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Comparing Aircraft Wake Turbulence Categories with Induced Power Calculations

NEW WAKE TURBULENCE CATEGORIES (WTC) COMPARED WITH THOSE FROM EUROCONTROL, FAA and ICAO

Every aircraft produces wake turbulence during flight. The strength of wake turbulence depends on various factors, for example aircraft mass, wingspan, speed or wing geometry. However, FAA, EUROCONTROL and ICAO consider only aircraft mass and wingspan for categorization of aircraft wake turbulence. In this approach, other variables related to flight mechanics and aircraft design are used to calculate induced power. Based on these calculations, new aircraft wake turbulence categories are presented and compared to FAA, EUROCONTROL and ICAO categories.

What is wake turbulence?

Wake turbulence is defined as turbulence which is generated by the passage of an aircraft in flight. This turbulence in the wake of an aircraft in flight is principally caused by wing tip vortices. Wing tip vortices decay gradually and can produce a significant rotational influence on an aircraft encountering them for several minutes after they have been generated.

The formation of wing tip vortices is a direct and natural consequence of the generation of lift by a wing. Lift is generated by air being deflected by the wing and accelerated downward. This creates the vortex sheet with the downwash. The wake vortex rolls up at the wing tip and forms the wing tip vortex, resulting in swirling air masses that trail behind the wingtips.

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

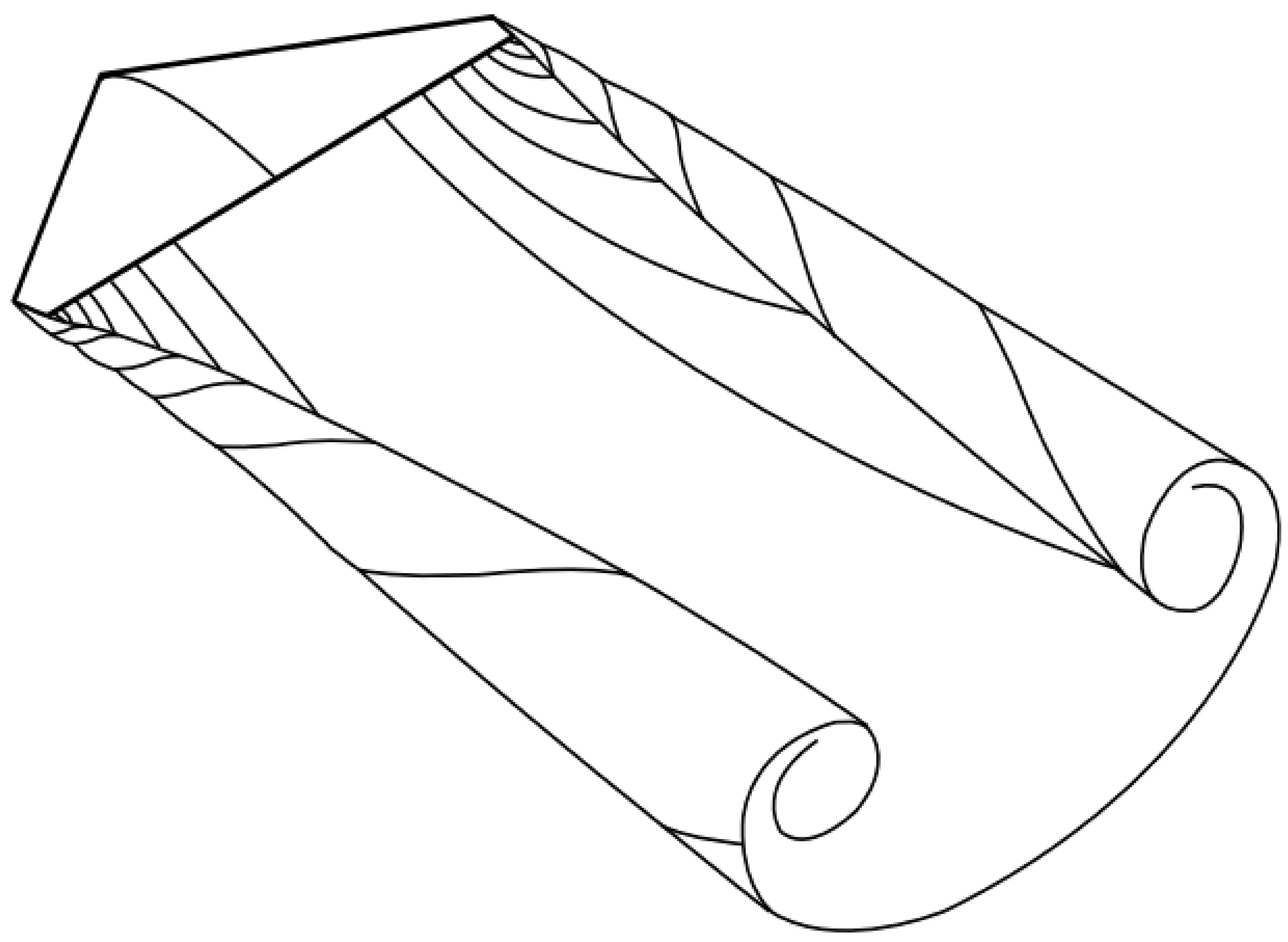

Figure 2: The vortex wake behind a lifting wing (Source: Boeing)

