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Research Article

EXPERIMENTAL INVESTIGATION OF A VARIABLE GEOMETRY DUCTED PROPELLER

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ABSTRACT

The paper presents preliminary results of experimental research on the variable geometry of a ducted propeller. The purpose of this work is explore the area of application of the ducted propellers of variable geometry. The paper contains the description of a test station and a model, initial tests' results of some selected geometries intakes and exit vents in comparison with an open propeller.

Keywords: ducted propeller, variable geometry, flow velocities.

INTRODUCTION

According to the research on the development of ducted propellers in research institutes and leading companies in aviation industry it was possible to use them for two ranges of velocity. The first velocity range is of over 200 m/s (0.6 Ma); fan jets have almost entirely overwhelmed the market of communication and military subsonic aircrafts. There are some designs of power plants with free propellers designed for such velocities, such as Piagio Avanti, An 70 with turbofan, Tu 95.

However, due to a number of limitations of this type of propulsion, they are in small numbers – i.e. a fraction of percent among all turbofan planes. Another range of speeds for ducted propellers is 0–40 m/s. Ducted propeller is frequently used in airships and hovercrafts. Presently there are not any large scale manned aircrafts flying under 0.6 Ma. The shroud for small and large velocities are designed on the basis of different criteria, thus, their nozzles are of different shape. The decelerating nozzles used for turbofans slow down the incoming stream and Ma number of blade tips what decreases efficiency as a result of compressibility. Moreover, a ducted propeller blade works the same way as the blade with endplate – extension is more effective, outer part of the blade can be much more loaded, larger thrust and power can be obtained from the propeller surface with significantly lower level of noise. Much smaller diameter of ducted propeller lowers the speed of blade tip. For lower speed, accelerating nozzle is used. Increased air velocity in the leading edge is accompanied by decreased pressure, what results in additional thrust. Thanks to additional thrust from the ring, ducted propeller generates higher thrust for the same power.

Numerous research that proved the increase of ducted propeller in comparison to free propeller have been conducted. Sources [1, 2, 3] state that the increase of static thrust for the ducted propeller, depending on design, is from a few percent for constant pitch propellers, up to 39% for controllable-pitch propellers. In present, constant geometry shrouds are used. Constant geometry of the shroud must be designed in the same way as constant pitch propeller as a compromise between take-off and in-flight conditions – for large and small propeller advance ratio.

PRESENTATION OF RESEARCH PROJECT

Alike in propellers a change of blade setting angle angle seems a natural solution, a change of shroud profile with increasing velocity seems to be natural for shrouds. Nevertheless the task is much more complicated than in case of propeller setting angle. It was assumed that changeable leading and trailing edges of the shroud cannot be used, as such geometry is not possible to obtain in currently known technologies. The first, and the most absorbing stage, as it turned out later, was to develop a feasible construction. The use of shape memory alloys was not taken into consideration, as they are still in the testing phase. A number of variable geometries of construction variants were considered for intakes and outlets of aircrafts with thrust vectoring and without it, and also the models existing in the nature. The design of variable outlet geometry was more time-consuming, as the solutions from supersonic aircrafts were impossible to use for lower velocities. Another problem was the control of geometry as such. The use of solutions typical for large velocities was too complicated, expensive and, in our case, useless, because for smaller velocities the strengths in the tunnel are much lower. The selection of geometric measurements of the model was made on the basis of statistics and the results from available research and reports. On the basis of statistics and the assumed conditions, the main measurements of the shroud were selected, i.e. the ration length / case diameter 1.1:1 and relative thickness of case profile – below 10%. Inner diameter was 306 mm, outer diameter in the propeller surface was 386 mm, the length of case profile chord was 420 mm (for zero dilation angle of intake and outlet). Other geometric parameters of the model were also analysed, e.g. the size of spacing between propeller’s edge and the case wall. As on the basis on articles [4] and [6] it was concluded that the size of slit has a significant influence on propeller’s efficiency, whereas in other articles, concerning the exploitation of hovercrafts, it was concluded that the slit cannot be too small because it generates a risk of damaging the propeller. Finally, the slit was accepted as 1% of propeller’ blade radius. Initially, the case consisted of 128 elements; after numerous attempts it was simplified thanks to the use of biomimetics – overlapping and pressing “feathers” inspired by birds’ tails. Finally, 64 elements were used. The system of case cover control consists of 32 ball joints connected with two independent rings – one in the intake and one in the outlet. The turn of the ring causes the change of connectors angles against the crosswise plane, which generates a change in dilation angle of case intake and outlet. The design and construction of the case geometry was the most laborious task so far. A number of attempts were made with paper, composites, aluminium for different geometries, with the use of different solutions for hinges and geometry control systems.

