Simulation of Ambient Turbulence Effects on Capacity of a Single Runway Airport Equipped with the Vortex Forecasting System

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Scenario of the Airport Functioning

• The arriving aircraft are divided into 3 classes (heavy, large, and small). The probability of the aircraft membership of a specific class corresponds to the chosen frequency of the class arrivals (the results are for the ratio heavy/large/small = 10/65/25)

• The flow of arrivals is the Poisson one (with the parameter $\lambda$, which gives the mean number of arrivals per the time unit)

• The distances between two successive aircraft cannot be less than the wake vortex safe separation corresponding to the aircraft classes

• The runway is closed for landing operations during $t$ seconds after any aircraft landing (the results are for $t = 50$ s)
• Arriving aircraft are lined up forming a single queue at the given distance, \( R \), from the runway threshold (the results are for \( R = 200 \) km)
• The length of the aircraft queue is limited. Therefore not all aircraft could be lined up and should wait for a time (the service failure)
• All aircraft from the distance \( R \) have the same speed, \( V \) (the results are for \( V = 100 \) m/s)
• All aircraft uniformly reduce their speed to the landing speed corresponding to the aircraft class
• The wind values are random with the known probability distribution corresponding to the specific wind rose
Basis for Evaluation of Dynamic WV Separations

A control window is recognized as free of wake vortices if

• the vortices are outside of the window extended by the radius of the danger area and by the inaccuracy in prediction of the WV position
• or the vortices are inside the extended window but they are safe (the danger area radius is zero).

The dynamic WV separations are evaluated using the leader WV release times calculated for all the control windows. These separations depend on the aircraft in the pair under study with due account for IGE and weather conditions.

The vortex decay is evaluated according to the Greene’s model for different values of the turbulence kinetic energy (TKE). Ambient turbulence is assumed to be homogeneous. The results are given as functions of \( q = \sqrt{2TKE} \).
Two-Stage Safety Criterion for Evaluation of Danger Areas

The First Stage
The rolling moment due to wake vortices does not exceed 0.5 the aileron moment.

The Second Stage
(if the first-stage criterion is fulfilled)
The bank angle does not exceed 15°.

Assumption: The pilot reaction is 1 second.
Measure of Efficiency

The maximum value of the Poisson parameter, \( \lambda \), which provides that the service failure probability is not more than the chosen limit (the results are for the limit 0.2), is considered as the airport capacity, \( C \). The values of \( C \) calculated for the airport functioning according to the ICAO wake vortex separation rules (\( C_{\text{ICAO}} \)) and for the airport equipped with the VFS (\( C_{\text{VFS}} \)) give an indication of the VFS efficiency. The efficiency measure is

\[
\Delta C = C_{\text{VFS}} - C_{\text{ICAO}}
\]

expressed in percent of \( C_{\text{ICAO}} \).
Calculation Results

$\delta$ is inaccuracy in ambient turbulence measurements expressed in percent of the measured value.
**VFS Shortcomings**

<table>
<thead>
<tr>
<th>Desired Objectives</th>
<th>VFS</th>
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<tbody>
<tr>
<td>Improve the Airport Capacity under IFR</td>
<td>+</td>
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Ideas of Vortex Vision System (VVS)

Area of possible aircraft positions
Predicted aircraft position
Danger area borders
Forecasting distance
Wake
Indicative Data for WS
(Visualization Subsystem for Pilots)

Mnemonics frames of the Boeing company

Mnemonics frames at the HUD

Mnemonics frames at the multifunction display

wake
Landing of Aircraft Equipped with VVS
Calculation Results for Two Kinds of Systems

<table>
<thead>
<tr>
<th></th>
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<th>VFS</th>
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<tbody>
<tr>
<td>δ=0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>δ=20%</td>
<td>0.5</td>
<td>1.2</td>
</tr>
<tr>
<td>δ=50%</td>
<td>1.0</td>
<td>2.5</td>
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## Qualitative Comparison of VFS and VVS

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Conclusions

- Ambient turbulence plays crucial role in increase of a single runway airport capacity when using VFS
- To evaluate the efficiency of VFS as a whole (instead of the one for isolated values of ambient turbulence), it is necessary to know the long-term distribution of turbulence levels at the specific airport
- The results show a substantial increase in the VFS efficiency with the accuracy of ambient turbulence measurements for moderate and strong turbulence levels
- The preliminary results suggest that even greater benefits could be achieved using forecasting systems of the VVS type
- It should be stressed that the latter results are preliminary and obtained in the described simulation medium but they demonstrate that it is not unreasonable to give more attention to the VVS