Towards Wake-Resistant Aircraft for Safer and Greener Aviation

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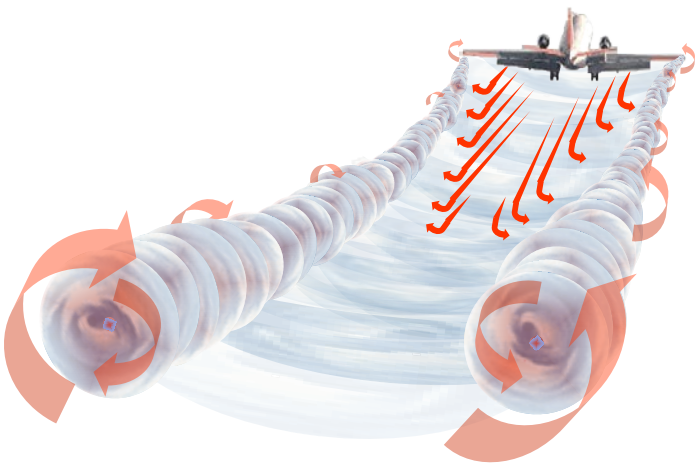
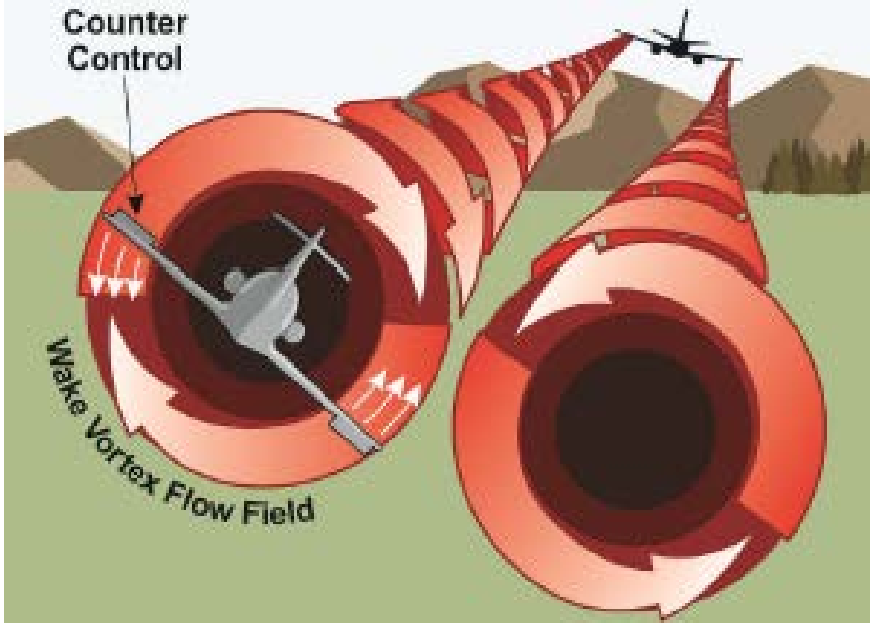
DLR

Introduction





Source: FAA Advisory Circular, Subject : Aircraft Wake Turbulence, AC No: 90-23G, 2/10/14

- Wake vortices are an inevitable, undesired side product of lift generation
- Wake vortex encounters can cause dangerous aircraft reactions
  - e.g. sudden rapid roll motion
  - ➔ safety threat
- Wake vortex based separation minima assure safe flight
  - ➔ capacity limiting

Motivation

- If wake-induced aircraft reaction could be reduced

  ➔ Safety increase
    - Lower pilot workload
    - Reduced risk of injuries

  ➔ Reduced separation minima <u>possible with the same safety standards</u>
    - Capacity gain

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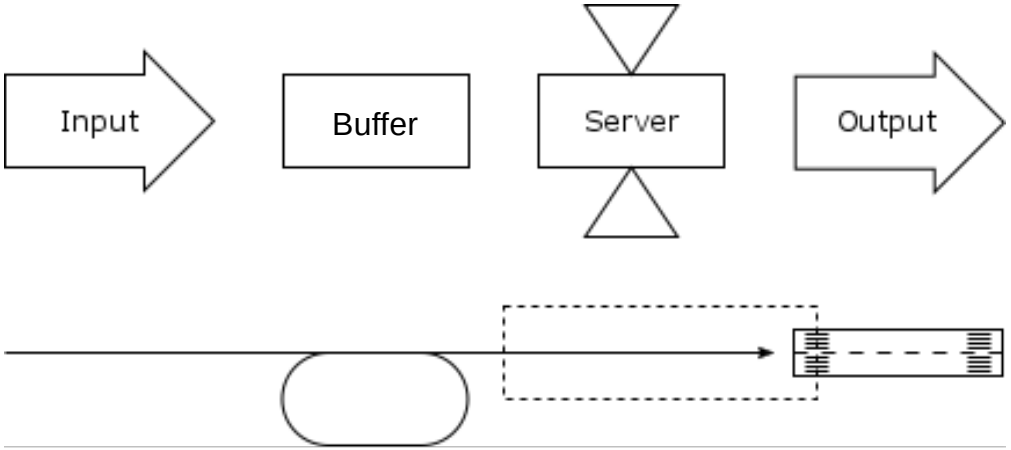
IS THIS GAIN NOTICEABLE?

Very Simple Analysis of Possible Capacity Gain

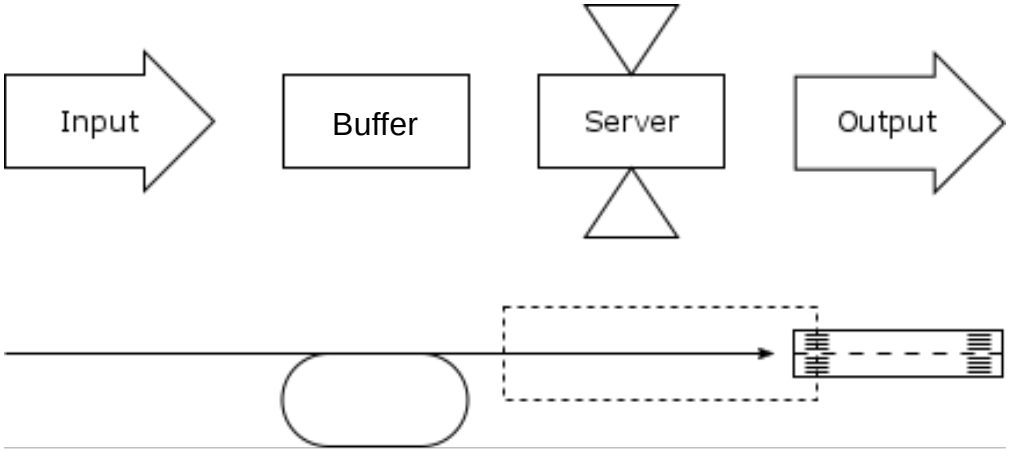
- Analysis of possible capacity gain of reduced separation minima compared to ICAO standard
  - for reduction by 0.25 NM, 0.5 NM, 0.75 NM and 1 NM
  - for 20%, 40%, 60%, 80%, and 100% of aircraft equipped with a wake impact alleviation system

