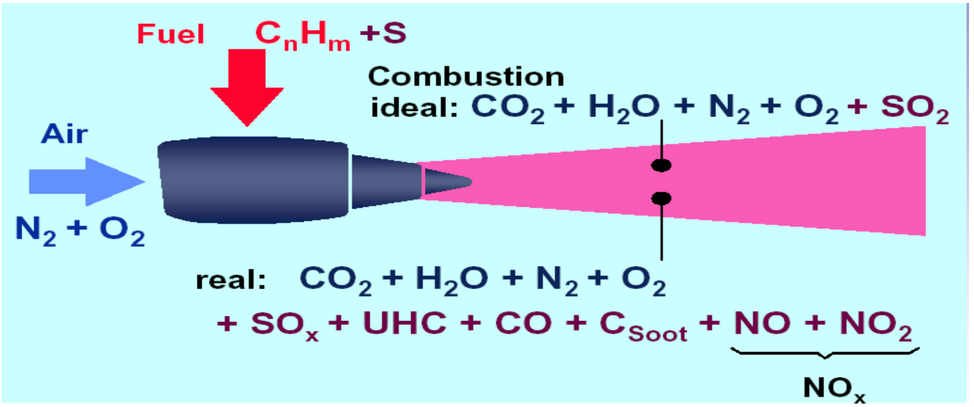
OUTLINE

- Motivation
- Emission Inventory
- Methods and Materials
- Results
- Concluding remarks

MOTIVATION

Airport air quality is crucial issue

Kyiv International Airport layout (part of the city)

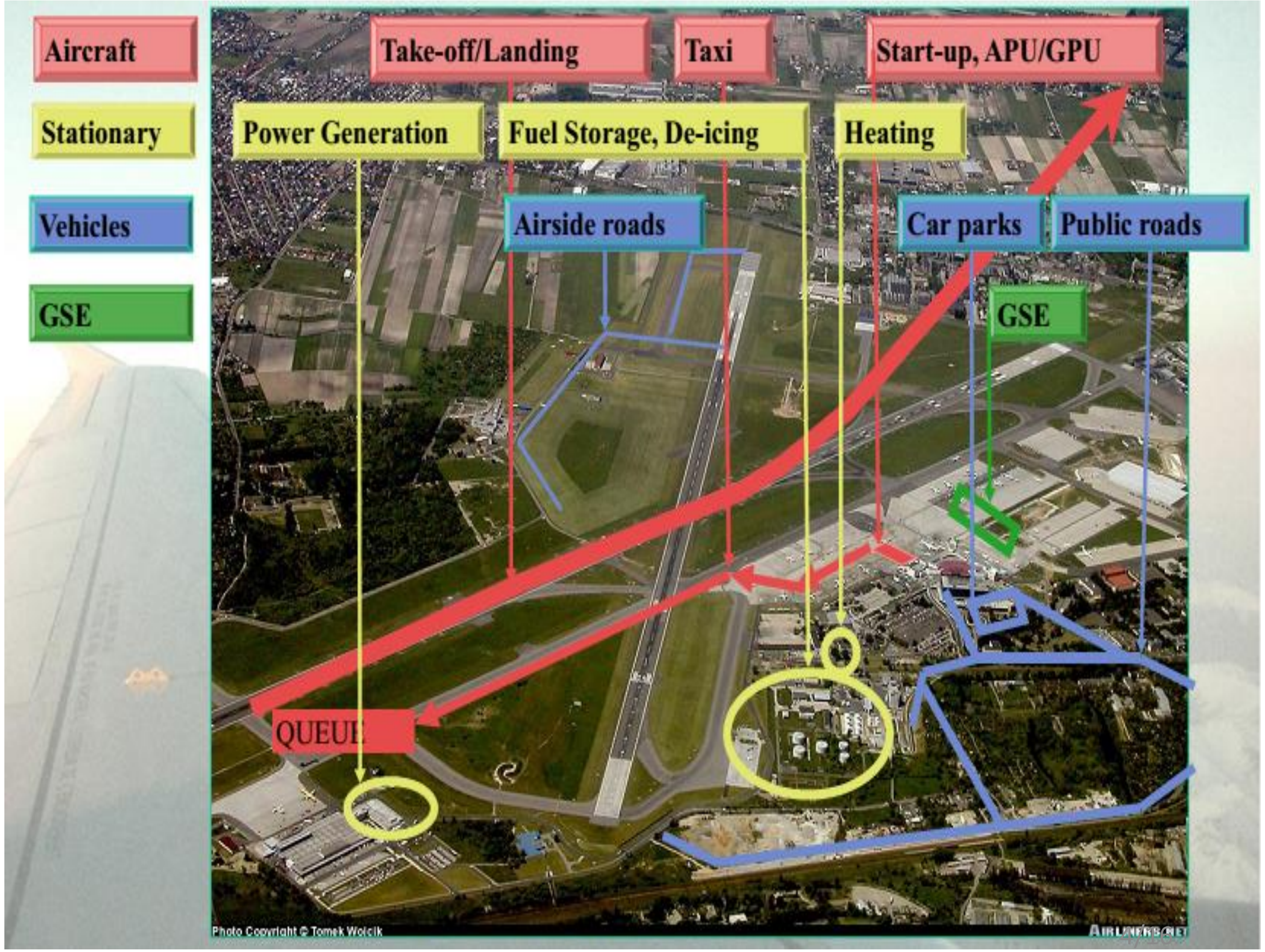


- ✓increasing air traffic trend;
- ✓rising tensions of airports expansion ;
- ✓growing public concern with air quality around the airport (adverse impact on human health of NOx and PM_{10}).

the development of civil airports should take into account environmental restrictions on the growth of air traffic.

MOTIVATION


Airport Emission Inventory
Sources of Airport pollution we need to consider :
Aircraft – departs/Arrivals
Aircraft Take-off/Landing/Taxi/Queues
Engine start-up
APU/GPU
Ground Service Equipment
Special equipment
Vehicules
Roadways (landside et airside)
Parking lots
Stationary Point Sources
De-icing equipment
Fuel storage
Heating plant
Generating stations
Stationary Area Sources
Fire Training
Grass cutting
Fuel storage
5


