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# WIND TUNNEL TESTS OF THE PUSHER PROPELLER – AN ASSESSMENT OF ACCURACY

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***Abstract***

*A pusher propeller is one of popular types of the airplane propulsion. It is applied especially in light sport aircrafts and in the UAVs (Unmanned Aerial Vehicles). Its main advantage is that the engine with the pusher propeller does not affect the visibility from the cockpit and allows placing an electronic equipment in the front part of the UAV's fuselage. The main disadvantage of the pusher propeller is that its performance may be worse than the tractor propeller, because of a stream distortion caused by the fuselage. It should be taken into account during propeller tests. The most accurate way is to investigate the pusher propeller in the presence of the complete airplane, as a part of airplane wind tunnel tests. However, this approach is possible in a late stage of the airplane design, when the geometry of the airplane is fixed.*

*In the paper, an alternative, innovative approach for the propulsion tests has been presented. The propeller was investigated in a wind tunnel in a presence of the aft part of the fuselage, including a root part of the wing. A typical propeller and a ducted fan have been investigated. The results has been compared with the results of the wind tunnel tests of the complete airplane (with powered propulsion) to evaluate the accuracy of this methodology. The investigated propulsion was designed for a joined wing UAV, ILX-32 MOSUPS.*

***Keywords****: air transport, air propulsion, wind tunnel tests, pusher propeller, ducted fan*

## 1. Introduction

A pusher propeller has been applied as an aircraft propulsion since early days of aviation and it still is a popular type of single-engine (rarely multi-engine) airplane propulsion. It may be applied especially in light aircraft, which are a specialty of Institute of Aviation [10, 11]. Advantages of this propulsion, according to [5], is:

- *Unobstructed forward view,*
- *Reduced cabin noise,*
- *Normal force aft of the centre of gravity increases stability,*
- *Turbulent high-speed wake does not flow over a fuselage or a nacelle, and, at least theoretically, will result in less drag,*
- *The stream tube will energize the flow in front of propeller and suppress flow separation on the body, even at high angle of attack.*

One of the most important disadvantages of pusher propellers is that *the fuselage ahead of the propeller may distort flow inside the stream tube, causing asymmetric disc loading and increased blade stresses. This distortion may affect the propeller's performance* [5]. Another problem occurs during take-off or landing, if the pusher propeller placed in the aft part of the fuselage. In this case, the angle of attack is high and the propeller blades tips are close to the ground. Thus, it is necessary to apply a high undercarriage. In this case, it may be advantageous to apply a ducted fan, which diameter may be smaller than a typical propeller, and a duct protects blades from hitting the ground. A ducted fan may also have better performance for low flight speed and be less noisy, than typical propeller [6, 8].

The following paper concerns a pusher propeller designed for the joined-wing UAV, ILX-32 MOSUPS (Fig. 1), which was intended as a scaled model of a future manned airplane. In this case, the canopy had to be placed in front of the front wing, because of requirements of good visibility. To keep the centre of gravity of the airplane in a proper location, the power plant had to be placed in aft part of the fuselage, i.e. in pusher configuration [4]. As a propulsion, a propeller and a ducted fan were considered.

*Fig. 1. ILX-32 MOSUPS in flight*

For investigation of MOSUPS, aircraft propulsion an innovative approach has been proposed in [2]. The investigated propulsion has been mounted to a model of the rear part of the fuselage. In this case, a root part of the aft wing has been included as well (Fig. 2). It was a way to model an influence of the airframe on the stream tube of the propeller without conducting the wind tunnel tests of the complete aircraft. An advantage of this approach is that the full-scale propulsion could be investigated in a small wind tunnel, which would be too small to process an investigation of the full-scale airplane. Moreover, the arrangement of the equipment was easier than in case of isolated propulsion.

The following paper presents a comparison of results of this investigation and results of wind tunnel tests of the full-scale MOSUPS aircraft (with and without a propulsion).

## 2. Wind tunnel tests of the propulsion

The investigation covered the 5-bladed ducted fan designed for ILX-32 MOSUPS aircraft ([1]) with diameter of 14”. Various fixed-pitch propellers have been investigated as well. The fan and all propellers were powered by the 3kW Turnigy RotoMax brushless electric motor. An electric power for the motor was supplied by 24 LiFe battery cells in 12s2p configuration (12 cells parallel, 2 in series). The voltage of fully charged batteries was 44.4V. The motor was controlled by the 120A Electronic Speed Control unit. The input signal of this unit was generated by the National Instruments USB-6211 I/O card, hidden inside the fuselage and connected to a computer.

A 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.