- Assessment of the capacity increase based on M/M/1 queueing model

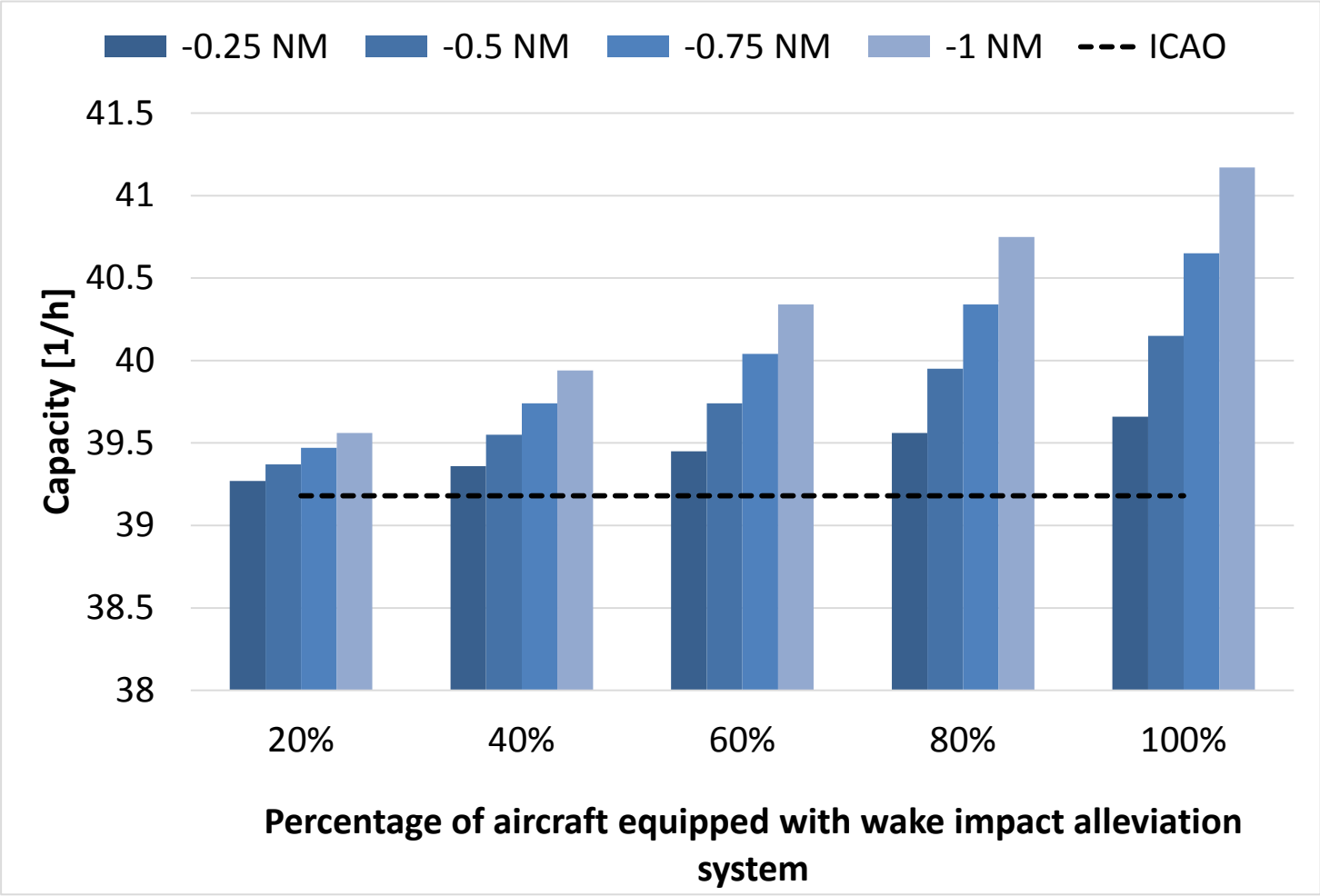


Underlying Assumptions for the Capacity Gain Analysis

- M/M/1 queueing model
- Runway operated in segregated mode for landing only
- Random aircraft pairings based on traffic mix corresponding
- ICAO separation minima are used as reference (assuming 2.5 NM for minimum radar separation)
- Separation distance is never reduced below minimum radar separation
- Delay of 200 s is assumed in case of ICAO separation minima (derived from average delay at highly frequented airport Gatwick)

