TESTING THE THRUST OF JET FANS IN A WIND TUNNEL

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ABSTRACT

In this research item we present a comparison on the calculated theoretical thrust of jet-fans and the values measured on a test station located within a high-velocity wind tunnel. The aim of this research was to perform a direct measurement of the thrust of the jet fan, along with the electrical parameters of the fan motor and direct velocity measurements in the jet fan stream, in an environment with a pre-defined air velocity (wind tunnel). The research was performed on two types of jet-fans ((1) 355mm diameter, approx. 37 N nominal thrust and (2) 50 mm diameter, approx. 2,8 N nominal thrust). The jet fans were placed in a boundary layer wind tunnel, in a test section of approx. 4 x 3 x 10 m (W x H x L). As the wind tunnel has a rectangular cross section, different locations of the jet-fans were tested (bottom, middle), to unravel the effect of the configuration factor on the jet fan performance. The inlet air velocity varied from 0 m/s to 20 m/s. The goal of this research was to identify the performance characteristic of jet-fans, related to the ambient air velocity. This subject is important in the estimation of the jet-fan performance in analytical methods (such as PIARC manual) or in 1D modelling systems. Furthermore, the estimation of such performance is highly relevant to the use of jet-fans in ventilation ducts, as a mean to reduce the required operational pressure of exhaust fans in a long tunnels with transversal ventilation systems. The presented work will give an overview of the standardized methods for measuring and calculating the thrust of jet-fans, the results of the measurements performed in the road tunnel and a numerical analysis of a long exhaust duct with jet-fans installed (with and without modifications introduced after the wind tunnel tests).

Keywords: thrust, ventilation design, road tunnels systems, longitudinal ventilation,

1. INTRODUCTION

Tunnels built in Poland in most cases have longitudinal ventilation. The selection of appropriate jet fans is still very difficult due to the variability of their parameters in relation to the prevailing conditions inside the tunnel. Their effectiveness depends on the temperature, the flow velocity of the surrounding air as well as their location in relation to the tunnel geometry.

In longitudinal ventilation systems, the most important task is to maintain the appropriate flow velocity, necessary to maintain appropriate conditions in the comfort or fire ventilation mode. So the most important thing in the selection and design of jet fans is the appropriate determination of their ability to force flow in the tunnel. When fans are installed in a tunnel, their effective thrust will be limited compared to the value measured in ISO 13350. This is due to unfavorable fan placement (versus near walls and ceiling), non-centric placement within cross-section the tunnel and the ambient air velocity in the tunnel. These factors were investigated in this study.

2. MEASUREMENT INSIDE THE WIND TUNNEL

The measurements were based on continuous and simultaneous measurement of thrust, air velocity in the tunnel with temperature and fan power consumption. The thrust was measured in the fan axis, above the fan, while it was hanging freely on the lines (see figure 2 and 3). The power consumption of the fan with a diameter of 355 mm was measured separately for each phase. The fan was tested in the configuration of star "Y" (1st gear) and double star "YY" (2nd gear) at 50Hz power frequency. The Y configuration gives approximately half of the volume flow of the YY configuration. Additional variable was the location of the fan within the tunnel, as shown on Fig. 1. The smaller jet fan (50 mm, 2,7 N) was installed in various configurations near the floor of the tunnel, and also in a configuration of the pair of devices see Fig. 3, right.

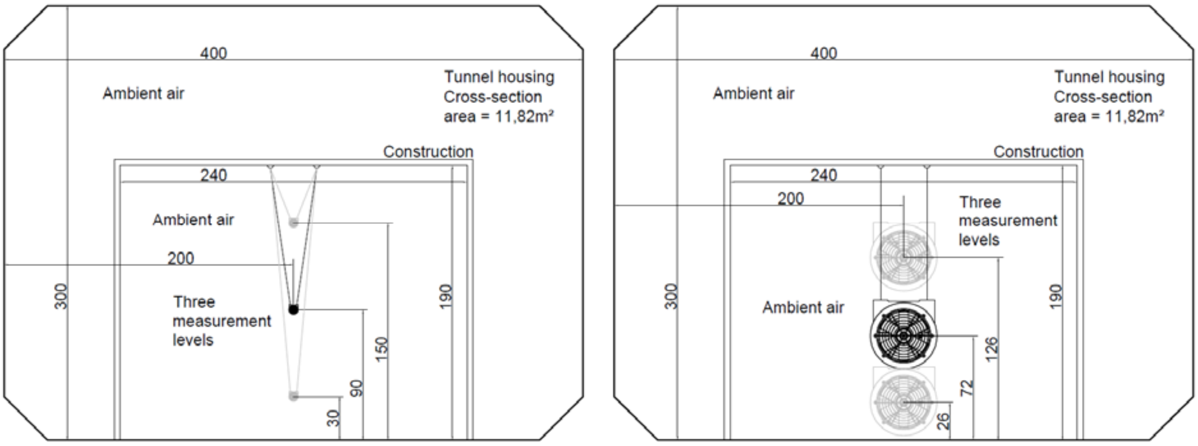

Figure 1: Measuring station, three measurement levels for jet fan 355mm, and three levels for jet fan 50 mm.

