# ROTOR PARAMETERS OF SMALL WEIGHT HELICOPTERS

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## Abstract

In recent years, a significant number of one and two-seats small weighted helicopters have appeared. This fact makes it possible to analyse the parameters and determine the parameter dependencies for this helicopters class. Knowledge of such dependencies is necessary for the preliminary design stage. The analysis performed in this paper and the comparison of it with the statistical data of all the categories of helicopters made it possible to determine the necessary corrections in the methods for design the parameters of the little helicopter's rotor systems.

## 1. NOMENCLATURE

| | |
|---|---|
| $C$ | chord, m |
| $C_t$ | rotor thrust coefficient |
| $D$ | main rotor diameter, m |
| $DL$ | disc loading, Pa |
| $g$ | gravitation acceleration, m/s$^2$ |
| $m_0$ | maximal take-off mass, kg |
| $N_b$ | number of blades |
| $r$ | rotor radius, m |
| $\mu$ | advance ratio |
| $\pi$ | Pi number |
| $\sigma$ | rotor solidity |
| $\Omega R$ | blade tip speed, m/s |

## 2. INTRODUCTION

A small helicopter that is available to take off near a home is the most comfortable vehicle for personal usage. Thus, the interest of such aircraft was provided for a long time. Due to technology development, one and two-seated helicopters have become more compact and lightweight. There are examples of such helicopters in the Fig.1. Main part of such rotorcrafts belongs to Ultralight and Very light helicopters on the European Union territory according to the European classification. The airworthiness standards for Ultralight helicopters are normalized by national governments but the standards for the Very light class are established by EASA. Separated requirements, that are not similar to requirements applying to light helicopters, are due to the lower level of the potential danger of these classes of helicopters. The limitations of a take-off mass of Ultralight and Very light rotorcrafts limit their kinetic energy and do them more safely than other aircraft towards people and environment. This is the reason that explains why certification methods have been simplified and liberal flight rules requirements introduced for these aircraft classes.. There is a big amount of new Ultralight and Very light helicopters that appear in the last 25 years. This fact allows to conduct a statistical analysis of their parameters. 34 serially produced and experimental helicopters with maximal take-off mass (MTOM) from 260 to 730 kilograms, were analysed for this research. Complete statistical data was not collected for all rotorcraft, but collected ones are sufficient enough to determine tendentious of small helicopter’s rotor systems development.

There are two trends for small helicopters preliminary design. On the one hand, they should obey the laws of mechanics and, accordingly, the general rules of helicopter design. On the other hand, the scale factor has a significant effect for such small-size rotorcrafts. According to it, this is important to compare functional dependencies of helicopter’s parameters with dependencies which were determined on the base of processing of the statistical data for all weight categories. Such an analysis is needed for specialists who deal with the preliminary design stage of small helicopters development. The rotor system is the base of the helicopter, so it was selected for initial analysis.

The most comfortable approximation of statistical data of all class helicopters was given in paper [1]. Due to this fact, the main part of comparisons of small helicopter’s statistical data with general tendentious was done with using of dependencies which are given in the above-mentioned paper.

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## 3. GEOMETRICAL PARAMETERS OF THE MAIN ROTOR

The disk loading is one of the most important parameter of the helicopter’s main rotor. This parameter affects the flight dynamics and other characteristics. As a rule, the decrease of this load leads to the growth of the relative lifting capacity in the hovering flight but also increases the rotorcraft's stability to the wind gusts, and also it gives the ability to use smaller hangars for a helicopter parking. The existing practice of helicopter design shows that the value of disk loading is changing due to the mass of the helicopter. The value of disk loading for some of the heavy helicopters can be up to 700 Pa. However, the smallest rotorcrafts have the lowest value of disk loading, which is about 100 to 170 Pa. There is also the dependence of disk loading from maximal flight speed for big rotorcrafts. But, the value of maximal speed for small helicopters is changing in a small range, so that it does not make sense to use speed as parameters for disk loading correlation. The data of the existing single rotor and coaxial helicopters is given in the Fig. 2. Disk loading for coaxial rotors was calculated as disk loading for equivalent single rotor with doubled rotor solidity. Presented data shows that coaxial helicopters have a bigger value of disk loading, so it means that data for the main rotor expedient to approximate separately for coaxial and single rotor helicopters. It can be seen that the row of the helicopters has an identical mass and located at the mark of 450 kilograms. It explained due to historical circumstances – the border of the ultralight class of aircraft was fixed on this mark for a long time in Europe, so many aircrafts limited their mass characteristic on this level. Currently, the rules of law in some countries have changed, so this limit will become invisible in the coming years.

