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Aerodynamic Research of the Experimental Prototype of the Variable Geometry Wind Turbine

Aleksandrs Urbahs[1], Margarita Urbaha[2], Kristīne Carjova[3]

[1–3] *Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Latvia*

***Abstract* – The aim of this research is to develop a vertical rotation axis variable geometry wind turbine (WT). The experimental prototype is being manufactured with the help of CAM (Computer-aided manufacturing) technologies – computer-based preparation of the product manufacturing process. The Institute of Aeronautics of Riga Technical University is using CNC (Computer Numerical Control) machines for manufacturing the innovative WT and its components. The aerodynamic research has been done in T-4 wind tunnel at an air flow rate from 5 m/s to 30 m/s. The power increase of the variable geometry WT is a topical issue. Installation of such WTs in wind farms is possible and is subject to further research.**

***Keywords* – Aerodynamic experiment, computer-aided manufacturing (CAM), computer numerical control (CNC), vertical rotation axis, wind tunnel, wind turbine.**

I. Introduction

The world's energy consumption is constantly growing and it is likely to grow along with the development of different countries [1]. It is forecasted that by 2050 energy consumption in the world may grow by 3.5 times [2]. In accordance with the EU's climate and energy regulations, Latvia, as an EU member state, has to achieve the use of 40 % renewable energy sources out of total energy consumption. To ensure energy independence, it is essential to expand the use of renewable energy sources. This would support energy independence as well as inner entrepreneurship.

Wind turbines (WTs) can be classified either by their purpose or by their effectiveness, which is indicated by the conceptual scheme of the wind turbine – a type of rotation axis and rotor [3]. WTs can have both horizontal and vertical rotation axes. Turbines with horizontal rotation axis are called collinear, while turbines with vertical rotation axis [4]–[6], [8]–[10] – orthogonal. The turbine with the horizontal rotation axis is called collinear because its efficiency directly depends on the direction of the wind. According to Albert Betz's law, the maximum possible power coefficient that might be obtained by the WT in real environment is $\xi = 0.593$ [1]. Nowadays, collinear WTs may reach a power coefficient in the range of $\xi = 0.46$ to 0.47 [2], [8]. It means that the efficiency of these WTs is up to 47 % of air flow energy and it is notably close to the maximum possible value.

This research is being done for the market of low-power wind turbines, which is currently growing in Latvia and has great potential for use. The aim of this research is to develop a variable geometry wind turbine (WT). The experimental prototype is being manufactured with the help of CAM (Computer-aided manufacturing) technologies – computer-based preparation of the product manufacturing process [11], [12]. CNC (Computer Numerical Control) machines are being used for the manufacturing of the WT and its components. The power increase of the variable geometry WT is a topical issue. Installation of such WYs in wind farms is possible and planned for further research.

II. Experimental Prototype Development

It is possible to manufacture complicated shape and high precision components (blade profiles, folding rotor elements, tower parts, etc.) for the experimental prototype of the variable geometry WT with the help of automated production and CAM technologies. To manufacture the experimental prototype and its components, “Beaver VICTOR VW09” 3-axis milling machine and “StepDir 10060” laser cutting device are being used. The experimental prototype corresponds to the industrial prototype with parameters shown in Table I.

TABLE I

PARAMETERS OF VARIABLE GEOMETRY WT INDUSTRIAL PROTOTYPE

Parameter	**Value**
Power	1 kW
Weight	200 kg
Height (with foundation)	10 m
Foundation area	8 m^2
Rotor area	4 m^2
Rotor height	2 m

The WT experimental prototype is to be manufactured to a scale of 1:7 in compliance with the original drawings and assembly schemes (Fig. 1). All WT components are being manufactured in accordance with the planned materials – the tower is to be made of steel, the blades – of carbon and fiberglass composite materials, the drawbars and folding mechanism components – of aluminium and steel.