Figure 2: Thrust measurement (left) Jet Fan 355mm on the station (right)

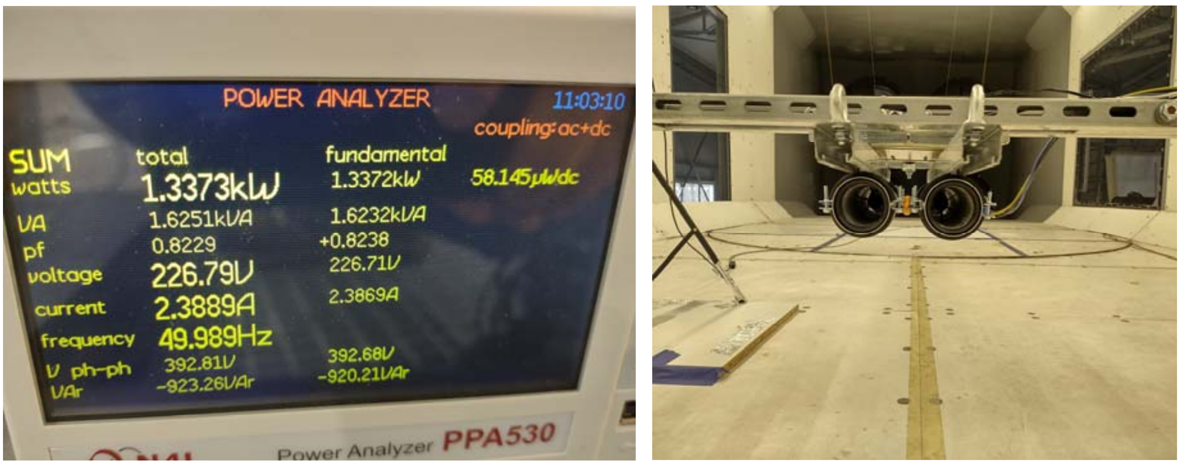

Figure 3: Power consumption measurement (left) A pair of jet fans 50mm (right)

All the measured thrust forces were brought to comparative values, ie. multiplied by (1,2/ρ) in accordance with [1]. Moreover, the thrust force determined theoreticaly, i.e. according to the formula, has been introduced:

$$T = \dot{m} \cdot (v_{jet} - v_{ambient})$$

Table 1. Theoretical thrust data

T	N	thrust
$\dot{m}$	kg/s	mass stream
v_{jet}	m/s	velocity in jet fan
$v_{ambient}$	m/s	ambient velocity

Table 2. Jet fan data to determine theoretical thrust

	v_{jet}	T
355, YY 2nd gear	18.08	37.34
355, Y 2nd gear	9.04	9.41
50, 1920x125	34.3	2.75
50, 1860x125	30.3	2.16

Theoretical thrust was always determined based on the thrust given by the manufacturer or measured outside the wind tunnel. The same as it is in design practice see table 2.

3. RESULTS

During the measurements in the "Y" configuration, the thrust in the range of about 5÷6 m/s corresponded to the theoretical thrust force. When measuring in the "YY" configuration, the thrust was always 0 N before the ambient velocity reached 14 m/s. The electric power consumption always decreased insignificantly with the increase of the ambient velocity.

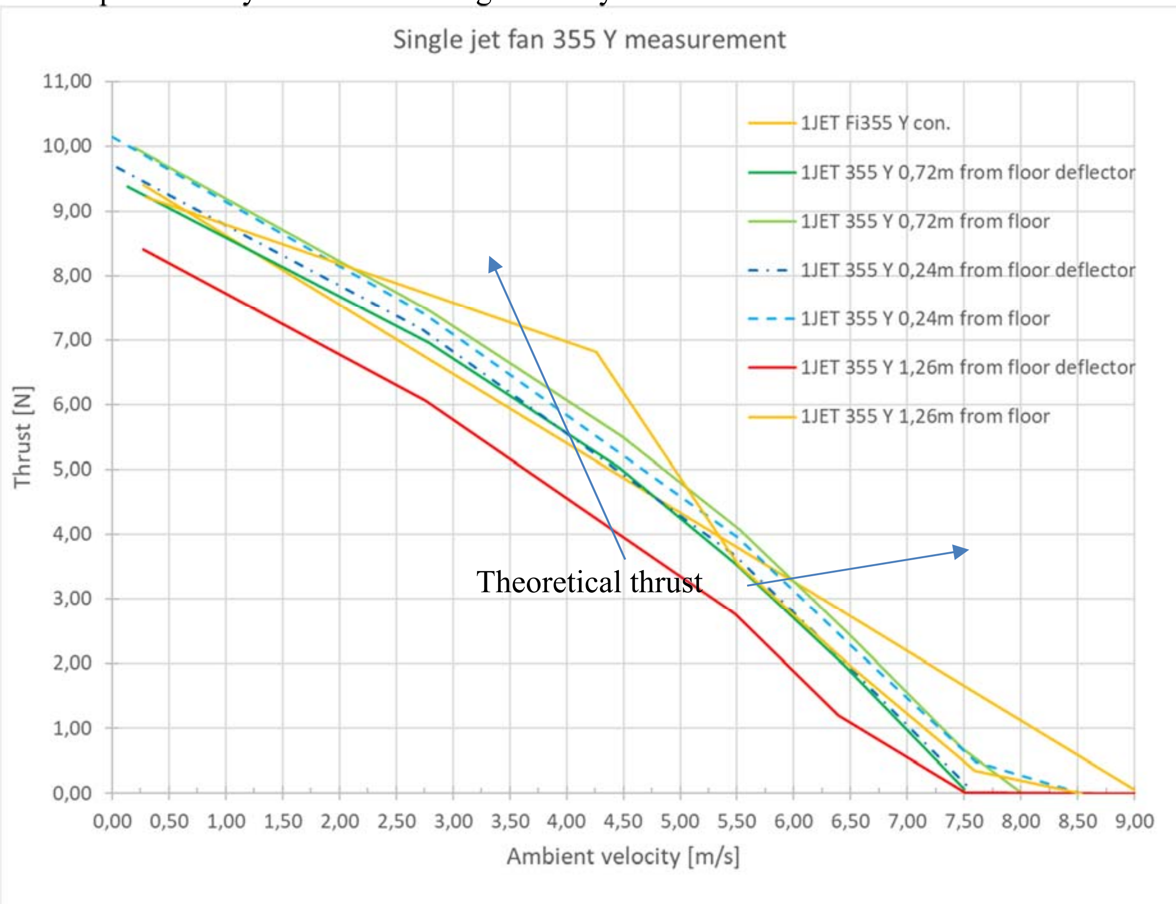

Figure 4: Measurement results for a 355mm jet fan in "Y" configuration.

