

Health Relevance of Aerodynamic Emissions from Wind Turbines

An Interdisciplinary Assessment

Author: Dr. med. Stephan Kaula

Physician specialized in general medicine

Years of clinical experience in environmental medicine / low-frequency noise-related health effects

Active in the medical-scientific investigation of health effects from technogenic wind turbine emissions

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Abstract: In addition to sound in the context of acoustics, wind turbines primarily generate aerodynamic emissions such as structured pressure pulses, vortices and tower vibrations, which are energetically dominant. These phenomena are based on physically proven mechanisms and coherently explain the clinical observations and affected persons' reports from a medical-physiological point of view. The current regulations, which are based solely on acoustic parameters, fall short of the mark. An extension of the emissions assessment and urgent protective measures appear necessary on the basis of the precautionary principle.

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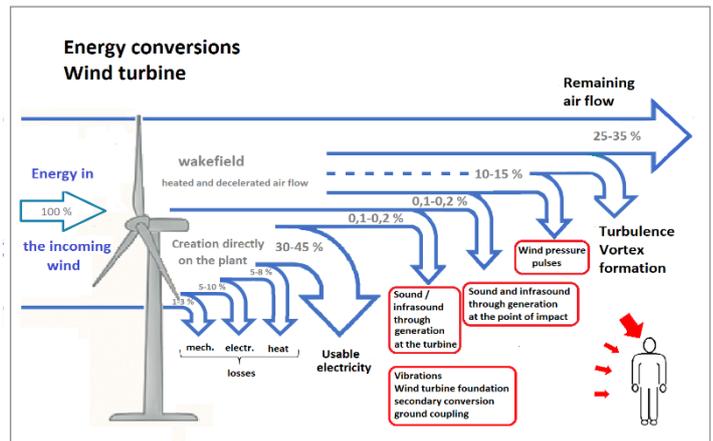
1. Wind turbine emissions and “infrasound”

Preface

The physics of wind turbines is energetically dominated by the flow of large air masses. It should come as no surprise, then, that the direct effects of these aerodynamic emissions can burden nearby residents and cause health impairments.

The wind industry extensively studies these airflow dynamics, as they are critical to power generation efficiency and the structural stability of these high-tech installations. Despite being scientifically well-understood, these types of wind turbine emissions—and their impacts on residents—have not been addressed within emission protection frameworks, even though their relevance is obvious. Instead, emission regulations for wind turbines focus solely on far less energetic acoustic noise. (This principle also applies to large industrial fans.)

The German Federal Environment Agency (Umweltbundesamt) is obligated to act preventively, particularly when sufficient evidence of harmful environmental impacts exists, even if scientific uncertainties remain (§5 BImSchG, Art. 191 AEUV). There has been more than enough evidence of health impacts on residents living near wind turbines. Notably, a comprehensive Danish case study ([Link](#)) found anomalies such as significantly increased use of sleep aids and antidepressants. These results would likely have been even more pronounced had wind direction and distance been factored in (see above).



These aerodynamic processes and their effects on residents cannot be captured or regulated through acoustic standards like the TA-Lärm (Technical Instructions on Noise), as they involve fluid dynamic (non-acoustic) phenomena governed by different physical principles than sound or infrasound in the strict acoustic sense. Moreover, low-frequency fluid dynamic phenomena can easily be confused with or misinterpreted as sound, leading to a significant underestimation of the energy involved in these emissions, their range, and potential health consequences.

The exclusive interpretation of low-frequency pressure phenomena from wind turbines as mere acoustic noise emissions, i.e. "wind turbine infrasound", is a gross violation of physics.

The attempt to deal with these Emissions in corresponding acoustic regulations leads to a very serious underestimation and ignoring of the essential real emission burdens for residents.

2. Sound and Infrasound

The term **sound** already has varying definitions. Historically, it was limited to the range of human hearing. However, even audible events like a "bang" are excluded from some narrower definitions of sound (as harmonic waves).

The term **infrasound** is particularly poorly chosen as an umbrella category. It indiscriminately groups all low-frequency, inaudible phenomena—regardless of whether they are actual sound. For example, periodic air movements with frequencies below 20 Hz or very long wavelengths, which are not technically acoustic sound, are often labeled as infrasound.

A pulsating wind (caused by the rotor blades disrupting airflow) is **not a sound wave** but still exerts low-frequency, periodic pressure on objects (humans, animals, or measurement devices like microbarometers or microphones).

The Problem:

Microbarometers and microphones cannot inherently distinguish between **sound pressure** and **flow-induced pressure (stagnation pressure)**. Such measurements are prone to misinterpretation. Equally important is *where* measurements are taken. The pulsed wind generated by a turbine rotor moves strictly downwind in the turbine's wake, which only reaches the ground hundreds of meters or even kilometers away. During so-called "infrasound measurements" (e.g., by the Baden-Württemberg State Institute for the Environment, LUBW), microbarometers

were partially buried and shielded from gusts ([Link](#)). Near the ground, turbulence and background noise are extreme, potentially capturing acoustic infrasound from the turbines. However, the aerodynamically induced wind pressure pulses—which occur at height and downwind—are overlooked.

Monitoring stations for nuclear weapon tests, like IGADE, detect the extremely long-wavelength shockwaves of explosions and are often called "infrasound stations." While they do register infrasound, the original pressure wave from a nuclear detonation is **not a sound wave**.

These conceptual ambiguities and misinterpretations of the term “infrasound” lead to serious misunderstandings to the detriment of emission protection for residents.

2.1 Distinguishing Between Sound and Flow-Induced Pressure Phenomena

Harmonic Sound

In conventional harmonic sound, a source induces **elastic vibrations** in air, which propagate as waves without bulk airflow. Particles oscillate briefly around their resting positions.

Example: A vibrating guitar string pushes air molecules, transferring motion to adjacent particles. When the string returns, the first particles are "pulled back," repeating the cycle **periodically**. This creates a sound wave with constant wavelength (a tone) propagating at the **speed of sound**. Multiple tones form a chord.