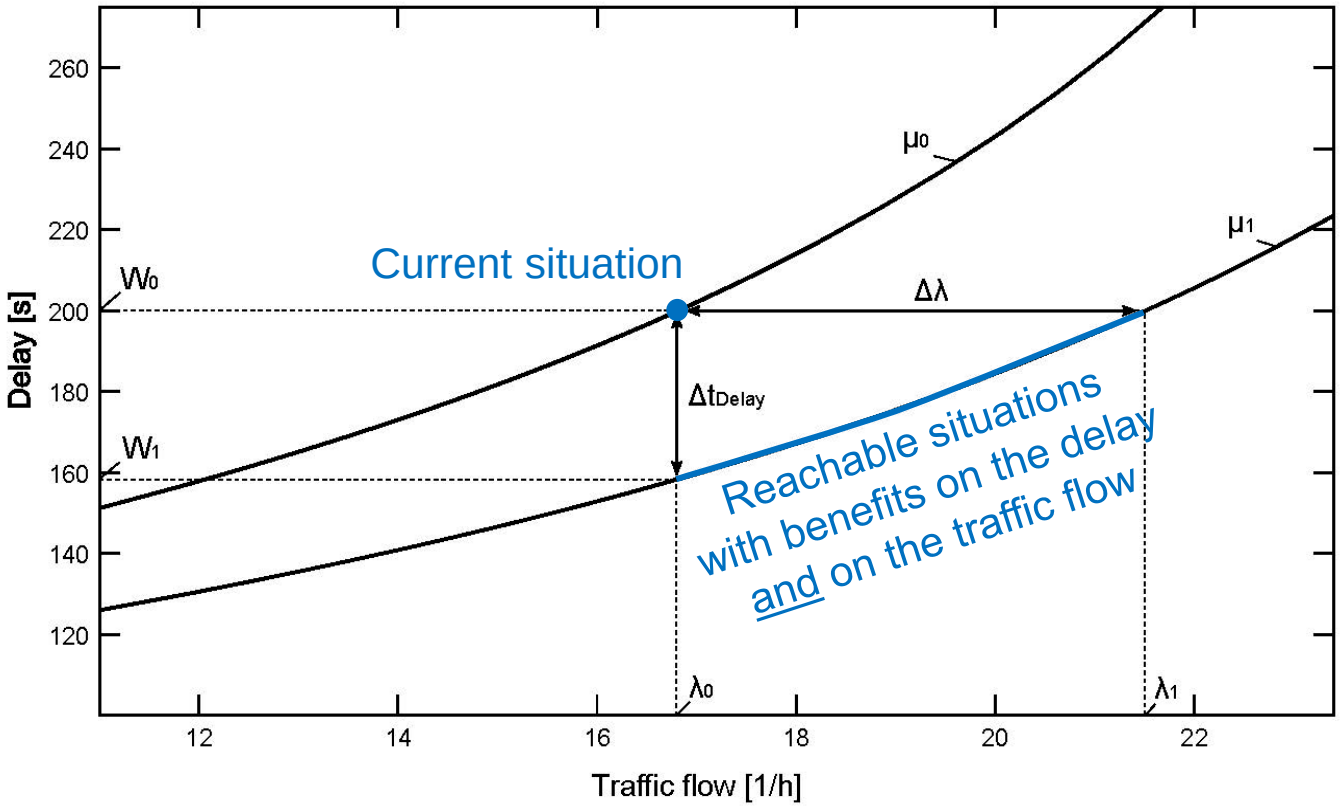


Resulting Capacity Gain

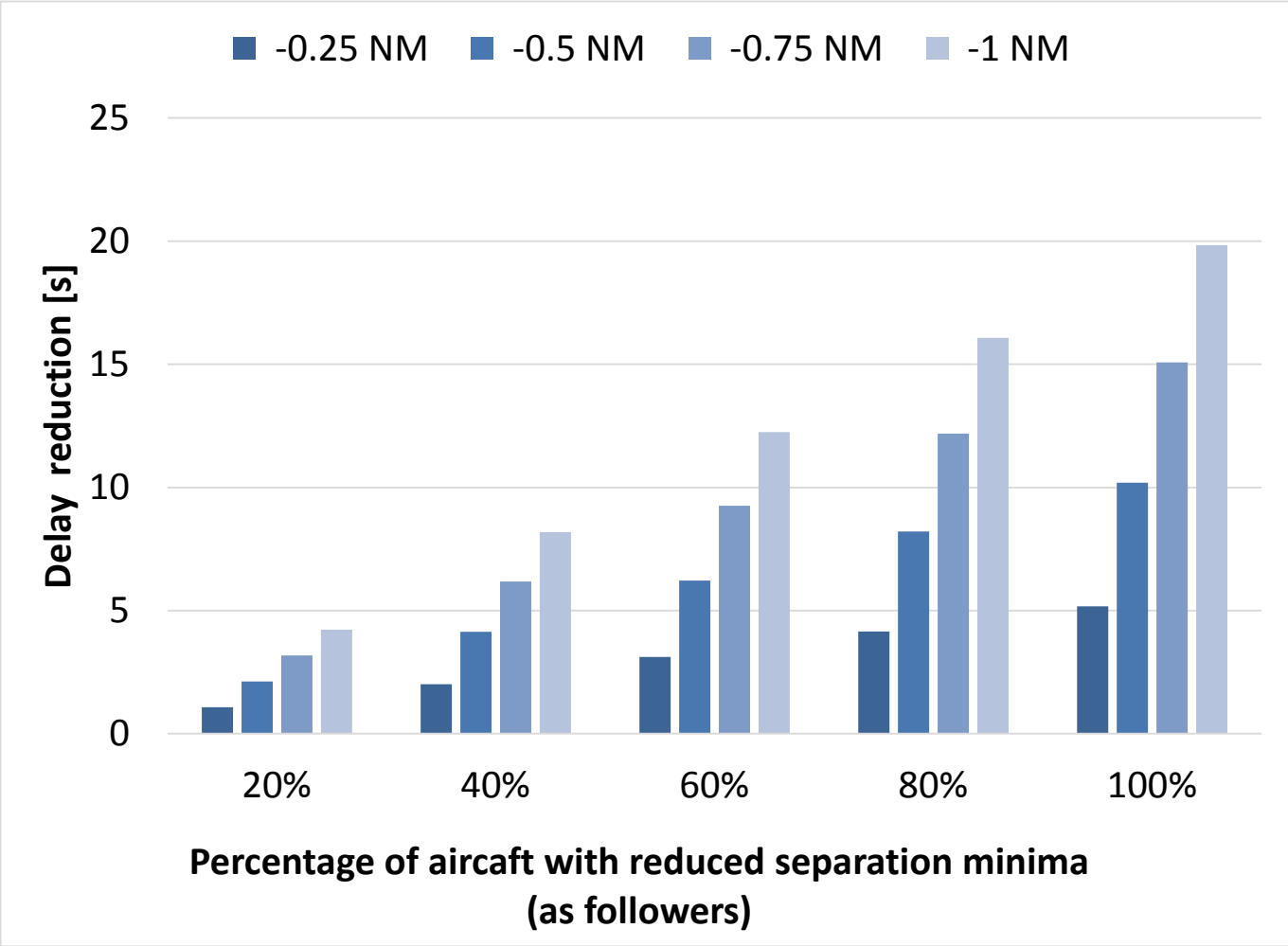


Exploiting a Capacity Gain

- Capacity increase can be used for
  - Increase in traffic flow
  - Reduction of delay (i.e. time spent in holding)
  - Combination of higher traffic flow and shorter delay



Resulting Mean Delay Reduction



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    - Capacity gain → reduced delay and/or increased traffic flow
      → lower emissions (fuel burn and noise)
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- Approach to mitigate aircraft reaction during encounter

  ➔ Wake impact alleviation control system

HOW?

