# A Light statistical method of air traffic delays prediction

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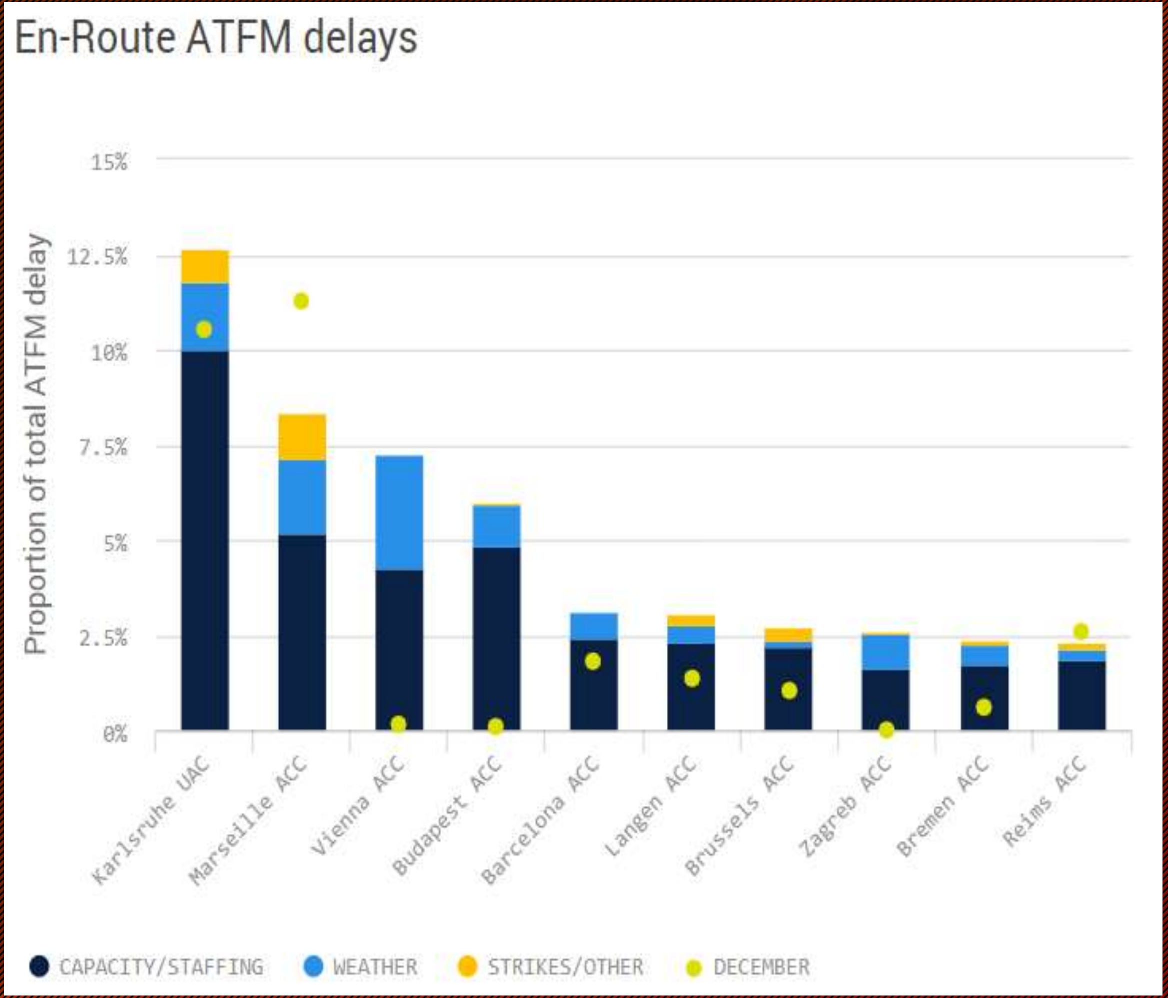
# 1.1 Delays in Europe