Aircraft
Take-off/Landing
Taxi
Start-up, APU/GPU
Stationary
Power Generation
Fuel Storage, De-icing
Heating
Vehicles
Airside roads
Car parks
Public roads
GSE
GSE
QUEUE
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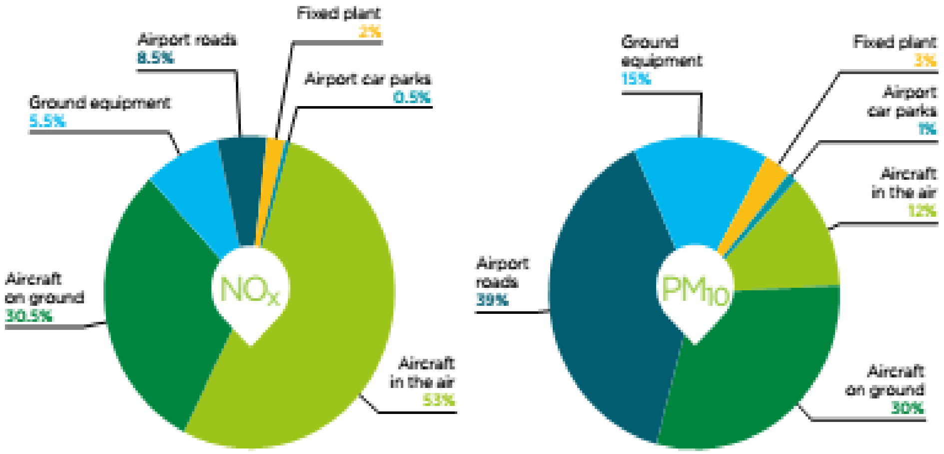
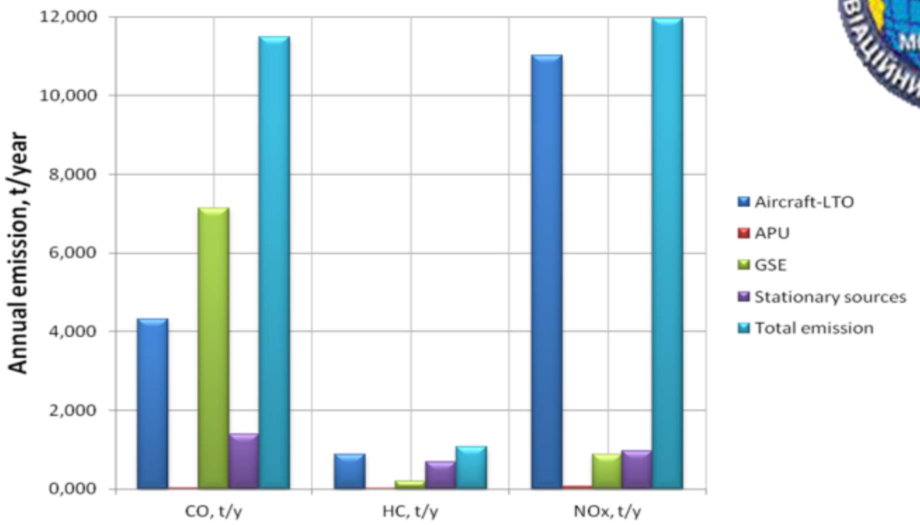
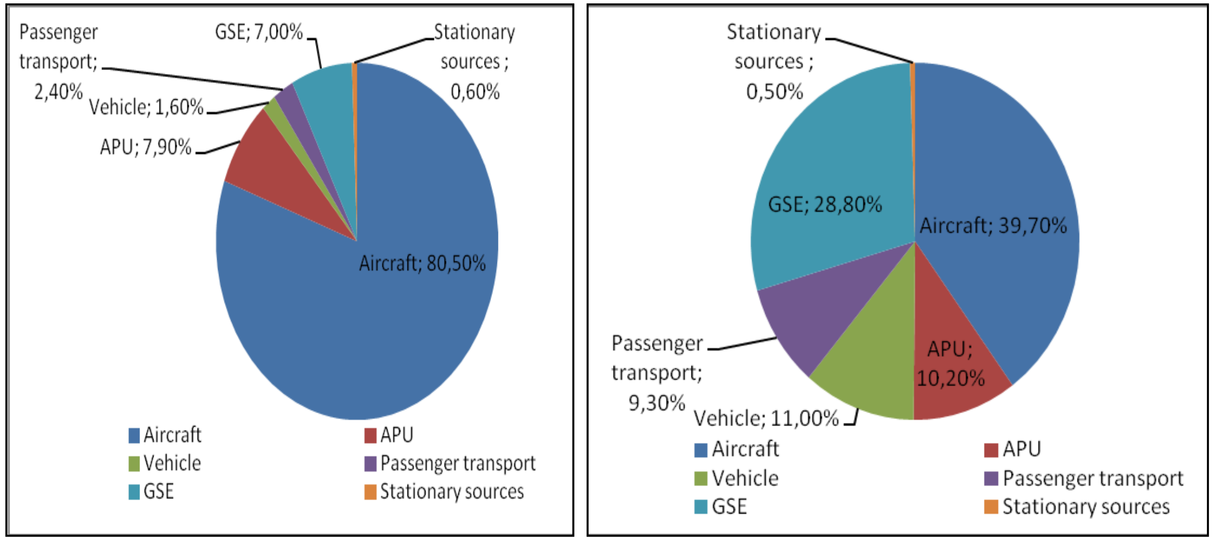
EMISSION INVENTORY



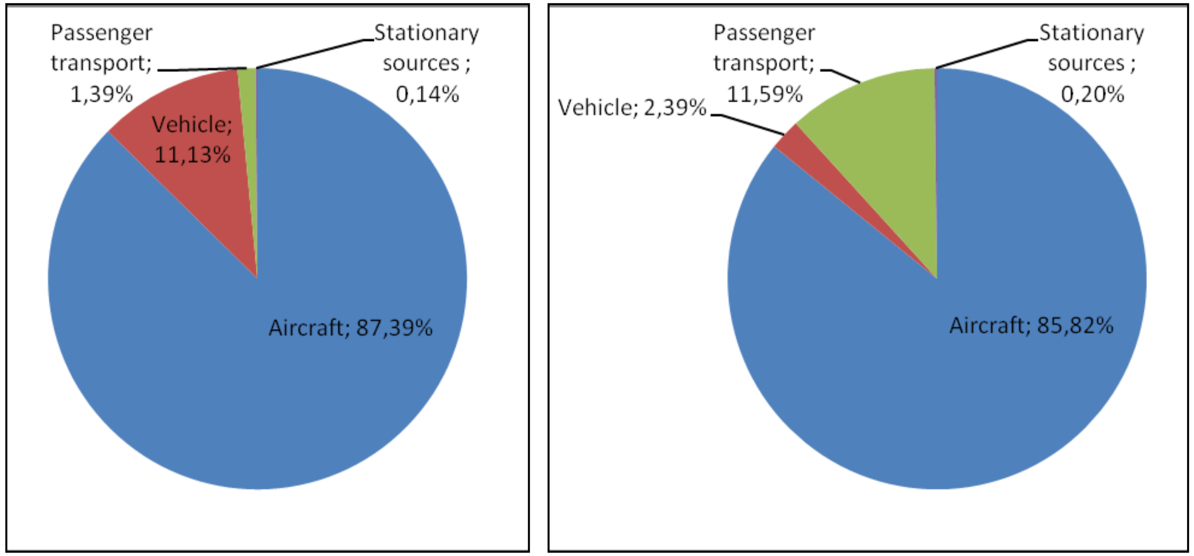
NO_x (a, for Gatwick) and PM_{10} (b, for Heathrow) emissions