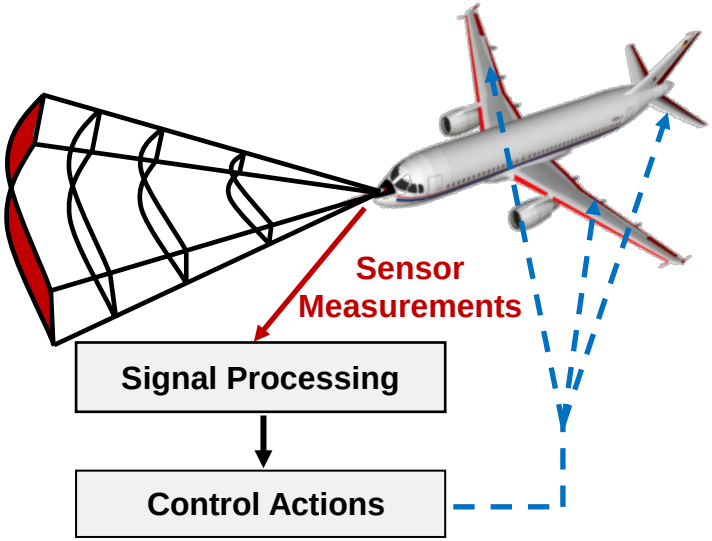
Considerations for an Active Wake Impact Alleviation System

- Modification of feedback control laws could be considered but might be undesirable from the loads perspective if higher gains are used all the time

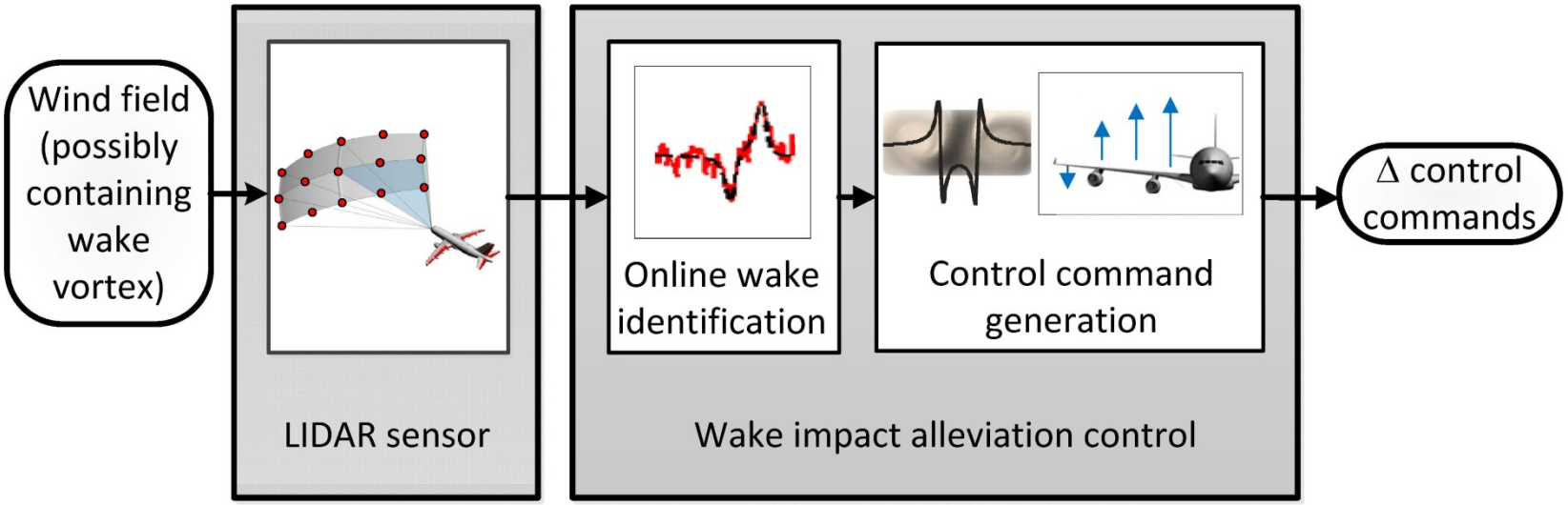
  ➔ detection or prediction (WEPS-P / WEAA) of the wake vortex required

- Forward-looking Doppler LIDAR sensor could be used for detection and for triggering a gain scheduling (not considered here)

- Sensor information about disturbance also allows <u>feedforward disturbance rejection</u>