Both thrust and moment are measured with beam strain gauges. The drive was fixed to the inside part of the bearing. The possibility of turn was limited by weight balance. The measurement of pressure difference on airscrew disc was realised with a total head probe. The measurement of dynamic pressure with Prandl’ probe. Pressure sensors were connected to a digital manometer. The measurement of rotational speed was done with a transoptor, temperature and humidity were measured with a portable mini weather-station.

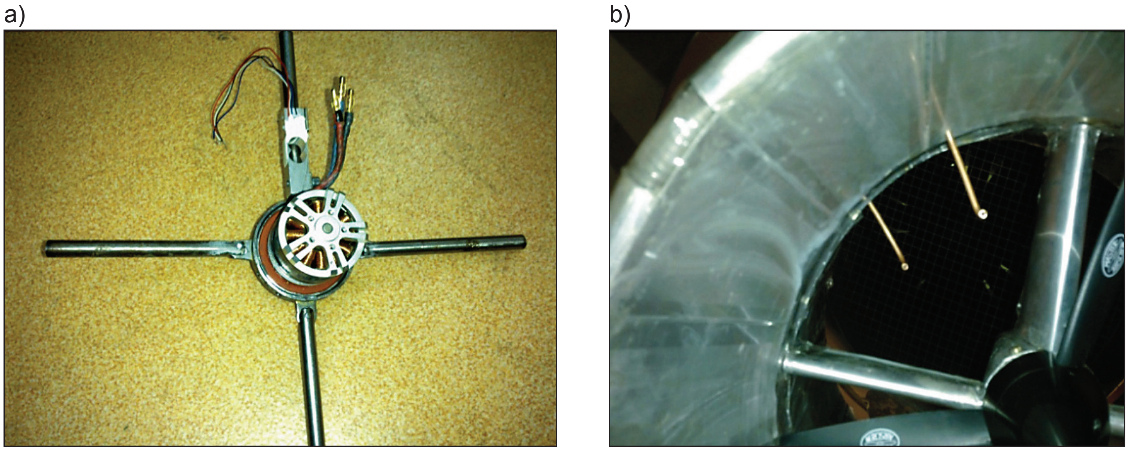

Fig. 1. a) drive fastening with strain gauge for moment measuring, b) measurement of total pressure jump at propeller disc

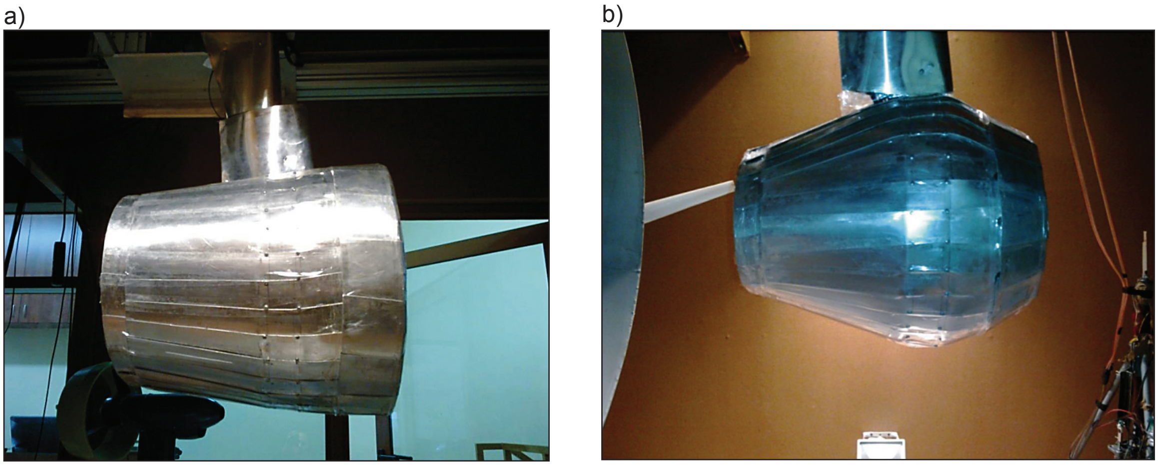

Fig. 2. The photographs present a ready shroud: a) shape appropriate for small flow velocities, b) shape appropriate for large flow velocities over 40 m/s

Initial characteristic measurements of the geometry were assumed as a ratio of intake surface to the surface of propeller actuator disc to the ratio of outlet to the surface of propeller working disc. The geometry marking 1.69/1.09 says that it is the geometry of inlet surface equal to 169% of the propeller disc and the outlet surface equal 109% of the propeller disc.