The total annual emission from the sources at Dnipropetrovsk Airport



NO_x (a) and PM_{10} (b) emissions at Frankfurt Airport

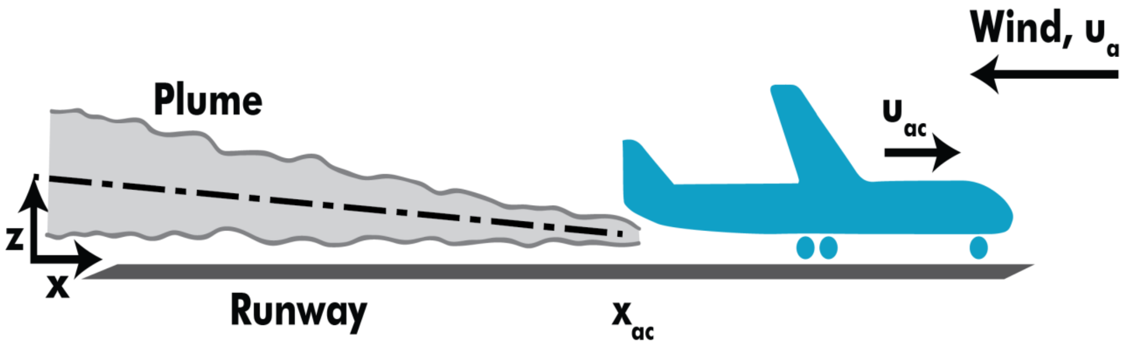


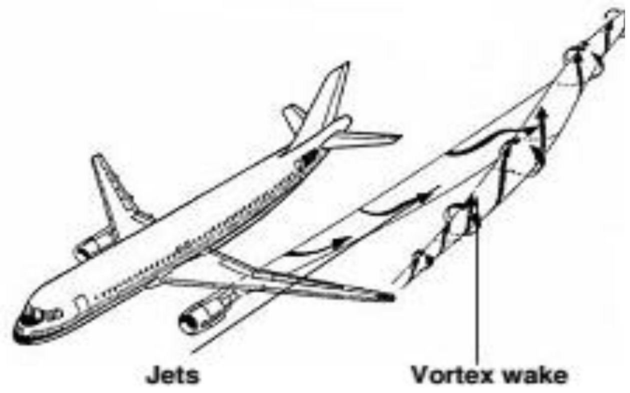
NO_x (a) and PM_{10} (b) emissions at Boryspil Airport

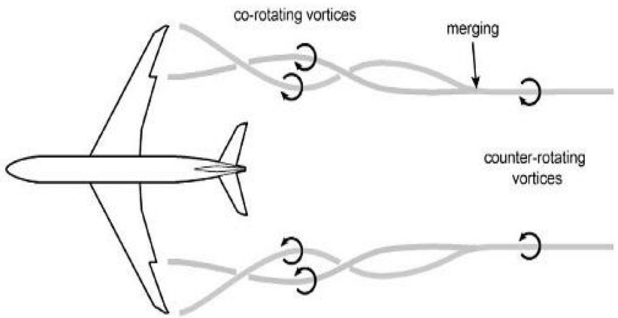
RESULTS

Emissions do not display yet total character and level of aircraft impact on air quality. The factors, which may provide a difference between emission level and air pollution concentrations:

- *type of the engine in aircraft power unit;*
- ***height** of the engine installation at power unit;*
- *the dynamic of exhaust gases jet from aircraft engine;*
- *character of an aircraft movement (parking, taxing, accelerating on the runway);*
- *meteorological parameters, as wind velocity and atmospheric stability.*



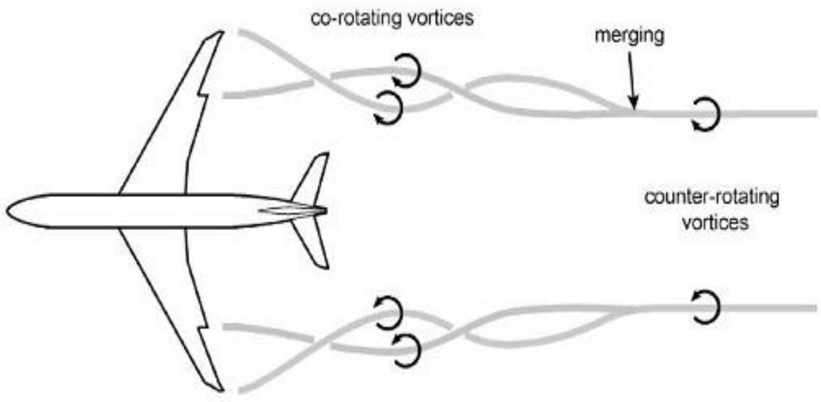




LAQ is about concentration, not emission.

Aircraft is special source of air pollution:

1. **Jet of exhaust gases**;
2. The most part of LTO cycle the aircraft is maneuvering on aerodrome surface, which **significantly impacts on the structure and behavior**;
3. An aircraft wake is composed of **the engine jets**, which are entrained into **the counter-rotating wing** (tip, flap) **vortices**.



Vortex wake generation behind the aircraft
[F.Garnier, 2005]

The **Gaussian plume model** is used for prediction of vertical and horizontal dispersion of air pollution, it has been adapted for point, line and area sources:

$$C(x;y;z;H)=\frac{Q}{2\times\pi\times\sigma_y\times\sigma_z\times u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\times$$
$$\times\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

The **initial plume parameters** depend on **aircraft** and **engine type**, **engine operation mode** (jet flow temperature and velocity at exhaust nozzle) and **meteorological conditions** (ambient air temperature, wind velocity and direction).

LAQ is about concentration, not emission.

CAEP/12-MDG-FESG/1/WP/13 initiated a feasibility study towards a concentration –based LAQ metric.

- LASPORT is based on **Langragian** dispersion model LASAT (Germany);
- AEDT is based on **Gaussian** dispersion model AERMOD (USA);
- Open-ALAQS is based on **Gaussian** dispersion model (EUROCONTROL):
- PolEmiCa used combined approach of **Eulerian/Gaussian** methods (NAU, Ukraine).

EI, Q

Engine emission model – Emission factor assessment for aircraft engines, including influence of operational and meteorological factors.

S_j, Δh_A, X_A, σ_x, σ_y, σ_z, q

Jet model – model of contaminants transport and dilution by exhaust gases jet. Assessment basic parameters of jet: length of jet penetration “$\mathbf{S_j}$”, height “$\mathbf{\Delta H_a}$” and longitudinal coordinate “**Xa**” of buoyancy effect of jet, dispersion characteristics ($\boldsymbol{\sigma_x}$, $\boldsymbol{\sigma_y}$, $\boldsymbol{\sigma_z}$). Assessment concentration value in jet “**q**”.