Historical Definition: Sound was once limited to the **audible range** (~20 Hz–20 kHz). The dimensionless unit **decibel (dB)** references human perception and is **not an absolute physical measure**. Converting dB to SI units (e.g., Pascals) requires additional assumptions.

	classical sound	transitional case	no sound		
	Harmonic Sound	Shock-event	Explosion (nearfield)	Implosion (nearfield)	Wind-Pressure-puls
What moves?	Soundwave	Shockwave	Air + pressurewave	air + pressurewave	air
Proagation-Speed	Speed of sound	Speed of sound t	Speed of sound/+	Speed of sound	Wind-Speed
Physic-Discipline/ Measurement Unit	Acustik dB	Acustik dB Surplases due to Impulsivness	Aerodynamics SI-Units	Aerodynamics SI-Units	Aerodynamics SI-Units
Spectrum	discrete	continious	continious	continious	continious
Groundcoupling			Repelled	Attracted	

The "Infrasound Scandal" BGR/ Holzheu : Minister Altmeier must issue a public apology

In this context, reference should be made to the alleged "[conversion error](#)" of the [BGR](#) (Federal Institute for Geosciences and Natural Resources) in the interpretation of its "infrasound" measurement data in infrasound and the representation in dB units. The BGR measures pressure pulses in so-called SI units and not sound in the dimensionless unit dB. The basic prerequisite for such a "conversion" into the sound measurement unit dB is, in addition to other assumptions, that it is sound in the acoustic sense at all. However, the latter is very questionable, as it could just as well be aerodynamically induced wind pressure pulses, which are not sound at all, at least up to a distance of 3 km from the wind turbine, where the residents live, and therefore may not be converted. This applies in particular to the area in the immediate vicinity of the turbines up to an area (downwind) of the turbines up to approx. 3 km.

Impulsive Noise (bang/shock-event)

In physical terms, a bang is sometimes defined as sound and sometimes as non-sound (because it is not harmonic) (Akustik: Physikalische und technische Grundlagen, Springer, 1980). It therefore occupies an intermediate position. Here, the source only impacts the air **once**, so that **no periodic oscillation** occurs. Therefore, a bang, like a "noise", has no **clearly defined** wavelengths (in contrast to harmonic sound). Instead, the bang has a **continuous frequency spectrum**, i.e. components over a wide frequency range with a maximum. Depending on its composition, a bang can be bright, dull or even inaudible. Its pressure wave propagates at the speed of sound. In acoustics, bangs are considered more disturbing than harmonic sound of the same volume due to their impulse content, especially if the

bang is repeated. The pressure signature of wind turbines corresponds to a periodically repeating bang event in the infrasound range, which is clocked by the rotor blade passage frequency. (see section below: Rotor blade tower passage) The special characteristic is not taken into account here.

Detonation

Detonations are **not sound**. They are caused by a **sudden, explosive increase in volume**. In an explosion, material vaporizes suddenly and the expanding gas creates a **shock wave** that can initially be **supersonic**. As the distance increases, it slows down to the speed of sound, turning the explosion into a bang event.

Implosions work in reverse and are a **sudden decrease in volume**. Here, too, the volume changes, but the pressure wave only propagates at the speed of sound from the start. As the volume transport decreases faster with distance than the pressure amplitude, an implosion also becomes a bang event at some distance.

Wind pressure pulses or pulsating wind

Wind is **not sound**, but an **air flow that moves forward at wind speed**. A pressure front with a **wind pressure pulse** forms at the front of a moving air cell when it hits an obstacle (or slower wind). (Wind noise is caused by **turbulence** at boundary layers of air cells moving at different speeds. This turbulence can excite vibrations that become audible as noise or whistling).

Key Insight: These **wind pressure pulses** only generate wind pressure or dynamic pressure when they hit an obstacle or slower air cells. In contrast to sound, this resulting pressure front is followed by a volume of air flowing behind it. The energy of the wind pressure pulses is therefore determined by the kinetic energy of the air cell that follows and not by the change in pressure caused by the purely elastic resonance of the air molecules, as is the case with sound. A measured dynamic pressure of a pulsating wind may therefore be just as high in a measuring device as the sound pressure of a sound wave, but its energy is (by a factor of 100 to 1000 times) higher and thus also its potential effect!

Figuratively, this could be compared to breakers (wind pressure pulses) being thrown against a cliff by a storm, as opposed to a wave just sloshing up and down (acoustic infrasound).0

Fourier Analysis Pitfalls

Fourier transforms are routinely applied to pressure/time data (e.g. from micro barometers), but are only useful for harmonic sound or sounds that are partially composed of harmonic sound. For example, identifying a strange sound in a machine can indicate the vibration of a faulty part and help isolate it. However, applying Fourier analysis to impulsive noise (with continuous spectra) makes no sense. However, periodically recurring impulsive noises mathematically result in harmonic frequencies in Fourier series, which have no equivalent in the real world (e.g. vibrating components). In particular, high and many harmonics, as can be detected in the wind turbine signal even at great distances, are an expression of the strong deviation from a (harmonic) infrasound wave. Fourier analysis can therefore help to recognize turbine signatures in the midst of noise, but it is not proof that these are purely acoustic phenomena.

3. What happens behind a wind turbine ?

Preliminary Note

Imagine standing behind a wind turbine and observing how the rotor blades rotate - similar to a propeller that repeatedly covers the sun for a short time. Just like this "fluttering light and shadow effect", a fluttering slipstream is created behind the wind turbine: The rotor blade pushes in front of the wind so that the air flow directly behind it abruptly breaks off and builds up again after the blade has passed. This resulting "slipstream gap" in the incoming

wind creates a sudden drop in wind pressure, followed by a rapid rise again. This is basically an implosion (see also rotor blade/tower passage). If you are standing near a passing train, you will feel a similar pressure wave.

