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AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Comparing Aircraft Wake Turbulence Categories with Induced Power Calculation

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Abstract

Purpose – Definition of new Wake Turbulence Categories (WTC) based on the calculation of induced power of aircraft on approach. This requires the parameters aircraft mass, span, approach speed, air density, and Oswald factor (calculated from wing aspect ratio, wing sweep, wing taper ratio, winglet height, and fuselage diameter). This is considerably more detailed than other metrics based on aircraft mass only or aircraft mass together with wing span.

Methodology – 89 different aircraft are selected which vary significantly in their parameters. Parameters are determined from the Internet; Oswald factor and induced power is calculated. Suitable boundaries of the new WTC (CAT I, II, III, IV) are determined based on induced power. Aircraft with their new categories are presented and compared to FAA, EUROCONTROL, CAA and ICAO WTCs.

Findings – Induced power can be derived not only from induced drag (as a function of lift), but also from the energy in the vortex. When compared to FAA, EUROCONTROL, CAA and ICAO WTC, the new Wake Turbulence Categories seems to offer categorization with more consistency.

Research limitations – New (reduced) wake separation minima are not considered. Physics based separation minima would need a double classification of each aircraft: a) classification related to wake vortex generation as done here and b) classification related to rolling resistance. Wake separation minima would then be allocated from a pairwise comparison.

Practical implications – Physics based WTC may categorize more reliable, which increases safety when applied to given separation minima.

Originality – Induced power has not been used as metric for wake turbulence before.

Objective

- Proposing new Wake Turbulence Categories based on Induced Power Calculations to describe physical effects of Wake Turbulence
- Comparison of „HAW Hamburg Wake Turbulence Categories“ to etablished WTC (FAA, CAA, EUROCONTROL and ICAO)

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Introduction

What is Wake Turbulence?

- **Disturbance in the atmosphere which is generated by the passage of an aircraft in flight.**

- **Vorticity comes from the entire span and is a direct consequence of the generation of lift by a wing.**

Figure 1: The vortex wake behind lifting wings descending through a thin cloud layer (Source: Airliners.net)

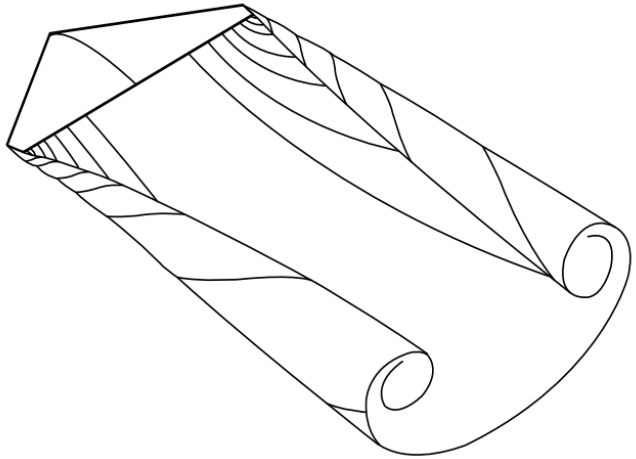

Figure 2: The vortex wake behind a lifting wing (Source: McLean 2005)

Literature Review

- Generation and dissipation models
- Severity of wake encounters and safety assessment
- Wake vortex detection
- Wake vortex prediction and monitoring
- Wake separation reduction/optimization