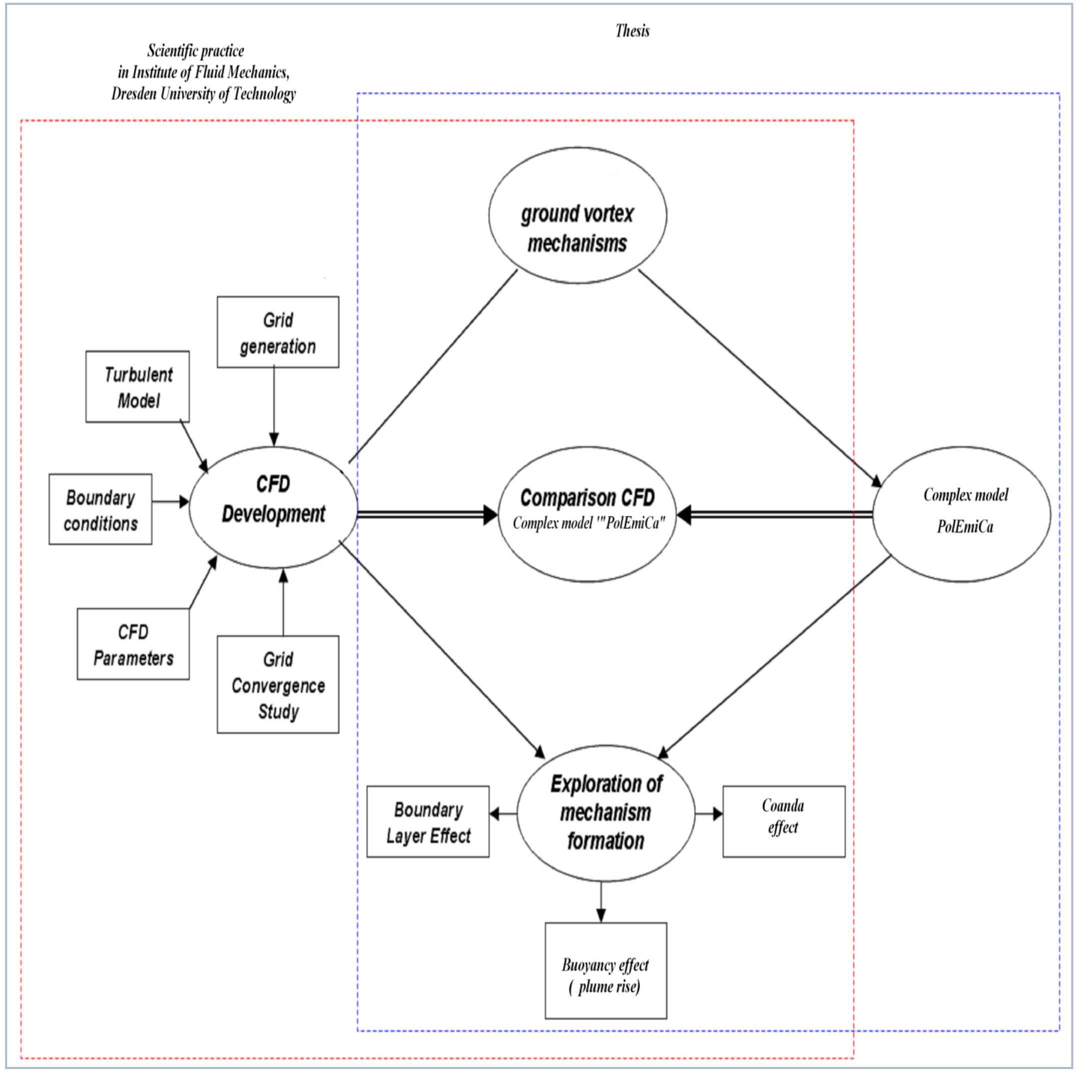
q

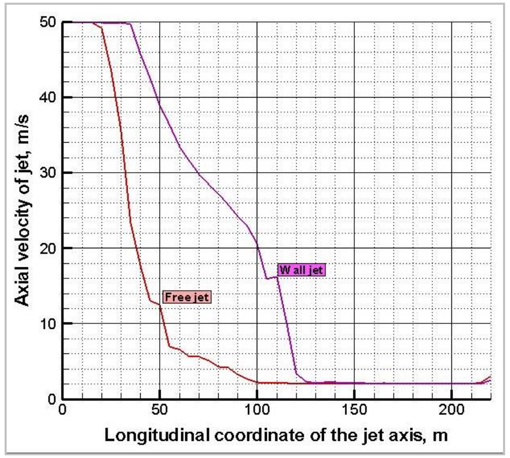
Dispersion model – dispersion of the contaminants in the atmosphere due to turbulent diffusion and wind transfer. Assessment concentration value in ambient air “**q**”

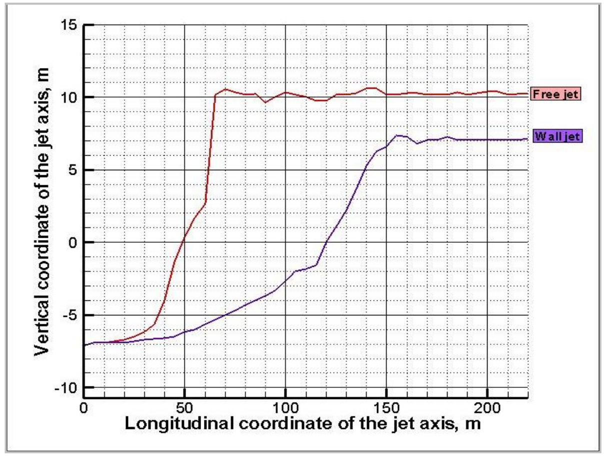
Usually LAQ addresses to emission, usually taken as the integral over the certification LTO, ICAO Doc 9889.

