

PAPER • OPEN ACCESS

Investigation of the effects of end faces design on parameters of cycloidal rotor

To cite this article: Ar.A. Dekterev *et al* 2018 *J. Phys.: Conf. Ser.* **1105** 012029

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Investigation of the effects of end faces design on parameters of cycloidal rotor

Dekterev Ar.A.¹, Dekterev A.A.^{1,2}, Dekterev D.A.^{1,2}, Goryunov Y.N.²

¹ Kutateladze Institute of Thermophysics SB RAS, 1 Lavrentyev Ave., 630090, Novosibirsk, Russia

² Siberian Federal University, 79 Svobodny Ave., 660041 Krasnoyarsk, Russia

E-mail: dek_art@mail.ru

Abstract. The paper is devoted to a numerical study of the characteristics of a cycloidal rotor depending on its construction features. It is established that the 2D simulation does not adequately resolve the investigated problem. This is connected with the complex three-dimensional structure of the flow formed by rotor. The 3D calculations allow detecting sucking in airflows into the end faces of rotor. This requires studying the effect of the end faces construction. Two rotor geometry options with open and closed end faces are considered. The significant dependence of formed flow structure behind the rotor, rotor thrust, and energy characteristics depending on the design of its end faces is established.

One of the types of prospective propellers for aircraft is the cycloidal rotor [1-4]. It is a device with horizontal axis of rotation, to which the airfoils (blades) are arranged in parallel. Controlled angle of attack of the rotor blades allows changing the thrust vector almost instantly, which is one of the advantages of the propulsion device of this type. It provides vertical take-off and landing as well as high maneuverability of the aircraft.

The idea of using a cycloidal (rotary) propulsor was proposed by Robert Hooke in 1681 and it has been used industrially since 1925 as a ship screw for ships with increased requirements of maneuverable qualities. In 1909, the Sverchkov's aircraft became the first aircraft in the history, built on the principle of cyclogyro, however, the 10 h.p. engine of the Büschi design could not even budge the "Airplane". Until 1935 active research was conducted in Germany, the USA, England, France and other countries. After half-century of stagnation in the development of aircraft with cycloidal propellers, this scientific direction once again began to gain momentum in the world science, the subjects are engaged scientific teams from South Korea, Singapore, the United States of America and China, a special European corporation CROP was founded.

Modern studies of the cycloidal propulsor can be divided in two directions: the creation of unmanned aerial vehicles of small dimensions [2], [3], [7]; creation of aircraft for transportation of people and cargo. Abroad (South Korea, the United States, China, Italy) small-sized aircrafts from 0.03 to 100 kg have been already created and flight tests have been conducted, but large-scale aircraft using cycloidal rotors such as a propulsor yet have not been created.

Carrying out literature analysis allows establishing that for the rotors of the size ~1.0m, different authors offer the following optimal parameters:

- the number of blades: 4 - 6;



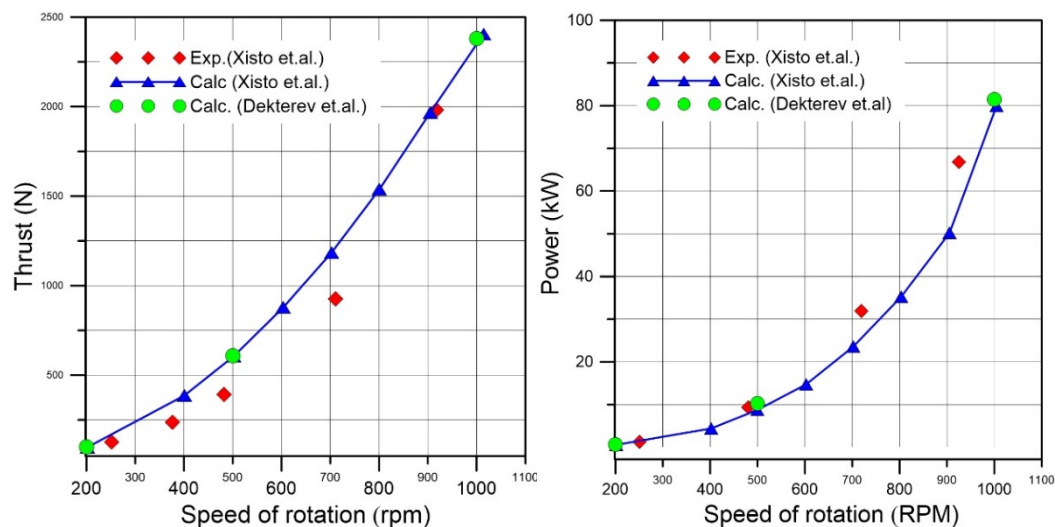


Figure 1. The thrust (a) and the power (b) depending on the rotor rotation speed.

- chord of blades: 0,3 m;
- blade profile: NACA0016 - NACA0018;
- maximum angle of attack of the blades: 30° - 35° .

