Wake Vortex Detection by Convolutional Neural Networks

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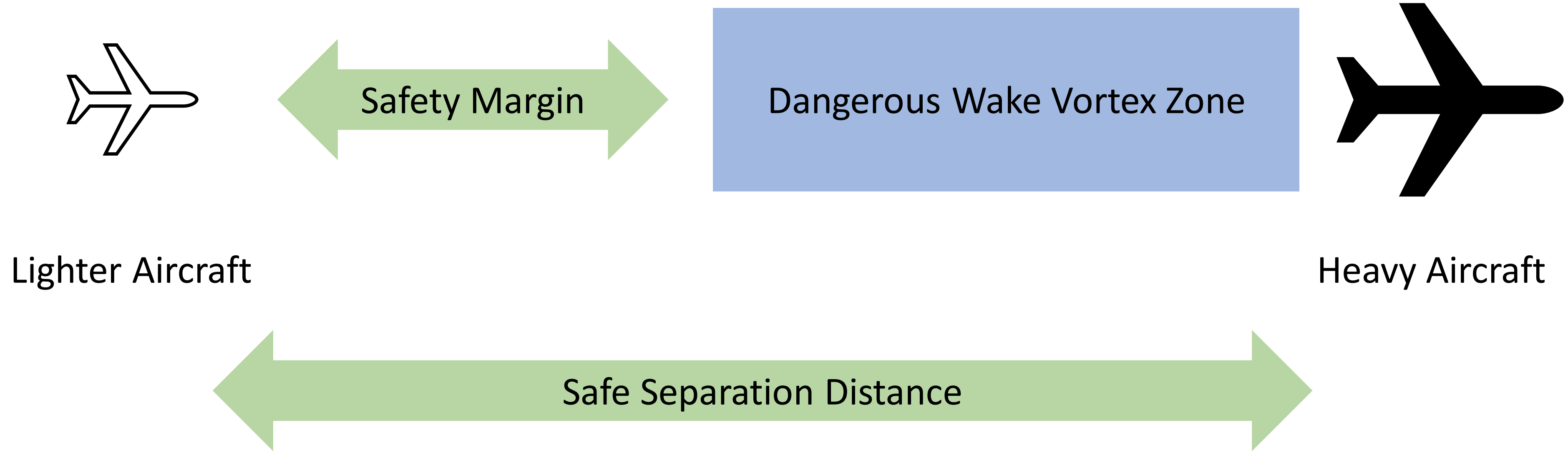
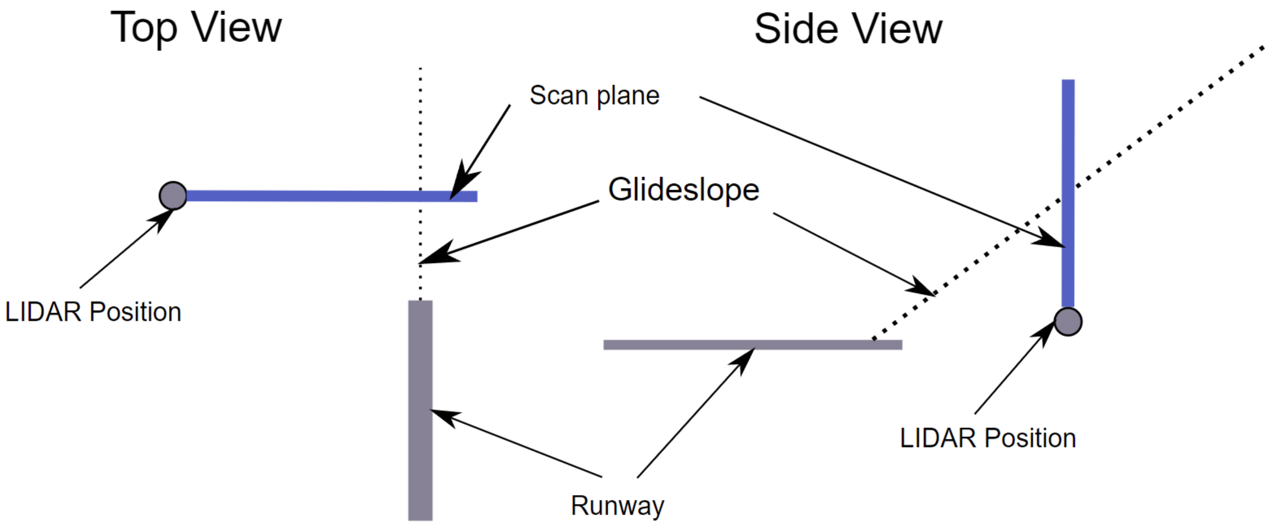
A Hazard of the Wake Vortices