POLEMICA MODEL

Improvement of complex model PolEmiCa (jet model) by Fluent 6.3

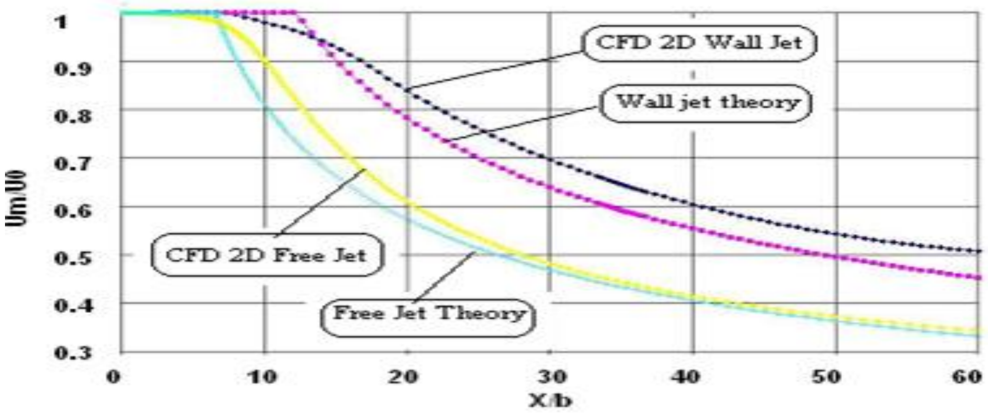






Maximum velocity decay (a) and buoyancy effect (b) of free and wall jet

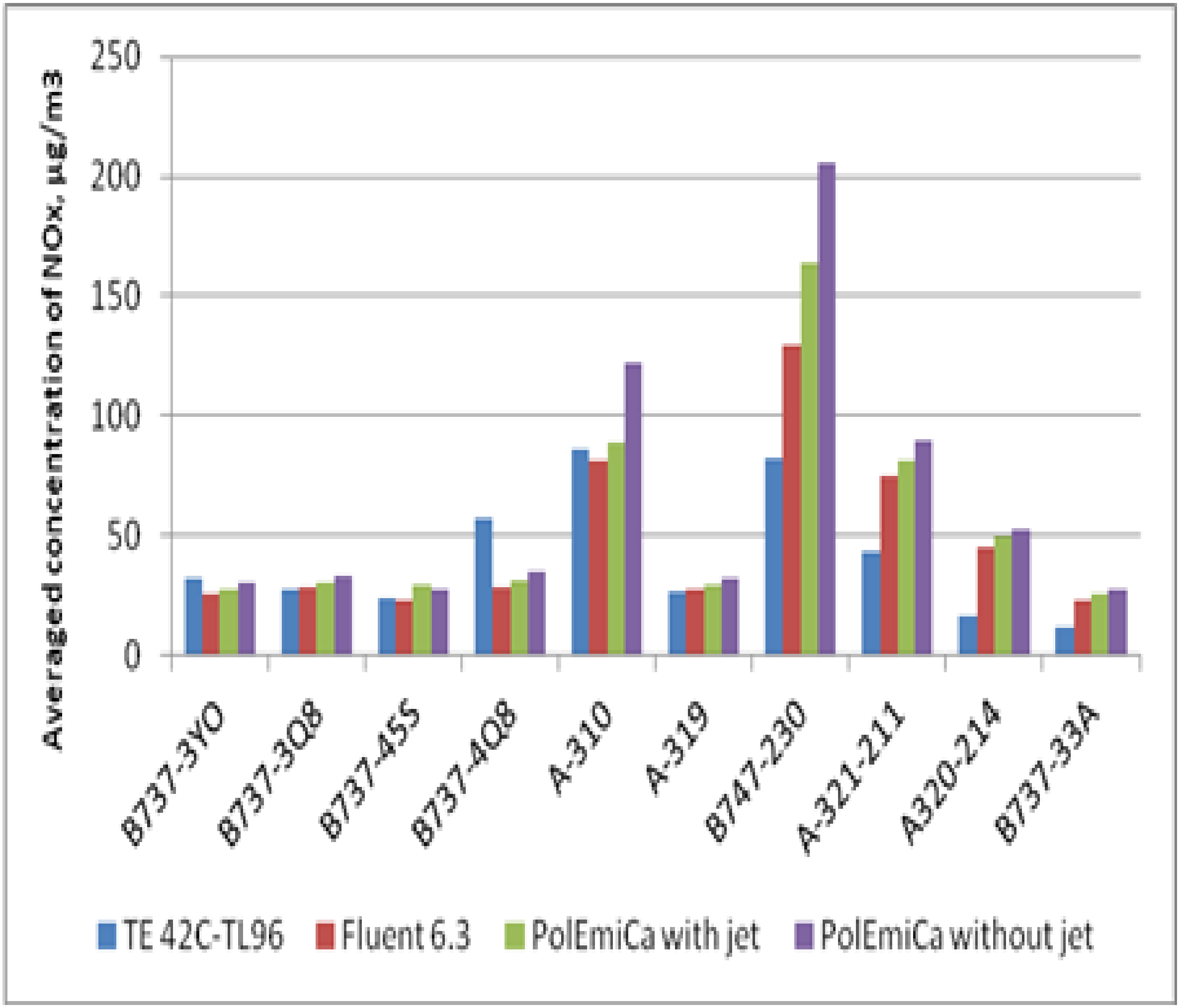
Obtained by Fluent 6.3 numerical results are supplemented with similar **ALAQS studies:**



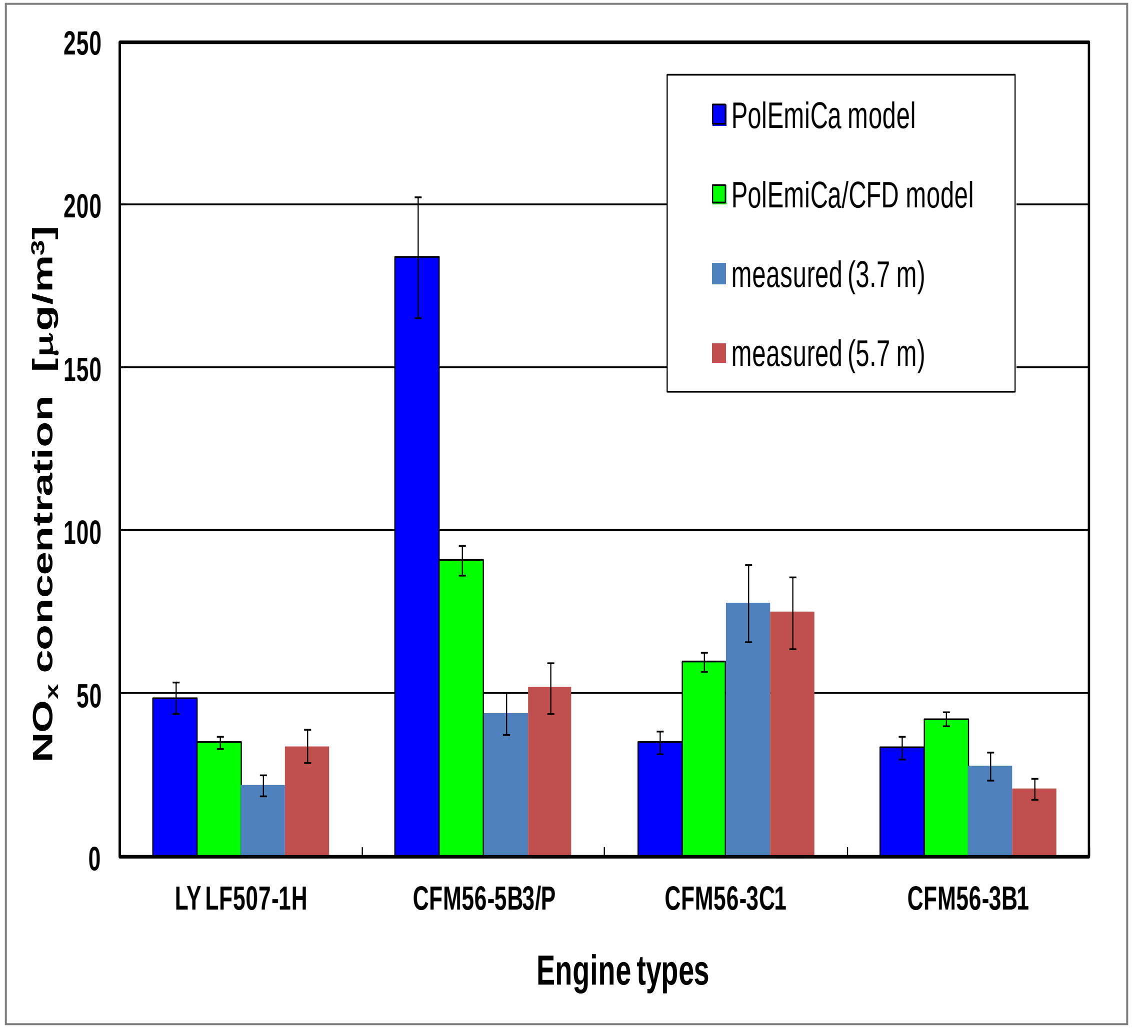
Um-axial velocity, m/s; Uo-jet exhaust velocity; b-jet diameter.