**Delays**

| | December 2019 | | Full year 2019 | |
|---|---|---|---|---|
| Average delay on arrival (all causes, per flight) | 11.4mins | ↓11.6% | 12.2mins | ↓11.6% |
| Av. arrival punctuality (all causes) ⓘ | 79.3% | ↑2.8% | 77.4% | ↑1.8% |
| Av. ATFM delay (en-route) per flight | 1.18mins | ↑65.9% | 1.57mins | ↓9.0% |
| Av. ATFM delay (airport) per flight | 0.51mins | ↓21.8% | 0.60mins | ↑0.8% |
| Av. ATFM delay (total) per flight | **1.69mins** | ↑24.2% | **2.18mins** | ↓6.5% |



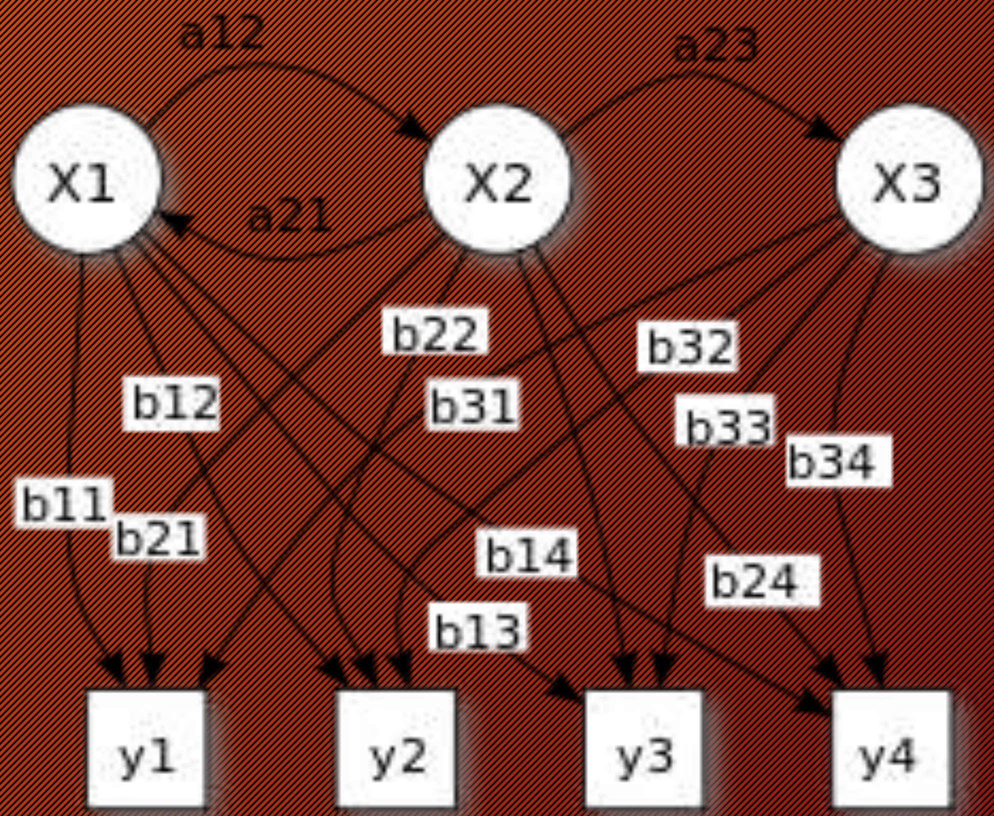
En-Route ATFM delays

# 1.2 Main causes of delays

- **Airline.** Includes delays occurred by passenger and baggage caring side; cargo loading; aircraft and ramp handling; technical problems and aircraft equipment settings; damage of aircraft; flight operations and crew.
- **Airport**. Contains delays caused by airport facilities; restrictions at destination and departure airports.
- **En-route**. Air traffic flow management (ATFM) due to Air Traffic Control (ATC) en-route demand; ATC staff and ATFM equipment.
- Governmental includes delays from security and immigration reasons.
- **Weather.**
- **Miscellaneous**
- Reactionary is a result of the late arrival of aircraft, passengers, cargo, or crew.