It should be noted that two rotorcrafts come out of the common trend. Both of them were in a number of pioneers of new generation small helicopters design. Particularly, the high value of disk loading has a single rotor helicopter – M80 Masquito (not Mosquito XE) and coaxial Berkut-SL. For the first one, it seems that, the designers have not enough design statistics and experience for the development of the small helicopters, whereupon they have used the main rotor with a small diameter. As for the second one, rotorcraft became overweighed. Particularly, it had three gearboxes. Both of these helicopters are not currently produced serially.

The dependence of the disc loading from the MTOM in the degree 1/3 is justified in [1, 2, 3]. At the same time, the proposed approach of taking into account only the exponentiation dependence for small helicopters [3] gives a significant error. According to it, the approximation functions will be defined as: single rotor helicopters(Curve 1, Fig. 2)

$$DL = 18.68 m_0^{1/3} - 6.44 \tag{1}$$

coaxial helicopters (Curve 2, Fig. 2)

$$DL = 18.45 m_0^{1/3} + 18.12 \tag{2}$$

The data of rotor diameters and curves from MTOM are presented in Fig. 3. These data were calculated from the disc loading by the relation

$$D = \sqrt{\frac{m_0 g}{\pi DL}} \tag{3}$$

It's interesting to see that the curve of the main rotor diameters which approximated for data of single rotor helicopters for all weight categories [1] (Curve 3, Fig. 3) shows smaller values of the rotor diameters, which are comparable with diameters of coaxial small helicopters. Moreover, it has a gentle slope. This difference shows that even though all the helicopters obey the common trends, the approximated curves will have breaks with the next increasing of MTOM. The different slopes of the curves for small helicopters and heavier rotorcrafts can be explained by the required speed of big helicopters for efficient transport operations. The speed of small helicopters is just about the same level for all rotorcraft and designers are working on increasing load capacity often considering speed as a less important factor.

The main rotor blade section of little helicopters, as a rule, has a relative thickness of 12-15%. This value is bigger than the value for helicopters with bigger take-off mass, which often have tip chord about 8-10% of the thickness. Such difference is in the small speeds of horizontal flight of the one-two seats rotorcrafts. The main rotor chord is more clearly depend on MTOM and blades number. The increasing of blades quantity leads to the chord reduction. It should be noted that almost all Ultralight and Very light helicopters have two-bladed main rotors with the common teeter hinge. Only three helicopters are equipped with the three-bladed main rotors. Such rotors have more difficult construction and bigger parking sizes, because impossibility to set blades in the longitudinal direction to decrease the transverse size. The total cost is rising onto the price of one blade. However, these rotors have advantages too. The rotor disk becomes more compact, the level of vibration is reducing. Especially, reducing the vibration level could be sensitive for single rotor helicopters. Something better situation could be for two blades coaxial helicopters. The azimuth of the interference of those rotors could be set in a position that the oscillations of the blades will be in the counter phase. As a result, the vibration could be reduced up to 1.5 – 2 times in the most characteristic airspeeds range of the flight.

As mentioned before, only three low-mass helicopters have three-bladed rotors. Of course, it is impossible to determine the behaviour of functions based on three parameters, so a parallel dependence on two-bladed rotors was used to construct the dependence curve for three-bladed rotors.

Chord statistical data and approximation functions for small helicopters are shown in Fig. 4 (Curve 1, 2). Functions for the all helicopters [1] are shown in the same figure (Curve 3, 4). It can be seen, that despite common similar tendentious, the parameters of the small rotors have a difference with general dependencies [1, 8]. The chord value is increasing slower then the mass for little rotorcrafts. The two-bladed rotors could be approximate by the next relation:

$$C = 0.0619\frac{m_0^{0.226}}{N_b^{0.426}} \tag{4}$$

It should be noted that the aspect ratio of the blades of small rotorcrafts is in the range of 14 - 23, which is within the limits typical for helicopters of heavier classes [6].

The rotor solidity is also one of the important parameters of the main rotor. Often, the small value of this parameter increases the performance of the helicopter in the hover flight mode, but at the same time, its value should be large enough to fly in conditions of maximal airspeed and altitudes of the dynamic ceiling for this rotorcraft. Generally, the solidity of the rotor is increasing while the mass of the helicopter is rising, but this common tendentious has the bouncing structure, which is sharply increased while changing of blades quantity. Getting into account that the absolute number of small helicopters have two-bladed main rotors, it could be constituted the reverse situation when solidity is decreasing while the mass of helicopter is rising (Curve 1 Fig. 5). The scale factor is the main reason why the solidity is rising while helicopter mass is decreasing. Particularly, it's difficult to produce a technological rotor blade with the required - centre mass position for the small dimensional main rotor.