Theoretical Basics

Theoretical Basics

Influencing Factors

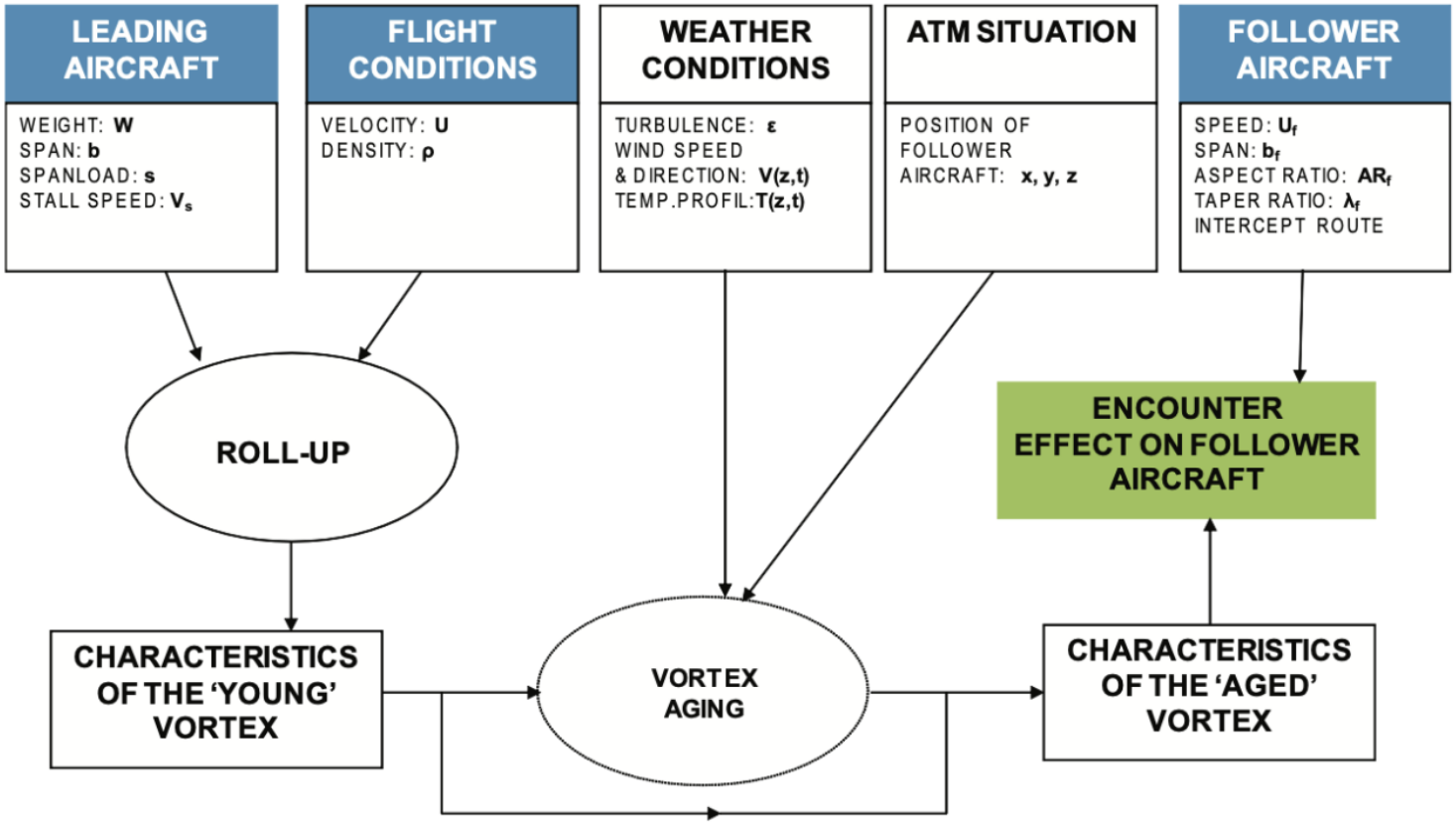

Figure 3: Factors affecting wake encounters (Source: Liu 2007)