For the purpose of the experiment a computer measurement system was used in a module version operating in DasyLab environment. This allowed for conducting the experiment according to the requirements of modern metrology. The frequency of probing was 10 000 Hz, and the size of sample was 4096 points for each channel. Initial pilot measurements were made, and then 33 most promising configurations were selected. The range of intake regulations ranged from 238 mm to 405 mm, what makes from 60 to 177% of the propeller disc. The measurements were made within 10 days in 2 months (February – May), when pressure, humidity and temperature changed. The aim of the experimental research was to examine the influence of shroud geometry changes on aerodynamic characteristics of the power unit and to increase the usability of ducted propeller by the velocities that have been uneconomical so far or this type of drives without variable geometry. The investigation was conducted in aerodynamic tunnel TA 1000 in the Department of Fluid Mechanics and Aerodynamics in Rzeszów University of Technology.

RESEARCH RESULTS

The information was obtained about the aerodynamic characteristics of individual geometries, e.g. change of thrust coefficient for different outlet geometries for constant intake diameter and for reverse situation. The largest static thrust was obtained for the largest possible opening of average outlet dilation (geometry 1.75/1.16), what is in line with the theory of ducted propeller theory [1, 2, 7]. The increase of flow velocity in the front part of the tunnel, which is an airfoil, by the work of the propeller and advance velocity cause significant velocity increases in the leading edge, thus significant underpresure that gives a resultant pointed forward which generates an additional thrust. Slight broadening of the part of duct behind the propeller's disc is used to lower the velocity of outgoing air from the shroud, what makes the energy loss significantly lower. For geometry 0.67/0.63 the largest velocity of thrust zeroing was obtained, larger than the velocity thrust zeroing of the propeller itself.

The results of the experiments are still at the stage of processing, however, initial conclusions can be already drawn. For a given power unit, for individual geometries the relation between the ability to generate static thrust and thrust for large velocities is reversely proportional: the larger thrust increase, the larger resistance and lower total thrust of the drive for larger velocities with geometries generating the largest thrust. By changing the shroud geometry, its efficiency can be increased significantly.

