THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620, e-ISSN 2668-3156
DOI: https://doi.org/10.35219/AnnUgalShipBuilding/2025.48.15
2025

AERODYNAMIC STUDY OF A RECREATIONAL VESSEL DESIGNED FOR NAVIGATION IN THE DANUBE DELTA

Miron Emanuel
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati,
47 Domneasca Street, 800008, Romania,
E-mail: em215@student.ugal.ro

Radu Bosoanca
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati,
47 Domneasca Street, 800008, Romania,
E-mail: radu.bosoanca@ugal.ro

ABSTRACT

The paper presents a study on the aerodynamic influence of wind on the hull of a sailing vessel, analysed both without sails and in full sail configuration, at different wind speeds and angles of incidence, in order to determine its aerodynamic torsor. The methodology included 3D modelling of the hull using Rhinoceros software, creating the lines plan, and building the physical model through printing and assembly. The resistance to forward motion was estimated using the Delft Series method, through tabular calculations in Excel and specialized software such as MaxSurf Resistance. The aerodynamic study itself was conducted in the naval wind tunnel, after calibrating the six-component balance and verifying the velocity distribution, with tests performed for the vessel both with and without sails, at various wind speeds and angles.

1. Introduction

The aim of the study was to identify the main dimensions of the sailing vessel, create a 3D model, and determine the hydrodynamic and aerodynamic characteristics, both with and without sails. Based on the 3D model and conducted analyses, the mast was validated, the optimal and maximum wind speeds for sailing were determined, and the optimal sail settings for maximizing lift were established. The results have direct applicability in planning tourist routes, reducing fuel consumption through the combined use of the engine and sails, and increasing passenger comfort by keeping the heel angle below 7°.

2. Ship description

The study focuses on the "lotca", a traditional wooden boat from the Danube Delta, valued for its stability, shallow draft, and manoeuvrability. Usually built from oak or poplar, it is equipped with a mast and a sail that assists propulsion in addition to rowing. Although not designed for speed, the lotca exemplifies efficient and sustainable navigation, adapted to the shallow waters and variable winds of the Delta.

In Table 1 the main characteristics of the ship are presented.

Table 1. Main characteristics of the vessel

L_{OA} [m]	9, 62
L_{WL} [m]	8, 94
L_{BP} [m]	8, 48
B [m]	2, 15
D [m]	1, 0
Bow height [m]	1, 77
Stern height [m]	1, 37
T [m]	0, 5
Displacement [t]	2, 7
v [Kn]	12

3. Methodology for creating the 3D model

3.1. Method for establishing the plane lines

The transverse dimensions of the boat were obtained through precise measurements using a level and laser device, establishing a reference line and regular measurement intervals along the longitudinal axis. The collected values were compiled and converted into half-breadths, forming the basis for the 3D model.

3.2. Creating the 3D model

Points from the half-breadths table were interpolated in Rhinoceros to generate the transverse curves, keel, and deck line. Surfaces were smoothed using the "Smooth" command, and the geometry was checked with "Check," "Zebra," and "Show Edges" for continuity and topological correctness.

Fig.1. 3D model

3.3. Creating the lines plan

The lines plan was constructed through longitudinal, transverse, and horizontal sections, graphically representing the theoretical hull surface. A network of vertical and horizontal lines on the plan facilitated the drawing of waterlines, longitudinal curves, and frames. The sections were numbered and organized to reflect the complete structure of the vessel, and the combination of the three projections formed the complete grid of the lines plan.

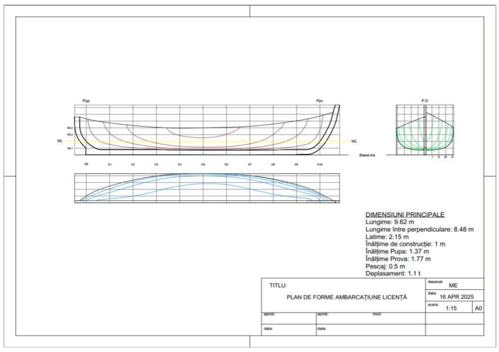

Fig.2. Lines Plane

3.4. Methodology for 3D printing the vessel

The model scale was chosen based on the wind tunnel dimensions, and the model was divided into immersed and emerged parts and then into sections suitable for printing. Each piece was analysed in OrcaSlicer for positioning, supports, print paths, and filament consumption.