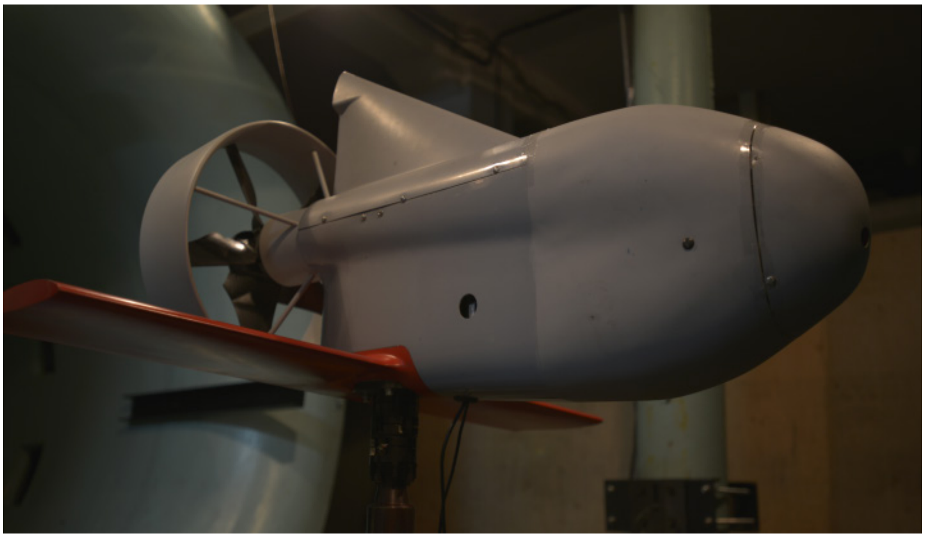

*Fig. 2. The ducted fan of ILX-32 MOSUPS investigated in the wind tunnel*

To enlarge an available time of measurement, the engine was turning on only for a few seconds, when the angle of attack and wind tunnel flow speed was stabilized.

The propulsion wind tunnel tests were conducted in the T-1 wind tunnel in Institute of Aviation (Fig. 3), which is a closed circuit, open test section wind tunnel. The test section diameter is 1.5 m and the flow speed ranges from 12 up to 45 m/s. The tunnel is using a 55 kW 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) [2, 9].

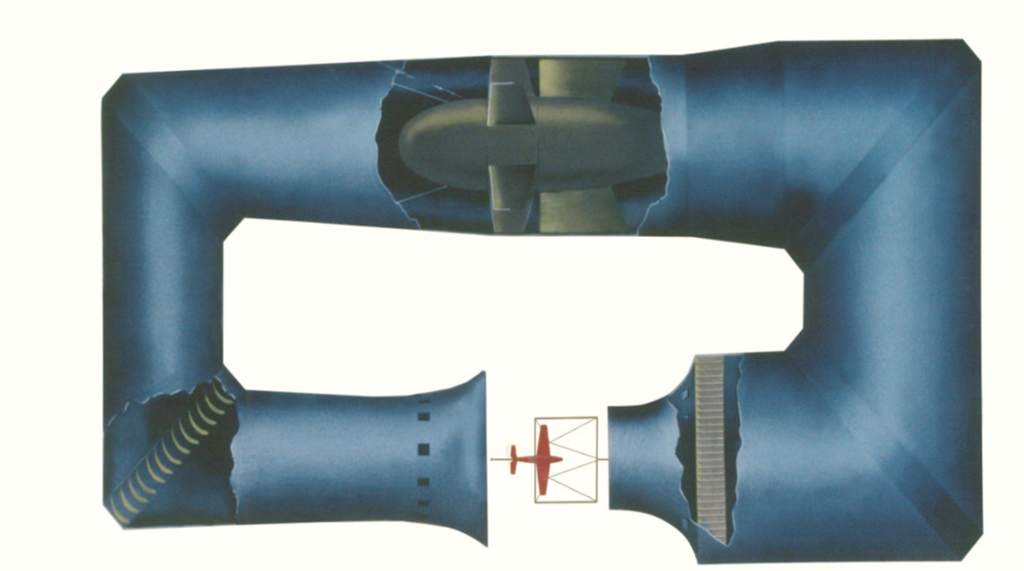

*Fig. 3. The T-1 wind tunnel*

## 3. Reference wind tunnel tests

The propulsion investigation was also a part of wind tunnel tests of the complete MOSUPS airplane (Fig. 4). This stage of wind tunnel tests programme concerned the first prototype of the airplane with the wingspan of 3.1 m and take-off weight of 25 kg. It was intended to use the investigated object to flight tests after completion of the wind tunnel tests. Thus, the measurement equipment used for the wind tunnel tests only was limited to the 6-component strain-gage balance I6B200 mounted inside the fuselage [3, 4, 7].