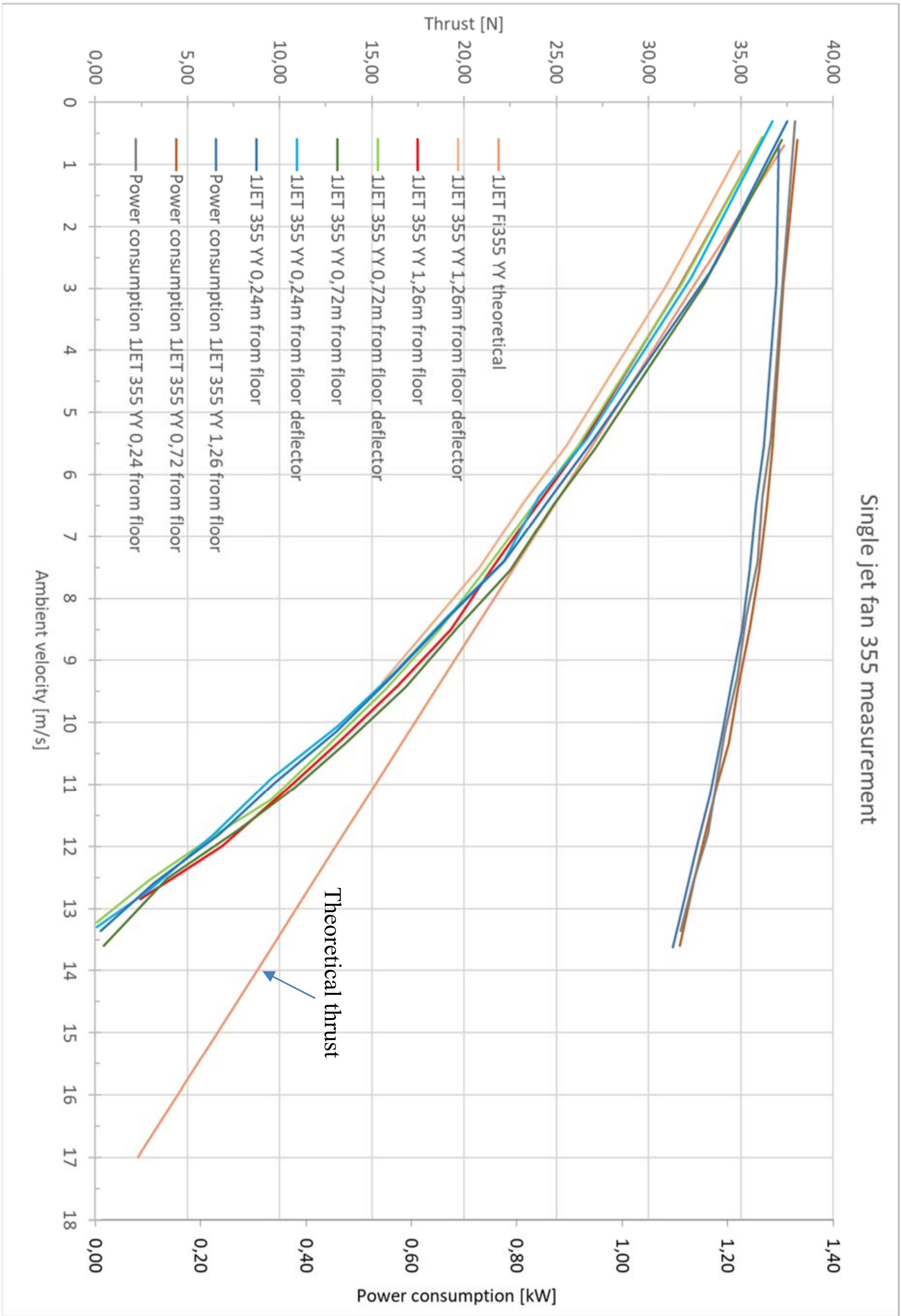

Figure 5: Measurement results for a 355mm jet fan in “YY” configuration.