Calculation method

The presented approach to categorize wake vortex strength considers the Induced Power contributed by the respective aircraft to its wake vortex. By using correlations and equations derived from flight physics, the following equation is used for the calculation of the Induced Power:

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

g: gravitational acceleration
b: wingspan
e: Oswald factor
m: aircraft mass
ρ: air density
V: approach speed

Result & comparison

The above-mentioned equation is used to calculate the Induced Power of 89 different aircraft that vary significantly in mass, wingspan and other characteristics. Based on the results of this calculation, the following "HAW Hamburg Wake Turbulence Categories" (HAW Hamburg WTC) are proposed in accordance with the Induced Power an aircraft contributes to its wake vortex:

CAT I : > 15 MW; CAT II: 5– 15 MW; CAT III: 1-5 MW; CAT IV: < 1 MW

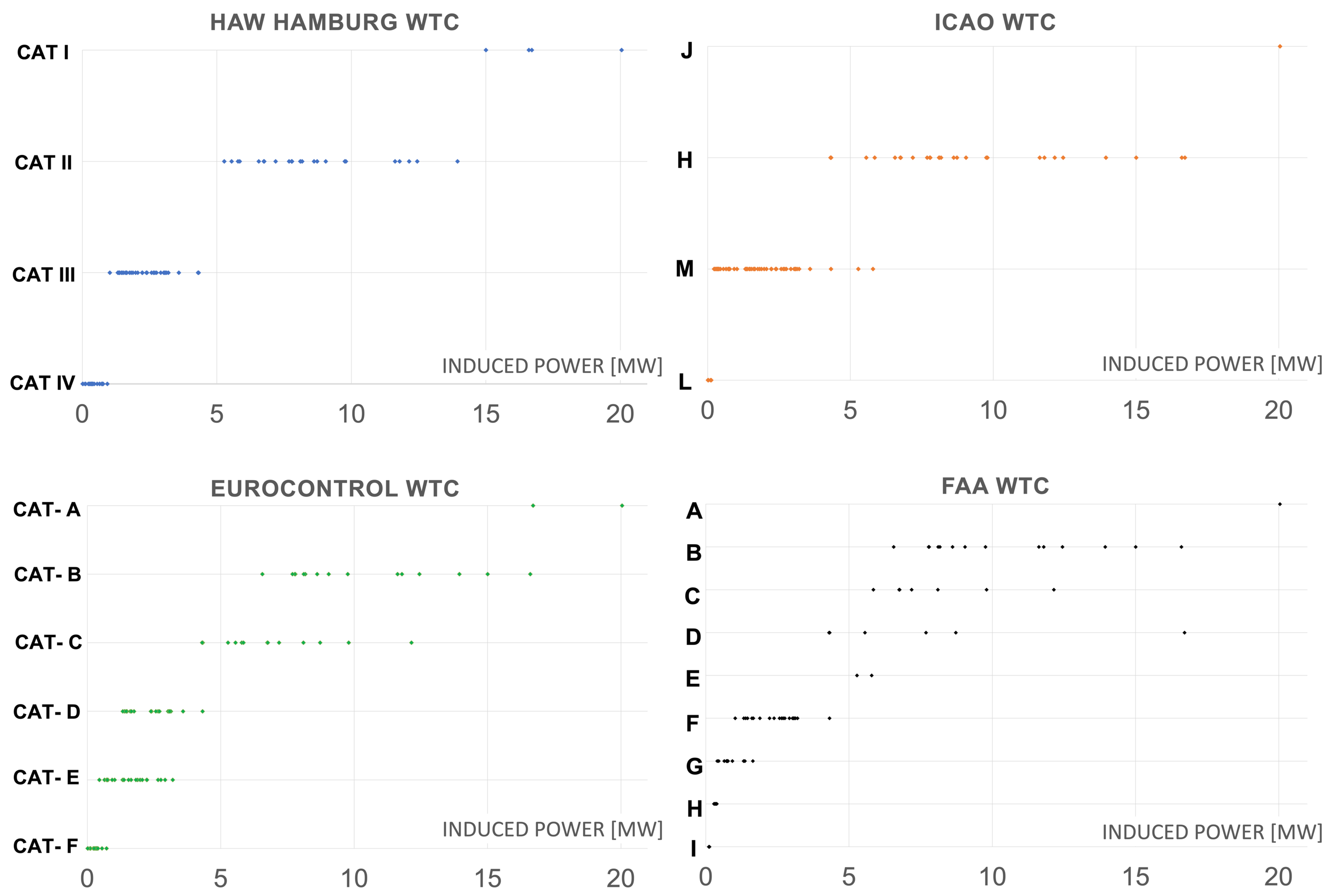

Figure 3: Comparison of Wake Turbulence Categories (WTC). HAW Hamburg WTC are clearly better than those from ICAO, EUROCONTROL and FAA.