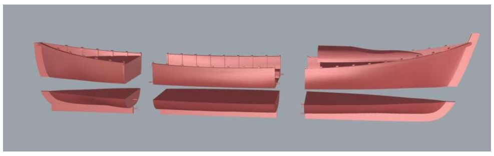

Fig.3. Division of the Submerged and Emerged Parts

3.5. Preparing the model for testing

Printed pieces were assembled, glued, filled, and sanded to achieve smooth surfaces. The model was painted, the mast and sails were constructed and mounted, and the centre of gravity was determined for proper fixation in the aerodynamic wind tunnel.

Fig.4. The Final Printed Mode

4. Estimation of Resistance Performance

The resistance to forward motion of this vessel was evaluated using three complementary methods: Max Surf with the Delft method, PHP for small ships using the Mordvinov-Papmel method, and the Delft III method employing spreadsheet calculations in Excel for a comprehensive practical assessment.

Thus:

Max Surf Resistance – Delft Method

- Based on a semi-empirical approach, founded on systematic testing of hull forms in hydrodynamic basins.
- The 3D model of the vessel was imported into the program, and analyses were performed for speeds between 10 and 14 knots.
- The total resistance obtained ranged from 2.7 kN to 4.2 kN.

PHP (Preliminary Hydrodynamics Performance) for Small Ships – Mordvinov-Papmel Method

- A program was developed for small vessels, which decomposes resistance into friction, viscous pressure, wave, and aerodynamic components, with corrections for appendages and empirical coefficients.
- The total resistance for the same speeds ranged from 2.49 kN to 3.85 kN, and at the vessel's service speed of 12 knots, RT = 3.13 kN.

Practical Delft III Method

- An improved version of the Delft series, including the effects of hull heel, leeway angle, and appendages.
- Total resistance is calculated as the sum of the components: friction (RF), residual (RR), additional resistance due to heel (RH), and aerodynamic (RAH, RAM, RAR).
- At 12 knots, RT = 3.43 kN.

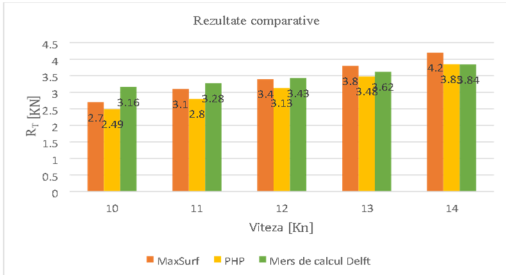

Fig.6. Ship resistance results

5. Pre- Experimental Methodology

5.1. Calibration of the Six-Component Balance

The calibration of the six-component hydro-aerodynamic balance (BH6) is a crucial step to ensure accurate and precise measurements, performed before each test. The process begins with aligning the balance base horizontally using laser levels, followed by mounting metal frames with pulleys to apply calibrated forces and moments. The BH6 software sets absolute and relative zero points, defines a 20 Hz sampling rate, and records load/unload cycles for translations (Fx, Fy, Fz) and rotations (Mx, My, Mz). Calibration constants and measurement errors are determined with the CALIB program, which also establishes the interdependence matrix to avoid cross-talk between channels.

CONSTANTELE DE ETALONARE -	EROAREA DE MASURA
Calibrations constants [Volt/physical unit]	Measuring error [%]
6.754	.94712
9.441	.30901
12.417	.20087
9.489	.04514
5.545	.44057

Fig.7. Calibration Constants and Measurement Errors in CALIB

5.2. Airflow velocity and pressure distribution in the wind tunnel

For aerodynamic tests, a virtual grid in the wind tunnel is established, and a Pitot tube measures airflow pressures at defined nodes. Pressure data are collected via a 16-channel scanner and converted to velocity, producing detailed distributions of airflow at two reference speeds, enabling accurate assessment of flow uniformity in the measurement section.

v,p	Z [mm]									
					270					
					200					
					100					
					0					
Y [mm]	-190	-150	-100	-50		0	50	100	150	190
					-100					
					-200					
					-270					