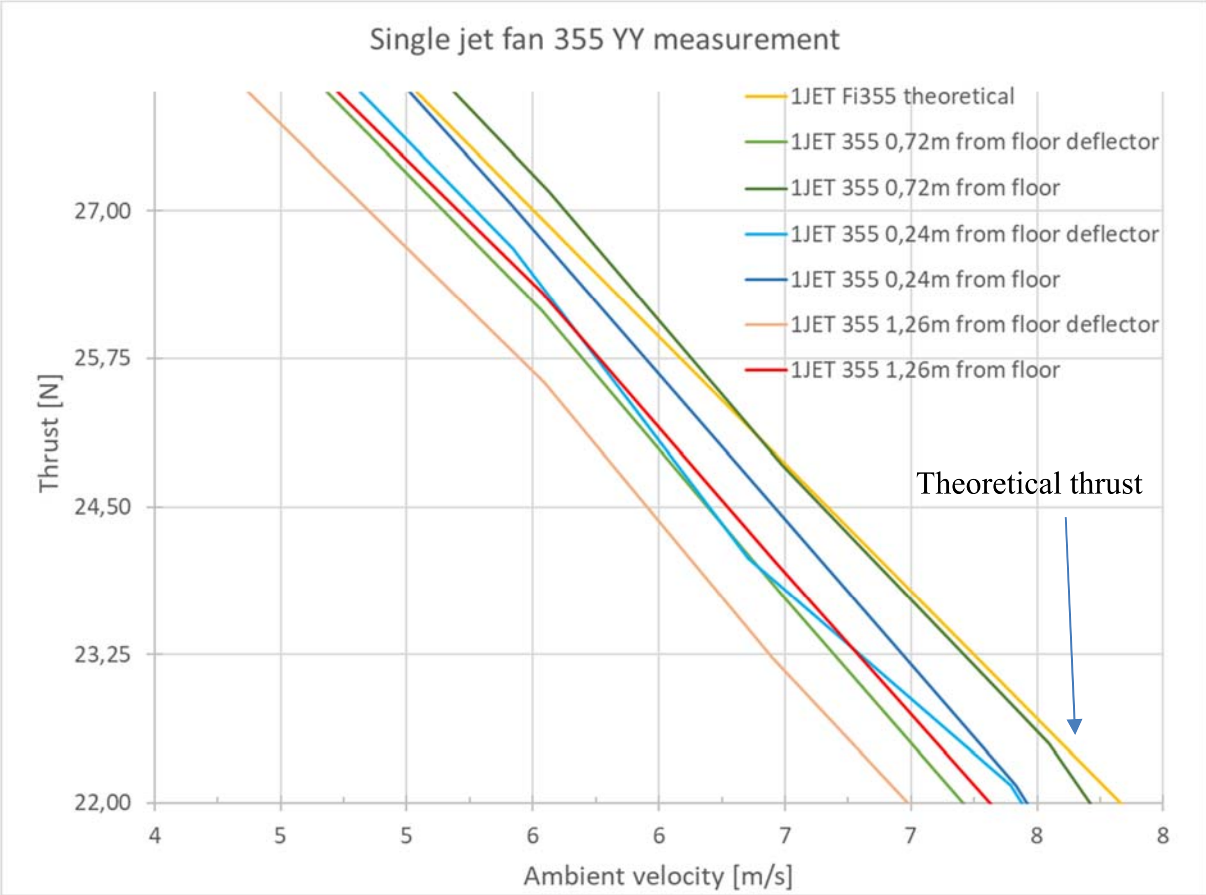

Figure 6: Clipping measurement results for a 355mm jet fan in “YY” configuration.

On the figure of the results from the YY configuration, it can be seen that the thrust force in each case for that particular jet fan had a greater value without the deflector than with the deflector.

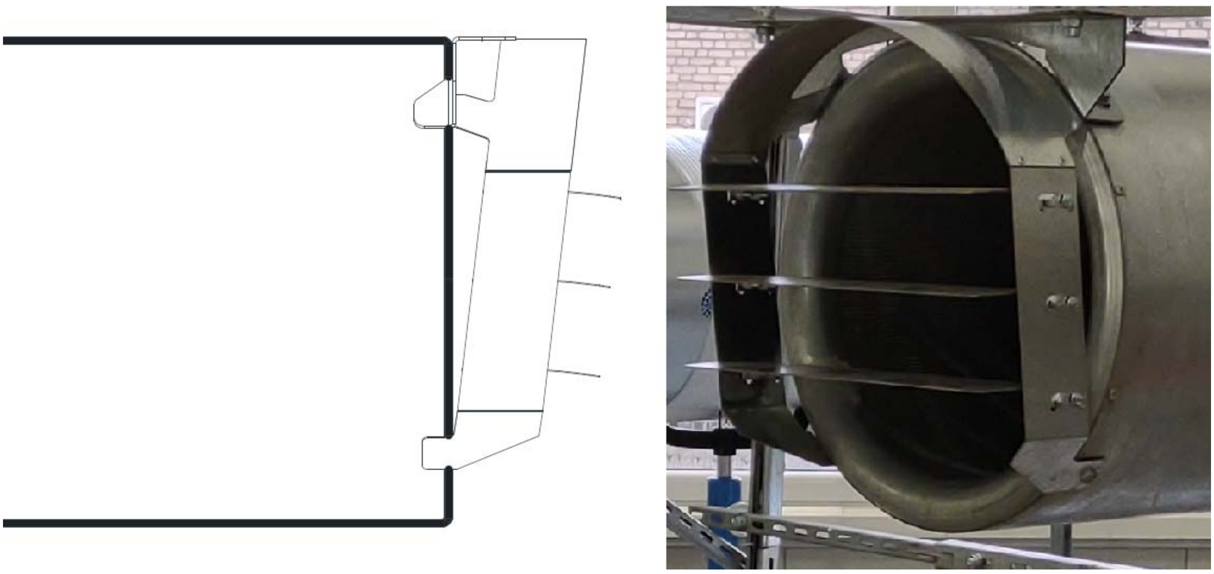

Figure 7: Detail of the deflector. Lamellas 0.1 m wide and 0° angle with respect to the flow axis