The minimal value of the rotor solidity which can give the ability to do the flight without stall on the tip of the outcome blade should be used according to the method [3,4,5]. The flight in conditions of maximal speed or maximal altitude is considered. The stall limit is estimated based on the limit value of the ratio $\left(\frac{C_t}{\sigma}\right)_{lim}$. It should be noted that the parameters of the maximal speed of flight that relative to the tip speed of the rotor are almost independent from mass in the range of little helicopters and are in the very narrow range of μ=0.2–0.3 (Fig. 6). The limit ratio $\left(\frac{C_t}{\sigma}\right)_{lim}$ for such μ is in the range of 0.18 – 0.22 for example according to [3]. In case maximal value of $\left(\frac{C_t}{\sigma}\right)_{lim} = 0{,}22$ the limit value of the rotor solidity is minimal and parallel the approximation curve which is characterized for two-bladed rotors (Curve 3, Fig.4) and all the small helicopters are in the right area. The solidity limit function is the same as the statistical Curve 1 (Fig. 5) when the minimal value of $\left(\frac{C_t}{\sigma}\right)_{lim} = 0{,}18$ is. This indicates that the limit criteria of the absence of stall for outcome blade is dominating one for small helicopters design procedure.

## 4. TIP SPEED OF THE MAIN ROTORS

As known, the tip speed of the main rotor depends on rotor sizes and flight speed. Classically the value of tip speed for helicopters is about 180 – 230 m/s [3, 4, 5, 6]. But the main part of small helicopters has less tip speed even to 150 m/s. Often small values of the tip speed allow to get good thrust performance for rotors in hovering flight mode and flying with low speed. Besides, low tip speeds generate lower vortex noise, the noise of periodic processes comes to infrasound frequency less then 20Hz, where the human ear cannot hear it. Manufacturers have to pay for the low tip speed by increasing the weight of the transmission and blades.

The flight airspeed almost has not influence to the choice of tip speed, taking into account the fact, that the airspeed of small helicopters is not big, and their parameters are far from wave crisis. The tip speed data shows that they depend on the rotor diameter and this dependence is almost linear (Curve 1, Fig.7). The total exponentiation dependence, which is gotten in [1], for all helicopters (Curve 2) is flatter than real statistical data for small helicopters. At the same time, a significant error is observed for the smallest rotors. In this regard, it is possible to use the upgraded exponentiation dependence for the smallest size helicopters, described by the following expression:

$$\Omega R = 57.967 D^{0.6149} \tag{5}$$

## 5. CONSLUSION

Analysis of main rotors parameters shows that general tendentious, which are specific for main rotors of all-weight helicopters, is preserves for small rotorcrafts. However, there are a number of features that should be considered while the preliminary stage of design is proceeding. These features are due to the fact that small helicopters have not significant speeds of flight, tip speeds of these helicopters are lower – the blades are far from wave crisis, the rotor solidity has a small value too. The scale factor has an influence almost on all parameters. The statistic parameters and relations presented in this paper could be useful for designers who are working with the preliminary design of small helicopters.

## 6. LITERATURE

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a) b)

Fig.1. The small weighted helicopters:
a – single rotor helicopter Cicare CH-8 (Argentina), MTOM-480kg,
b – coaxial helicopter Rotorschmiede VA-250 (Germany), MTOM-500kg