# 1.2 Delay prediction

- Artificial Neural Networks
- Linear regression
- Classification and Regression Tree
- Markov approach (probability theory)



# 2. Delay prediction based on the aircraft model

$$X_i = X_{i-1} + Tt,$$

$$X_i = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}, X_{i-1} = \begin{bmatrix} x_{i-1} \\ y_{i-1} \\ z_{i-1} \end{bmatrix}, T = \begin{bmatrix} V\cos(\gamma)\cos(\alpha) \\ V\cos(\gamma)\sin(\alpha) \\ V\cos(\gamma) \end{bmatrix},$$

where $X_i$, $X_{i-1}$ are matrixes of current and previous airplane location; $T$ is a matrix of directional velocities; $V$ is an airplane velocity; $\alpha$ is airplane heading; $\gamma$ is a pitch angle; $t$ is a time between iterations.

$$V_{ground} = V_{TAS}\cos(\alpha - \beta) + U\cos(\beta - \varphi),$$

where $V_{TAS}$ is true airspeed; $\beta$ is ground track angle; $U$ is a wind speed; $\varphi$ is a wind direction.

# 3. Light statistical method

The time of airplane arrival at destination airport can be estimated from statistical data processing. Numerous of historical flight data is used to statistical trajectory data analysis. Statistical data utilize the action of different factors into delay estimation including weather and airline side. Light Statistical Method of Delay Prediction (LSMDP) grounds on loop comparison of current airplane coordinates with results of statistical data processing of available data from previous historical flights at the same flight path. The structural scheme of LSMDP is shown in Fig.1