LES method was used to reveal the unsteady ground vortex and turbulence characteristics of fluid flow near aerodrome's surface. **Smagorinsky-Lilly** subgrid-scale model was used to model the smaller eddies (fluctuation component of instantaneous velocity of modeling fluid flow).

Valiadation of complex model PolEmiCa by measurement campaign at Athens and Boryspil airport

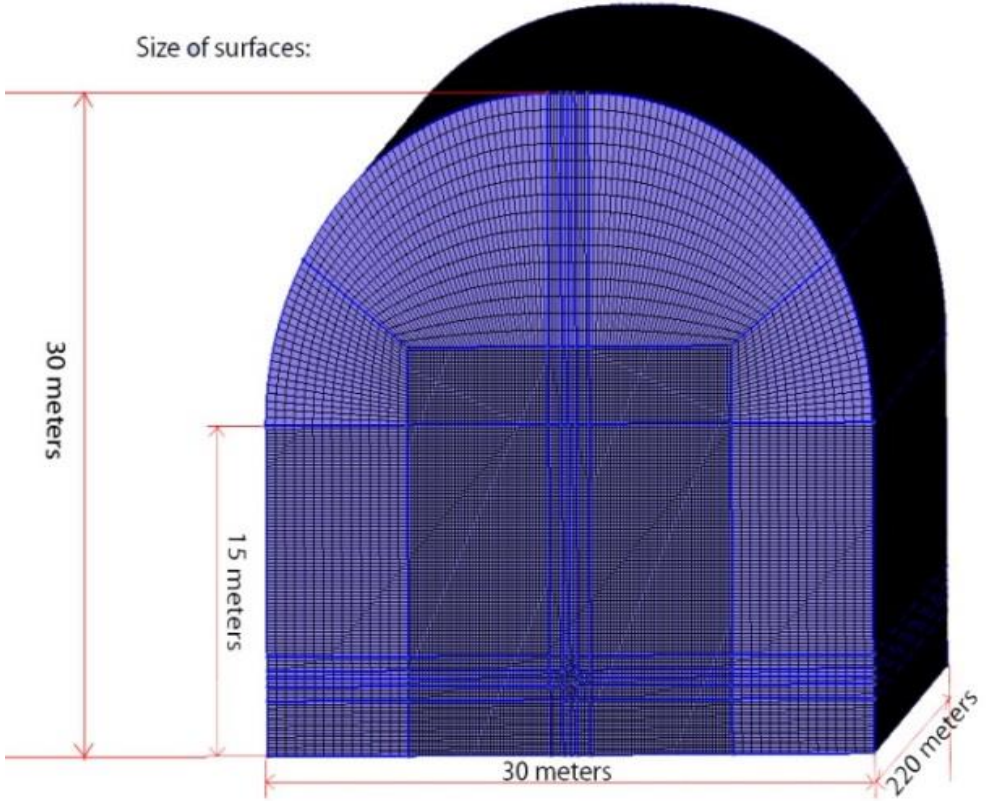


Comparison of measured and modeled averaged concentrations (1 minute) of NOx in plume from aircraft engine for maximum operation mode



Comparison of measured and modeled averaged concentrations (3 s) of NOx in plume from aircraft engine for maximum operation mode

OpenFOAM: Computational domain, boundary conditions, turbulence model, solver



Computational mesh in vertical plane

The specific methods:

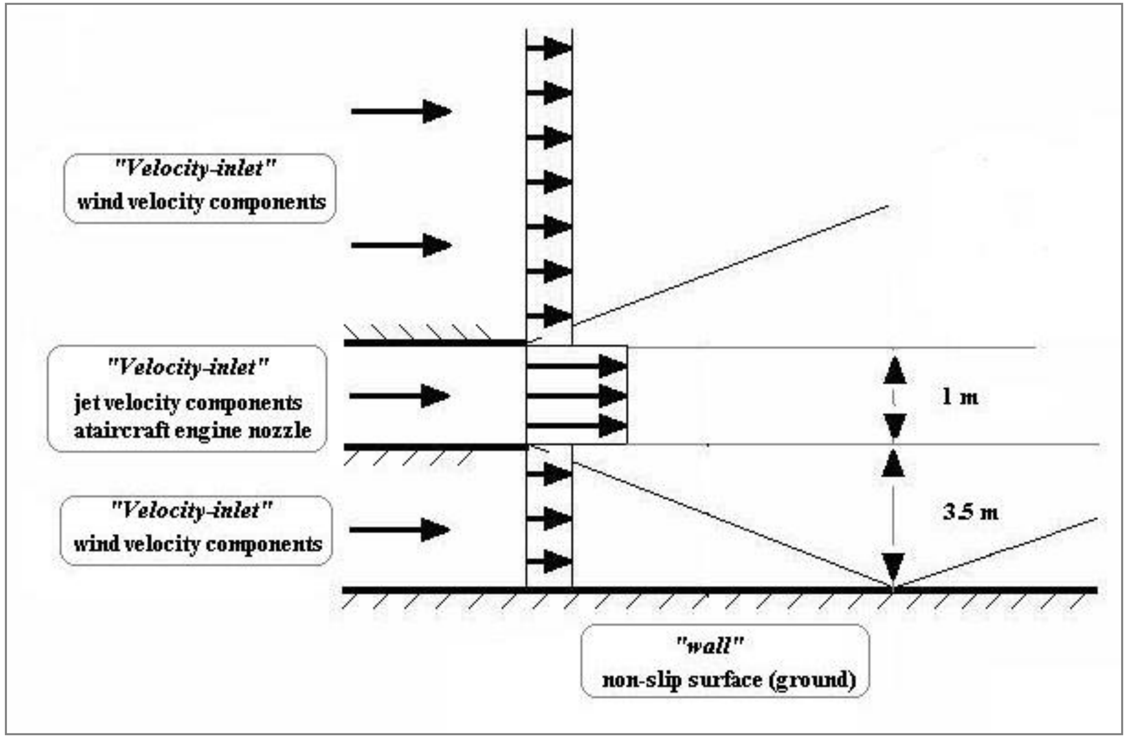
- **second order** upwind for pressure, momentum, k and epsilon;
- the **Simple scheme** is used for pressure – velocity coupling.

All calculations were made with steady-state solver (*buoyantBoussinesqSimpleFoam*) for incompressible flows with taking into account temperature difference between the jet (T=423 K) and atmospheric air (T=300 K).

K-epsilon turbulence model was used to evaluate the turbulence characteristics of fluid flow.