Wake Vortex Encounter Scenarios

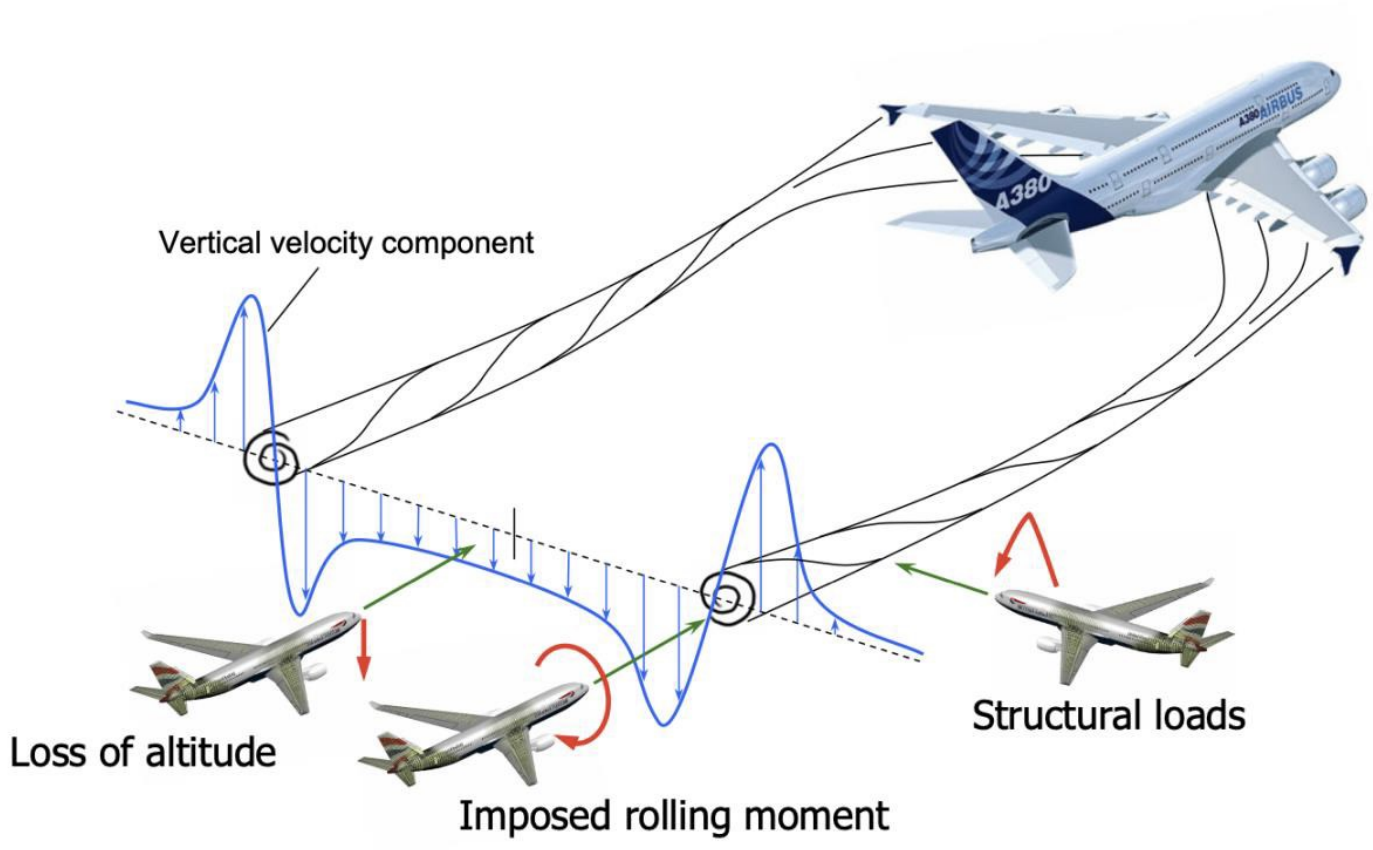

Figure 4: Three different wake vortex encounter scenarios (Source: De Kat 2007)

Theoretical Basics

Wake Turbulence Classification

Table 1: Comparison of different Wake Turbulence Categories (WTC)

ICAO WTC	EUROCONTROL WTC	FAA WTC	CAA WTC
J – SUPER H – HEAVY M – MEDIUM L – LIGHT	CAT-A CAT-B CAT-C CAT-D CAT-E CAT-F	A B C D E F G H I	J – SUPER H – HEAVY UM – UPPER MEDIUM LM – LOWER MEDIUM S – SMALL L – LIGHT
Considers maximum takeoff weight	Considers maximum takeoff weight and wingspan	Mainly considers maximum takeoff weight	Considers maximum takeoff weight

Methodology

Methodology

- **Approach considers induced power, which is the power induced into the wake of an aircraft while generating lift.**