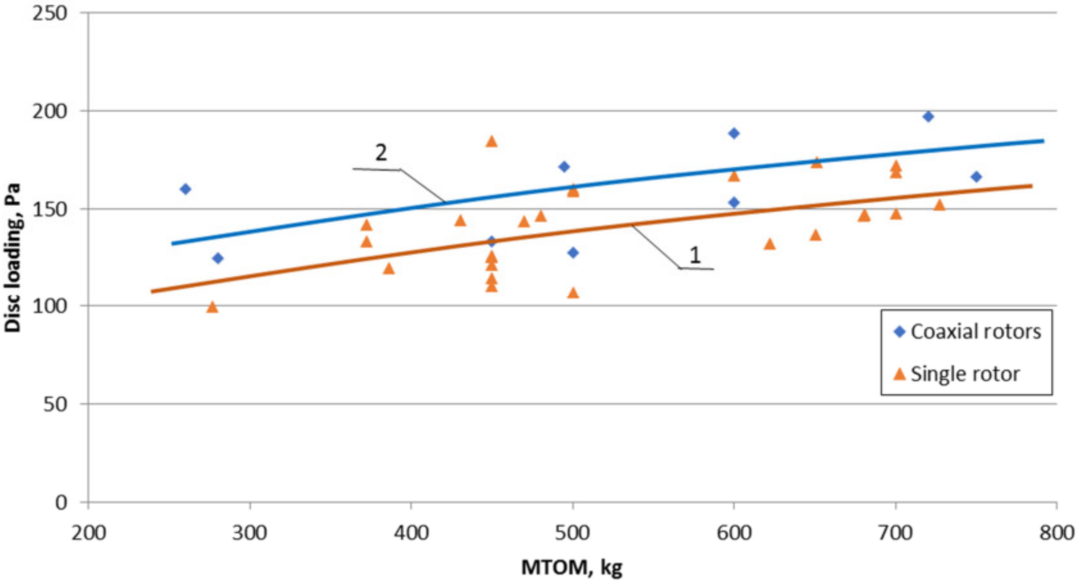

Fig. 2. Dependence of disk loading from MTOM (1 - approximation curve for single rotor helicopters, 2 - approximation curve for coaxial helicopters)

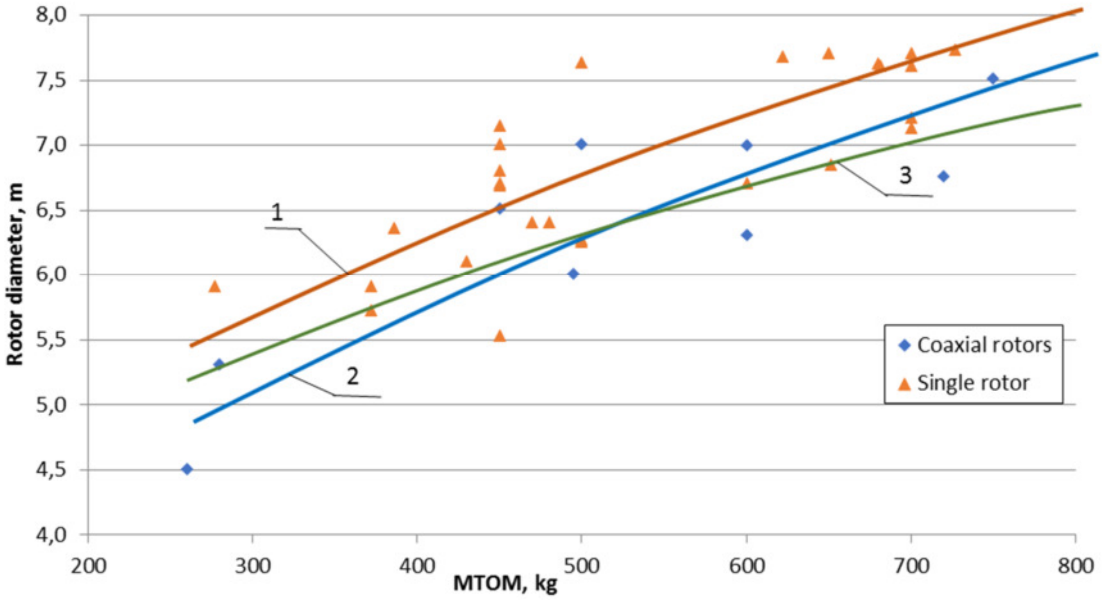

Fig. 3. Dependence of the main rotor diameter from MTOM (1 - approximation curve for single rotor helicopters, 2 - approximation curve for coaxial helicopters, 3 - rotor dependence according to [1])

