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ANALYSES OF AIRFLOW AROUND DUCTED FAN PROPULSION SYSTEM IN PUSHER CONFIGURATION USING PIV METHOD

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Abstract

A ducted fan is a propulsion system which has a lot of advantages, especially much higher efficiency than unshrouded propellers for lower speed, high safety and much smaller diameter. Thus it is gaining more popularity especially in the UAV (Unmanned Aerial Vehicle) department.

The paper presents results of the wind tunnel tests, which concern an UAV in an inverted joined wing configuration, ILX-32 MOSUPS. In this case the duct is located shortly behind the wing, which may enhance aerodynamic interference. To take this into account, the wind tunnel test object included an aft part of the airframe.

The wind tunnel tests included flow visualization, which has been performed using PIV (Particle Image Velocimetry) method and more traditional techniques, such as minitufts and smoke. Additionally thrust measurements, for various configurations of propulsion system, including an unshrouded propeller, have been performed.

1 Introduction

A ducted fan is commonly used as a propulsion for low speed vehicles, like airships or hovercrafts. It is often considered as a light, single-engine aircraft propulsion as well. A reason is that the ducted fan has better performance, than typical propeller, for the speeds up to 50 mph ([7]). The static thrust of the ducted propeller may be 30% – 50% higher than the unshrouded propeller with the same diameter and power consumption [8]. Thus it is possible to reduce its diameter without reduction of thrust. This propulsion may also be less noisy than typical propeller ([8], [10]). The safety of this propulsion is also improved. Taking it into account, the ducted fan may be concerned as a propulsion of light airplanes, which are one of specialties of Institute of Aviation ([15], [16]).

In the publications, which describe the ducted fan (for example [2], [4], [7], [8], [14]), an axisymmetric model of the isolated propulsion is commonly used. However, in some cases this simplification seems to be inappropriate. Preliminary tests of the ducted fan designed for the large inverted-joined-wing UAV, ILX-32 MOSUPS ([5], [6], [9]) indicated that the static thrust of the isolated propulsion may be 25% greater than the thrust measured with a presence of airframe [2]. Taking this into account, the authors decided to analyze the flow around this ducted fan during the wind tunnel tests ([3]).

In the wind tunnel tests, the aft part (last 0.4 m) of the fuselage, with the vertical stabilizer and a root part of the aft wing have been modelled to simulate the conditions in which the propulsion system will be working in the aircraft.

2 Wind Tunnel Tests Technique

2.1 Investigated Object

The investigation covered the 5-bladed ducted fan designed for ILX-32 MOSUPS aircraft, with diameter of 14” ([2]). The fan was powered by a 3kW Turnigy RotoMax brushless electric motor. A power supply for the motor consists of 24 LiFe battery cells in 12s2p configuration (12 cells parallel, 2 in series). The voltage of fully charged batteries is 44.4V. The motor was controlled by a 120A electronic speed control unit. The input signal of this unit was generated by the National Instruments USB-6211 I/O card, installed inside the fuselage and connected to a computer.

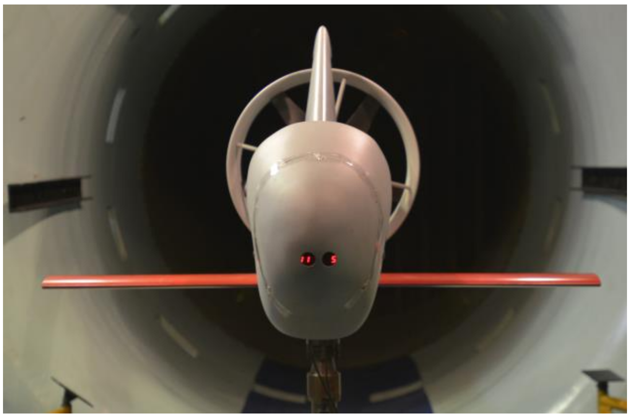

Fig. 1. The investigated object

The thrust of the propulsion was measured in two ways. First one was a dyno hidden in the fuselage and connected with the motor. The second way was the strain-gage balance HWG6 connected with the fuselage. The balance was also a fixing of the model to the wind tunnel test stand which enables setting the angle of attack and the sideslip angle of the object. Two ways of measurement was applied to determine changes of the fuselage drag caused by the propulsion.

2.2 Wind Tunnel

The propulsion wind tunnel tests was conducted in the T-1 wind tunnel in Institute of Aviation (Fig. 2), which is a closed-circuit wind tunnel with an open test section.

Fig. 2. T-1 wind tunnel

The diameter of the wind tunnel test section is 1.5m and the flow speeds ranges from 12 up to 45m/s. The tunnel is using a 55kW electric motor and a four-bladed constant speed fan. The speed is controlled by changing the angle of the blades (for higher changes) and vent flaps (for precise control of the speed) [3], [11].