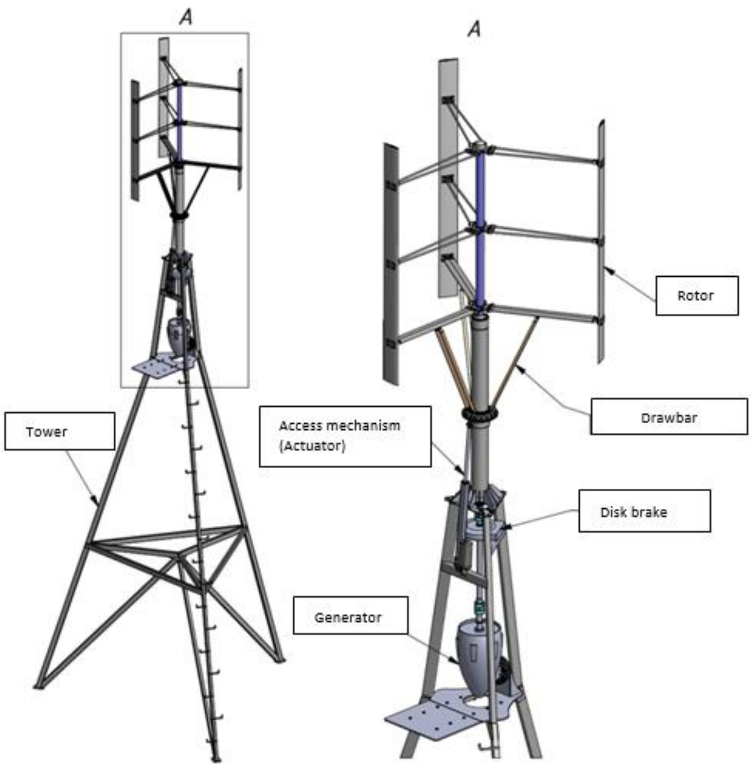

Fig. 1. Variable geometry vertical rotation axis WT.

The experimental prototype is being made for demonstration purposes, aerodynamic research, material and blade folding mechanism tests. There is a servomechanism attached to demonstrate how the rotor blades are folded and a micro generator for demonstration purposes.

III. AERODYNAMIC RESEARCH

Aerodynamic experiments require the use of proper equipment, i.e. extensometers, fasteners for blades and fasteners for wind tunnel balance [13]–[15]. Such equipment was manufactured from fiberglass by using CAM programs. Since this additional equipment may significantly affect the results of aerodynamic research, the components were manufactured with precision not less than 0.02 mm. After the manufacturing, configuration was done taking into account of the specific data of WT blade experiments. The aerodynamic research was done in T-4 wind tunnel [2], [3] at the Institute of Aeronautics of Riga Technical University (Fig. 2, Table II).

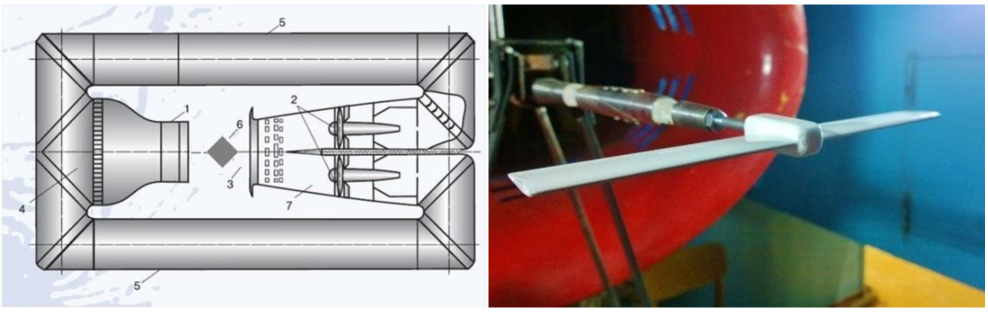

Fig. 2. Principal scheme of T-4 wind tunnel and WT blade experimental prototype during the aerodynamic research
1 – nozzle, 2 – fans, 3 – open work area, 4 – pre-chamber, 5 – return passage,
6 – research model with an alpha mechanism, 7 – diffuser.