The rotor blades function like an airplane wing: their curved shape creates negative pressure on the rear side (upper side of the airplane wing) and positive pressure on the front side (lower side of the airplane wing). This pressure difference drives the wind turbine.

Critical Note: These wind pressure pulses are directed into the wake field and only reach the ground with the wake field. They would therefore not be measured directly under the turbines (the measurement in the immediate vicinity of the turbine are the effects of the rotor blade-tower passage, see section below). The wind pressure pulses are pulsating wind and explicitly not sound!

Barotrauma in Bats

The pressure differences swirl most strongly near the tips of the rotor blades (similar to a hurricane). Here, the pressure collapses particularly abruptly, an effect that can be fatal for bats: Their lungs cannot withstand the rapid alternation of negative and positive pressure and rupture (barotrauma). The bats therefore do not die from "infrasound" (in the acoustic sense). In the same way, the main health-threatening wind turbine emission for wind turbine residents is also not acoustic infrasound!

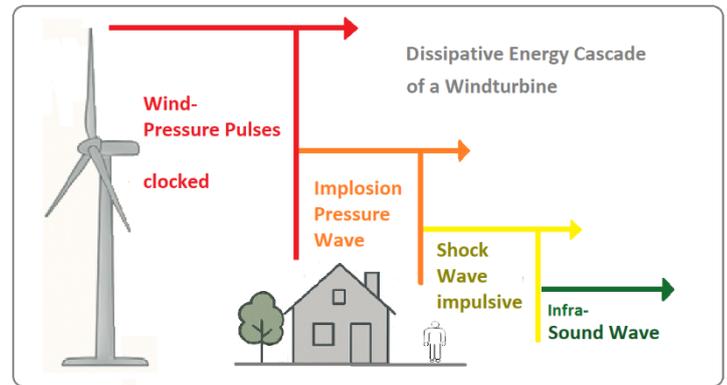
3.1 The Wake Field

Wind pressure pulses and their aerodynamic correlates and developments in the wake field of wind turbines

Behind the rotor of a wind turbine, a complexly structured, dynamic field of highly agitated air flows is formed. (video [link](#)) This is caused on the one hand by the lateral deflection of the incoming wind due to the inclined rotor blades, and on the other hand by pressure differences along the rotor blade surface, which stimulate the formation of vortices. Accordingly, four forms of pressure disturbances arise, which can also represent successive phases of the same pressure disturbance.

- a. **wind pressure pulses** and **vortex structures** that propagate at wind speed,
- b. when negative wind pressure pulses hit an obstacle, a kind of soft **implosion** and subsequent explosion pressure waves are created which propagate at the speed of sound.
- c. at a distance from the turbine, these change into highly **impulsive acoustic shock waves**.
- d. as the impulse content of the bang (shock) wave decreases at a greater distance, the sound component start to dominate the **infrasound wave**. Only then it can be adequately evaluated with the means of acoustics.

The first two are not sound in the sense of acoustics and contain considerably more energy. This development from a clocked air flow into vortices, then an implosion pressure wave, then an impulse-containing bang (shock) wave, which increasingly loses its impulse content and finally the transition into a pure sound wave (then ultimately into heat) follows a **dissipative energy cascade**. ([Link](#))



These four forms of pressure disturbance are characterized by a decreasing energy content and merge smoothly into one another. Residents are exposed to all four forms, although the current emission protection guidelines only consider and evaluate the lowest-energy form of a harmonic infrasound wave!

a. Wind pressure pulses with wind speed

It is important to note that not only is the airflow itself three-dimensionally and periodically structured over time, but that the wind pressure also represents a coherently moving air mass with directional characteristics – i.e., it is not a mere scalar quantity but one with vector-like properties capable of transmitting momentum or force.

A significant transfer of energy occurs only when such a high-energy, periodic airflow structure strikes an obstacle (e.g., a building or the turbine tower). This can lead to mechanical effects such as the lifting of roof tiles (similar to aircraft wake vortices), the rhythmic flexing of roof structures, or the movement of windows and doors within their seals. Direct physiological effects, in particular on the sensitive vestibular system, are also to be assumed, but extra-aural (not through the auditory system) subconscious perceptions are also likely.

An inaudible pressure pull of only 1-2 Pa over 0.5 seconds can have a greater physiological effect than a noise of 80 dB.

And these aspects are not even addressed by the German TA-Lärm!

b. Pressure pulses with sonic velocity and volume flow of air

In this process – particularly at rigid, non-deformable structures such as the turbine tower or a house located in the wake zone – an impulse-laden pressure wave is generated. This wave propagates at the speed of sound and can penetrate the surrounding airflow structures.

c. „Acoustic" shock wave rich in impulsivness

Only after the decay of the energetically dominant transport of air volume and mass – typically not before a distance of over 3 km (depending on its directivity, which decreases with $1/r$, ground coupling, and other factors) – does this pressure wave manifest as

d. a purely "acoustic" shock wave rich in impulsivness.

Why is this important?

The energy contained in a moving volume of air is primarily determined by the kinetic energy of the flowing air mass.

In contrast, the energy of a harmonic acoustic wave is determined by its sound pressure level.

Therefore, the aerodynamic energy associated with wind pressure pulses is approximately 100 to 1000 times greater than that of a harmonic infrasound wave.

Physical basis: Energy in the air flow v.s. acoustic wave

1. Energy in an airflow (volume flow)
A directional airflow contains kinetic energy

$$E_{\text{Volumenfluss}} = \frac{1}{2} \cdot \rho \cdot V \cdot v^2$$

- ρ = Air density (~1.2 kg/m³)
- V = Volume of the air packet
- v = Flow velocity

2. the energy of an acoustic wave (harmonic pressure fluctuation)

$$E_{\text{Schall}} = \frac{p^2}{\rho \cdot c}$$

- p = Sound pressure amplitude
- c = Speed of sound (~343 m/s)

This energy is relatively small because

- The sound pressure in the infrasound range is usually less than 1 dB
- There is no air volume transport

Summary:

- The rotor generates a periodically pulsed, directional airflow.
- Upon impact with an obstacle in the wake zone, this flow transforms into a directional pressure front traveling at the speed of sound, accompanied by a trailing air volume.
- Only at greater distances from the turbine (>3 km), where the trailing airflow has dissipated, does this pressure front manifest as an impulsive acoustic event – now without any accompanying air mass transport.
- Over time, the impulsiveness decreases and only now can one speak of normal acoustic infrasound.