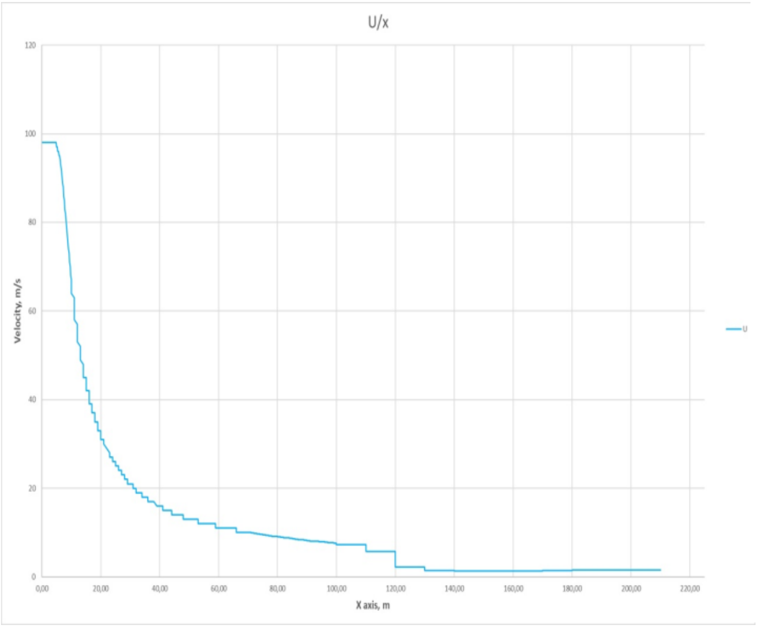
Boundary conditions

- The nozzle section of aircraft engine exhaust is set as a “**velocity inlet”** with velocity magnitude 98 m/s and temperature 423 K ;
- The computational surfaces adjacent to the engine section at which ambient conditions is also set as “**velocity inlet**“ with wind velocity 2 $m \cdot s^{-1}$ and temperature 300 K;
- The external lateral surfaces of computational domain at which ambient conditions are set also as “**velocity inlet”**;
- The ground surface, which is corresponding to the bottom of the computational domain, is set as “**wall**” implying a non-slip condition for velocity and with temperature 300 K.
- The computational surface opposite to the aircraft engine exhaust nozzle, at which flow field (mixture jet and ambient air) leaves computational volume, was set as “**pressure-outlet**”.

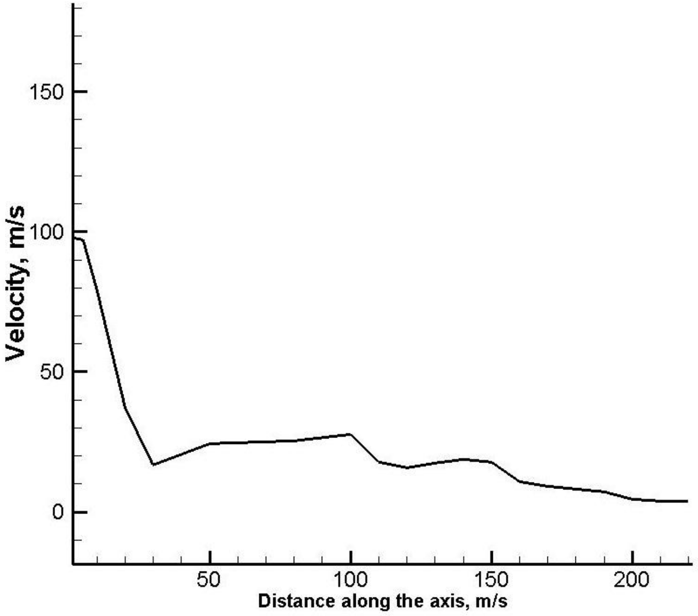


Boundary conditions for CFD simulations of exhaust gases jet from aircraft engine near ground

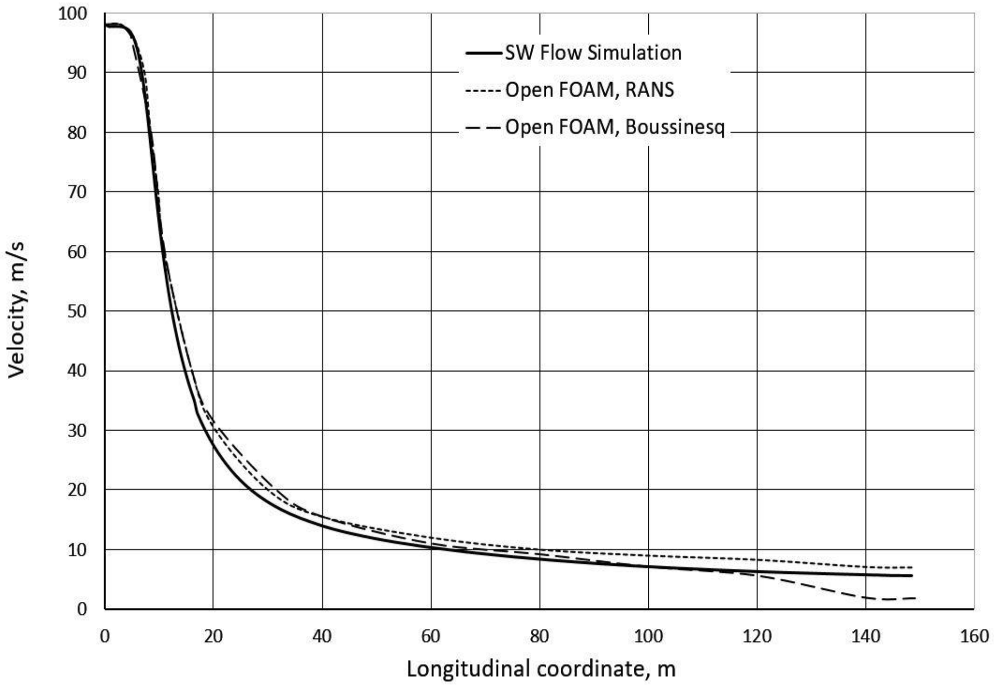
Results of simulation



a)



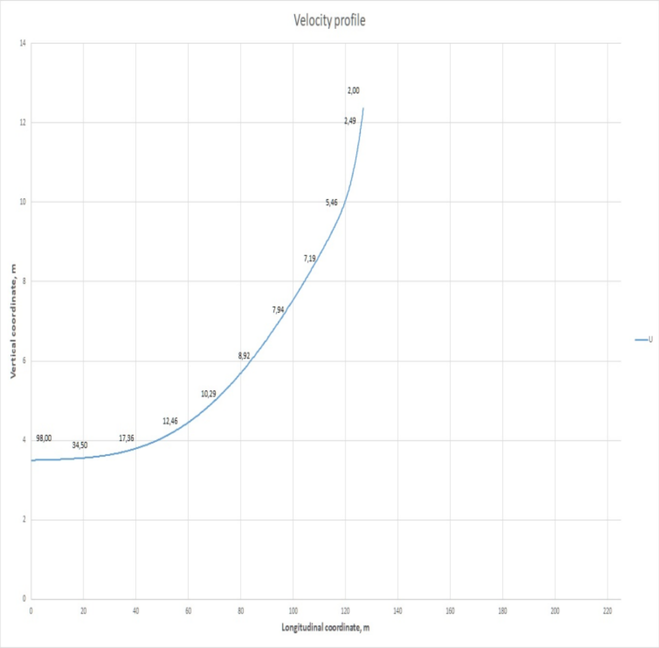
b)