TABLE II

TECHNICAL PARAMETERS OF T-4 WIND TUNNEL

Parameter	**Value**
Air flow velocity	5 m/s to 30 m/s
Air flow velocity (work area)	Up to 2×10^6
Total pressure	Atmospheric
Dynamic pressure	Up to 550 Pa
Number of motors	2
Max electric power	14 kW
Number of fans	2
Number of blades (each)	8
Work area dimensions	
Nozzle cross section (elliptic)	1.2 m × 0.7 m
Work area length	1.1 m

The flow rate was adjusted to determine the following parameters:

- blade efficiency at a given operating speed;
- blade characteristics;
- power coefficient;
- blade rigidity;
- construction strength;
- blade vibration;
- aerodynamic resistance factor;
- other parameters for determining the total efficiency of the WT.

The aerodynamic lift (C_L) and aerodynamic drag (C_D) at different angles of attack (α) of aerodynamic profile NACA 0012 blade can be seen in Table III.

TABLE III

AEROFOIL NACA 0012 RESULTS

Wing λ = 13.33			
α	C_L	C_D	E
0	0.000	0.0065	0.00000
2	0.132	0.0079	16.70886
4	0.263	0.0119	22.10084
6	0.397	0.0192	20.67708
8	0.528	0.0293	18.02048
10	0.660	0.0424	15.56604
12	0.784	0.0578	13.56401
14	0.905	0.0750	12.06667
16	1.020	0.0950	10.73684
18	1.098	0.1160	9.465517

The obtained results allowed the authors to calculate the aerodynamic quality E. As seen from the table, the maximum aerodynamic quality is reached when the angle of attack $\alpha = 4°$, which is considered as the optimal mounting angle of WT blades.

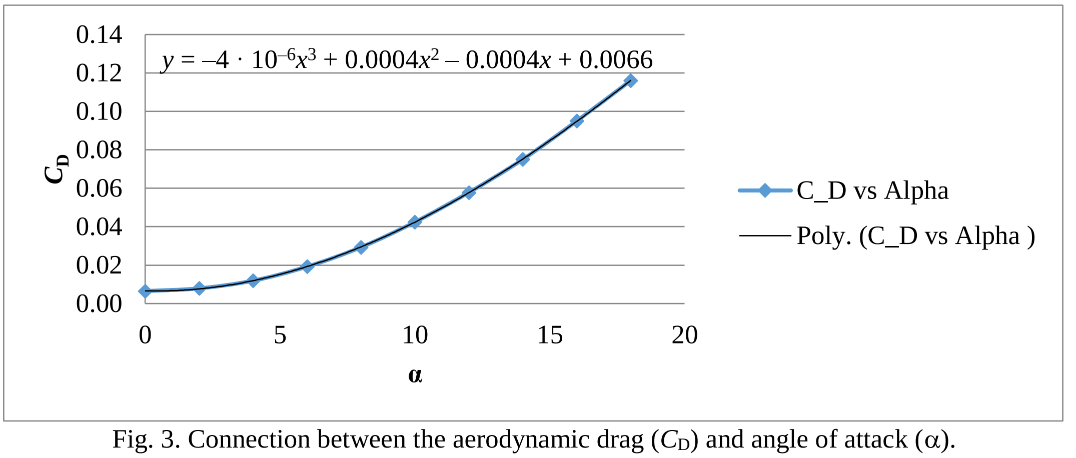

Fig. 3. Connection between the aerodynamic drag (C_D) and angle of attack (α).

In Fig. 3, the connection between the aerodynamic drag (C_D) and angle of attack (α) is seen. The aerodynamic drag increases along with the increase of the angle of attack, so the WT blade must be fixed with a bracket.