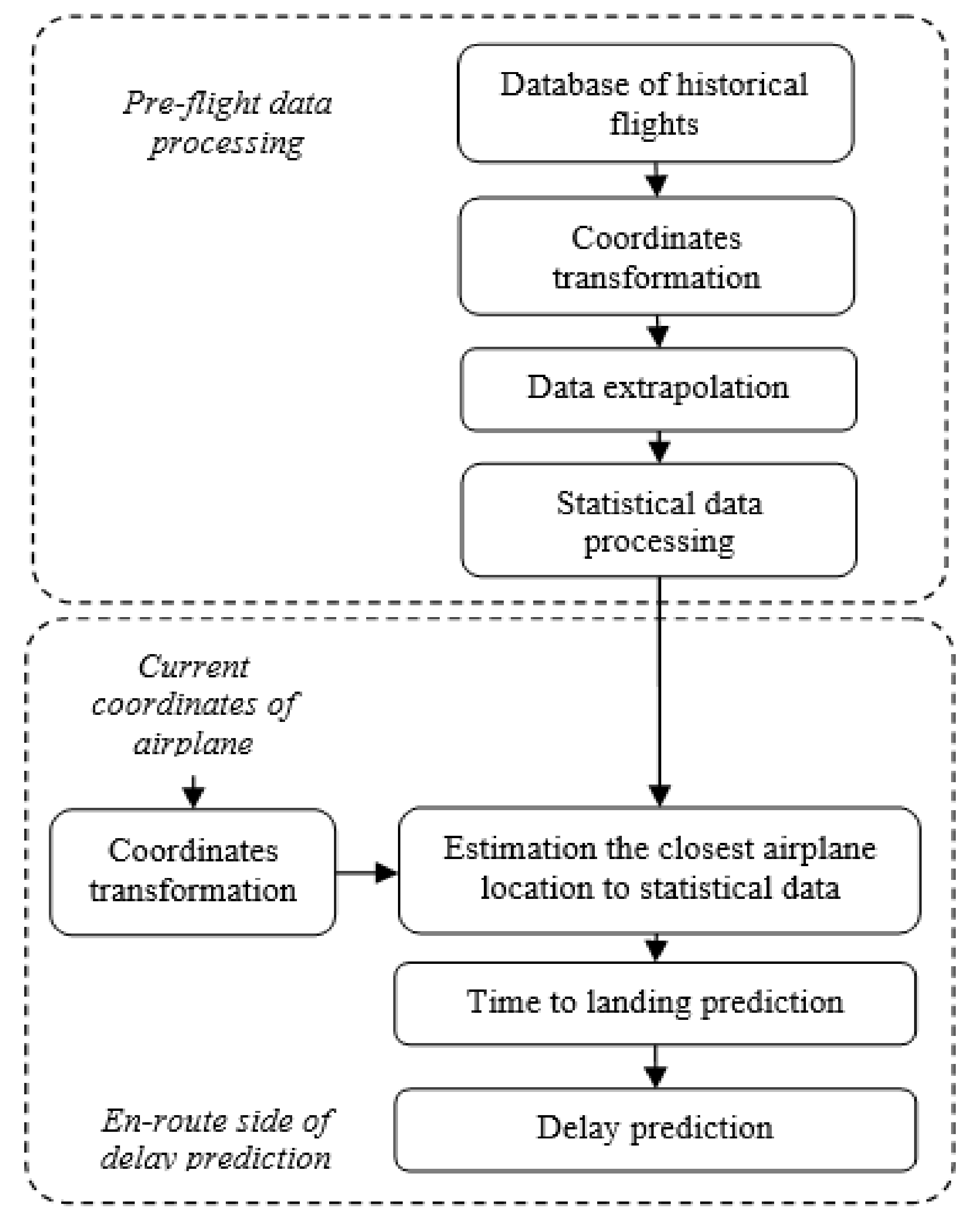
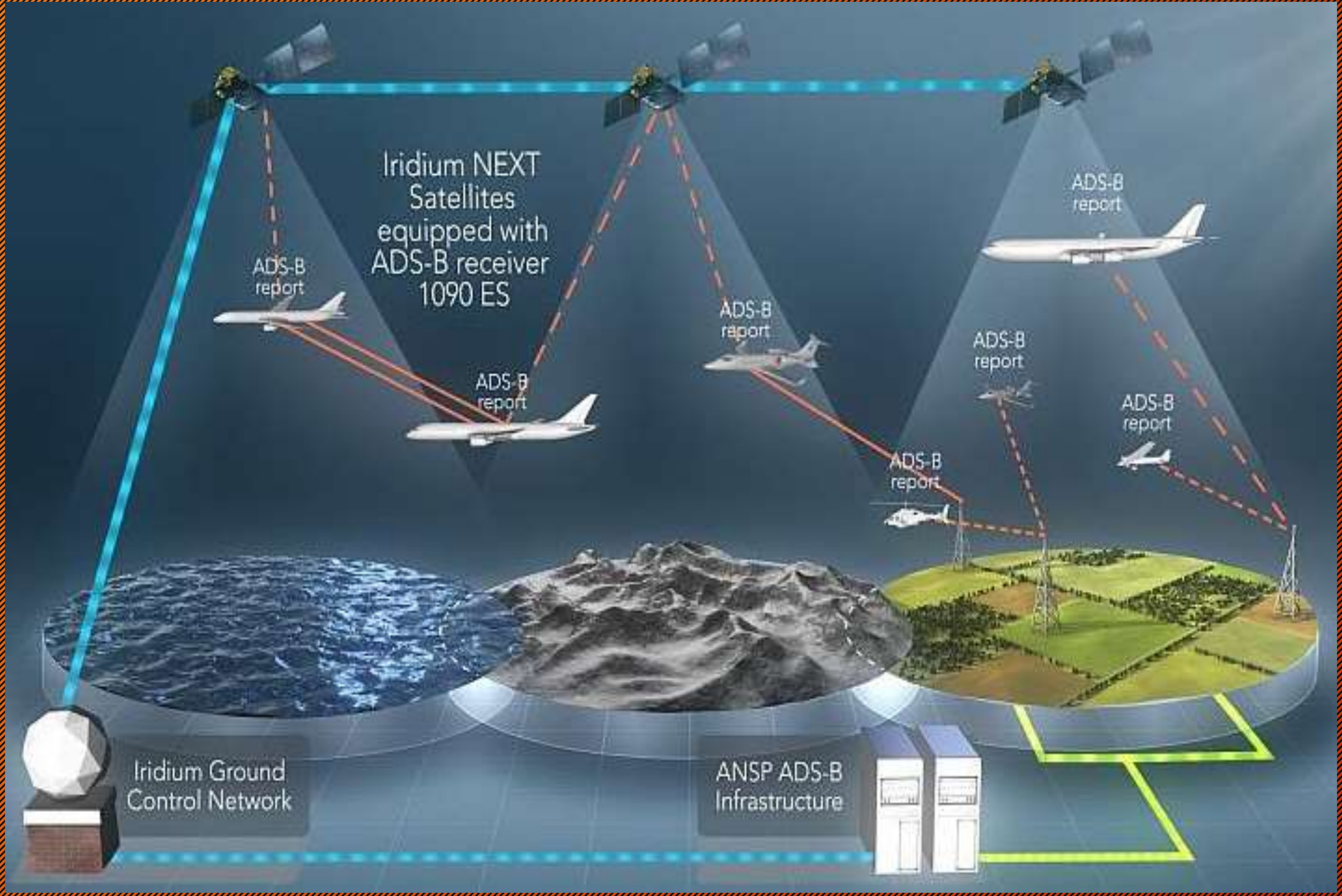