3.2 Structure of the wake field

In wind energy, the cylindrical wake field of the wind turbine rotor is divided into three zones: (The rotor blade tower passage, which is important for “infrasound” emissions, is not considered here for the time being).

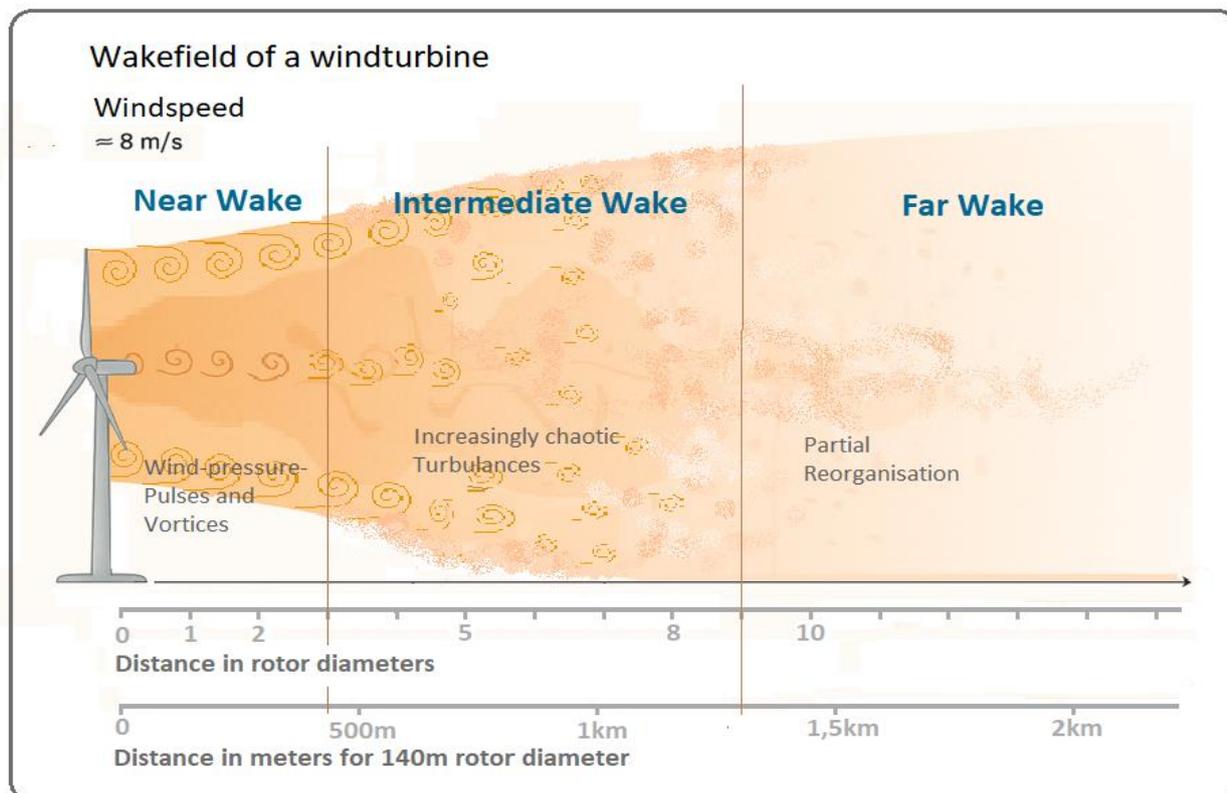
The near field (near wake) The intermediate field (intermediate wake) The far field (far wake)

The distances at which this smooth transition between them takes place and also where the generated aerodynamic pulses and vortices reach the ground depend on the rotor diameter, tower height, topography, wind speed, turbulence intensity and other atmospheric parameters. However, there are rough guide values that are generally recognized.

3.2.1 Near Wake

Range: approx. 0–2 to 3 rotor diameters (D) downstream of the wind turbine

- The rotor blades generate significant pressure differences between the windward and leeward sides due to wind stagnation and the aerodynamic lift profile (similar to an aircraft wing). These differences can already reach about 100 Pa at a wind speed of 8 m/s.
- These pressure gradients are carried downstream with the airflow and are accompanied by dynamic flow patterns, forming strongly structured and coherent vortex systems due to lateral deflection:



a. Wingtip vortices:

Three huge interlocking spirals of air are created at the tips of the rotor blades, which rotate backwards with the wind like corkscrews from each rotor blade. ([Link](#)) These vortices “hem in” the large rotor slipstream and stabilize it, similar to a kind of dyke that separates the wake field from the unbraked wind outside. Wingtip vortices are particularly well known in aviation as a significant hazard for aircraft following a larger machine. The wingtip vortices of aircraft taking off can travel hundreds of meters downwards and cover roof tiles. The speeds achieved by wind turbine rotor blades in relation to the air, their dimensions and the upwind profile are fully comparable with the wings of large aircraft. This is why safety distances from wind farms to airports must be maintained (but not to residential areas?).

b. The central vortex:

As the rotor circles, a central vortex with a horizontal axis forms around the slipstream of the nacelle as the center.

c. Trailing edge vortices:

An additional “whirlwind” appears at the trailing edges of the rotor blades, which also continues spirally within the cylindrical wake field and ends in the wingtip vortices.