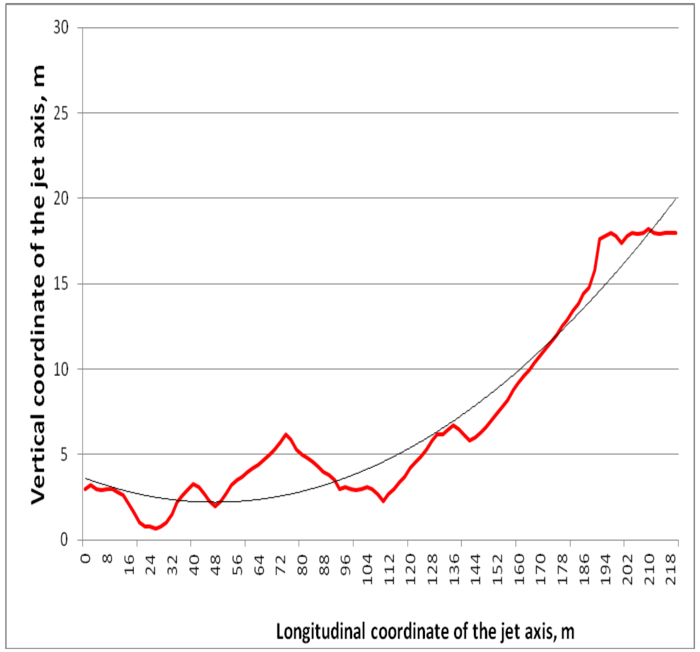
c)

Maximum velocity decay along the axis of the jet due to OpenFOAM (a) Fluent 6.3 (b), Flow Simulation (c)

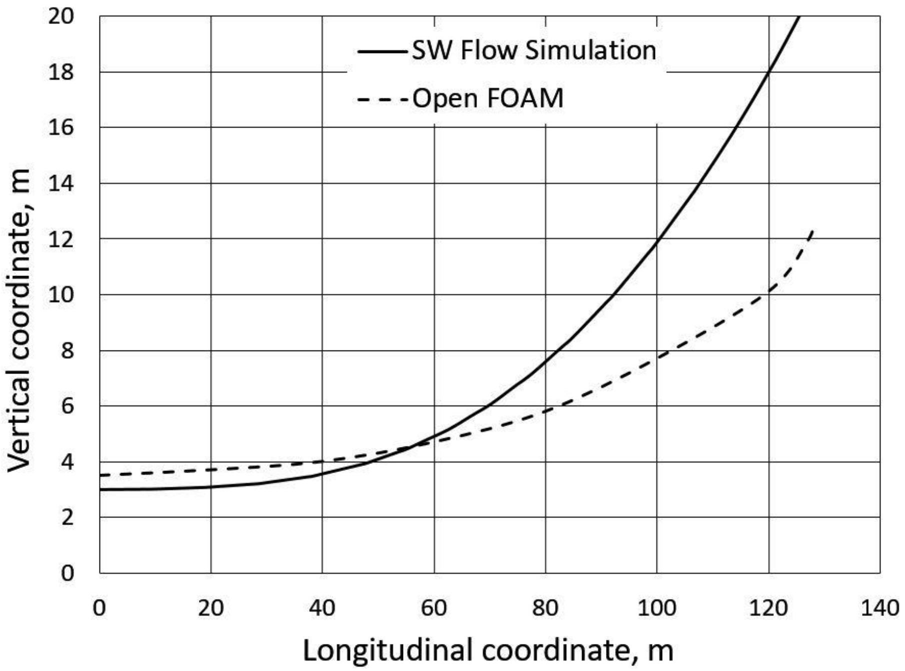
Results of simulation



a)



b)

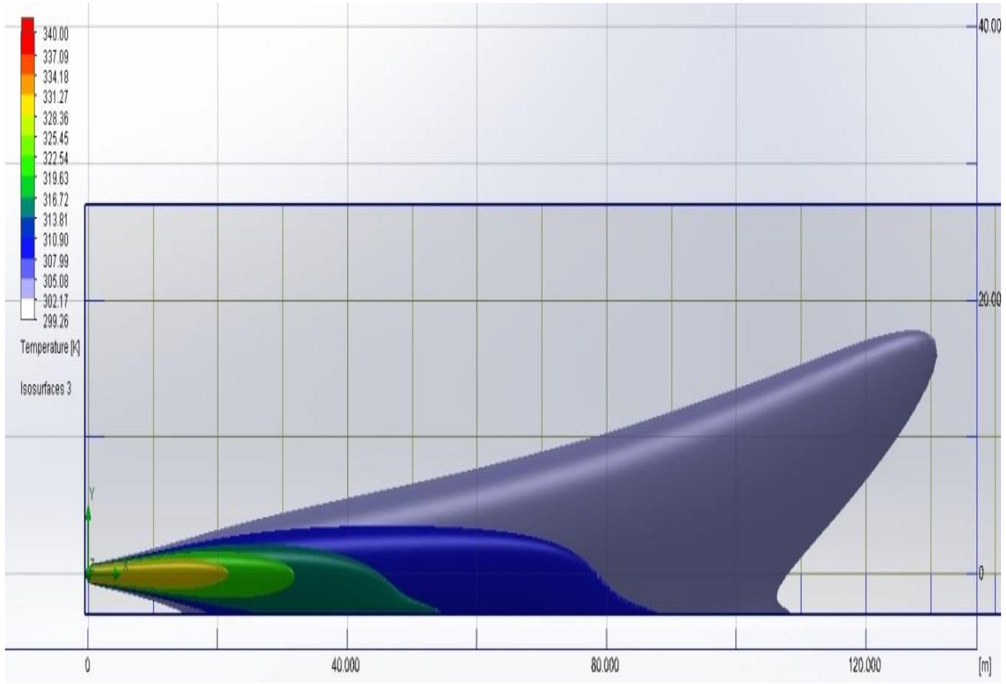


c)

Buoyancy effect of exhaust gases jet:
longitudinal and vertical coordinates of jet axis due to OpenFOAM (a), Fluent 6.3 (b) and Flow Simulation (c)

Results of simulation:

Parameters	Calculation results of modeling			
Initial conditions $U_j = 98\ m \cdot s^{-1}$, T_j = 423K	Open FOAM	Fluent 6.3 Mesh 1	Fluent 6.3 Mesh 2	PolEmiCa previous version
Height of jet rise Δh_A, m	8,5	15,5	17,0	40,4
Longitudinal coordinate of jet rise X_A, m	130,0	170,0	165,0	125,0
Length of jet penetration, S_{jet}	190	205	210	200



Comparison between OpenFOAM numerical results and semi-empirical jet model calculations (used by complex model PolEmiCa) show that buoyancy effect parameter as height decreases in 4 times wall jet.

CONCLUSIONS:

The **specific features of aircraft** as a special source of air pollution, needs to be included **in emission and dispersion modeling** of airport air quality. Particularly, eliminating the fluid dynamics of the jet from aircraft engines may <u>overestimate</u> the height of the buoyancy of the exhaust gases jet, <u>underestimate</u> its length and radius of expansion, dispersion characteristics and accordingly pollutant concentrations.

Thank you for your attention!