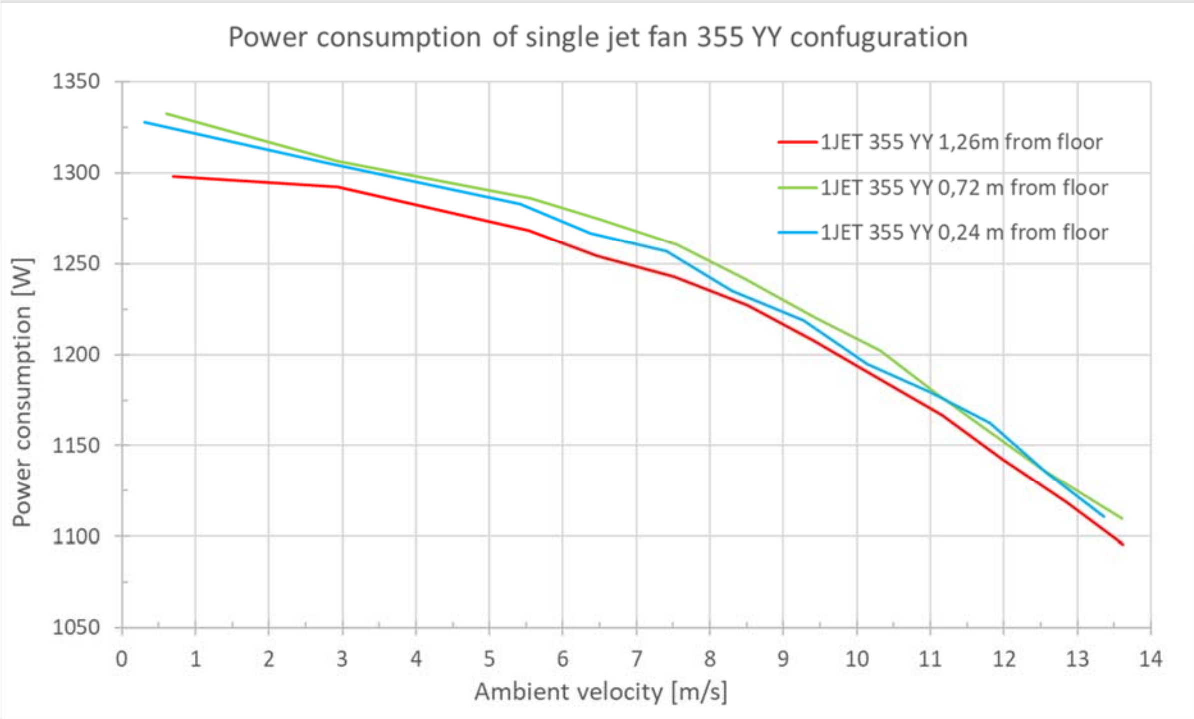

Figure 8: Power consumption measurement for a 355mm jet fan in "YY" configuration.

Figure 7. The jet fan gets its power from the mains also when its thrust is 0 N as it still generates the flow.

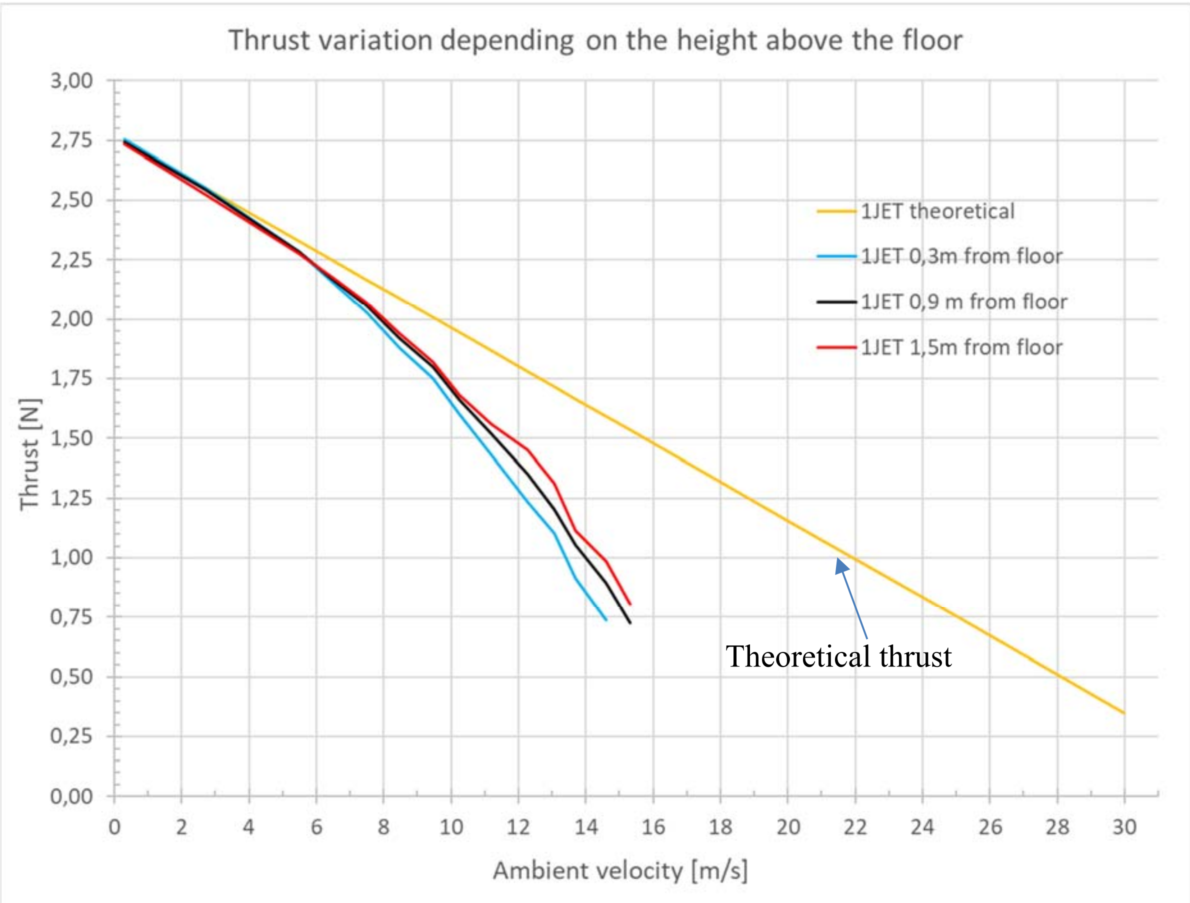

Figure 9: Measurement results for a 50mm jet fan in 1920x125 configuration (brushless motor).