3.2.2 Intermediate Wake

In the intermediate wake field of the turbines, the vortices break down into smaller and smaller vortices and their previously ordered structure becomes more chaotic and turbulent. However, all vortex structures still reflect the fundamental frequency of the rotor blade passage, but not necessarily that of the passage at the tower, but rather spatially ordered and increasingly time-shifted (out of phase). So there is still a high degree of order in the chaos. (Video [Link](#)) This information of the energetically dominant **aerodynamic wind pressure pulses** is therefore retained and continues to propagate until it hits an

obstacle such as a house roof. Here, secondary energy conversions into deformation and mechanical vibrations, periodic pressure drops with air volume transports, and also highly impulsive infrasound occur.

The wake field becomes the source of secondary pressure disturbances

This means that, far from the turbine, the entire wake field of a wind farm itself becomes a source of low-frequency pressure pulses and also infrasound, in the middle of which residents have to live! The authorities' assumption that the wind turbine is the only and even a point source of the "infrasound" emission is therefore untenable.

Range: approx. 3–8 (up to 10) D

- The wake inclines downward due to slower, ground-proximal air layers and begins to spread along the surface.
- As negative pressure disturbances, the wind pressure pulses are drawn into the layers of air close to the ground faster than the chaotic turbulence.
- Vortices start to interact and merge.
- Supersonic pressure pulses continue to propagate through the aerodynamic structures.
- Coherent vortex structures begin to disintegrate into more chaotic, turbulent patterns.
- The wake expands laterally and vertically.
- The core area of the wake remains partially distinguishable.
- Secondary noise and low-frequency pressure pulses emerge from the disintegration of trailing vortices at obstacles ([Link](#)).
- This phase is characterized by acoustic phenomena especially relevant at low frequencies, such as amplitude modulations caused by unstable vortex dynamics.
- In wind farms, the wakes of multiple turbines superimpose to form a **broad wake carpet** that can cover extensive ground areas. This collective flow structure can stretch across kilometers and significantly influences local wind distribution, turbulence intensity, and acoustic emissions.

3.2.3 Far Wake

In the far field, the energetically significant volume flows have largely diminished and thus the impulsiveness of the pressure pulses dominates, which penetrated the air flows and vortices unhindered. The pressure pulse that occurs during the rotor blade tower passage has become the dominant pressure pulse. The pulse content then decreases as the last higher-energy component to such an extent that the acoustic infrasound components predominate. In any case, the low-frequency energy signature of the wind turbine can still be measured as wind turbine infrasound at a distance of **over 30-50 km**.

Range: from approx. 10–15 D; depending on wind conditions, up to 20–50 D

- The flow begins to partially recover; wind speed increases again.
- Turbulence becomes more diffuse and stochastic.
- The supersonic pressure pulses become more acoustically dominant while their impulsiveness gradually declines. Nevertheless, they continue to penetrate aerodynamic structures across tens of kilometers and can still be detected as impulsive infrasound by highly sensitive monitoring stations (e.g., IGADE).
- The wake has expanded substantially in both width and depth.
- Some numerical simulations ([Link](#)) indicate the potential reorganization of large-scale flow structures.

Influence of Wind Speed:

At higher wind speeds (beyond the approx. 8 m/s used as a reference here), significantly more energy is released in the near wake – as kinetic energy increases with the cube of wind speed. This results in a much more energetic, yet spatially shorter near-field zone that transitions more rapidly into turbulence. The associated wind pressure pulses and pressure waves are also substantially more intense. Particularly under strong wind conditions, pressure waves

propagate farther and deeper within the near-ground air layers and only convert into acoustically dominant, impulsive “bang”-type waves at greater distances.

4. The Rotor Blade–Tower Passage (RTD) The Central Pacemaker

Preliminary Considerations

As described earlier, the rotor blades periodically “cut through” the incoming wind stream, interrupting it and then releasing it again. Due to their angle of attack and aerodynamic lift profile (similar to an aircraft wing), this interaction generates fast-moving aerodynamic flow cells and vortices that carry significant pressure differences further downstream in a structured pattern with the wind.

Two Distinct Transport Mechanisms for Negative Pressure Disturbances:

a. Wind Pressure Pulses

These wind pressure pulses are continuously generated across the rotor disk, though they arise at varying points and slightly different times despite following a periodic rhythm. We refer to these primary pressure disturbances as *wind pressure pulses*, since their considerable energy stems not only from pressure differentials, but especially from the kinetic energy of the moving air mass.

From a physical standpoint, wind pressure pulses are negative pressure disturbances — that is, a relative underpressure with a leading pressure drop front, followed by a suction phase, and then a trailing positive pressure wave that restores the previous flow and pressure conditions. These disturbances travel as “pulsing” air currents with approximately \pm wind speed, and predominantly propagate downwind.

Wind pressure pulses — which may evolve into coherent vortices — are structured and organized, but not acoustic in nature. They “travel” at only $\sim 8\text{--}15$ m/s, which is about two orders of magnitude slower than sound waves or implosion pressure waves. They may persist for kilometers, even into the far wake, and upon impact with an obstacle, their energy is transformed into deformation, secondary pressure waves, and sound.

b. Implosion Pressure Wave

When a wind pressure pulse encounters an obstacle — especially during the moment when the rotor blade passes directly in front of the tower (rotor blade–tower passage = RTD) — a type of gentle implosion occurs. In this process, the positive stagnation pressure (in wind direction) in front of the object cancels out with the negative pressure of the wind pulse behind the rotor blade. The result is an *implosion pressure wave*, which then propagates at the speed of sound.

(Compare this with the averaged pressure–time curve from the study “*Acoustics Report Redacted—Rural Sheep Farm in Scotland 2023*”, discussed under *Evidence and Scientific Significance*, which closely resembles such an implosion pressure wave and also shows strong directivity.

This non-acoustic pressure wave serves as the central pulse of the high-speed wind turbine signal — the widely measurable “drumbeat” in the wind turbine orchestra.