Fig.8. Virtual Grid of the Measurement Section

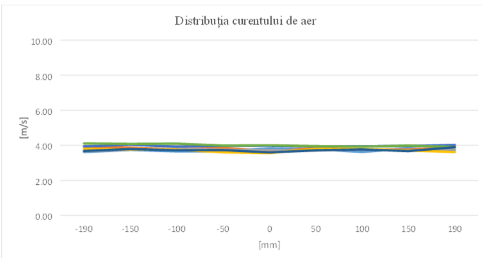

Fig.9. Airflow distribution in the measuring section of the wind tunnel

6. Aerodynamic testing process

6.1. Testing methodology

The testing process began with securing the model on the six-component balance, ensuring that the emerged part did not touch the floor of the wind tunnel. The motor was then started, and the desired airflow speed was set: approximately 8.33 m/s for tests without sails and 4 m/s and 8.33 m/s for tests with sails, in order to evaluate both performance under extreme conditions and the optimal sailing regime. The models were tested at angles of incidence with 30º increments, covering the full range from 0º to 330º. Data was acquired using specialized software from both the Pitot tube and the balance, at a rate of 1000 measurements per second over five seconds, to obtain precise average values of pressure and forces.

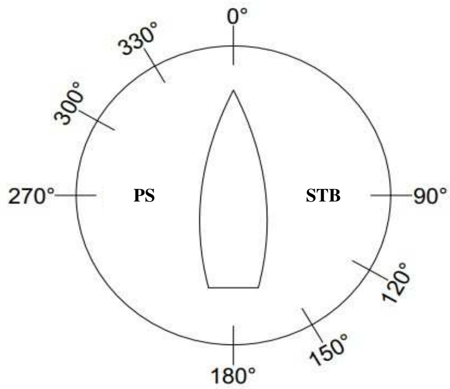

Fig.10. Angle of Incidence Diagram

6.2. Data processing following Aerodynamic tests

The data obtained from the aerodynamic tests were processed in Microsoft Excel, using as input parameters the geometric and physical characteristics of the model (lever arm, angle of incidence, wind speed, frontal area, model length, and air density), as well as calibration constants, the inverse interdependence matrix, and the measured balance values.

Brat[mm]	Beta[º]	V_{wind}[m/s]	Se[m²]	A_I [mm]	ρ[kg/m³]	
-0,28	180	7,904723	0,1208	0,687	1,26	
2,986	6,754	9,441	12,417	0,489	5,545	Constante etalonare
1,11557	-0,02519	-0,0519	0,02296	-0,08093	-0,16679	Inversa matricei de interdependență din Calib
0,01681	0,98751	0,01167	0,02004	-0,0624	0,01389	
0,03973	0,09769	0,99949	-0,01466	0,01211	0,00625	
0,01141	-0,66177	0,01097	0,98664	0,02813	-0,0144	
-1,26954	0,02732	0,07191	-0,0215	1,09205	0,2304	
-0,15893	0,00681	0,02586	-0,00123	0,00302	1,02365	
2,402424	1,508715	3,925798	-0,061654	0,038524	0,207571	Date măsurate

Fig.10. Input data table

For the **model with sails,** testing at 4 m/s revealed a significant increase in rolling and yawing moments, caused by the airflow interaction with the sails. The highest aerodynamic coefficients were recorded at 90° and 270°, confirming the sails' role in generating lift and lateral propulsion.

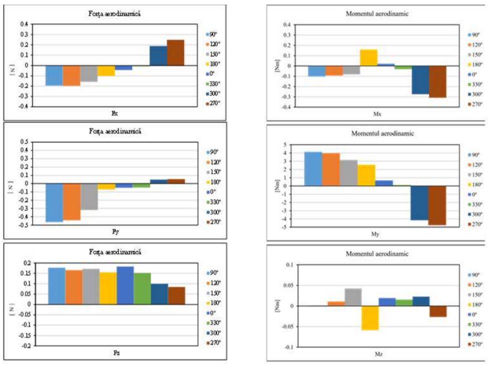

Fig.11. Forces and Moments for the model with sails at a wind speed of 4 m/s

For the **model without sails**, tests were conducted at wind speeds of approximately 8 m/s for angles between 0° and 330°. The aerodynamic forces (Fx, Fy, Fz) and moments (Mx, My, Mz) showed consistent variations in lift and drag coefficients, with maximum values at 0° and 150°, corresponding to headwind and beam wind conditions.