2.3 Particle Image Velocimetry (PIV)

The PIV is a modern technique of measurement and visualization of the flow velocity field ([1], [12]). To make the measurement, seeding particles (the DEHC oil in this case) must be atomized in the flow. Droplets of the seeding are illuminated with lightsheet (i.e. a laser light, formed in a thin sheet by the lenses) and photographed by a camera. The diameter of a seeding droplet is a few microns. For every measurement the camera grabs two frames. The time interval between frames in presented measurements was Δt=80 µs. In the post-processing phase the measured velocity field is obtained by determination of the particles displacements (Adaptive Correlation scheme, with integration windows size of 64x64 pixels with 50% window overlap). The displacements are divided by the time interval Δt to calculate the velocity field. The outlier vectors and missing data was removed in post-processing with the use of average and median filtering [13].

The PIV system consisted of dual-cavity solid-state (Nd:YAG) nanosecond pulse laser and digital 4 MP camera. The frequency of measurements was 7 Hz. The flow was seeded with a droplets of Di-Ethyl-Hexyl-Sebacat (DEHS, CAS-No. 122-62-3) with mean diameter of 2 µm according to the seeding generator specifications. The Stokes number for the parameters of the flow and the particles was Stk = 0.02. In order to provide uniform seeding distribution in the test section, the seeding was introduced to the flow behind the investigated model (because of closed circuit of the wind tunnel). The particles images were recorded with Dantec Dynamic HiSense camera with 2048x2048 pixel sized sensor.

During presented investigation the velocity fields around the fan have been obtained in a vertical plane, distanced from the symmetry plane of the investigated object of 100 mm. The powered and windmilling fan have been investigated for angles of attack of 0°, 5° and 10°. The undisturbed flow speed was 25 m/s.

The velocity maps obtained by the PIV system were postprocessed to achieve the axial velocity distribution behind the duct outflow, along the line parallel to the fan's plane (as presented in Fig. 3). The Z=0 point is located on the fan axis.

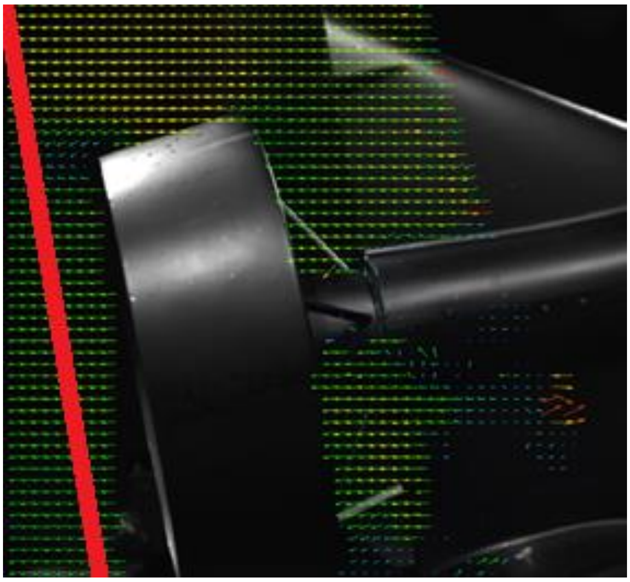

Fig. 3. An exemplary velocity field (free-wheeling fan, α=10°) and the line of outflow velocity distribution

3 Results

3.1 Powered Ducted Fan

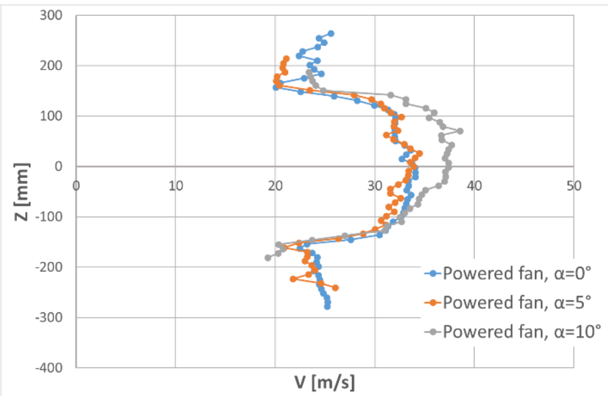

Fig. 4. Outflow velocity distribution behind the powered fan

In Fig. 4 the axial velocity distributions behind the duct outflow for various angles of attack and for the powered fan have been presented. The slipstream area is clearly visible as an area of increased flow speed. For the angle of attack of 0 and 5° the slipstream speed values are very similar (about 33 m/s), while for the angle of attack of 10° this value is equal to 37 m/s approximately. It means that this part of the ducted fan gives more energy to the stream, than for the lower values of angles of attack. However, it does not mean that the total thrust must increase, because in other areas of the stream, the speed and thus the energy, may be reduced.