It carries significant energy up to 3 km away, both through air volume transport and impulsive force. Even at distances of several tens of kilometers, it can still be detected as an infrasound wave by highly sensitive monitoring systems such as IGADE.

Duration:

This rotor blade-tower passage (=RTD) process takes around **0.4 to 0.8 seconds** due to the geometry and the dynamic pressure equalization movement, in which the rotor blade moves increasingly in front of the tower, covering it with its full blade width and length from its slipstream and then releasing it again. This is well above the purely geometrically affected passage angle of around **10 to 20°** (0.1-0.2 s), as the pressure reaction leads and lags in time. This event therefore physically begins shortly before the tower passage and gradually subsides after the passage. This results in a kind of gentle implosion, after which the old pressure and flow conditions are restored.

Spectrum:

This implosion generates a continuous spectrum as a basically aperiodic signal with a maximum in the infrasound range. Due to the duration, geometry and dynamic pressure equalization movement, this frequency peak is typically in the range of **1.6 to 2.4 Hz**.

This process is repeated three times with every rotor revolution - i.e. typically every 2-3 seconds - and thus generates a periodic spectrum with harmonics of the fundamental frequency of the rotor passage for purely mathematical reasons. The aforementioned frequency peak of the continuous implosion event is therefore usually at or between the **second and third harmonics** and is determined by their heights.

Power of the implosion event:

Approximately 1/30 of the rotor circumference is involved in the implosion process. For a wind turbine with an electrical output of **6 MW**, around **2 MW** of aerodynamic power is generated in the wake region. Rough estimates suggest that about **20–60 kW** of this is converted into the **pressure implosion** during a single rotor blade tower passage (RTD) event. Additionally, the abrupt changes in **volumetric airflow** during the tower passage contribute to the event's dynamics. The resulting displacement of air can significantly **amplify** the actual **impulse energy**.

Asymmetric propagation:

The special nature of the rotor blade tower passage is that the rotor blade approaches from one side and the wind pressure shadow with a relative negative pressure is located behind the tower, which also interacts here and distorts the implosion and its pressure wave downwind and asymmetrically. As a negative pressure disturbance, the implosion pressure wave is not only attracted by other zones with relative negative pressure, but also by the slower flowing air layers near the ground.

Why is this the case?

Negative pressure gradients create a kind of **directional "flow striving"** - air molecules from higher pressure areas (or directions) "flow in".

- In air layers close to the ground, the **flow velocity is reduced** (ground friction, vegetation, buildings).

- There, the **negative pressure** can literally "suck in" the air in the **direction of flow**, as this is where the **resistance** to directional dispersion is at its lowest.

It can therefore be said that **the implosion wave is "pulled down" into the flow close to the ground** by its own pressure geometry and **channeled there in a directed manner**.

Although this implosion pressure wave also travels upwind at the speed of sound, it propagates particularly asymmetrically and increasingly downwind close to the ground (without vegetation/buildings, especially at heights of 1 to 12 m above the ground) over a distance of several kilometers.

4.1. Dominance ranges of the various energy components of the RTD / wind pressure pulses in their impact on residents

Three Phases/Components of the Implosion Pressure Wave

The implosion pressure wave is accompanied by an airflow component – an initial underpressure (“air suction”) followed by positive pressure. This volume displacement clearly distinguishes it from a purely acoustic event, as it transfers significantly more energy.

If the wave propagated spherically, it would transition into a standard acoustic shockwave within less than 100 meters. In reality, however, it is channeled along near-ground air layers and diverted downward with the wind. Combined with ground coupling, this leads to a much slower attenuation of the pressure pulse – approximately proportional to $1/r$ rather than $1/r^2$.

Under typical wind conditions (approx. 8 m/s), the transition into a purely impulse-driven wave typically occurs beyond 2 km distance. This impulse component remains physiologically impactful, as the human body responds more strongly to sudden pressure changes than to harmonic infrasound.

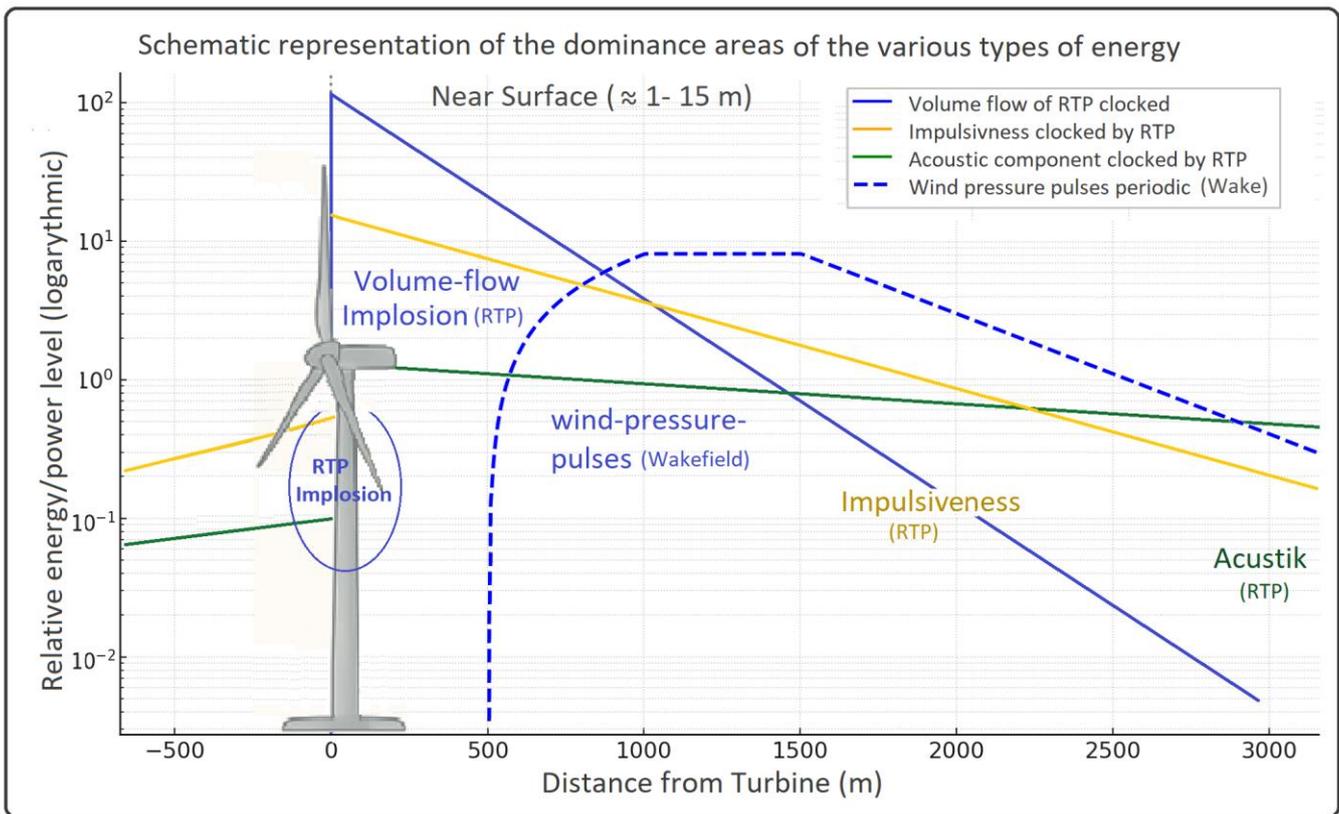
Interaction field RTD/wind pressure pulses