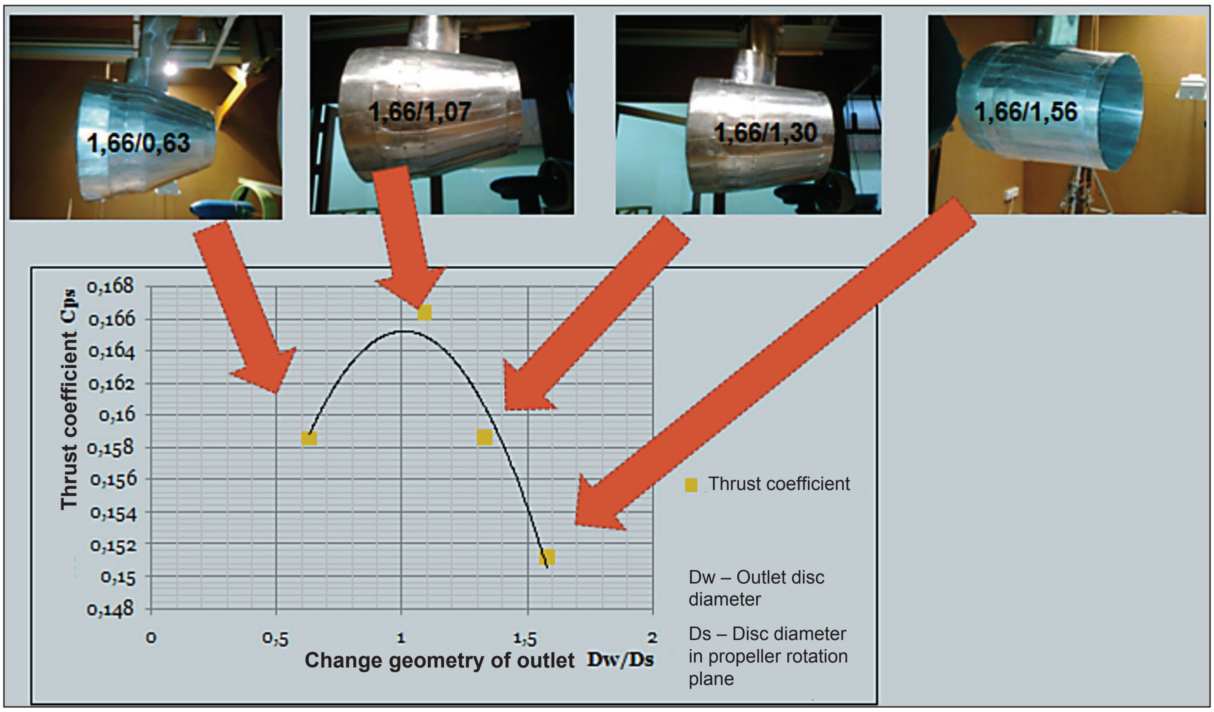

Fig. 3. The value of thrust coefficient for the changing outlet geometry of constant inlet diameter of 166% of the propeller disc for 5 m/s

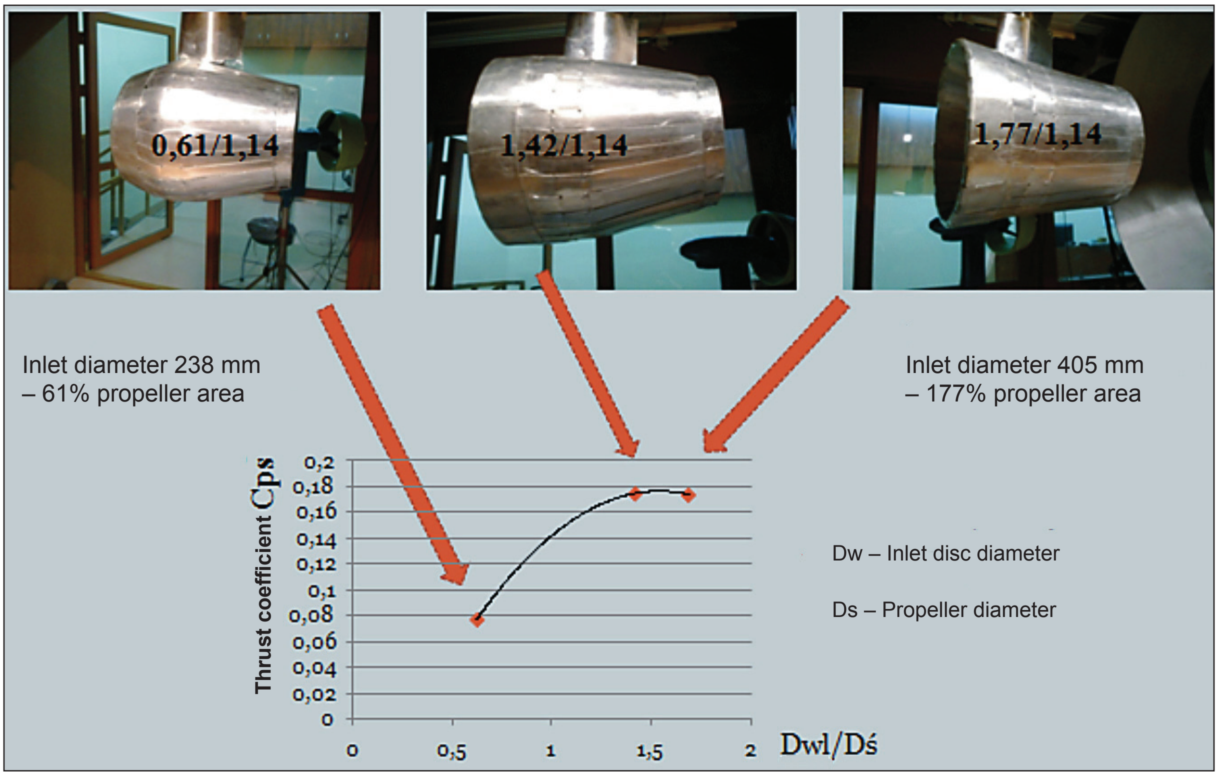

Fig. 4. The value of thrust coefficient for the changing inlet geometry of constant outlet diameter of 325 mm for 5 m/s