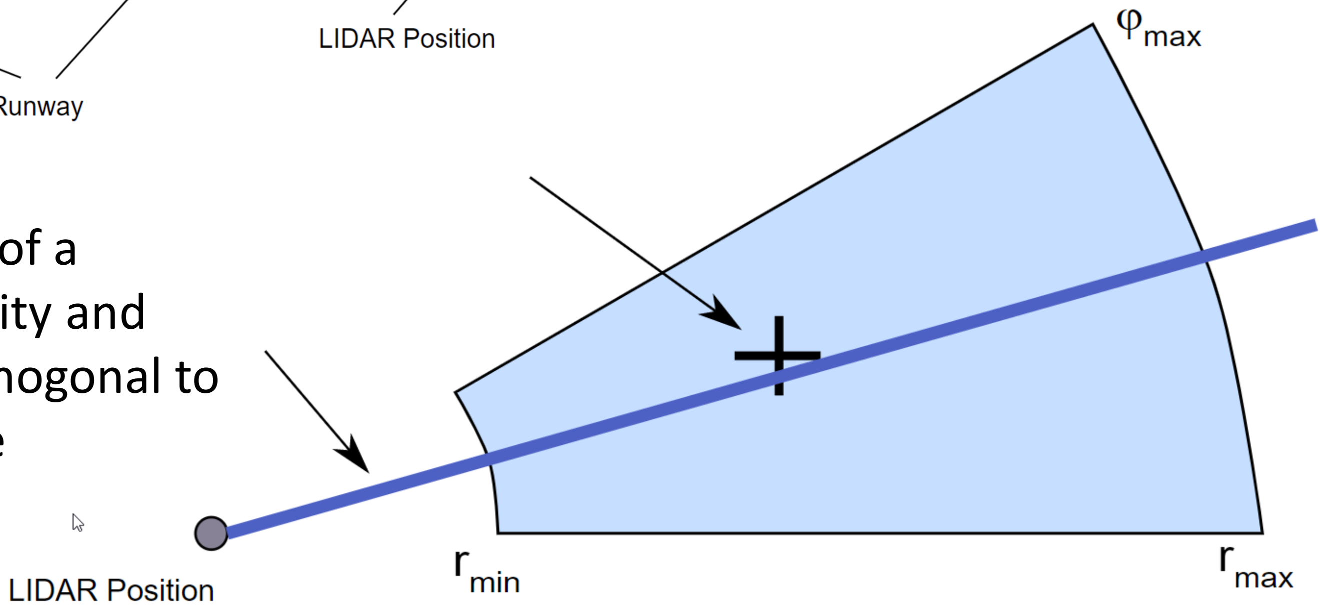


Excessive separation distances can lead to inefficiency in airspace usage, especially in terminal airspace of major hubs with highly mixed traffic. Stronger concerns were raised with the introduction of Airbus A380 super-heavy aircraft. Direct Vortex measurements and detection can help to analyze potential threats and increase efficiency.