In addition to the implosion pressure wave caused by the rotor blade-tower passage (RTD), residents are also affected by wind pressure pulses.

Although the wind pressure pulses follow the same basic frequency (RTD), they occur out of phase due to flow delay and overlap with the other components to form a complex field. These wind pressure pulses also transport considerable kinetic energy through the movement of entire air packets. However, they are completely ignored in official noise assessments.

The following diagram shows the loads of the various emission components - according to their energetic and therefore health relevance. The transitions between the volume flow, impulse and sound ranges are fluid and depend on numerous factors such as wind direction, ground conditions and tower height.

However, it is clear that up to a distance of at least 3 km, the aerodynamically generated, high-energy components (volume and impulse pressure) dominate the exposure of residents. Nevertheless, all components above the green line (= purely acoustic harmonic infrasound) are consistently ignored in the official assessment.



Interpretation of the Zones in the Diagram

- **Volume transport (blue, implosion zone)** at the blade-tower passage frequency (RTD) dominates up to about **800–1000 m**. This involves real air mass movement caused by the rotor blade implosion cycle.
- **Volume transport via wind pressure pulses** (energy stored in the wake and released upon ground impact) may extend **beyond 3000 m**.
- **Impulse transfer (orange, shockwave character)** shapes the zone from **1000–3000 m**, while flow effects gradually diminish.
- Only beyond **2500–3000 m** does the **acoustic domain (green)** dominate, with classical far-field sound (harmonic waves without directed impulse).
- From distances (**over approx. 5 km**), the impulse strength also loses significance - here one can speak of a purely acoustic infrasound component, as is currently used in official assessments. In the Fourier series of the signal measured from there, the base frequency should clearly dominate and the harmonics should have lost considerable amplitude.

Factors that delay the transition between domains (in order of relevance):

1. Ground coupling and low-altitude propagation (surface waveguides, reflections)
2. Rotor size and pulse strength
3. Terrain profile (e.g., valleys, slopes)
4. Atmospheric layering and wind gradients
5. Multiple turbines with phase-coherent interference

4.2 How the wind pressure pulses reach residents

The wind pressure pulses also penetrate through houses, because just like infrasound, windows and doors only need to vibrate by fractions of a millimeter in their seals. This explains the cases in which residents could see curtains moving to the rhythm of the wind turbines when viewed from the side. This is an expression of a high energy conversion that would not be triggered by harmonic infrasound. However, an infrasound measurement would probably not have measured any excessive values here and the limit values would have been complied with. The high-energy volume flow component is not measured. Even a standard roof truss is a huge “open door” for these wind pressure pulses. Unlike infrasound, however, the wind pressure pulses carry a significantly higher energy). And if infrasound affects people almost simultaneously from all sides, these wind pressure pulses tend to affect them from only one side. The human nervous system registers such differences in particular!

All this explains (in contrast to a mere acoustic infrasound effect) why people go into the cellar or move their bedrooms to the side facing away from the turbines so that they do not feel the wind turbine emissions so strongly.

Residents whose houses are detached or unprotected, often "in the first row" or on slopes with wind are particularly affected. In contrast to harmonic infrasound, significantly higher levels of exposure are felt locally - although these are not correctly recorded by microbarometers: These primarily measure rapid changes in pressure, while the physiologically relevant effects are primarily caused by volume flows and momentum transfer.

There is therefore a disconnect between measured values and the actual suffering of affected people and animals - a systematic blind spot in official assessment practice.

Physiological effects

In addition to the known influence on the vestibular system (balance, orientation, nausea, sense of space) and tactile receptors (skin perception, pressure sensation, vibrations), it is being discussed whether impulse-like pressure waves - as they occur in wind turbines - can also trigger organ-mechanical effects. These include in particular

- Resonance induction in the thoracic region (e.g. chest, diaphragm), which can cause a feeling of oppression or “internal pressure”,
- Movement of visceral structures (stomach, intestines, pericardium), which can trigger vegetative reactions such as cardiac arrhythmia, nausea or circulatory instability in sensitive people,
- Influencing respiratory mechanics through subtle pressure changes on the body surface,
- possibly an indirect effect on the vagus nerve, which could be reflexively activated by external mechanical impulses (e.g. on the neck or in the chest area) (similar to sudden pressure during diving or the Valsalva reaction, a mild barotrauma that is repeated for hours.).
- It is considered likely that low-frequency pressure fluctuations are processed by the auditory system even below the threshold of conscious perception—much like the subconscious detection of breathing rhythms or approaching mass via ground vibrations. Infrasound may thus act as an evolutionary signal of warning or resonance.