This part of the tests has been conducted in the T-3 wind tunnel, which is a closed circuit, open test section wind tunnel with the test section diameter of 5 m and maximum flow speed of 90 m/s. The wind tunnel is powered by the 5600 kW electric motor and the 8-bladed variable pitch fan.


*Fig. 4. The complete MOSUPS airplane in the T-3 wind tunnel*

## 4. Comparison of results

The tests in the T-3 wind tunnel were aimed mostly on obtaining aerodynamic characteristics of the airplane for analyses of its stability and performance. Thus, analyses of the propulsion in this wind tunnel were limited. Only two versions of the propulsion were investigated in both wind tunnels:

- Ducted fan in “V2” version,
- Fiala 20x10 propeller.

Both propulsions were investigated with powered and non-powered engine (the propeller/fan was locked or freewheeling). For the powered engine, a difference of axial force between powered and locked propeller/fan (effective thrust, $T$) has been obtained for both test objects. This approach was caused by the control system of the airplane engine, which locks the propeller/fan during non-powered flight. Thus, $T$ represents an effect of turning on the engine. Adopting this parameter enables an exploitation of results of the same wind tunnel run – for turned on and turned off engine.

In Fig. 5 the effective thrust versus flight speed has been presented for both types of propulsion and both test objects (for the angle of attack $\alpha$=0°).

For the propeller, the static thrust values obtained in both wind tunnels are nearly the same. The difference increases when the speed increases. It may be an effect of a wake behind the front wing and behind the fuselage. The thrust measured in the T-1 wind tunnel is slightly overestimated (the maximum difference is about 6 N for 25 m/s). For the ducted fan, the difference between effective thrust values obtained on both test objects are less – up to 4.5 N.

In Fig. 6, the effective thrust versus angle of attack has been presented for both test objects and for ducted fan only (for the speed of 25 m/s). In this case, the effective thrust values measured on both test object are very similar. The maximum difference is for angle of attack $\alpha$=6° and is caused by low battery power.

