The main objective of this project is to investigate the phenomenon of generation and propagation of infrasound waves that are inaudible by humans, but may be created by operating wind turbines. The scope of the first phase of the planned tasks will include development of a numerical model of a wind turbine that takes into account the main sources of low frequency acoustic emission signals, i.e.: the mechanical noise coming from the gondola and the aerodynamic noise generated by the rotating blades. The proposed model will consider the design parameters and the technical solutions in currently produced wind turbines. For its development modern computer tools that enable integration of physical phenomena from in various fields, including structural mechanics, acoustics, aerodynamics and thermal phenomena into one multiphysical model, will be used.

The numerical model of a wind turbine will include the following specifically defined set of parameters: type (geometry) of the acoustic wave emission sources: point, surface, linear; sound power of the sources with the division on the sounds coming from the gondola and from the rotating blades, measures describing the acoustic in low and infrasonic frequency range; meteorological parameters: wind direction, humidity, temperature, atmospheric pressure, absorption coefficient through the atmosphere, ground type, data on the characteristics of sound absorption by the soil, topography and the possibility of including obstacles (preparation of digital terrain model based on the information contained on hypsometric topographic maps). In addition, the model will take into account the so-called acoustic background.

In the next step, the developed model will be used for numerical calculations using the finite element method. Simulation studies will aim to determine the impact on the obtained results of selected construction and technical parameters of the turbine. Furthermore, the following will be evaluated: the impact of weather conditions (wind speed and direction, temperature, humidity, atmospheric pressure, etc.) and the topography of the wind power plant surrounding (type of soil, absorption and reflection from the surface, shielding by obstacles) on the path of propagation (the trajectory) of low-frequency acoustic waves in both the near and far field. Based on the results obtained from simulation studies the surface and spatial sound field distributions around the considered wind turbine will be determined.

Implementation of the numerical model of a wind turbine requires development of a mathematical dependency digitally describing the acoustic signals generated during its operation. For this purpose estimation and optimization algorithms will be used, such as the least squares method, Nelder-Mead simplex method and evolutionary algorithms, which will be integrated in a specially designed computer program. The study will include the results of preliminary studies conducted so far by the project team lead by the principal investigator. In the estimation and optimization process of model parameters as the fitting indicator the residual norm and correlation coefficient will be used. This task will integrate the existing algorithms for determination of such parameters of the developed mathematical model, which in the end will enable for digital identification of the form of the infrasound signal source regarded to the turbine.

The physical phenomena considered in the project are associated with generation and propagation of infrasonic waves during operation of wind turbines, and relate to the air mass flow between the blades and the mast and to the vibro-acoustic waves produced by the mechanical and electrical components located in the gondola that propagate in space and along the mast to the ground and further on the surface of the earth. The equations of motion are generally based on two fundamental principles, i.e. the principle of conservation of energy and the principle of conservation of mass (continuity condition). In order to conduct research studies on the propagation of acoustic waves in the transient state and in the frequency domain (harmonic study) the equation of acoustic wave dynamics will be applied. The wind will be modeled using the equations of fluid mechanics, i.e. the Navier-Stokes equation. In addition, the model will integrate the laws describing dynamics of the mechanical stresses arising in linear media and the laws of thermal conductivity.

The final stage of the research studies will include execution of the verification process according to numerical and experimental data. This process will regard to measurements performed previously in the research laboratory of small wind energy at the Institute of Electricity and Renewable Energy Opole University of Technology and results of measurements conducted in the field on operating wind turbines. For the purpose of the project the following research hypothesis was adopted: it is possible to model the processes related to the generation, development and propagation over time in various media of low frequency acoustic signals emitted during operation of wind turbines of high power, various construction and method of operation, in such a way that a reasonable compliance of model with the measurement data will be obtained. This regards to the creation of a mathematical model describing the source of disturbance, which results in generation of acoustic waves.
The undertaken issue states a new research, both in Poland and abroad. So far, there are no attempts to create a multiphysical model of an infrasound noise source, which originates from a wind turbine that has been verified experimentally. Previous studies have taken the turbine as a single entity, and assumed point source in the models for acoustic waves. A definitely new approach is to develop a multiphysical model that takes into account all possible sources of noise and to simulate infrasound generation and propagation by changing meteorological, topographical and technical parameters of the wind turbine. No mathematical models have been developed allowing describing in an unambiguous way the generated signals nor simulations of their propagation for a set of terrain parameters under environmental conditions. It should be emphasized that there are no results of basic research tests aiming at understanding the phenomenon of generation as well as propagation of infrasound noise emitted by wind power plant.

Such studies are planned within the scope of subjected proposal. Investigating the phenomenon and performing its objective and multivariate evaluation is an extremely important issue from a cognitive point of view and has also got a utility value.

The problem of artificial infrasound formation, propagation, its level and possible impact on the natural environment and especially on living organisms, is still valid and important from both cognitive and utility point of view. This is particularly true for wind power engineering, which infrastructure is dynamically developing in recent years in Poland, EU and worldwide. The issues of risks and, in particular, of health effects resulting from possible generation of low frequency signals of high pressure

level and prolonged time and their impact on living organisms are raised more and more often by the inhabitants of the areas, where individual turbines or large wind farms are to be located.

The final effect of the project will include mathematical model of low-frequency sound waves and a set of dependences, describing the area of their propagation what will be realized through numerical simulations. In consequence this will allow to evaluate the physical processes accompanying the studied phenomena and to determine the impact of a number of external factors and parameters on their time and space distribution.

Furthermore, on the basis of the proposed numerical model, there emerge the possibility of carrying out computer simulations, related to estimation of the impact of infrasound noise and vibrations, generated during wind turbine operation. This may be advantageous especially in future investments, since there will be no necessity of performing time-consuming and costly measurements requiring a wide expert knowledge.
The possibility of modeling and thus understanding the phenomena related to generation and propagation of low-frequency acoustic signals can contribute to the determination of the value of sound pressure levels emitted by wind turbines with given set of parameters and this in an unambiguous way and at the stage of design works, as well as while elaborating environmental impact reports.

In the author's opinion the proposed methodology will allow to examine physical phenomena related to generation, development in time and propagation of low-frequency acoustic waves emitted by wind turbine operation. The research team, led by the applicant, will have at their disposal professional research equipment which allows carrying out measurements and analyses of acoustic signals in the audible, low-frequency and vibro-acoustic range. The Institute is equipped with professional testing equipment that will enable for to perform measurement and analysis of acoustic signals in the audible and low-frequency range, as well as the vibro-acousic signals. In particular, the institute poses systems for recording and analyzing vibrations and sound, as well as the MATLAB software package, the main module of COMSOL Multiphysics and a system for measuring and analyzing of low frequency acoustic signals. For the realization of the project additional microphones for low-frequency registration with wind and rain shields and cables and necessary software licenses, are planned to be purchased. It is planned to perform measurements in the near and in the far field simultaneously, thus under the same meteorological conditions. The second measuring system will be applied for far field measurements, while the existing one in the near field. It is also planned to purchase chosen modules of the COMSOL software, which are necessary for realization of the planned research works. The Opole University of Technology poses a laboratory CentrumITLab, which is equipped with high performance computers. This laboratory will assure the execution of specific numerical simulations and all the analyzes of obtained data according to the project schedule.