LIDAR Measurements Setup

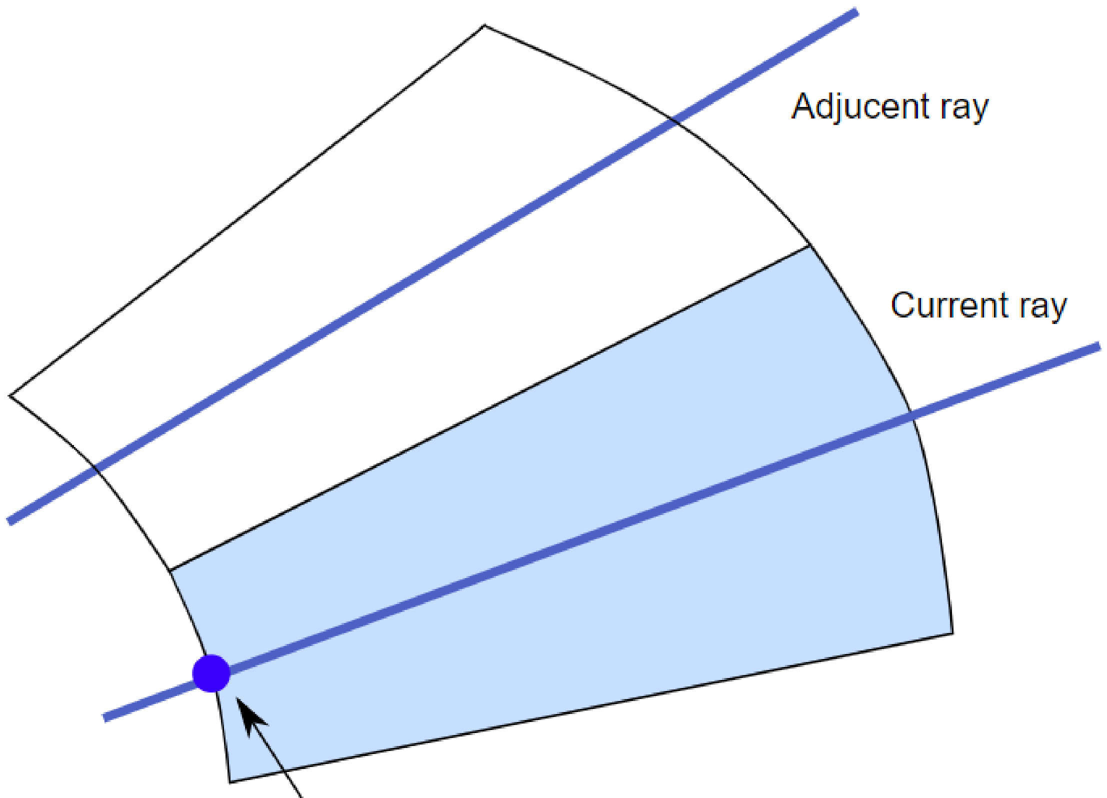


LIDAR measurements are valid withing specific distance limits (generally from 100 m to 600 m). Elevation angles a set as to capture the whole zone of potential vortex existence (generally from zero to 30 degrees)



LIDAR is positioned sideways of a runway in an immediate vicinity and scans vertically in a plane orthogonal to a runway extended centerline

LIDAR Measurement Structure



LIDAR digital output consists of a set of scans. Each scan corresponds to a single pass of LIDAR scanner's reciprocating motion At each elevation, LIDAR senses a projection of a wind speed (*v*) to a scan line at a set of distances.

Single LIDAR scan representation in polar coordinates

$$S = \{v(\varphi_i, r_j)\},$$
$$\varphi_{min} \leq \varphi_i \leq \varphi_{max},$$
$$r_{min} \leq r_j \leq r_{max},$$
$$i = 1..K, \quad j = 1..M.$$

Numbers of measurements in a single scan N = KM is determined by scan's angular (0.5°) and range (3 m) resolution.