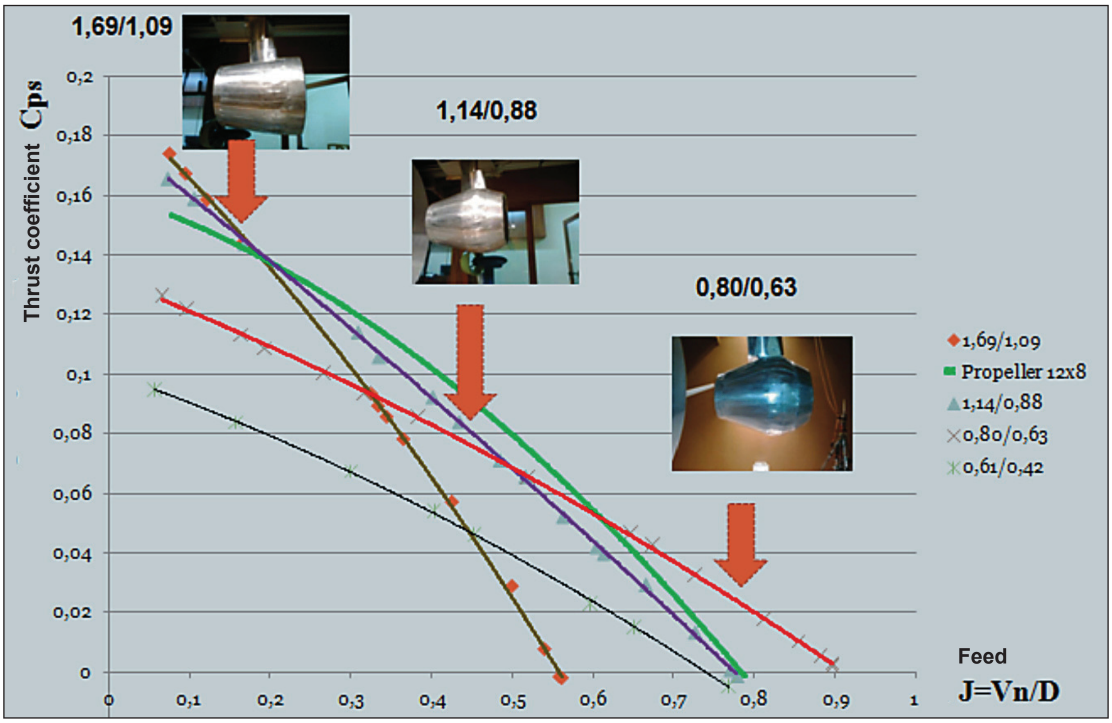

Fig. 5. The list of thrust coefficients and feed for selected geometries

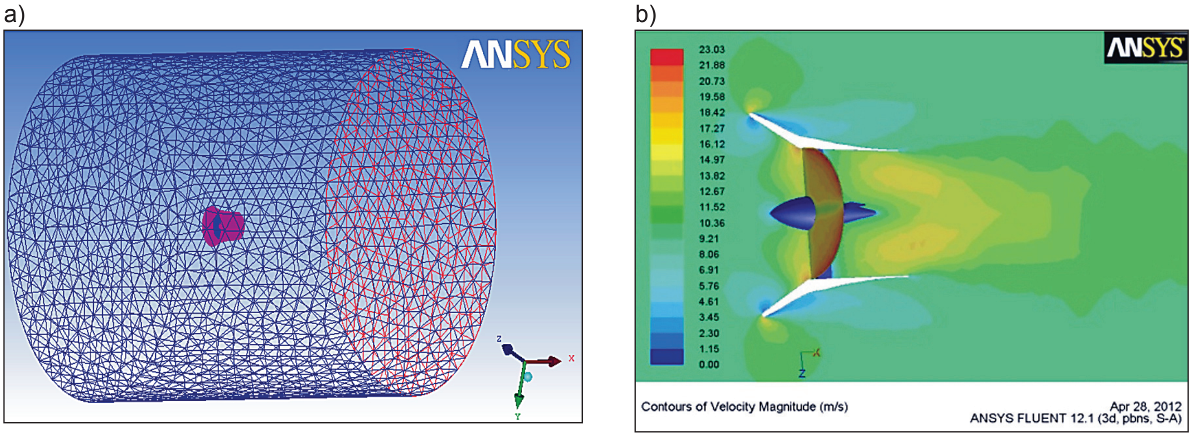
a)
b)