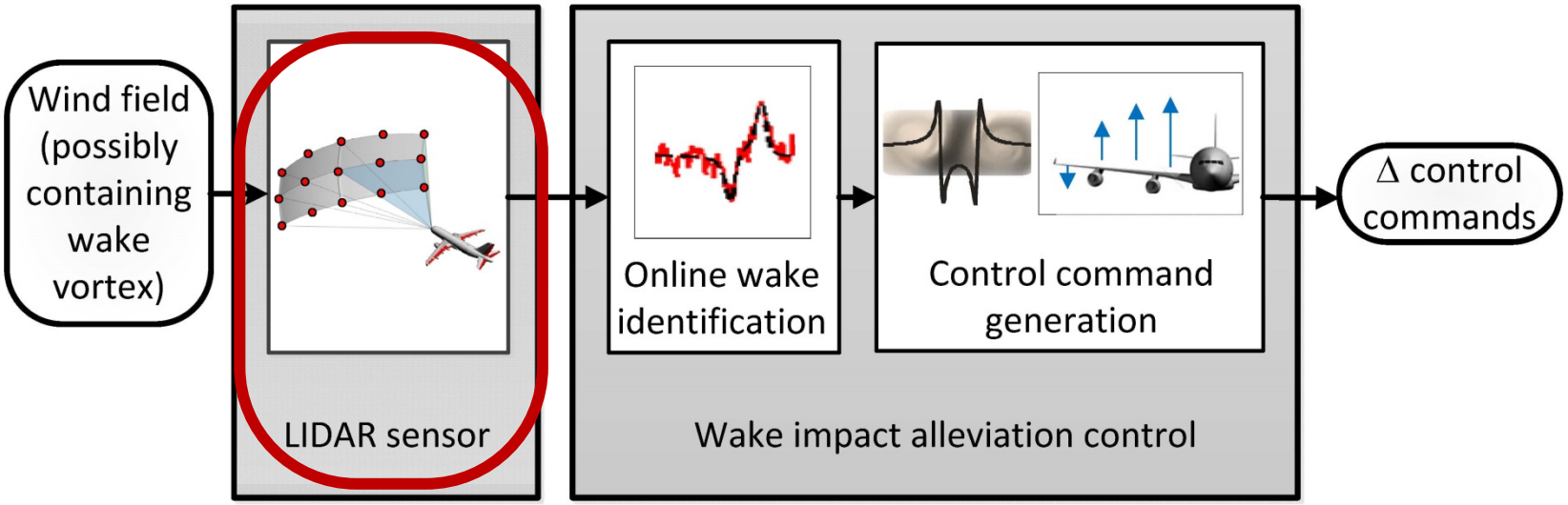


Concept for Wake Impact Alleviation



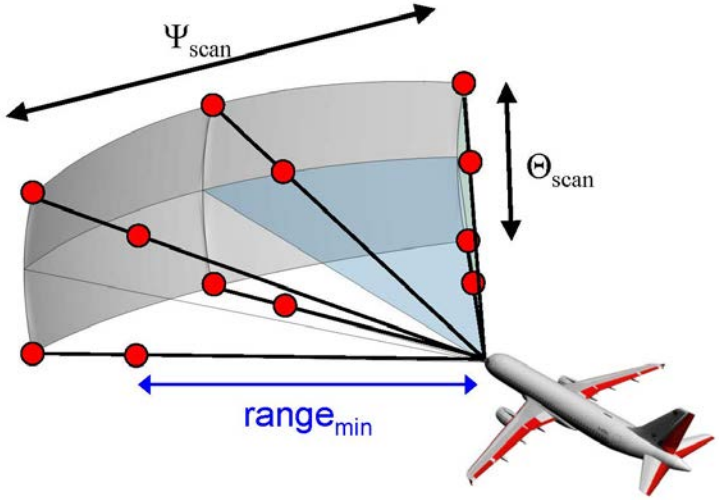
- **Remote Wind Sensing Using a Doppler LIDAR Sensor** (LIDAR = Light Detection and Ranging) measures relative wind velocity in line-of-sight direction ahead of the aircraft
- **Online Wake Identification** (OWI) estimates parameters of wake vortex model on the basis of the LIDAR measurements
- **Wake Impact Alleviation Control** (WIAC) determines the wake-induced disturbance moments resulting from detected wake vortex model and commands control surface deflections which compensate this disturbance

Remote Wind Sensing



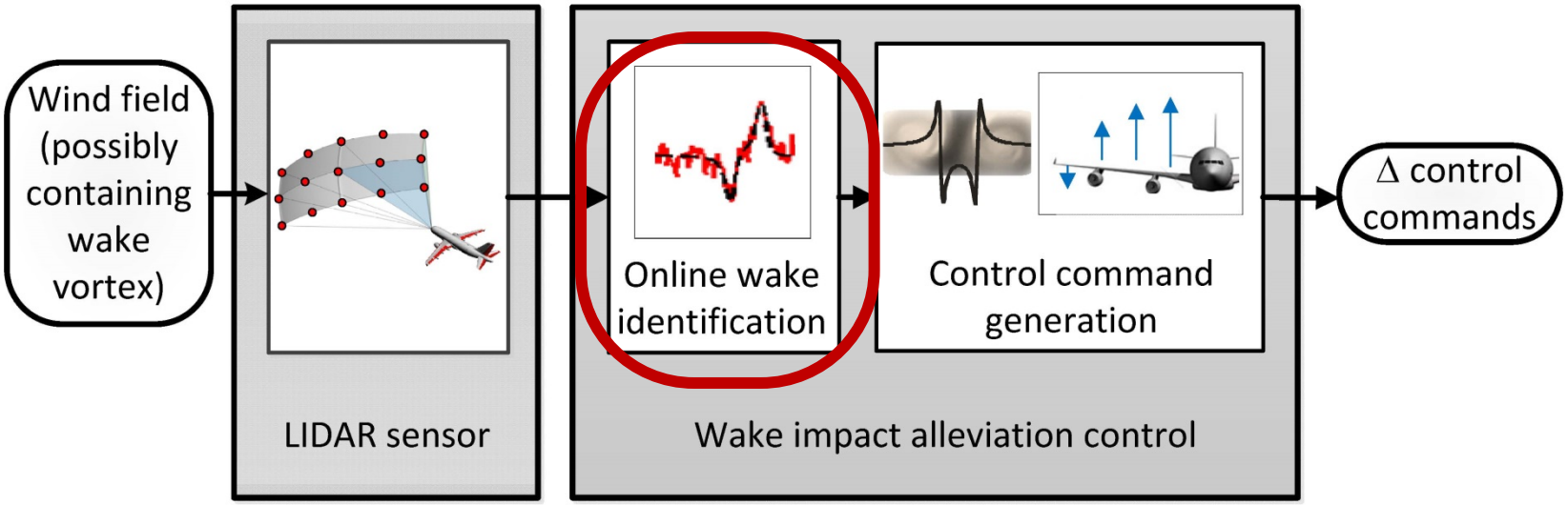
LIDAR Sensor

- LIDAR sensor measures wind velocities at different locations at short distances (60 – 90 m) ahead of the aircraft



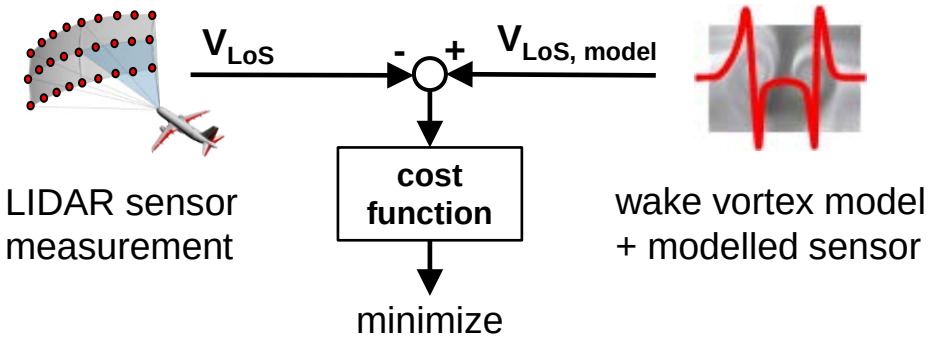
- Due to line-of-sight (LoS) measurement most information about wake vortex velocities is lost