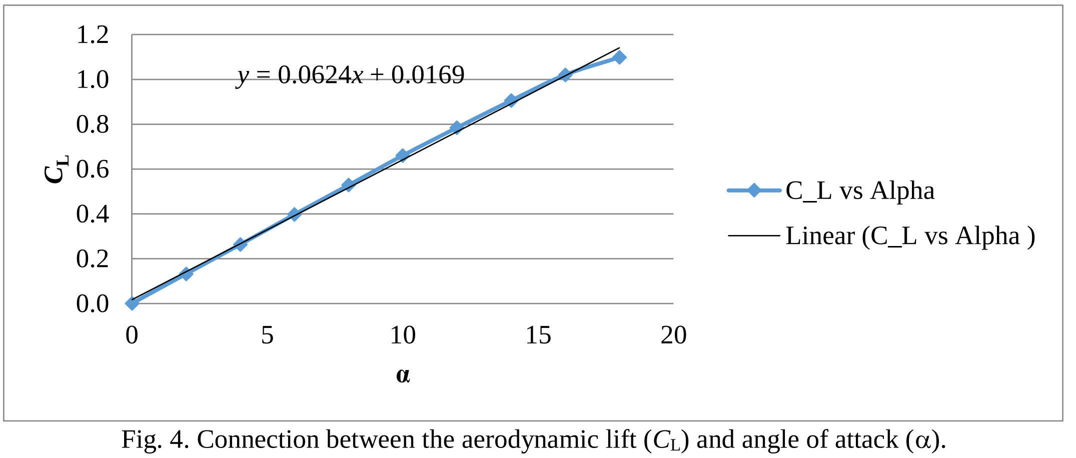

Fig. 4. Connection between the aerodynamic lift (C_L) and angle of attack (α).

In Fig. 4, the connection between the aerodynamic lift (C_L) and angle of attack (α) is seen. The aerodynamic lift increases along with the increase of the angle of attack, but it does not increase the aerodynamic quality.

WT initial data are provided in Table IV.

TABLE IV

WT INITIAL DATA

WT diameter	1.948	m
Radius	0.974	m
Wind speed	5	m/s
Rotation speed	130	RPM
Rotation speed	2.166667	RPS
Speed of blade	13.25962	m/s
Wing λ	5	
Wing λ	13.33	
Coefficient K_λ	0.375094	
C_X_0	0.0065	
Wing chord	0.15	m
Wingspan	2	m
Wing area	0.3	m^2
Air density	1.225	kg/m^3
ω	13.61357	
Wind velocity pressure	15.3125	

To calculate the power coefficient, the following formula was used:

$$C_P = M\omega = M2\pi n. \quad (1)$$

To calculate the speed ratio, the following formula was used:

$$Z = \frac{R\omega}{V_{\text{wind}}}. \quad (2)$$

The connection between the power coefficient C_P (1) and speed ratio Z (2) is provided in Fig. 5.