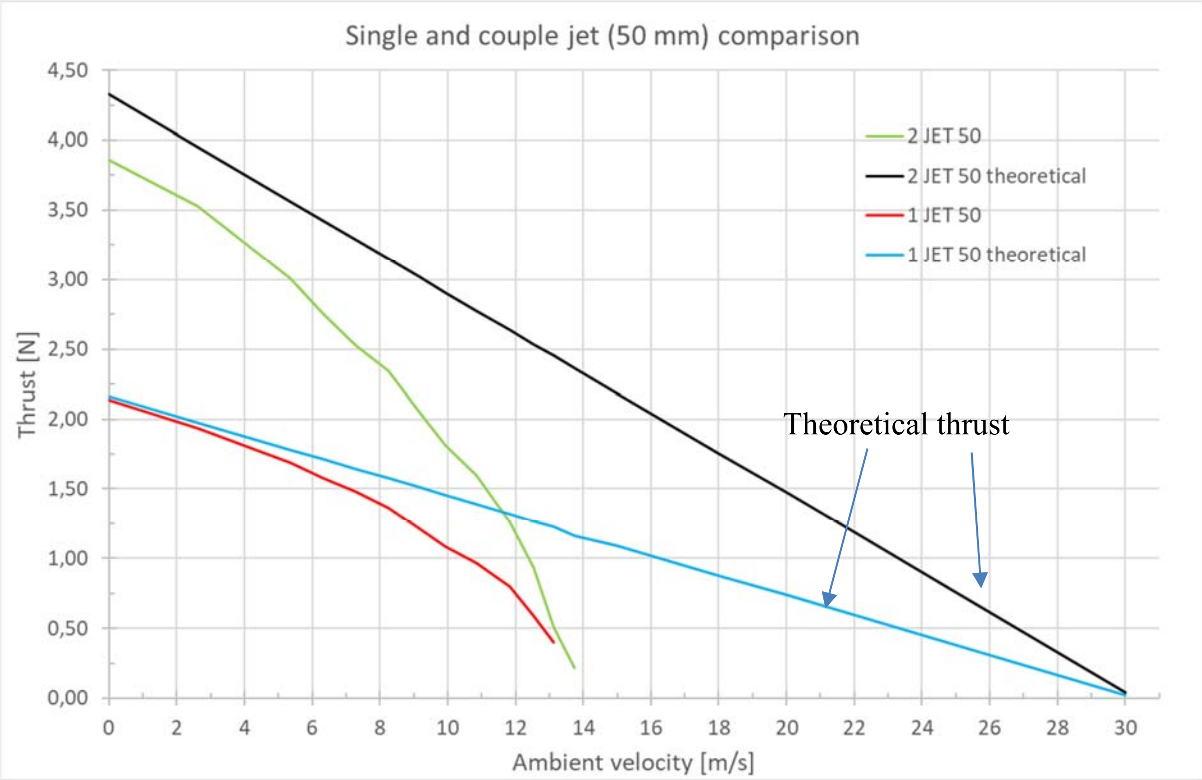

Figure 10: Measurement results for a pair of 50mm jet fans in 1860x125 configuration (brushless motor).