- **Induced Power is calculated with following equation:**

$$P_{wake} = \frac{2\,g^2}{\pi}\,\frac{1}{b^2\,e}\,\frac{m^2}{\rho\,V}$$

g : gravitational acceleration
b : wingspan
e : Oswald factor

m : aircraft mass
ρ : air density
V : approach speed

Derivation 1: Induced Drag

$$P_{wake} = D_i \cdot V$$

Derivation 2: Energy in the Vortex

$$P_{wake} = E_k \cdot V$$

D_i : induced drag
E_k : kinetic energy per unit length
V : approach speed

Results

Results

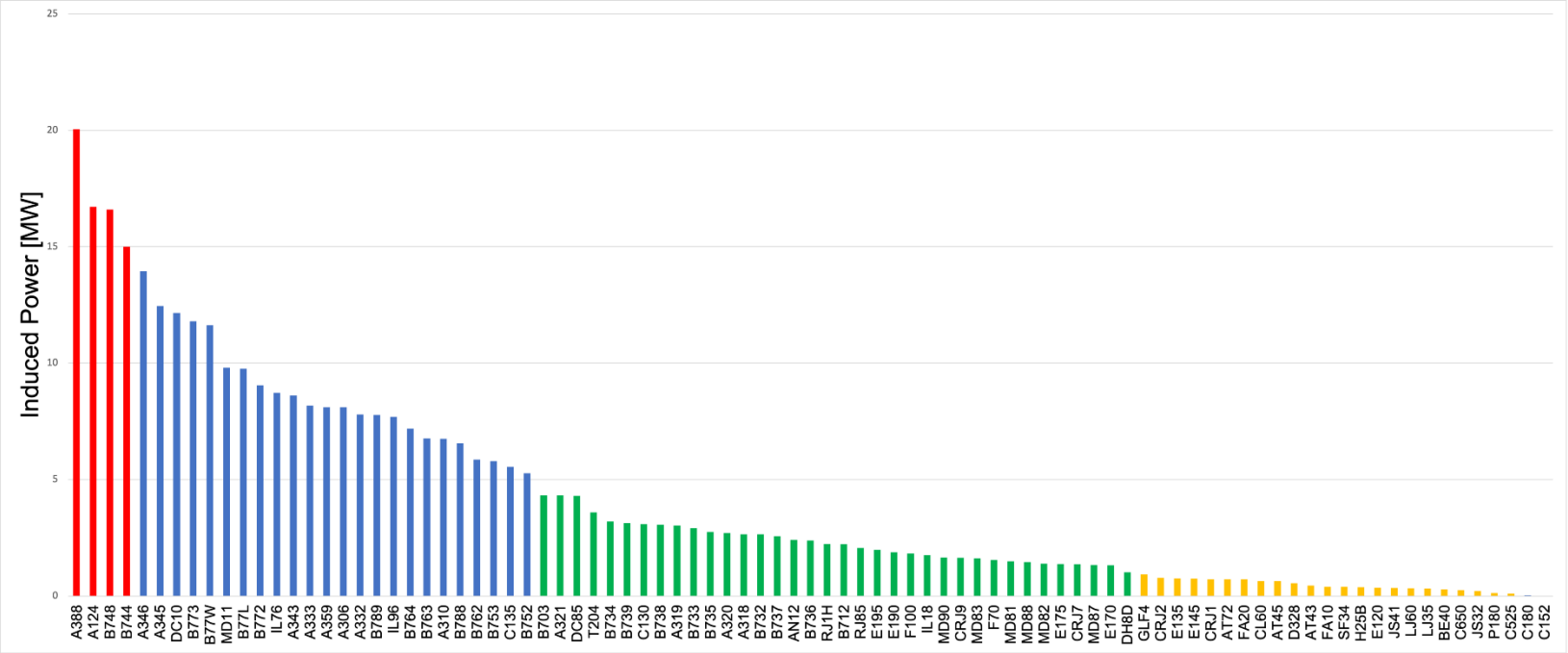

Figure 5: Examined aircraft sorted according to induced power in descending order

Results

Recommended WTC Classification

Table 2: Comparison of different Wake Turbulence Categories with proposed WTC

HAW HAMBURG WTC	ICAO WTC	EUROCONTROL WTC	FAA WTC	CAA WTC
CAT I (>15 MW) CAT II (5-15 MW) CAT III (1-5 MW) CAT IV (< 1 MW)	J – SUPER H – HEAVY M –MEDIUM L – LIGHT	CAT-A CAT-B CAT-C CAT-D CAT-E CAT-F	A B C D E F G H I	J – SUPER H – HEAVY UM – UPPER MEDIUM LM – LOWER MEDIUM S – SMALL L – LIGHT
Considers Induced Power	Considers maximum takeoff weight	Considers maximum takeoff weight and wingspan	Mainly considers maximum takeoff weight	Considers maximum takeoff weight