Wake Vortex Detection Algorithms

Existing ad hoc algorithms:
- based on direct analysis of the behavior of the wind speed projection
- high gradient values together with a change of sign along the adjacent ray, constitute the presents of a vortex

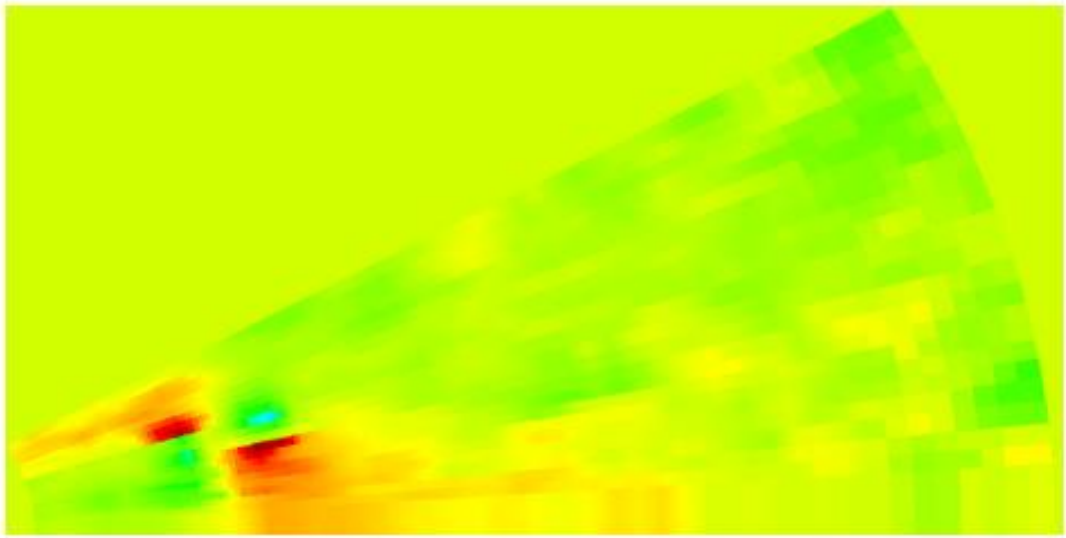
Advantage - can derive quantitative characteristics of a vortex:
- coordinates
- circulation strength

Assumptions:
- vortex has a delineated circular structure
- radial wind speed distribution has a particular shape: this assumption is **not correct** near a ground plane, when its interference with a vortex creates secondary vortex structures

Neural Network approach is less sensitive to **a priori** vortex structure. In this study, we use well-known object-detection process applies to bitmap representation of the scans.

Wake Vortex as an Image

We represent vortices as a tensor *I* of 3-component (red, green, blue) color vectors. A deterministic transform *(R, G, B) = C(λ)* is used to calculate a color from a wind speed *v*.



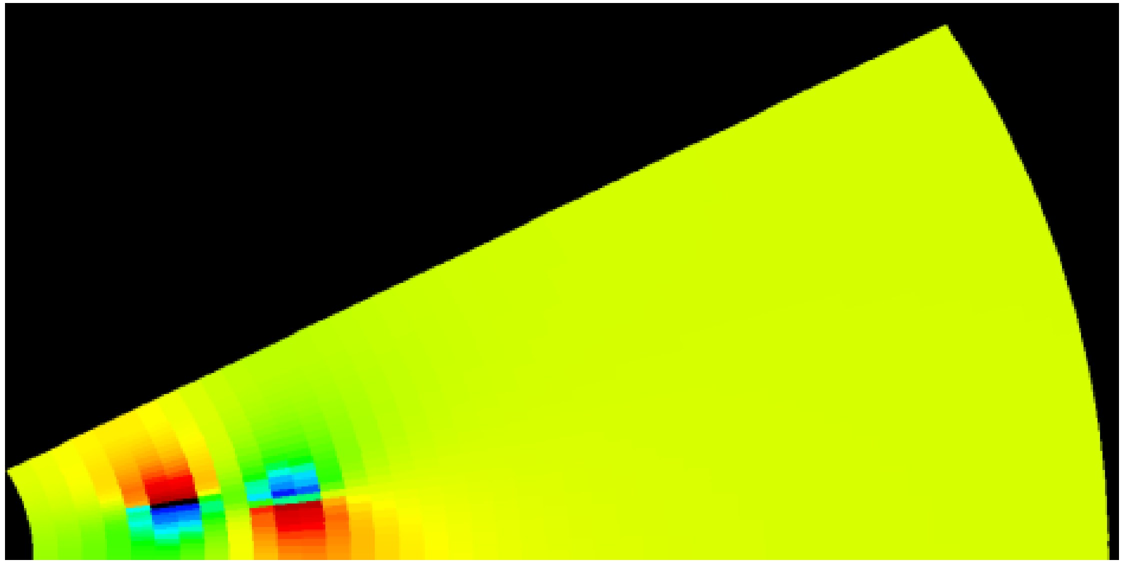
$$(R^{i,j}, G^{i,j}, B^{i,j}) = \mathcal{C}(\lambda_{i,j}).$$