A rotor version with a diameter $D = 1.2$ m, length $L = 1.2$ m with NACA 0016 profile with a chord length of 300 mm, and kinematics of blades identical to [1], [4], [5] was chosen for the test calculations.

In most papers [1], [4], [5], [6], the URANS approach with Spalart Allmaras and $k-\omega$ SST turbulence models are used to study the aerodynamics of rotor propulsors. In this paper, a more consummate two-parameter $k-\omega$ SST turbulence model with the use of wall functions was chosen for calculation. To approximate the equations, schemes of the second order of accuracy by time and space were used. The problem of a variable angle of attack of blades was solved due to realization of the kinematic scheme using the sliding grids technique.

The mathematical model in the two-dimensional formulation was verified according to the calculated and experimental data of Xisto et al. As can be seen in figure 1, the simulation data correlate with the literature data.

Preliminary 2D and 3D calculations for idealized geometry, which showed significantly different thrust and energy parameters of the rotor were performed. The difference was natural for different rotor rotation speeds.. This is because the flow was largely three-dimensional. Based on the results of 3D calculation, a significant air suction into the end faces of the rotor was revealed. In this connection, there was a fundamental need to study the effect of the end face design of the rotor on its characteristics. Two options of the rotor end face designs (open and closed) were considered (figure 2).

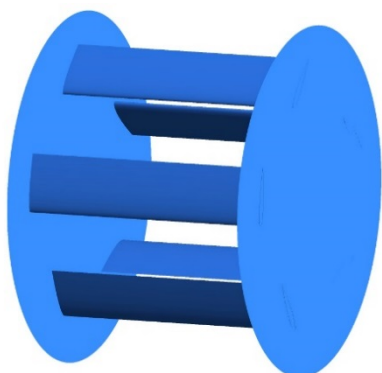


Figure 2. Geometry of the rotor with closed end faces.

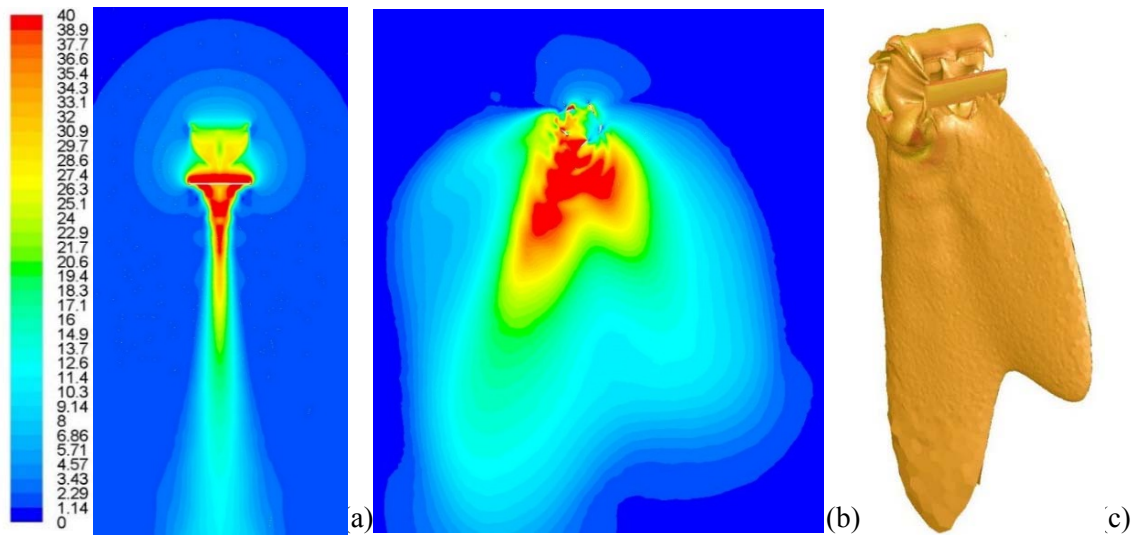


Figure 3. Velocity fields in the transverse (a) and longitudinal (b) sections and the velocity isosurface (c) for the rotor with open end faces.