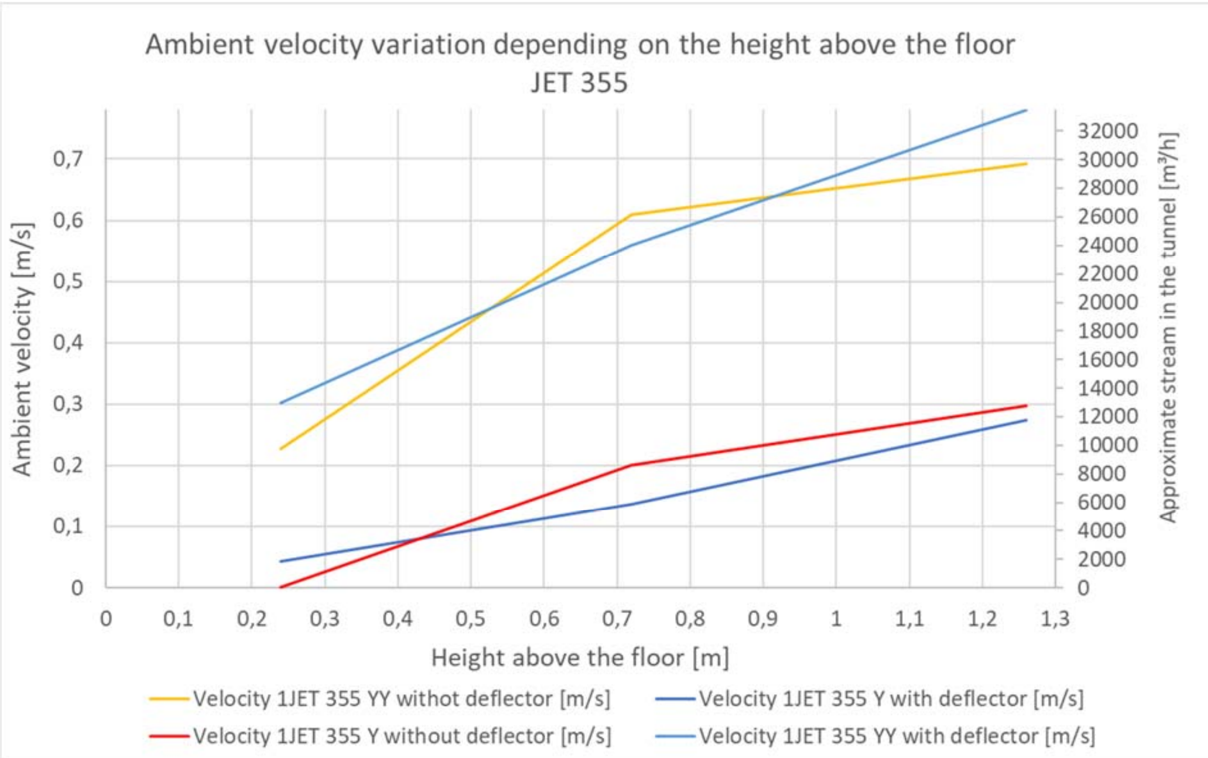

Figure 11: Measurement of ambient velocity during a 355mm jet fan working. Forcing the flow in the wind tunnel only by jet fan.

Induced air speed is highest if a deflector is used, but for the position 0,72mabove the floor the induced air speed is highest without a deflector (same tendency for the Y and YY - configuration). The reason is that the induced air speed is a result of both the theoretical thrust of the jet fan and the mounting factor as a measure for the efficiency of thrust conversion to genrating the flow.

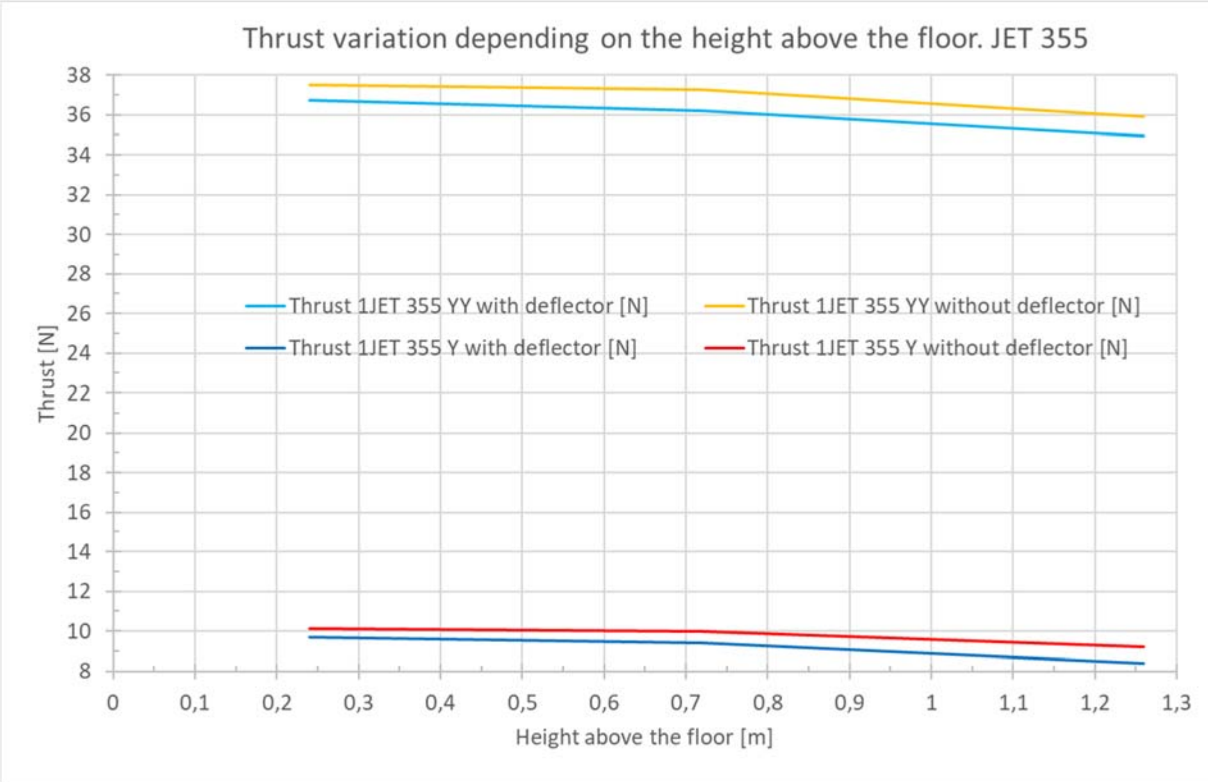

Figure 12: Measurement of thrust a 355mm jet fan. Forcing the flow in the wind tunnel only by jet fan.

Figures 11 and 12 relate to the same measurements who were taken when the fans of the wind tunnel were off. So the ambient velocity was induced by the jet fan 355 installed inside the wind tunnel. The magnitude of the generated speed and the approximate air flow in the wind tunnel are shown in Fig. 11. The flow generated in this way influenced the inlet of the jet fan, thereby reducing its thrust slightly see fig.11. It works like a feedback loop.