Online Wake Identification



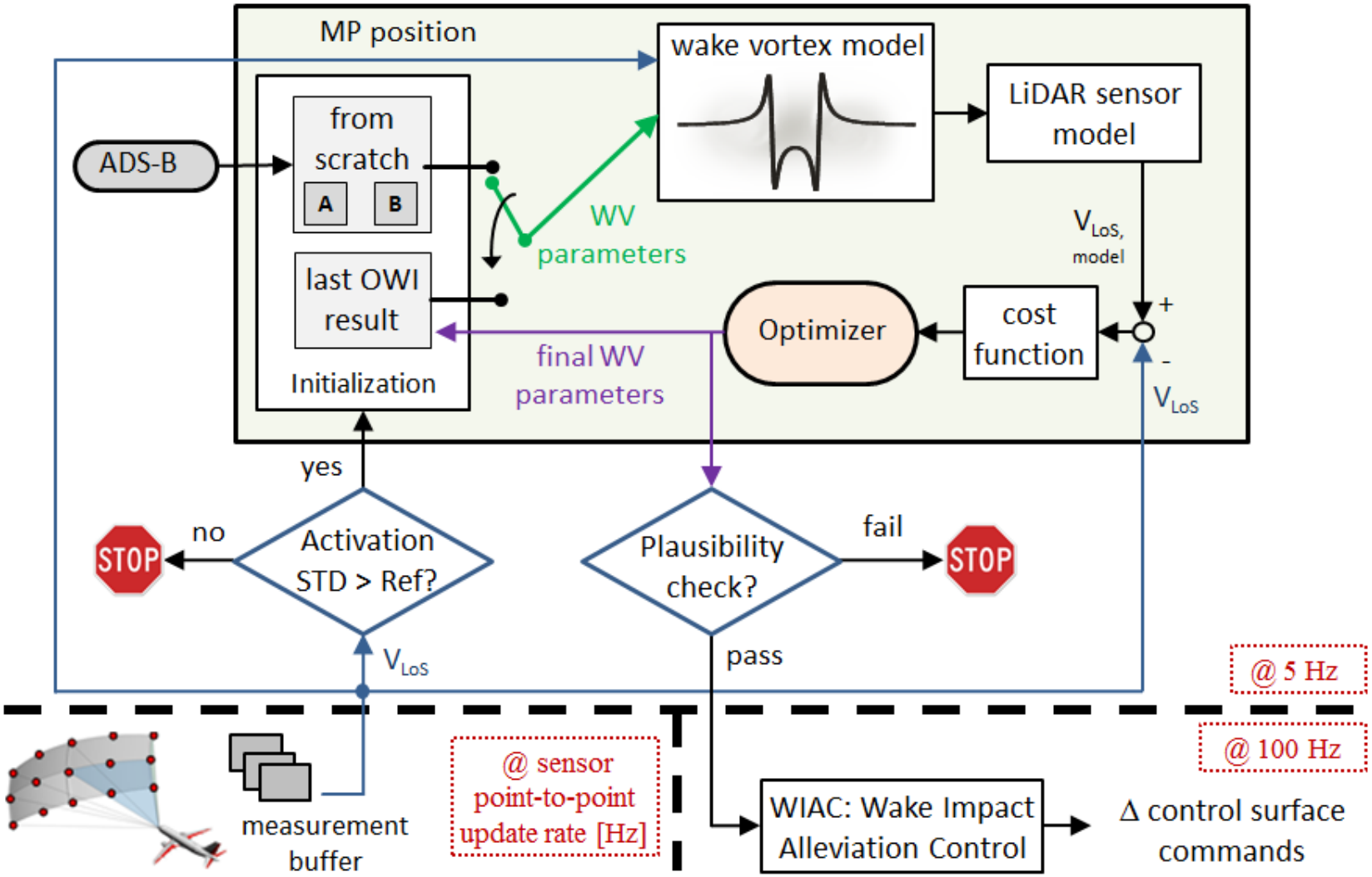
Purpose of Online Wake Identification

- Pure line-of-sight measurement contains very little information about relevant vertical wind velocity
- Wake identification algorithm is used to reconstruct the missing information about the disturbance (based on DLR Patent EP 2 340 438 B1)
- Maximum likelihood problem: minimization of error between line-of-sight wind velocities measured by LIDAR and reconstructed by wake vortex model with estimated parameters

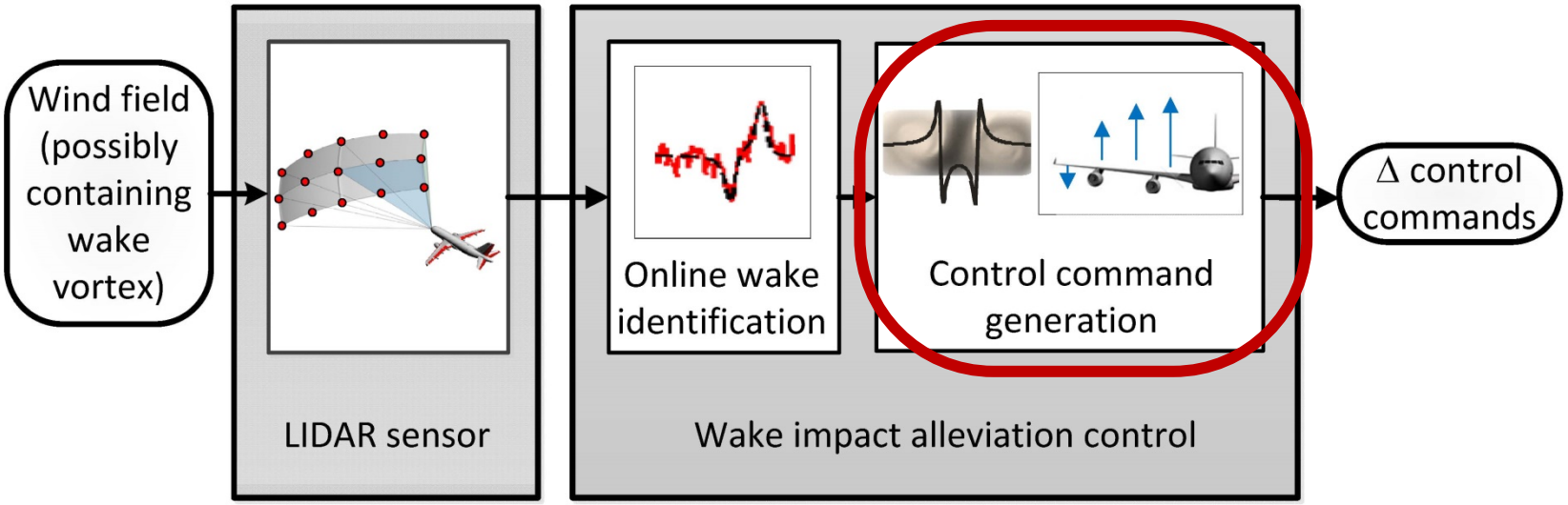


- OWI provides wake vortex model with estimated parameters as basis for wake impact alleviation control command generation