$$i = 1..K,\ \ j = 1..M$$

$$\mathcal{I} = \begin{bmatrix} (R_{1,1}, G_{1,1}, B_{1,1}) & \dots & (R_{1,H}, G_{1,H}, B_{1,H}) \\ \dots & \dots & \dots \\ (R_{W,1}, G_{W,1}, B_{W,1}) & \dots & (R_{W,H}, G_{W,H}, B_{W,H}) \end{bmatrix}$$

Modelling a Training Dataset - Generation

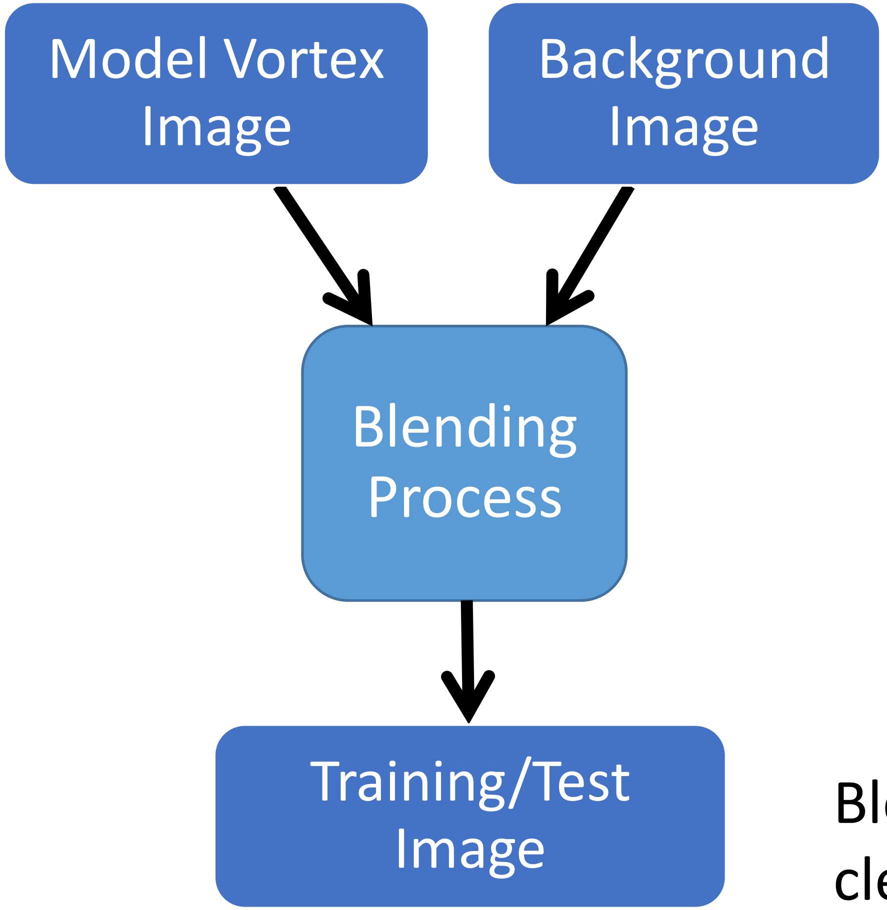
We use a model to generate set of LIDAR measurements for a varying set of parameters