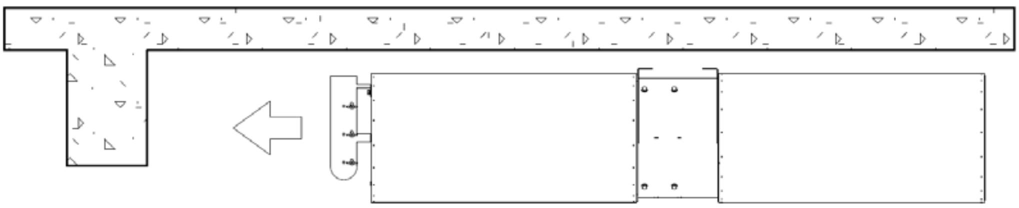

Figure 13: Obstruction in front of jet fan outlet

The thrust remains constant regardless of obstructions in front of the jet fan outlet fig. 13 as long as the fan is able to maintain its own flow. Parallel rough surface of the tunnel wall in relation to the flow does not affect the thrust.

4. CONCLUSIONS

Theoretically determined thrust from a practical design perspective may deviate significantly from actual flows in the higher velocity range f.e. above 6÷7m/s. In practice, however, design speeds are below 5 m/s.

In Figure 11 it can be seen that the same fan suspended at different heights generates different amounts of flows in the tunnel by induction. Flows differ from one another many times, although the thrust force varies slightly depending on the location above the floor in Fig. 12.

The thrust force does not determine the ability to induce air by the jet fan, nor the value of the generated flow.

There are many analytical factors in the literature that define the efficiency of jet fans depending on their location. On the basis of these measurements, it can be concluded that they relate to a large extent to the efficiency of generating the flow expressed by the basic value of the thrust force, and not to the thrust itself in practical terms.

In the practical design the thrust of the fan may not reach the expected value, due to installation factors and the loss of thrust with the airflow within the tunnel. The experiments performed here will be expanded to measure the flow generated by the jet fans, in order to determine the most efficient way to induce flow in tunnels.

Literature

[1] ISO 13350:2015 Fans — Performance testing of jet fans

[2] Michael Beyer, DI (FH) Eindimensionale Berechnungsmethoden zur Auslegung von Lüftungsanlagen in Tunneln unter besonderer Berücksichtigung dreidimensionaler Strömungseffekte. Institut für Verbrennungskraftmaschinen und Thermodynamik, TU Graz

[3] Road and Transportation Research Association (2006) Regulations for the equipment and operation of road tunnels. RABT.

[4] PIARC Technical Committee 3.3 Road Tunnel Operation (2008) Road tunnels: a guide to optimising the air quality impact upon the environment.

[5] Control of smoke flow using a jet-fan in an underground car park / Marek BOROWSKI, Marek JASZCZUR, Michał KARCH, Tomasz BURDZY // E3S Web of Conferences [Dokument elektroniczny]. - Czasopismo elektroniczne ; ISSN 2267-1242. — 2019 vol. 128 art. no. 10007, s. 1–5. — Wymagania systemowe: Adobe Reader. — Bibliogr. s. 4–5, Abstr.. — Publikacja dostępna online od: 2019-11-08. — ICCHMT 2019 : XII International Conference on Computational Heat, Mass and Momentum Transfer : Rome, Italy, September 3–6, 2019. — tekst: https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/54/e3sconf_icchmt2019_10007.pdf

[6] Parametry aerodynamiczne i charakterystyka wentylatorów strumieniowych — [Aerodynamicparameters and characteristics of jet fans] / Tomasz BURDZY // Chłodnictwo i Klimatyzacja ; ISSN 1425-9796. — 2020 nr 2, s. 50–51. — Bibliogr. s. 51.

[7] PIARC (2008), “Road Tunnels: Operational Strategies for Emergency Ventilation”, Technical Committee C3.3 Tunnel Operations, Working Group No. 6 Ventilation and Fire Control, World Road Association.

[8] S. Nawrat , S. Napieraj, Wentylacja I Bezpieczeństwo w tunelach komunikacyjnych, KU 0171pozycja wydawnictw naukowych Akademii Górniczo Hutniczej im. S. Staszica w Krakowie, ISBN 83-7464-026-X.

[9] Cao J, Tamura Y, Yoshida A (2013) Wind tunnel investigation of wind loads on rooftop model modules for green roofing systems. J Wind Eng Ind Aerodyn 118:20–34. https://doi.org/10.1016/j.jweia.2013.04.006.

[10] Ono Y, Tamura T, Kataoka H (2008) LES analysis of unsteady characteristics of conical vortex on a flat roof. J Wind Eng Ind Aerodyn 96:2007–2018. https://doi.org/10.1016/j.jweia.2008.02.021

[11] Wojciech Węgrzyński, Grzegorz Krajewski, and Grzegorz Kimbar. A concept of external aerodynamic elements in improving the performance of natural smoke ventilation in wind conditions. https://doi.org/10.1063/1.5019109

[12] Kempf, J. (1965), “Einfluss der Wandeffekte auf die Treibstrahlwirkung eines Strahlgeblases”, Schweizerische Bauzeitung, 83. Jahrgang, Heft 4.

[13] F. Tarada R. Brandt Impulse Ventilation for Tunnels – A State of the Art Review. 13th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, New Brunswick, New Jersey, USA, May 2009.
[14] Analiza poprawności odwzorowania wypływu strugi swobodnej izotermicznej z wentylatora strumieniowego — Analysis of the correctness projection of jet fan free isothermal airstream / Tomasz BURDZY, Marek BOROWSKI // Rynek Instalacyjny ; ISSN 1230-9540. — 2019 R. 27 nr 1-2, s. 19–22. — Bibliogr. s. 22.