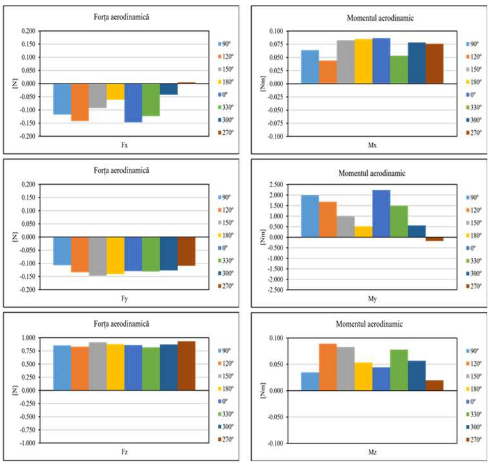

Fig.12. Forces and Moments for the model without sails at a wind speed of 8 m/s

In the case of the **model with sails**, tests at 8 m/s demonstrated an increase of lateral forces and a noticeable increase in moments, particularly between 120° and 150°. For certain extreme angles, testing was not possible due to excessive oscillations of the sails.

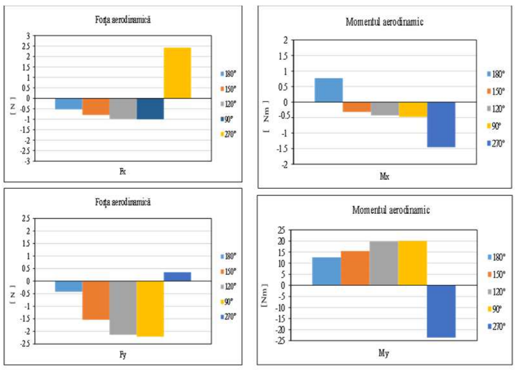

Fig.13. Forces and Moments for the model with sails at a wind speed of 8 m/s

7. Conclusions

The study aimed to evaluate the aerodynamic resistance of a *Lotcă*-type sailing vessel. The total resistance to forward motion was estimated using three complementary methods: the Delft III series (via MaxSurf and Excel) and the Mordvinov-Papmel component method implemented in PHP for small craft. The results showed that the lowest total resistance, 3.13 kN at a speed of 12 knots, was obtained using the PHP method.

For the experimental analysis, a 3D model of the vessel was created based on actual measurements. The experimental model 3D printed was tested in a wind tunnel. The setup was calibrated using a six-component balance, achieving measurement errors below 1%.

Thus, based on the comparative analysis of the results, it was found that the minimum aerodynamic resistance, both for the configuration without sails (I = 9.5) and for those with sails (I = 4.5 and I = 9.5), occurs at an incidence angle of 270°. However, at this angle, the vertical force reaches its maximum, while the lateral drift — predominantly to starboard — affects the heeling and yawing moments. Therefore, the 270° incidence represents a favourable compromise between low resistance and useful propulsive force, though it requires increased attention to stability and directional control.

Ideally, CFD modelling should be carried out prior to experimental testing, as it can serve as an effective method for determining resistance, forces, and moments acting on the vessel. However, in this case, it was not possible to perform CFD analysis beforehand.

8. References

[1] C. Marchaj, Sail Performance-Theory and practice, London: Adlar Coles Nautical, 1996

[2] Miron Emanuel, Studiul aerodinamic pentru o ambarcațiune de agrement destinată navigației în Delta Dunării, Facultatea de Arhitectură Navală, Universitatea "Dunărea de Jos" din Galați, 2025

[3] K. v. Dokkum, Ship Knowledge- Ship design, construction and operation, 4th edition, Dokmar Maritime Publishers B.V., 2007.

[4] F.Pacuraru, „ Curs Rezistenta la înaintare a navei," Facultatea de Arhitectura Navala, 2025.

[5] R. E. E. Lars Larsson, Principles of Yacht Design, Second Edition, London: Adlard Coles Nautical, 2000.

[6] B. Mordvinov, Spravocinic po malotonnajnomu sudostroeniu, Sankt Petersburg: Sudostroenie, 1988.

[7] R.Bosoanca, „Curs TEAN, Echipamente și instrumente de măsură," Facultatea de Arhitectură Navală, 2025.

[8] I. M. Viola și R. G. Flay, „Sail aerodynamics; Understanding pressure distributions on upwind sails," *Experimental Thermal and Fluid Science,* vol. 35, nr. 8, pp. 1497-1504, 2011

[9] F. Fossati, S. Muggiasca și I. M. A. Viola, „Wind tunnel techniques for investigation and optimization of sailing-yachts aerodynamics," în *2nd High Performance Yacht Design Conference*, Auckland, 2006.

[10] R.Bosoanca, „Curs TEAN, Capitolul 3.3-3.4," Facultatea de Arhitectura Navala, 2025.

[11] F.Pacuraru, „ Curs Arhitectura Navei," Facultatea de Arhitectura Navala, 2025.

Paper received on November 9 th, 2025