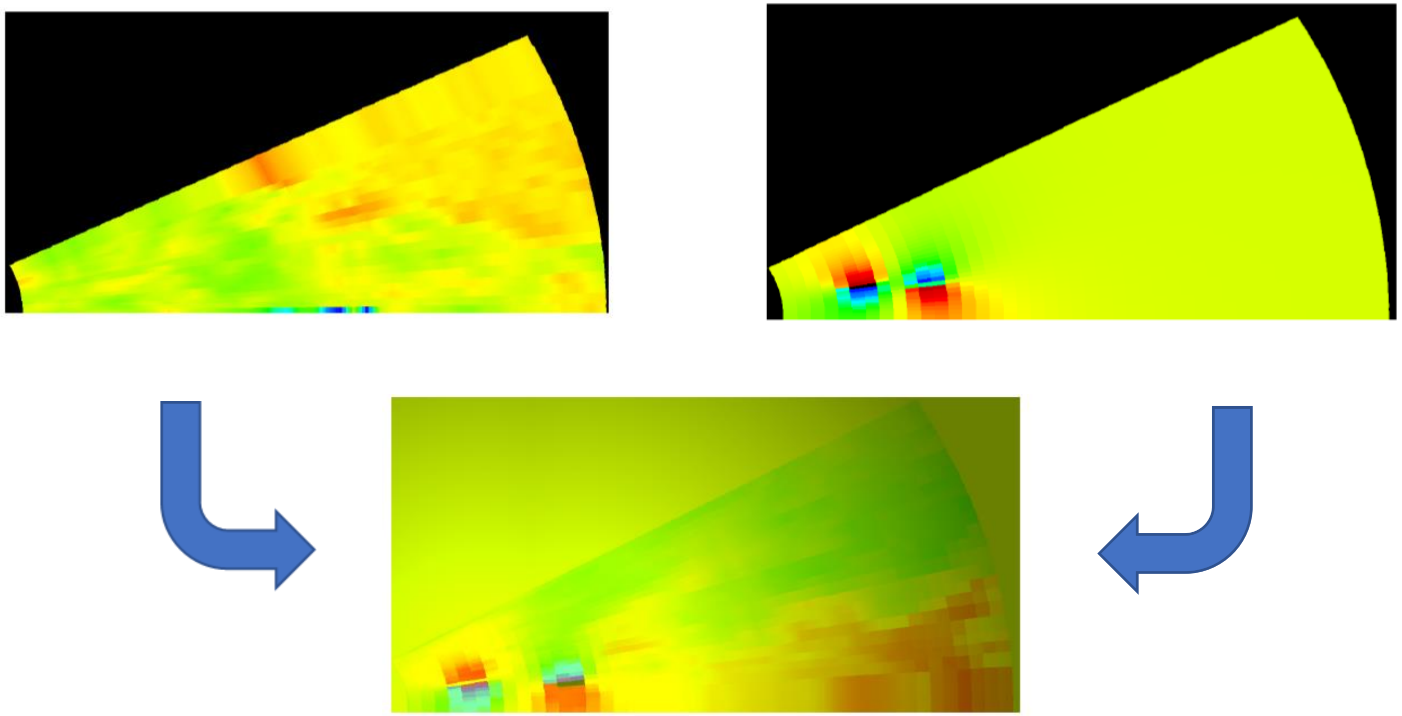


- Aircraft type:
  - Boeing B767, B777, B787
  - Airbus A380, A350, A340, A330, A319, A320
- Scan delay: 10, 12, 15 seconds
- Vortex generation height: 75 meters, 60 meters
- Ambient wind speed: minimum −2m/s, maximum 4m/s.

Total number of samples: 3024

Modelling a Training Dataset - Blending





Blending to obtain a training set:
clear background + generated vortex

Neural Network Training

- CNN Architecture used: Faster R-CNN with Inception V2 pre-trained on the COCO dataset
- GPU-based training with Tensorflow 2.0 library
- Number of classes: 1 (Vortex)
- Number of training steps: 200000
- Training set: 80% of the samples
- Testing set: 20% of the samples
- Validation of direct images

Detection Results

The rendering represents a sample detection of a real wake vortex.