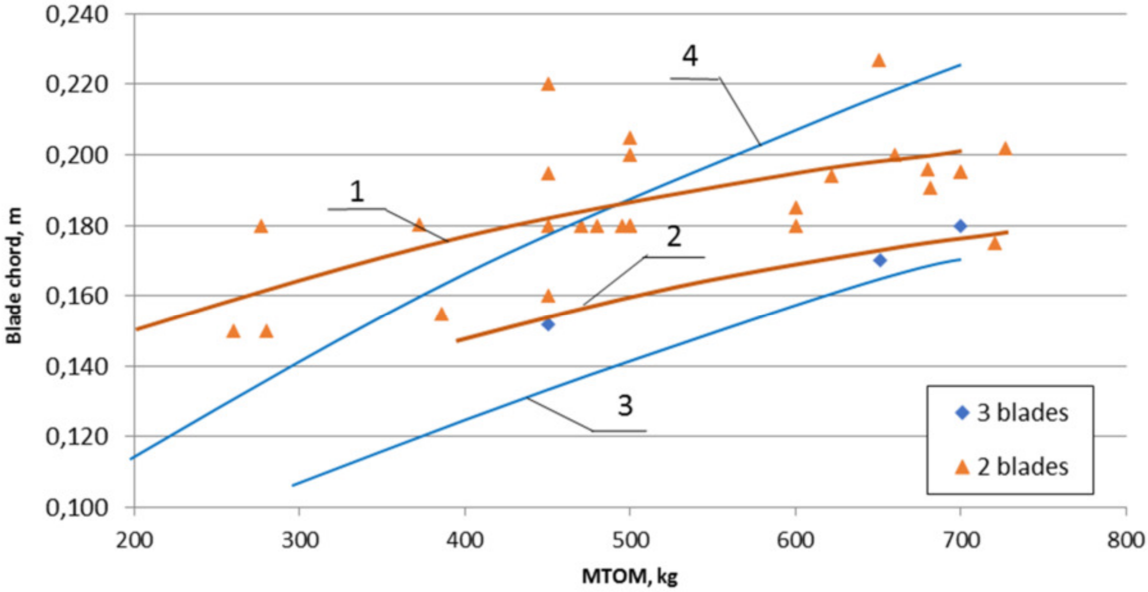

Fig. 4. Dependence of the blade chord from MTOM (1 - approximation curve for two-bladed rotors, 2 - approximation curve for three-bladed rotors, 3 - approximation curve for three-bladed rotors according to [1] 4 - approximation curve for two-bladed rotors according to [1])

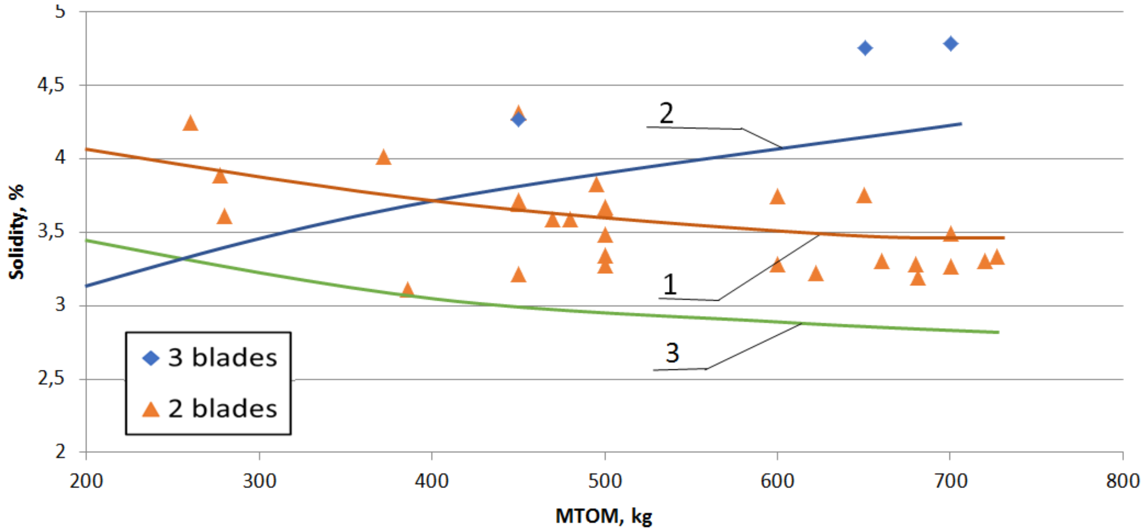

Fig. 5. Dependence of the rotor solidity from MTOM (1 - approximation curve for two-bladed rotors, 2 - approximation curve according to [1], 3 – the minimal value of the rotor solidity according to [3])