**Fig.1. Operation of LSMDP**

# 4. Input data (ADS-B)



The data transmitted in Automatic dependent surveillance-broadcast (ADS-B) include measurements of airplane coordinates by Global Navigation Satellite System (GNSS) or result of positioning by navigational aids, in case of GNSS malfunction. This data includes coordinates represented in latitude, longitude, and altitude (altitude form WGS84 ellipsoid) collected in the non-synchronize time of measurements. Each onboard transponder of ADS-B has its unique settings of data transmission, also multiple digital messages can be lost in the digital communication channel due to a line of radio transmission interruption or interference with other equipment.

# 5. Transformation for unique time

In our research we use a linear regression model with cubic splines of a second-order continuity:

$$S(t) = \sum_{j=1}^{N+3} B_{j,m}(t) C_j,\ 0 \leq i \leq T$$

where $C_j$ is a vector of control points; $B_{j,m}(t)$ are the basic functions of the B-spline; T is a time of flight.

As a B-spline basis function, we use a Cox-De Boor function

$$B_{j,1}(t) = \begin{cases} 1, \tau_j \leq t \leq \tau_{j+1} \\ 0, \tau_j > t > \tau_{j+1} \end{cases},$$

for $m \geq 2$

$$B_{j,m}(t) = \frac{t - \tau_j}{\tau_{j+m-1} - \tau_j} B_{j,m-1}(t) + \frac{\tau_{j+m} - t}{\tau_{j+m} - \tau_{j+1}} B_{j+1,m-1}(t),$$

where $\tau$ is a set of nodes

$$\tau_i = a + (i-1)\frac{b-a}{N-1}$$

where *a* and *b* are the firths and final points: *N* is a total number of available data points.

$$S=B\bullet C,$$

$$S = \begin{bmatrix} x_{11} & y_{12} & z_{13} & t_1 \\ x_{21} & y_{22} & z_{23} & t_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & y_{n2} & z_{n3} & t_n \end{bmatrix}; \; C = \begin{bmatrix} c_{11} & c_{12} & c_{13} & t_1 \\ c_{21} & c_{22} & c_{23} & t_2 \\ \vdots & \vdots & \vdots & \vdots \\ c_{n1} & c_{n2} & c_{n3} & t_n \end{bmatrix};$$

$$B = \begin{bmatrix} B_{1,m}(t_1) & B_{2,m}(t_1) & B_{3,m}(t_1) & \cdots & B_{n,m}(t_1) \\ B_{1,m}(t_2) & B_{2,m}(t_2) & B_{3,m}(t_2) & \cdots & B_{n,m}(t_2) \\ \vdots & \vdots & \vdots & & \vdots \\ B_{1,m}(t_n) & B_{2,m}(t_n) & B_{3,m}(t_n) & \cdots & B_{n,m}(t_n) \end{bmatrix},$$

where *S* is a matrix of splines; *B* is a matrix of basis functions; *C* is a matrix of control points

$$C=(B^T B)^{-1} B^T S.$$

The matrix of control points can be obtained from the solution by the least-squared method

# 6. Numerical demonstration

-We use flight data of AUI25

- Destination from Kyiv (Boryspil International Airport, KBP) to Kharkov (Kharkiv International Airport, HRK).

-81 flights

-From October 2, 2019, to January 1, 2020.

-Aircraft:

  - Embraer ERJ-190 (30 times)
  - Boeing 737 (51 times).

-Flight path length is 221 miles mean,

- Average flight time is 34 minutes.