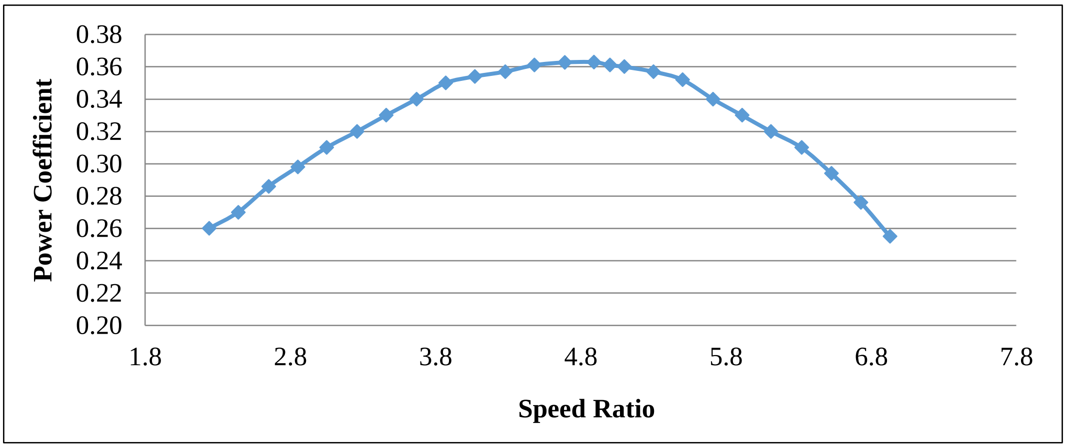

Fig. 5. Connection between the power coefficient and speed ratio.

From the calculated results it can be seen that the maximum power coefficient is reached at 130 rpm $C_P = 0.36$, which demonstrates the efficiency of the chosen aerodynamic characteristics and constructions.

IV. Conclusion

Vertical rotation axis WTs are a relatively new type of power plant, and they are still in the process of development. All of their analogues, which are currently available in the market, mostly have fixed geometry and massive braking systems, so they have the following disadvantages:

- special devices are needed to start up the WT;
- at high wind speeds and rotation speeds, WT blades have a large angle of attack, which leads to low efficiency;
- the reversed stress cycle builds up at forced WT stops and high wind speed, so significant safety factors shall be applied.

To avoid these disadvantages, it is not enough to install additional devices – the whole WT structure shall be reviewed. The automatic variable geometry is an innovative and energy efficient solution, because such a structure does not require human assistance during operation and continues to produce energy during low wind speeds.

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References

[1] A. Betz, *Introduction to the Theory of Flow Machines*, D. G. Randall, Trans. Oxford: Pergamon Press, 1966.
[2] Intergovernmental panel on climate change, *IPCC Special Report on Emissions Scenarios*, 2015. [Online]. Available: http://www.grida.no
[3] A. Urbahs, M. Urbaha, and K. Carjova, "Development and Assessment of Planetary Gear Unit for Experimental Prototype of Vertical Axis Wind Turbine," *Latvian Journal of Physics and Technical sciences*, vol. 54, no. 5, 2017. https://doi.org/10.1515/lpts-2017-0033
[4] E. M. Fateev, *Vetrodvigateli i vetroustanovki.* Moscow: OGIZ, 1948.
[5] P. Jamieson, *Innovation in Wind Turbine Design*. Wiley & Sons, 2011. https://doi.org/10.1002/9781119975441
[6] V. Lyatkher, *Wind Power: Turbine Design, Selection, and Optimization*. Wiley & Sons, 2013. https://doi.org/10.1002/9781118720851
[7] National Research Council. *Assessment of Research Needs for Wind Turbine Rotor Materials Technology.* Washington: National Academies Press, 1991.
[8] V. Rodionov, *Problemy nastojashhego i vozmozhnosti budushhego.* Moscow: JeNAS, 2010.
[9] Ja. I. Shefter and I. V. Rozhdestvenskij, *Izobretatelju o vetrodvigateljah i vetroustanovkah.* Minsk: Syelskogo Hoz-va SSSR, 1957.
[10] A. Urbahs, L. Ribickis, and R. Scavinskis, "Wind Powered Engine," LV patent No. LV14060, 2010.
[11] A. Urbahs and I. Jonaite, "Features of the Use of Unmanned Aerial Vehicles for Agriculture Applications," *Aviation*, vol. 17, no. 4, pp. 170–175, Dec. 2013. https://doi.org/10.3846/16487788.2013.861224
[12] A. Urbach, M. Banov, V. Turko, and K. Tsaryova, "The Characteristic Features of Composite Materials Specimen's Static Fracture Investigated by the Acoustic Emission Method," *Applied Mechanics and Materials*, vol. 232, pp. 28–32, Nov. 2012. https://doi.org/10.4028/www.scientific.net/AMM.232.28
[13] A. Urbahs, D. Titovs, M. Urbaha, S. Lučkinskis, and A. Aleksandrovs, "Multipurpose Alpha Mechanism for the Open-Jet Wind Tunnel," *Transport and Aerospace Engineering*, vol. 1, pp. 54–59, 2014. ISSN 2255-968X. https://doi.org/10.7250/tae.2014.010
[14] A. Urbahs, D. Titovs, V. Petrovs, S. Luckinskis, A. Aleksandrovs, K. Eglitis, "Aerodynamic Research Organization for a Novel Concept of Extremely Short Take-Off and Landing All-Surface Hybrid," in *Proceedings of the 3rd EASN Association International Workshop on Aerostructures*, Milan, Italy, October 9–11, 2013. pp. 266–275. ISSN 2309-7213. Available: http://www.easn.net/documents/?pagenum=2
[15] A. Urbahs, V. Petrovs, D. Titovs, S. Lučkinskis, A. Aleksandrovs, M. Urbaha, and K. Carjova, "Research of the Strain Gauge Balance Element for the Axial Force Evaluation in the Aerodynamic Experiment," *Journal of Engineering and Technology*, vol. 1, pp. 173–179. 2013. ISSN 1338-2330