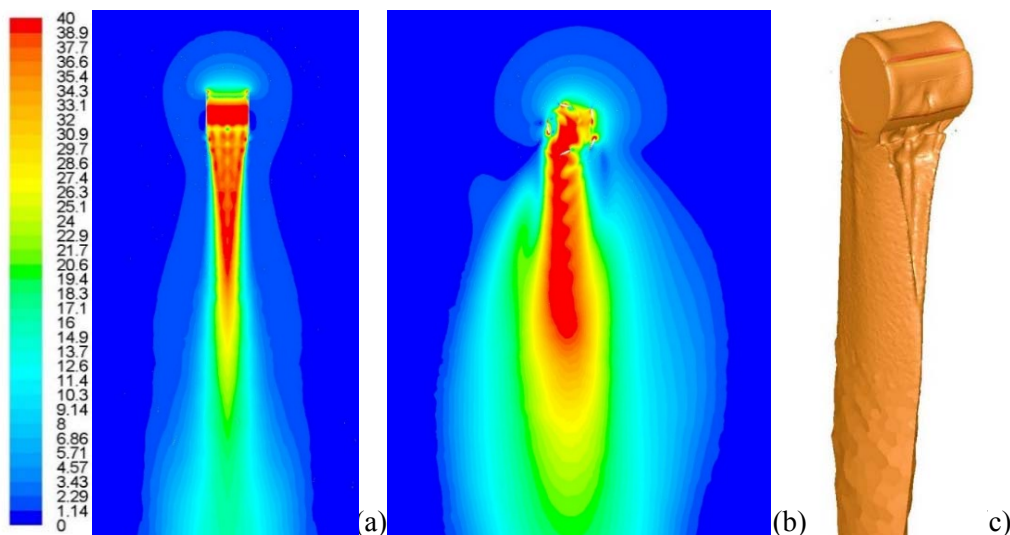


Figure 4. Velocity fields in the transverse (a) and longitudinal (b) sections and the velocity isosurface (c) for the rotor with closed end faces.

As was noted earlier, in the case of open ends, considerable air suction on the sides of rotor was observed. The flow formed behind the rotor, in this case has a flattened profile, narrow in the longitudinal section of the rotor and significantly stretched in the transverse section (figure 3). The structure of the flow differs radically from that obtained in two-dimensional calculations. In case of using closed end faces, the flow has a more pronounced core, not exceeding in width and height the size of the rotor (figure 4), which is more similar to the results of two-dimensional calculations.

Table 1 presents the results of 2D and 3D calculations for the rotor at speeds of 800, 1000, 1200 rpm for the two types of end faces - open and closed. It follows from the results that in the version with open ends the thrust generated by the rotor is slightly higher than that in the case where the end faces were closed, but the power expended by the rotor is substantially higher, which ultimately leads to a radical drop in the efficiency of the rotor.

Table 1. Rotor parameters.

Rotation speed, rpm	Thrust, kgF			Power, kW			Efficiency, kgF/kW		
	2D	3D Closed	3D Open	2D	3D Closed	3D Open	2D	3D Closed	3D Open
800	158,0	150,8	165,1	32	35,6	51	4,94	4,2	3,2
1000	247,2	234,4	249,1	61	63	94,5	4,05	3,7	2,6
1200	349,6	345,5	374,1	101	121	169	3,46	2,86	2,2

Conclusions

The calculations have shown that there is a significant dependence of the flow structure behind the rotor, as well as its thrust and energy characteristics, on the design of the end faces. In the case of open end faces, the thrust is higher by 10-15% than that with the closed end faces, however, the power used is much higher. In this regard, the efficiency of the rotor with closed ends is higher by 50%. In addition to prevention of air suction the closed end faces may act as rotorblade winglets. It can lead to the effect of reducing the induced drag created by wingtip vortices and increasing of rotor thrust. An analysis of this effect has been carried out in paper [8]. Considering this, the complexity of the rotor aerodynamics and the necessity of more careful calculation and experimental study can be noted.

References

- [1] Xisto C M, Leger J A, Pascoa J C, Gagnon L 2017 Parametric analysis of a large-scale cycloidal rotor in hovering conditions *J. Aerospace Engin.* **30** 1-23
- [2] Hu Y, Wang G, Zhang H, Liu J, Yang X and Zhu B 2017 The effects of advance ratio and blade number on the forward flight efficiency of cycloidal rotor *55th AIAA Aerospace Sciences Meeting, AIAA SciTech Forum* (AIAA 2017-0096)
- [3] Benedict M, Ramasamy M and Chopra I 2010 Improving the aerodynamic performance of micro-air-vehicle-scale cycloidal rotor: An experimental approach *J. Aircraft* **47** 1117-25
- [4] Leger J, Pascoa J and Xisto C 2013 Analytical modeling of a cyclorotor in forward flight *SAE Technical Paper* 2013-01-2271
- [5] Xisto C M, Pascoa J C, Leger J A, Masarati P, Quaranta G, Morandini M, Gagnon L, Wills D and Schwaiger M 2014 Numerical modelling of geometrical effects in the performance of a cycloidal rotor *11th World Conference on Computational Mechanics*, Barcelona, Spain
- [6] Lee C H, Min S Y, Lee J W, Kim S J 2014 Design and experiment of two-rotored UAV cyclocopter *29th Congress of Intern. Council of Aeronautical Sciences*
- [7] Iosilevskii G, Levy Y 2006 Experimental and numerical study of cyclogiro aerodynamics *AIAA J.* **44** 2866-70
- [8] Lebed V G, Kalkamanov S A, Pchelnikov S I 2017 Research of influence end losses on economic efficiency rotary *Aerospace Technic and Technology* N 1 pp 36-41