-We use software-defined radio to receive location reports of airplane transponder in ADS-B format

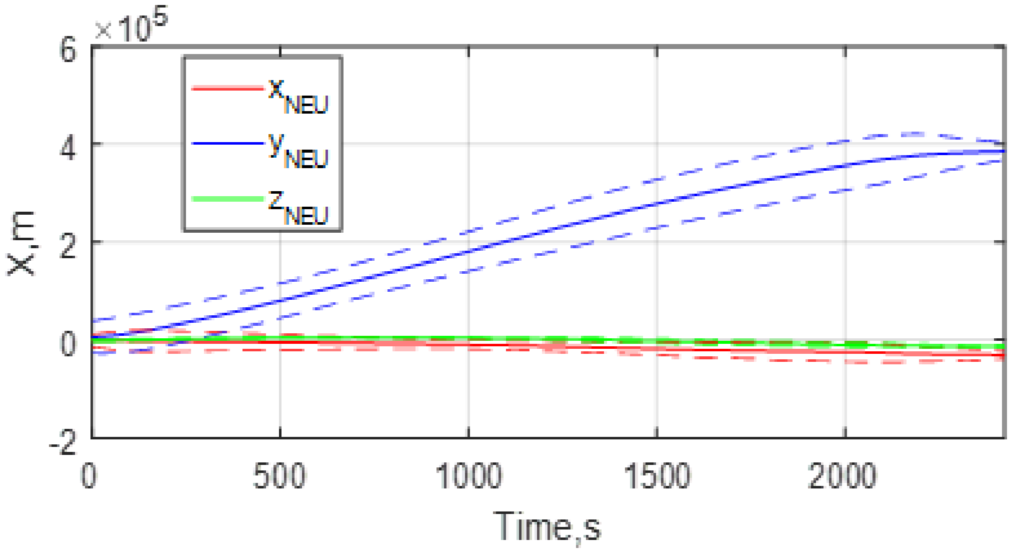


Fig.2. Mean locations of AUI25 route in NEU reference frame

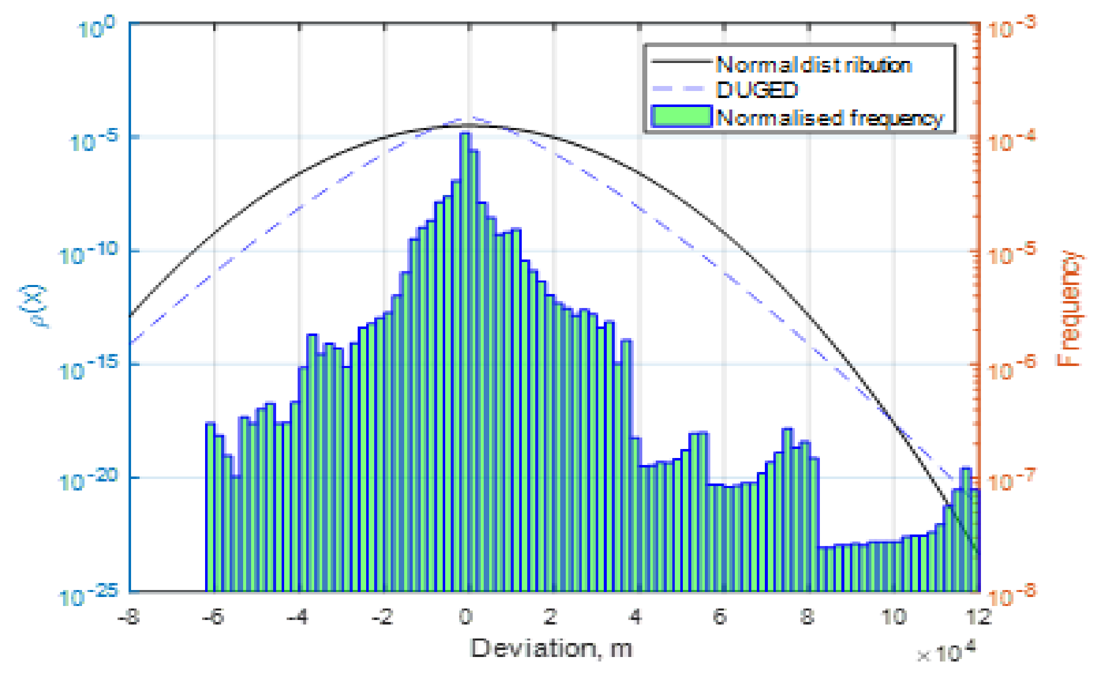


Fig.4. Histogram of trajectory deviations

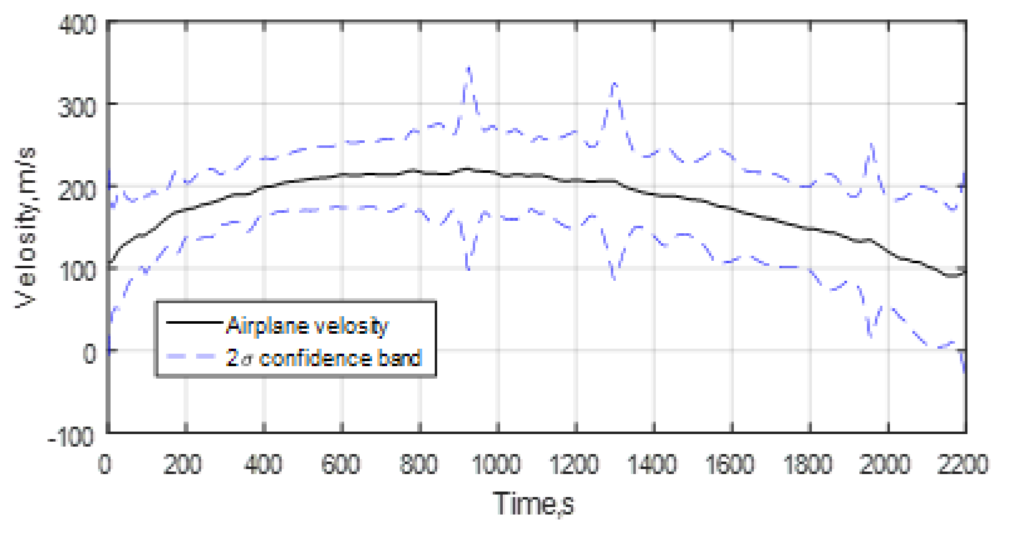


Fig.3. Velocity of airplane