HAW Hamburg WTC depend clearly on Induced Power. In contrast, all other WTC occasionally assign a smaller WTC to an aircraft with larger Induced Power. This is indicated by an overlap of categories when plotted versus Induced Power. FAA WTC seem especially inconsistent. EUROCONTROL WTC seem inconsistent comparing CAT-B and CAT-C.

Downwash and wing tip vortices have an impact on following aircraft. They are more dangerous, if formed by more Induced Power. Therefore, the newly proposed "HAW Hamburg Wake Turbulence Categories" (HAW Hamburg WTC) are based on Induced Power. As such HAW Hamburg WTC describe the physical effects better than established WTC and should be used instead.

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DLRK 2022
DEUTSCHER LUFT- UND RAUMFAHRTKONGRESS
DGLR
27. - 29. SEPTEMBER 2022 – DRESDEN
„Luft- und Raumfahrt - gemeinsam forschen und nachhaltig gestalten"

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Comparing Aircraft Wake Turbulence with Induced Power Calculations

Aircraft produce wake turbulence or wake vortex turbulence. The whole topic is covered with many scientific articles. Depending on their vortex strenght, aircraft are put in categories. The criteria for the categories vary. ICAO goes by aircraft mass and lists aircraft by category. EUROCONTROL goes by aircraft mass and wing span and also lists aircraft by category. Flight mechanics on the topic can be quite simple. The vortex strength can be calculated with what can be called "induced power" (see details on next page). A small systematic literature review on the term is performed, but not much was found. A number of aircraft were selected that are sufficiently different in maximum take-off mass, wing span and other characteristics. Included in this list are also aircraft that are known to have special characteristics like B757 and A380. The relevant parameters for these aircraft are determined: maximum landing mass, wing span, approach speed, and estimated Oswald factor. Then the calculated "induced Power" is compared with official categories from ICAO, FAA, and EUROCONTROL. Conclusions are drawn.

This is an abstract answering the Call for Papers for the German Aerospace Conference 2022.

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Die Leistung, die ein Flugzeug ständig in seine Wirbelschleppe einbringt (P_{wake}), wird primär durch die Masse des Flugzeugs bestimmt. Das ergibt sich elementar aus der Flugphysik

P_{wake} ist die induzierte Leistung, P_i und ergibt sich aus dem induzierten Widerstand (dem Widerstand durch Auftrieb, D_i) und der Flugeschwindigkeit, V.

$$(1) \quad P_{wake} = P_i = D_i V \quad .$$

Mit aus Vorlesungen bekannten einfachen Gleichungen, üblicher Notation in englischer Schreibweise (L: Lift oder Auftrieb, D: Drag oder Widerstand):

$$(2) \quad D_i = \frac{1}{2}\rho V^2 C_{Di} S \quad ;$$

$$(3) \quad C_{Di} = \frac{{C_L}^2}{\pi A e} \quad ,$$

$$(4) \quad mg = L = \frac{1}{2}\rho V^2 C_L S \quad .$$

Nun wird (4) aufgelöst nach C_L, eingesetzt in (3) eingesetzt in (2) eingesetzt in (1) und ergibt

$$(5) \quad P_{wake} = \frac{2g^2}{\pi} \frac{m/S}{Ae} \frac{m}{\rho V} = \frac{2g^2}{\pi} \frac{1}{b^2 e} \frac{m^2}{\rho V} \quad .$$

- Der erste Faktor zeigt Konstanten (Erdbeschleunigung, g).
- Der zweite Faktor beinhaltet Parameter, die im Flugzeugentwurf gewählt werden: die Flächenbelastung, m/S (nahezu konstant), Flugzeuggeometrie (die Streckung, $A = b^2/S$ aus Flügelspannweite, b und Flügelfläche, S) und Oswaldfaktor, e, der z. B. durch die Verwendung von Winglets erhöht werden kann.
- Der dritte Faktor steht für die Größe des Flugzeugs mit der Masse m und für Parameter, die aus dem Flugbetrieb weitgehend vorgegeben sind: Luftdichte, ρ (Flugplatzhöhe) und Anfluggeschwindigkeit, V gemäß ICAO oder FAA.
- Die zweite Darstellung erhält man durch Einsetzten von $A = b^2/S$. Jetzt fällt die Flügelfläche, S heraus aus der Betrachtung und es bleibt als Parameter die Flügelspannweite, b. Die Flügelspannweite ist durch Platzbegrenzungen an den Flughäfen für alle Flugzeuge nach ICAO oder FAA begrenzt. Im Fall des A380 ist die Flügelspannweite auf 80 m begrenzt. **Bei konstanter Spannweite wächst die Leistung in der Wirbelschleppe dann mit dem Quadrat der Flugzeugmasse**, m.