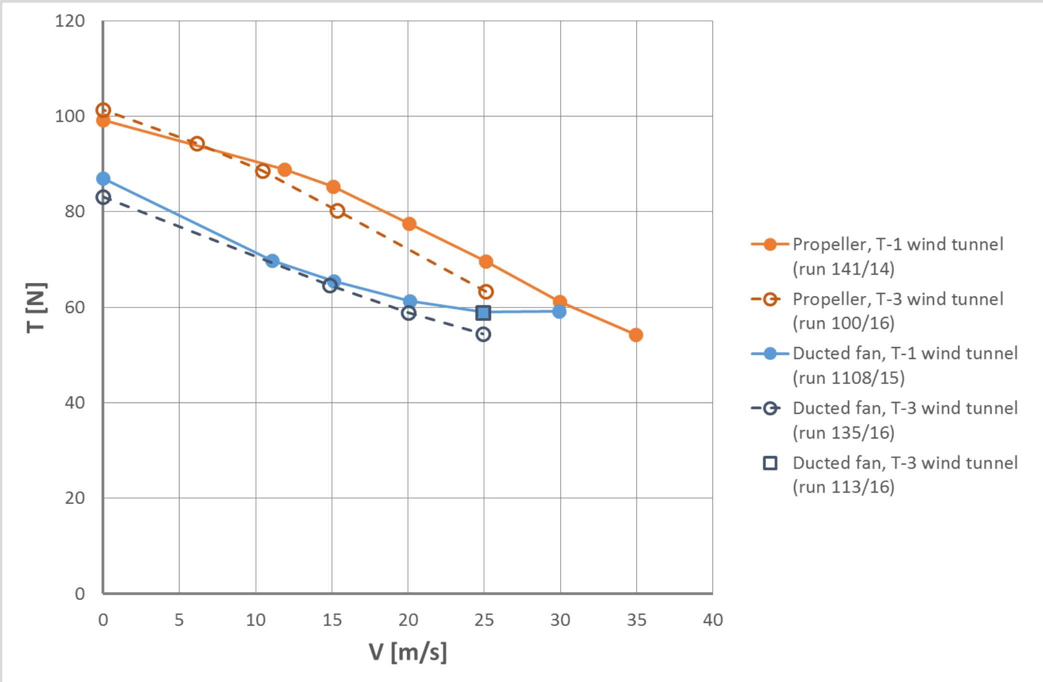


*Fig. 5. The effective thrust versus speed (α=0°)*

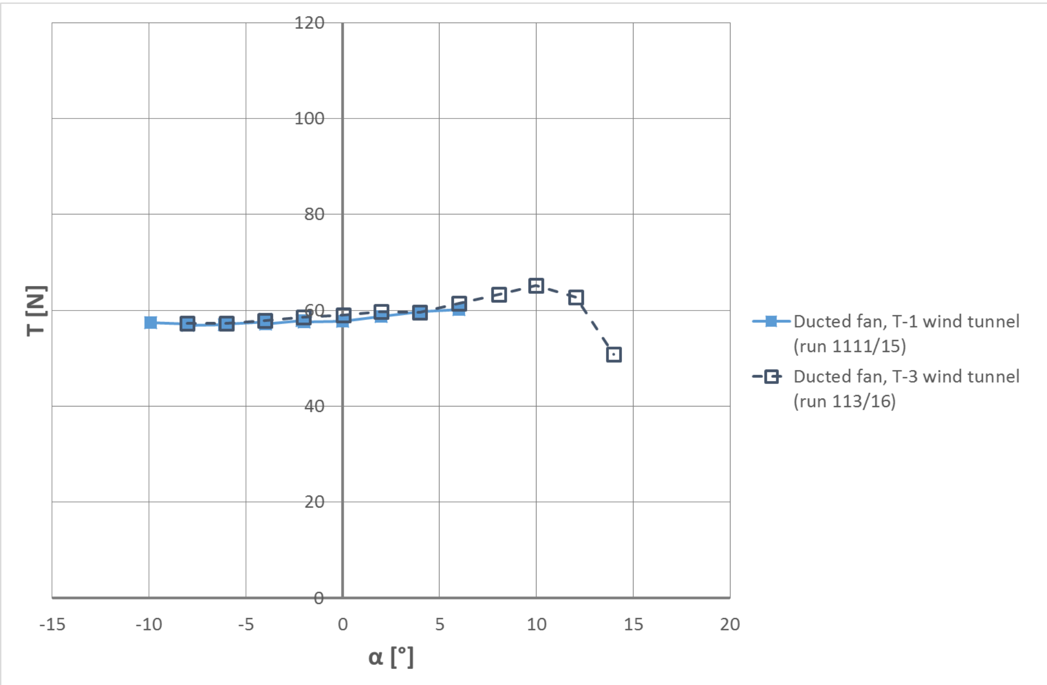


*Fig. 6. The effective thrust versus the angle of attack (V=25 m/s)*

It must be noted that for the ducted fan investigated in the T-3 wind tunnel two values of the effective thrust, measured in different runs for the speed of 25 m/s, are marked. A difference between them suggests that the test conditions were not the same. It may be caused by different values of rotational speed of the engine, battery charging or other parameters, which were not measured. In further investigation with application of this methodology, such measurement should be performed.

During the investigation of the ILX-32 MOSUPS propulsion a difference between the effective thrust measured in this way and on a complete airplane was not greater than 10% of the value measured on the complete airplane in the T-3 wind tunnel (Tab. 1).

Tab. 1. Comparison of effective thrust values for some characteristic cases

| | V | α | ΔT in T-1 | ΔT in T-3 | Difference | |
|---|---|---|---|---|---|---|
| | [m/s] | [°] | [N] | [N] | [N] | [%] |
| Ducted fan | 0 | 0 | 87.0 | 83.1 | 3.9 | 4.69 |
| | 25 | 0 | 57.8 | 58.9 | -1.1 | -1.87 |
| | 25 | 0 | 57.8 | 54.4 | 3.4 | 6.25 |
| Propeller | 0 | 0 | 99.3 | 101.4 | -2.12 | -2.09 |
| | 25 | 0 | 69.6 | 63.3 | 6.3 | 9.95 |

The measurement accuracy may be improved if a measurement of the electric power and rotational speed of the propeller or fan would be included to take respective corrections into account. In this case it was not possible because the airplane model was intended to flight after completion of the wind tunnel tests.

## 5. Conclusion

The comparison of results of wind tunnel tests, presented above, demonstrates that the thrust of a pusher propulsion (a propeller or a ducted fan) may be successfully investigated in a wind tunnel if a aft part of the airplane powered by the propulsion would be modelled. A difference between effective thrust values obtained in this way and during wind tunnel tests of the complete aircraft was not greater than 10%. The measurement accuracy probably may be improved if measurements of rotational speed and electric power of the battery would be performed.

An advantage of the methodology presented in the paper is that it may be applied during preliminary tests of the aircraft design. The investigated object may be smaller than a complete aircraft, so a smaller wind tunnel may be applied for the real-scale propulsion, which reduces costs of the investigation.

It must be noted that taking the aft part of the airplane powered by investigated propulsion into account is strongly advised for ducted fan tests. According to [1], a difference between static thrust values of the ducted fan measured with and without the aft part of the airplane was 25%.

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