The positive side: structural or technical measures could bring relief sooner than in the case of infrasound in the acoustic sense. And with the knowledge that local residents are exposed to the highest levels of these emission-pollution downwind at limited distances, it would be of fundamental importance to finally investigate this type of emission in more detail, acknowledge the exposure and take reasonably effective protective measures for the first time instead of ignoring this obvious wind turbine emission.

4.3 Tower Oscillation ("Belly Dancing")

Shortly before the rotor blade passes through the tower, the rotor blade is pulled towards the tower by the existing pressure difference of the relative negative pressure on the back of the rotor blade. As this gives the generator in the nacelle an additional torque, which it transfers to the tower in the form of a **bending load**, the tower pulls towards the rotor blade.

As the rotor blade passes through, the tower is suddenly subjected to tons of wind pressure and is also **pulled forward** by the relative negative pressure on the back of the rotor blade.

After the rotor blade has passed through, the conditions are reversed again. The back pressure that builds up again on the tower pulls on the relative negative pressure on the back of the rotor blade, which minimally brakes the rotor and causes a **bending load** in the opposite direction via the hub.

In this way, the tower performs a kind of belly dance, particularly at a height of 2/3, which is transferred to the foundation and then to the ground with a leverage effect.

The wind turbine is not a rigid pole in the ground, but can and must bend like reeds in the wind. If you were to push it against the nacelle on a calm day, it would oscillate by itself at a defined frequency. If the "belly dance vibrations" caused by the wind come close to this frequency, the resonance threatens to cause the tower to rock and break.

Depending on the wind, each oscillation of the tower acts like a kind of hammer on the ground. The triggered vibrations are transmitted in a circle around the turbines. This is comparable to the ground-vibration of a passing train. Depending on the subsoil, this structure-borne noise can be carried for kilometers and transmitted via the foundations to residential buildings, their walls, floors or even furniture. Rock substrates, frozen ground, high groundwater, buildings erected on natural ground without a gravel layer, concrete walls, ceilings and floors without sound insulation all have a favorable effect.

5. Evidence and scientific validity:

In the ongoing public debate regarding potential health impacts from wind turbine emissions, this paper integrates well-established physical principles with medical observations and consistent reports from affected residents. Taken together, these elements form a coherent interdisciplinary explanatory model – much like puzzle pieces that, once properly aligned, reveal a meaningful image. This coherence strongly suggests that a relevant, previously underrecognized causal relationship is being described.

1. Theoretically Confirmed Physical Principles (High Evidence)

These are based on established laws of fluid dynamics, acoustics, impulse transfer, and energy propagation:

- Differentiation between various types of pressure and sound phenomena (harmonic infrasound, explosive sound events, implosions, wind pressure pulses)
- Role of Fourier analysis in distinguishing impulsive vs. harmonic signals
- Periodicity of the rotor blade tower-passing frequency (RTD)

- Impulse transfer through pressure gradients in moving air
- Air volume flows and kinetic energy in near-ground turbulence
- Decoupling of volumetric transport and far-field sound pressure (documented in aerodynamic and acoustic literature)

2. Logically Derived Plausible Consequences (Moderate Evidence)

These follow logically from the physical foundations and are internally consistent:

- Wind pressure pulses as structured, non-soundlike pressure events
- Interaction of wake vortices with terrain profiles and near-ground airflows
- Amplification or damping via reflection and resonance in buildings
- Biomechanically plausible impulse transmission to tactile and vestibular sensors
- Findings from "*Acoustics Report – Sheep Farm, Scotland 2023*" (Huub Bakker et al.):
 - Measured negative pressure pulses are best interpreted as implosive in nature
 - Strong directional emission patterns depending on wind direction were observed
- These results support the hypothesis of a directed, non-spherical propagation mechanism

3. Clinical-Physiological Observations and Hypotheses (Lower but Relevant Evidence)

These are currently based on individual case reports and medical reasoning; although not yet systematically studied, they align with known biophysical mechanisms:

- The author had contact with ~300 individuals, nearly all living downwind of wind turbine installations
- Many report relief when sleeping in basements or on the side of the house facing away from the turbines – contrary to the expected uniform dispersion of harmonic infrasound
- In some houses, new structural cracks appeared after nearby turbines began operation, despite prior long-term structural stability
- Discrepancy between measured infrasound (e.g. via microbarometers) and subjective complaints
- Stronger effects in isolated dwellings, hillside houses, or those "in the first row"
- Symptom patterns resemble known effects from low-frequency, impulsive volumetric waves (e.g., submarine medicine, chronic vibration exposure)

6. Conclusion

The aerodynamic emissions of wind turbines – particularly wind pressure pulses, periodic pressure waves from energy-laden air displacement, vortex formation, and tower oscillations – involve significant energetic content and, according to current interdisciplinary evidence, can impair the health of sensitive organisms, particularly humans. Current regulations, which are focused almost exclusively on acoustic metrics, fail to capture these non-acoustic but highly impactful emission types. This represents a serious and now untenable gap in environmental and public health protection, likely responsible for chronic harm to many individuals.

There is therefore an urgent need for action out of a sense of responsibility towards public health and on the basis of the precautionary principle:

- **Installations where there is concrete evidence of adverse health effects should be shut down** until a full investigation and reassessment has been carried out.
- **The health effects of aerodynamic emissions must be officially recognized as a potential hazard**, and those already injured must be compensated and provided with medical care.
- **Immission control must be expanded to include aerodynamic emissions**, and the physical measurement methods must be corrected and supplemented accordingly.
- **Approval practice must be realigned** - taking into account the evidence shown and including medical, biophysical and fluid mechanics disciplines.