Results

Comparison

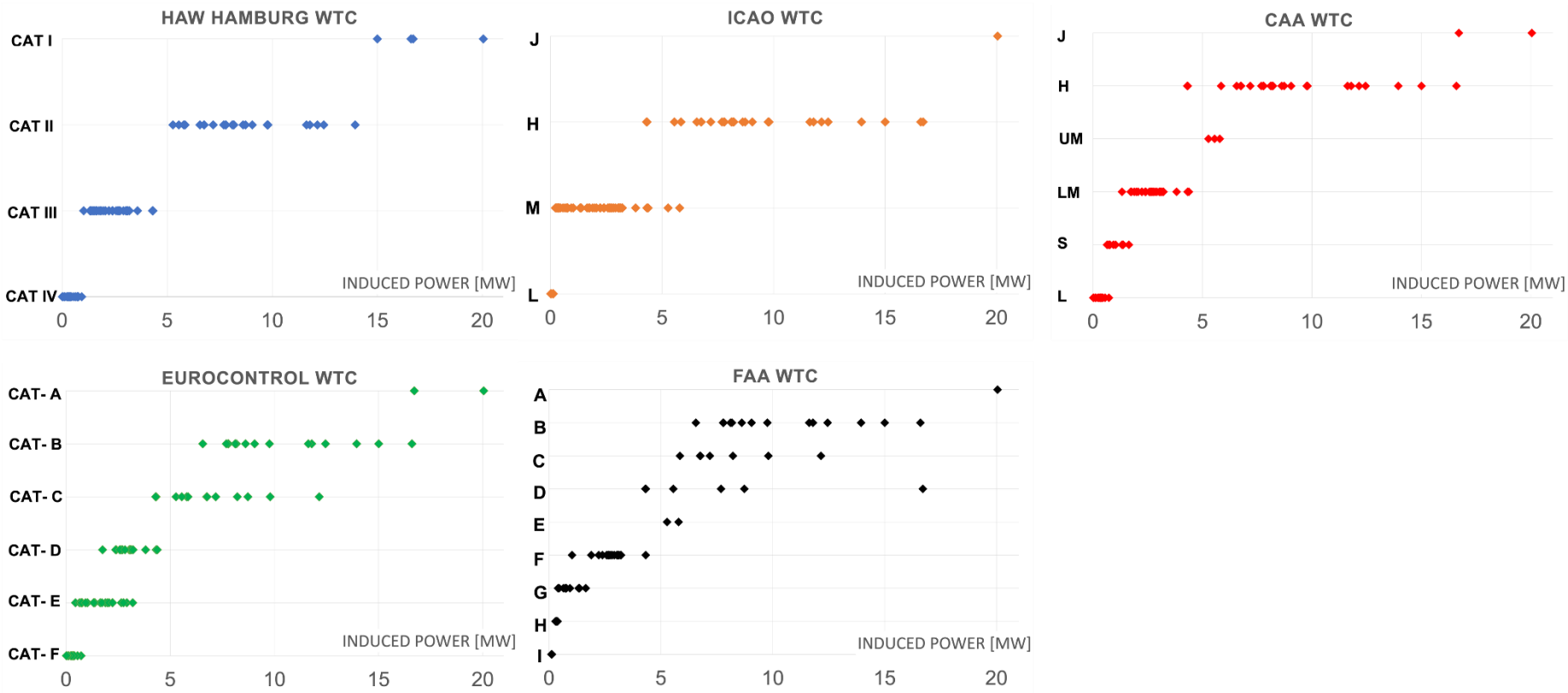

Figure 6: Comparison of Wake Turbulence Categories (WTC)

Summary

Summary

- Conventional WTC mainly consider weight and wingspan
- HAMBURG WTC are based on induced power and describe physical effects of wake turbulence better than established WTC
- Wake separation minima are not considered
  → additional classification related to rolling resistance needed

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