Results of the thrust measurement (Fig. 5) indicate that the axial force coefficient increases with the angle of attack increment similarly as for the windmilling fan or for the test object without fan.

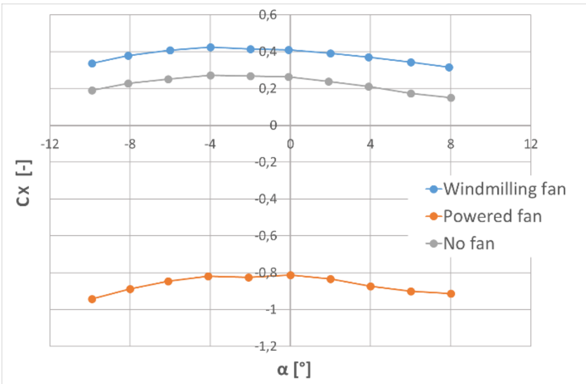

Fig. 5. Axial force coefficients for various configurations and angle of attack values

3.2 Windmilling Ducted Fan

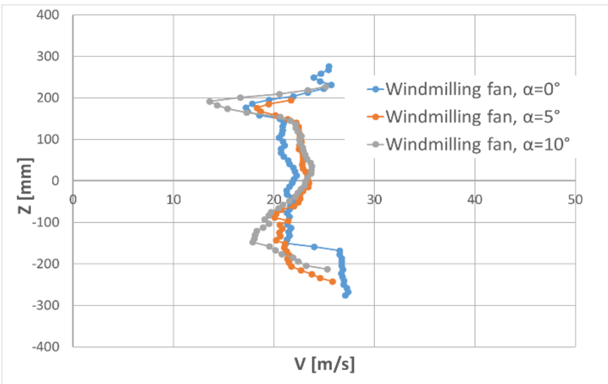

Fig. 6. Outflow velocity distribution behind the windmilling fan

In Fig. 6 the axial velocity distributions behind the duct outflow for various values of angles of attack and for the windmilling fan have been presented. For every value of angle of attack the flow speed behind the fan decreases to approximately 21÷23 m/s. One can also notice the areas of suppressed speed, which indicates sources of the aerodynamic drag. First area lies behind upper duct surface (for Z≈180 mm). In this area the speed decreases to 13÷18 m/s, depending on the angle of attack. For higher angle of attack the speed reduction is greater, which means that the aerodynamic drag of this part of the duct increases. It is an effect of the flow separation, as it is presented in Fig. 7 and Fig. 8. A tuft visualization presented in Fig. 7 shows that the flow separation appears in the upper half of the duct.

Fig. 7. A tuft visualization for windmilling fan, α=10°. A flow separation appears on the upper fan of the duct

The second area of reduced speed appears behind the wing and lower duct surface (for Z≈-150 mm) for high angle of attack. It may suggest that in this area the flow separation phenomenon occurs. In fact, for high angle of attack a vortex appears above the wing and in front of the fan (see Fig. 7).

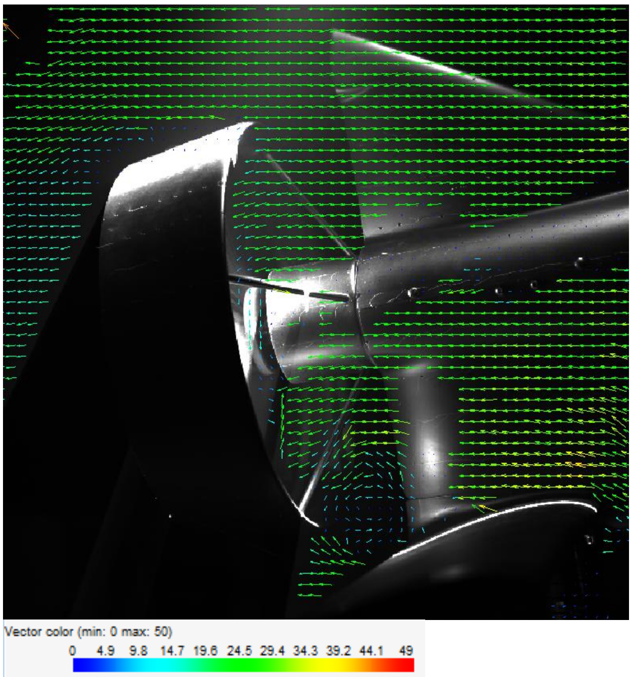

Fig. 7. The velocity field around windmilling fan, α=10°

4 Conclusion

As it was presented in the paper, the PIV method may be successfully applied to identify some phenomena, which appear in the flow around the ducted fan, like vortexes or flow separation areas. What is more, the quantitative results, like the velocity profile, may be used to find sources of the drag and to improve the propulsion's performance.

In further investigation, the velocity field should be obtained for other cross sections, to find a 3-dimensional distribution of the flow velocity.

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