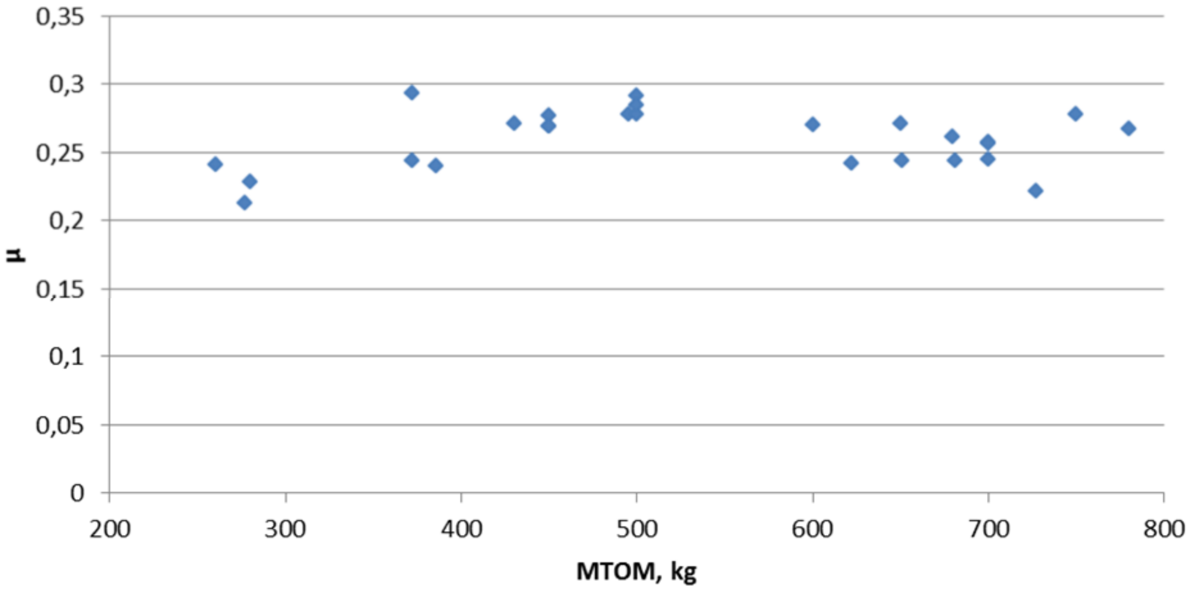

Fig. 6. Dependence of the helicopter advance ratio from MTOM.

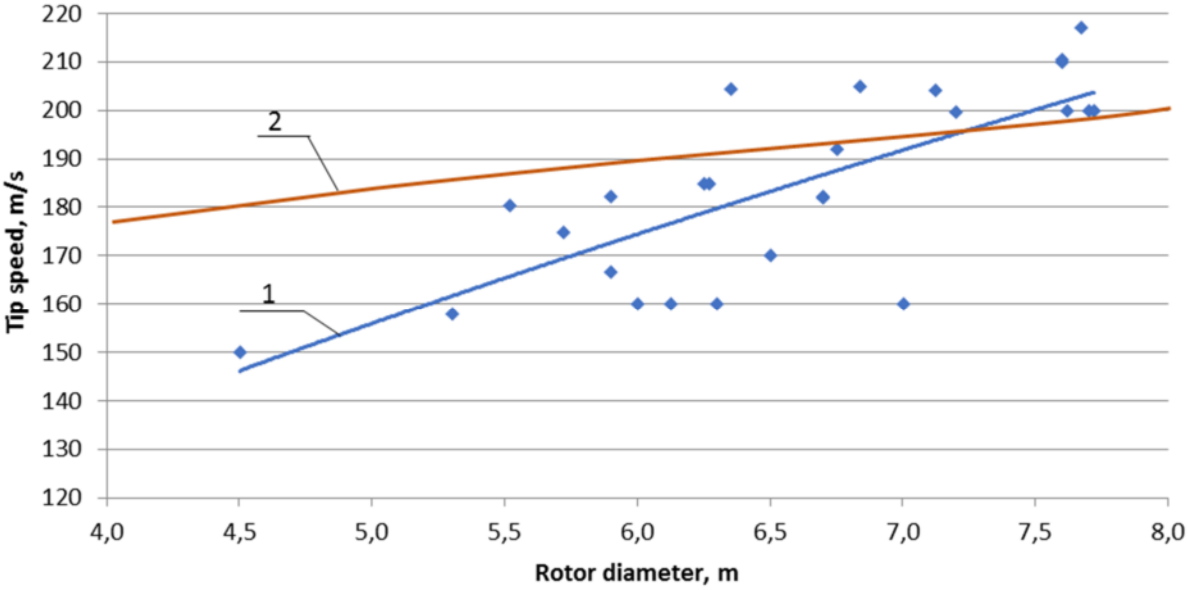

Fig. 7. Dependence of the blade tip speed from rotor diameter (1 - approximation curve, 2 - rotor dependence according to [1])