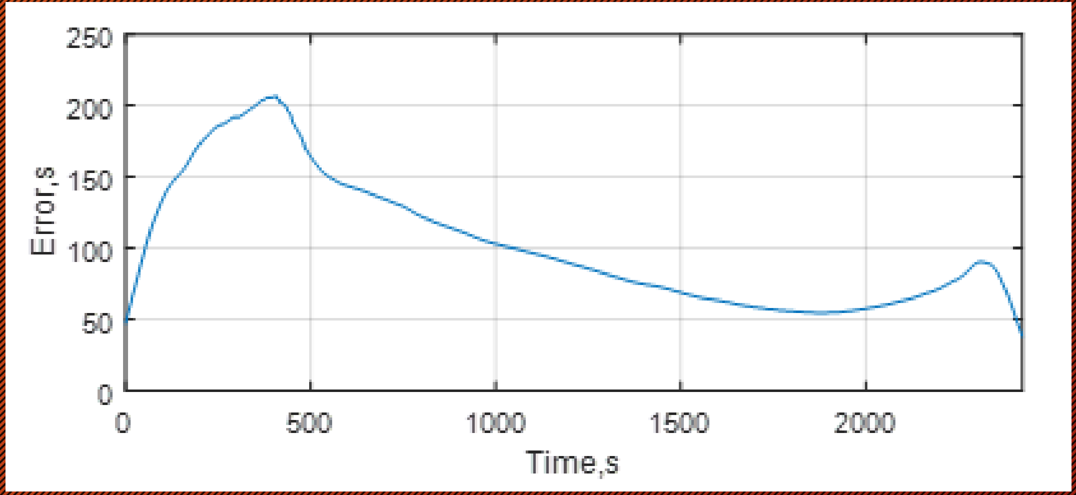


Fig.5. Mean squared error of delay prediction

# 7. Conclusions

- The problem of delayed aviation traffic in Europe was studied.
- Proposed by light statistical method to predict delays and minimize their impact
- Method was verified by air traffic data obtained from ADS-B receiver
- An error of delay prediction does not exceed 3 minutes for 30 minutes