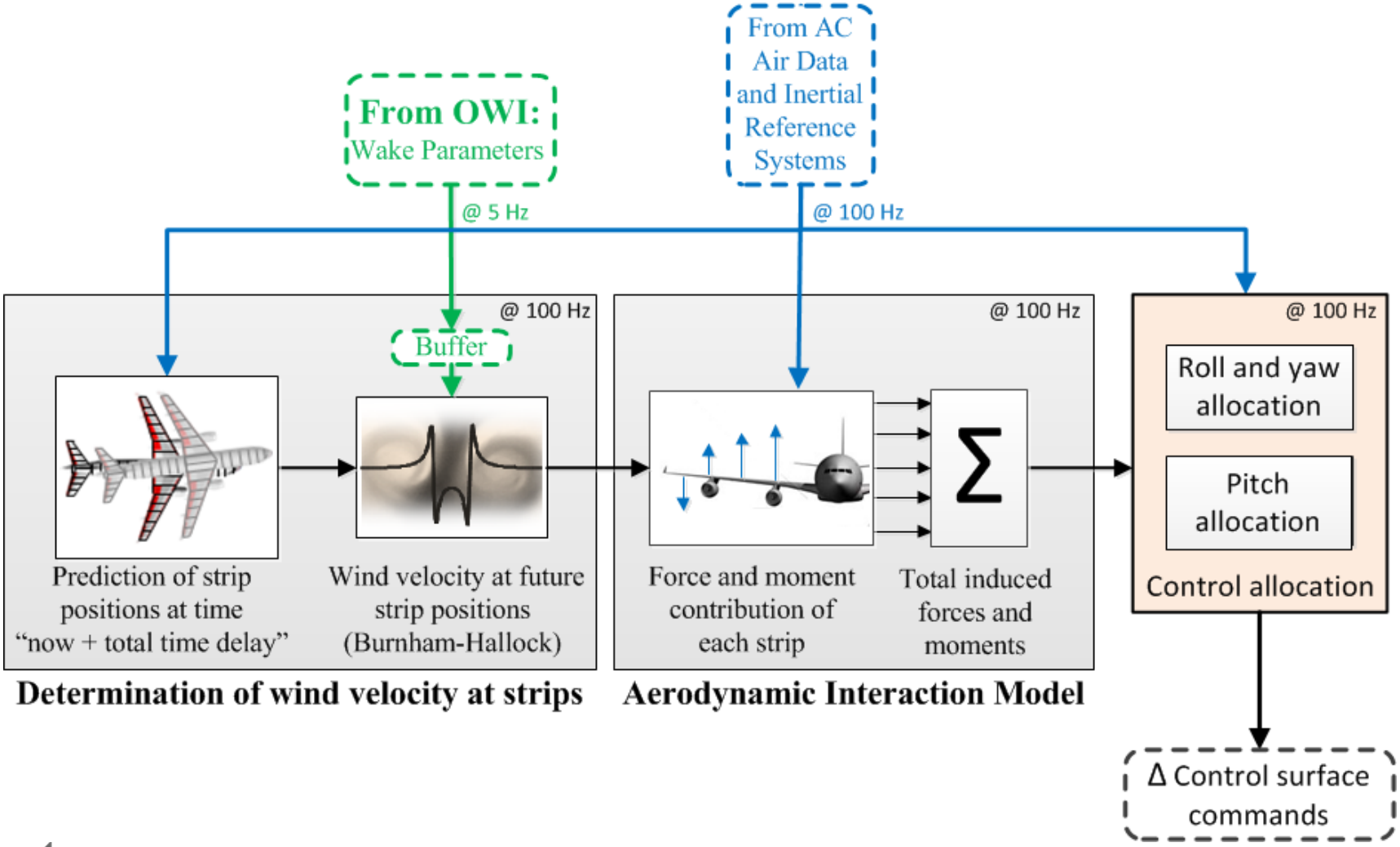
Online Wake Identification



Wake Impact Alleviation Control Command Generation

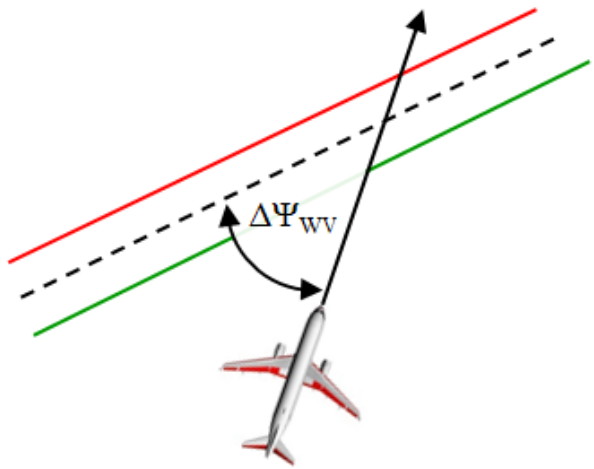


Wake Impact Alleviation Control Command Generation

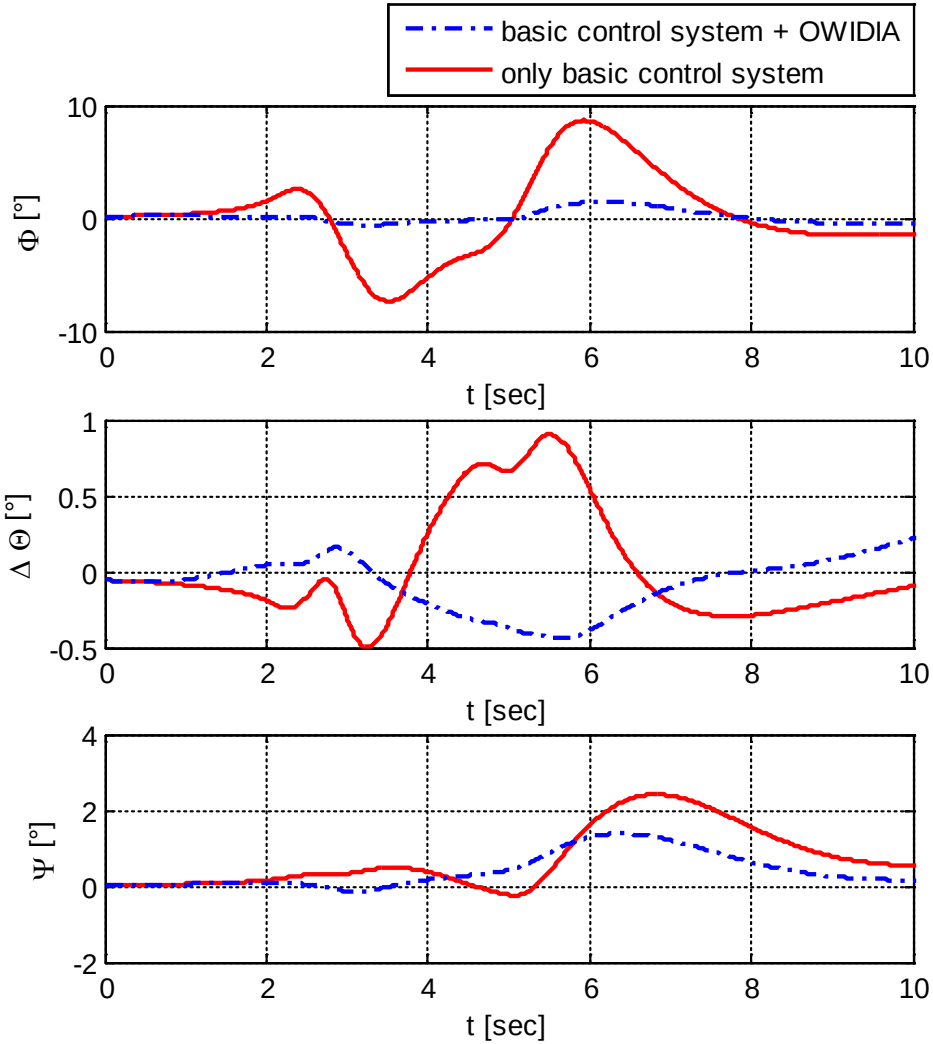


Performance of Wake Impact Alleviation

- A320 encountering wake of A340 during approach
- Encounter angles: 10° lateral, 0° vertical