Fig. 6. a) Calculation domain with the model, b) distribution of velocity for geometry 1.69/1.05

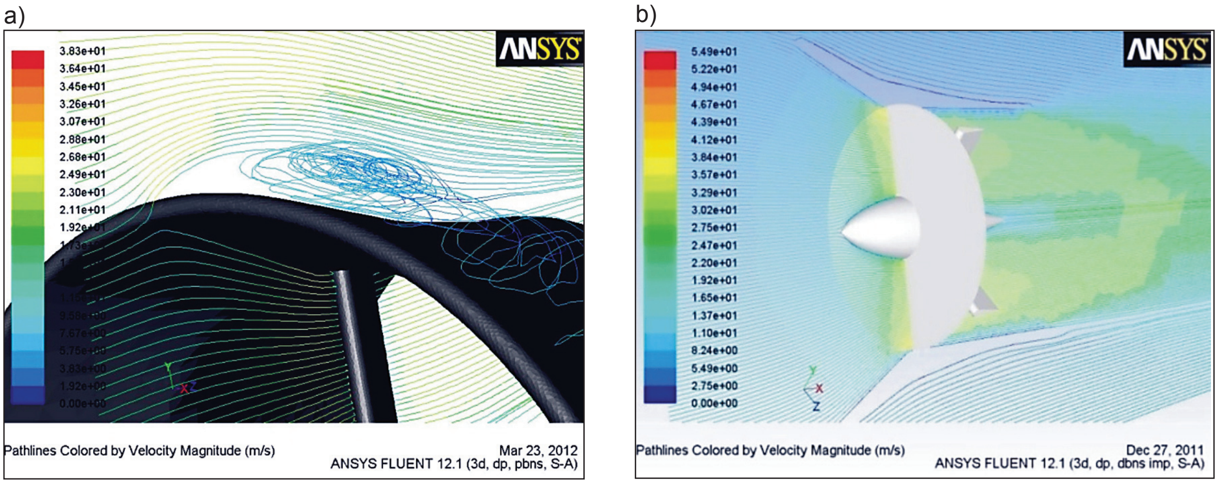
a)
b)

Fig. 7. Distribution of velocity with the flow lines of shroud 1.69/1.05 for 5 m/s for cases:
a) without a propeller, b) with the propeller – pressure step

Numerical research of flows were made with the method of finite volumes with a commercial bundle Ansys/Fluent. The continuation of numerical research in one of Polish academic centres is planned. The calculations are not at initial stage. In order to define optimum calculation conditions the comparative analyses of for the used non-structural, structural and hybrid grid, the model of flow and the method of mapping the wall surface and turbulence. In order to generate calculation grids ICEM CFD programme was used. In most simulations concerning the body a grid of PRISM type "wall layer" was used. In the area of the domain, a grid of TETRA type was used. The connection between the wall layer and body surface was made of PYRAMID elements. Numerical examinations will be conducted for a number of model configurations, in the first stage, for the shroud only – without the propeller; only after the results comparable to experimental data a propeller will be added with FAN function. It allows reconstructing the flow generated by the work of a given element, without giving its detailed geometry. The condition is defined by the moment added to the surface, proportional to the given pressure step.

In the visualisations of flow field with the flow lines the disorders in outer surface of shroud surface characteristic eddies and irregularities for the flow without the propeller can be seen.

CONCLUSIONS

Ducted propellers have many advantages, yet their basic disadvantage is their lower efficiency in comparison to free propellers. Our research shows that the change of shroud geometry has a significant influence on the change of aerodynamic characteristic of the drive and can make the quickest way to improve efficiency/productivity of the drives in certain ranges of velocities (propeller advancement). The development of advanced design methods allows generating new and more complicated tools. Advanced design systems using FSI analysis and the works on memory shape alloys can have a significant influence on the development of drive systems. The range of using such solutions is still enlarging – small and medium haul aircraft market and GA planes. Also the military UAV constructions of vertical take-off and landing use ducted propeller equally often due to the possibility to load a small propeller with larger power and higher efficiency for small velocities of flight. Despite such a high level of complexity in such constructions, it seems that full-scale attempts are not so difficult and should be conducted as soon as possible, due to potential benefits.

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