Aleksandrs Urbahs graduated from the Faculty of Mechanical Engineering, Riga Civil Aviation Engineering Institute, in 1981. In 1986 he was awarded a Dr. sc. ing. degree by the same faculty. In 1997 he was awarded a Dr.habil.sc.ing. degree by Riga Aviation University. From 1989 to 1999 – Vice Dean and Dean of the Faculty of Mechanical Engineering, Riga Aviation University. Since 1999 – full-time Professor at Riga Technical University. From 1999 to 2012 – Head of the Institute of Transport Vehicle Technologies, Riga Technical University. Since 2012 – Head of the Institute of Aeronautics, Riga Technical University. Since 2017 he has been Associate Member of Latvian Academy of Science. He holds more than 20 patents and has published more than 320 scientific papers.

His fields of research: aeronautics, nanomaterials, non-destructive testing, structural materials, unmanned vehicles, transport systems and logistics.

Address: Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Lomonosova 1A, k-1, Riga, LV-1019, Latvia.

Phone: +371 67089990

E-mail: Aleksandrs.Urbahs@rtu.lv

Margarita Urbaha graduated from the Faculty of Transport and Mechanical Engineering of Riga Technical University in 2011 and she was awarded the degree of Dr. sc. ing. Since 2012 she has been a Senior Researcher at the Institute of Aeronautics, Riga Technical University, and an Associate Professor at the Faculty of Transport and Mechanical Engineering, Riga Technical University. From 2010 to 2012 she was a Researcher at the Faculty of Transport and Mechanical Engineering, Riga Technical University. Since 2005 she has been a Project Manager at the Faculty of Transport and Mechanical Engineering, Riga Technical University. She is the author of 51 publications and 39 conference presentations.

Her fields of research: aeronautics, unmanned vehicles, nano-composite coatings, non-destructive methods of control, transport systems and logistics.

Address: Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Lomonosova 1A, k-1, Riga, LV-1019, Latvia.

Phone: +371 67089990

E-mail: Margarita.Urbaha@rtu.lv

Kristīne Carjova graduated from the Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, in 2016 and she was awarded the degree of Dr. sc. ing. Since 2017 she has been Lead Researcher and Head of Aircraft Theory and Structure department. From 2011 to 2016 – she was a researcher at the Institute of Aeronautics, Riga Technical University.

Her fields of research: aeronautics, non-destructive testing, structural materials, unmanned vehicles.

Address: Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Lomonosova 1A, k-1, Riga, LV-1019, Latvia.

Phone: +371 67089990

E-mail: Kristine.Carjova@rtu.lv