- Wake-induced aircraft reaction is significantly reduced
- 80% reduction of maximum bank angle during encounter



Just one illustrative example here! Please see other publications of the authors (AIAA Aviation 2014, CEAS EuroGNC2015, DLRK 2015 / CEAS Journal, …)

Conclusions

- A wake impact alleviation system can be used to significantly reduce the aircraft response during wake encounters
  - The LIDAR-based online wake identification and impact alleviation system OWIDIA is a promising approach for the mitigation of wake-induced aircraft reactions
  - Bank angle reduction of 80% is possible

- The wake impact alleviation system could be used to reduce separation minima
  - Simple estimations of possible achievements in terms of capacity gain suggest capacity increases of approximately 1.5 aircraft per hour (for 80% of aircraft at airport equipped with alleviation system) corresponding to approximately
    - 16 s maximum delay reduction
    - 1.5 aircraft per hour maximum traffic flow increase

  BUT based on a reduction of the separation minima of 1 NM

<u>The alleviation performance found in simulation leads to hope for a reduction of the separation minima even larger than 1 NM!</u>

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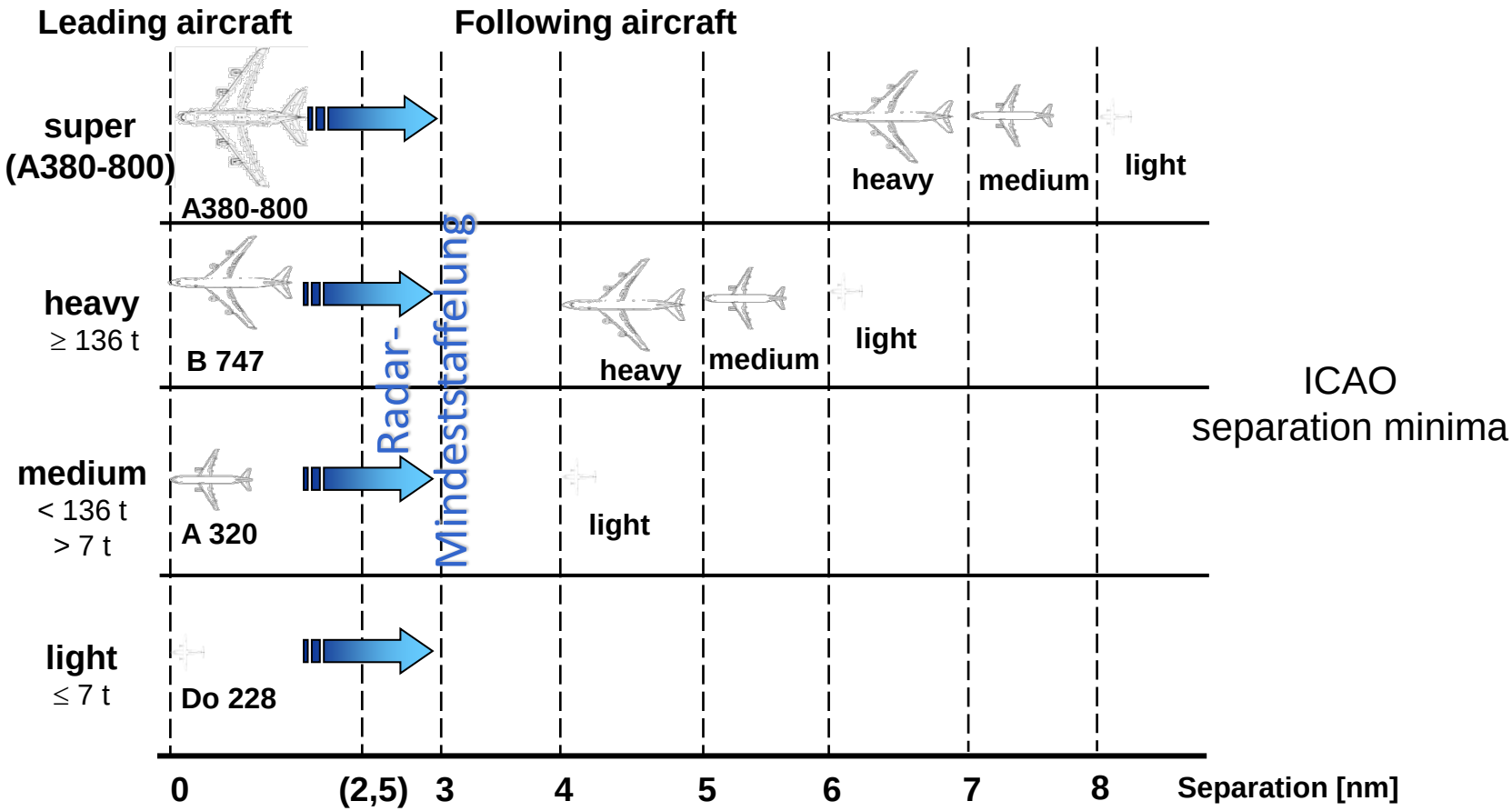

What You Should Remember…

- Mitigation of wake-induced aircraft response… (for the follower)
  → enables the same safety standard for shorter distances between generator and follower aircraft

- The proposed wake impact alleviation system…
  → would enable relaxation of separation minima for the equipped follower aircraft

- Magnitude of acceptable reduction of separation minima still needs further research

- Use case and business case still not very precisely defined

- The maturation of such a system is strongly connected to aircraft system technologies considered in CleanSky and CleanSky2 but most wake vortex activities are rather linked to SESAR and SESAR2020

  → Onboard technologies (→CleanSky2) for wake vortices impact alleviation do not seem to be included in the current programme. Unfortunately?

Thank you for your attention!

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