VARNA SCIENTIFIC AND TECHNICAL UNIONS

TECHNICAL UNIVERSITY - VARNA

SEVENTEENTH INTERNATIONAL CONFERENCE ON MARINE SCIENCES AND TECHNOLOGIES

Black Sea 2024

The Conference is Dedicated to the 50th Anniversary of the Establishment of the Shipbuilding Faculty at the Technical University of Varna

PROCEEDINGS

ISSN 1314 - 0957

October 18th, 2024

Varna, Bulgaria

SEVENTEENTH INTERNATIONAL CONFERENCE ON MARINE SCIENCES AND TECHNOLOGIES

The Conference is Dedicated to the 50th Anniversary of the Establishment of the Shipbuilding Faculty at the Technical University of Varna

Black Sea 2024

PROCEEDINGS

ISSN 1314 - 0957

October 18th, 2024
Varna, Bulgaria

VARNA SCIENTIFIC AND TECHNICAL UNIONS

BULGARIA
9000 VARNA
25, "TSAR SIMEON I" Str.

Phone: +35952 630 532
E-mail: nts@nts.varna.net
URL: nts.varna-bg.org
DOI: https://doi.org/10.7546/IO.BAS.2024.10

ISSN 1314 - 0957

Organized by:

VARNA SCIENTIFIC AND TECHNICAL UNIONS

AND

TECHNICAL UNIVERSITY - VARNA

With the Cooperation of:

BULGARIAN NATIONAL ASSOCIATION OF SHIPBUILDING AND SHIPREPAIR (BULNAS)

1881

"N. VAPTSAROV" NAVAL ACADEMY - VARNA

BULGARIAN ACADEMY OF SCIENCES (BAS):

INSTITUTE OF OCEANOLOGY - VARNA

BULGARIAN SHIP HYDRODYNAMICS CENTRE

* * *

Main Topics of the Conference:

(1) Oceanology

(2) Shipbuilding and Ship Repair

(3) Decarbonization in Shipping

(4) Ship Hydrodynamics

(5) Maritime Transportation and Port Operations

Members:

Dragomir PLAMENOV,
Rector of Technical University - Varna

Boyan MEDNIKAROV,
"N. Vaptsarov" Naval Academy - Varna

Svetlin STOYANOV,
Chairman of the Bulgarian National Association of Shipbuilding and Shiprepair (BULNAS)

Ivan IVANOV,
Technical University - Varna

Dimitar TODOROV,
ODESSOS Ship repair Yard, J. S. Co - Varna, Executive Director

Kiril PALAVEEV,
ULA Ltd. - Varna, Manager

Elena VELIKOVA,
Bulgarian National Association of Shipbuilding and Ship repair (BULNAS),
Executive Secretary

C O N T E N T S

(1) Oceanology:

(2) Shipbuilding and Ship Repair:

(3) Decarbonization in Shipping:

(4) Ship Hydrodynamics:

(5) Maritime Transportation and Port Operations:

Black Sea 2024

SHIP HYDRODYNAMICS

THE BOW FLEXIBLE SKIRT BEHAVIOR OF AN AMPHIBIOUS HOVERCRAFT DURING ITS FORWARD MOTION ON CALM WATER

Volodymyr ZAYTSEV*, Valeriy ZAYTSEV, Dmytro ZAYTSEV***, Victoria LUKASHOVA******

Abstract. *The paper presents a mathematical model of bow flexible skirt without diaphragm tightening under the hull of hovercrafts in the forward operation mode over calm water after the transition mode. Particular attention is paid to the stress-strain state of the shell of the bow flexible skirt when it is tightened under the hull after the transient mode. The developed complex of mathematical models allows to analyse in-depth the performance characteristics of hovercrafts before the completion of their design and before the beginning of construction.*
Keywords: *hovercraft, air cushion, bow flexible skirt, tightening, motion in operation mode, calm water, transition mode, mathematical model.*

INTRODUCTION

During operation, the bow flexible skirt (BFS) of an amphibious air cushion vehicle (hovercraft) is subjected to various static and dynamic loads, which cause changes in its shape. Forces and moments of a wave nature act on the BFS during hovercraft operation over still water, due to the impact of the air cushion (AC) moving across the water surface. This leads to the flexible skirt being pulled under the hovercraft's hull. The phenomenon of skirt pulling plays a key role not only in solving issues related to the hovercraft's directional stability but also in determining the magnitude of speed reduction in rough water and the probability of losing stability due to skirt pulling.

While the hovercraft operates in forward motion over still water, the water surface deforms under the pressure of the air cushion. Therefore, during the design process of the flexible skirt, it is crucial to determine the moment when the skirt begins to be pulled under the hull. Identifying the influence of design factors of the receiver and the removable elements of the flexible skirt on the pulling under the hull is particularly important during the transition phase of the skirt operation - from the moment when only the removable elements contact the water to the point when the flexible receiver itself starts making contact with the water.

The main external hydrodynamic forces acting on the bow flexible skirt during its pulling under the hull in the transition mode while the hovercraft is moving are usually divided into two components: the first component is related to the excess air pressure in the vehicle's air cushion and the flexible receiver of the BFS, while the second is associated with water resistance. This resistance arises on the removable elements of the BFS as a result of their contact with water and is directed parallel to the water surface, both when the hovercraft is moving over still water and over a disturbed sea surface. Due to the impact of water resistance on the removable elements under certain conditions, the BFS is pulled under the hovercraft's hull.

The behavior of the BFS in the transition mode depends on its ability to resist being pulled under, which

*** Volodymyr ZAYTSEV, Prof., Doctor of Technical Sciences, Chief of department, Dept. of Marine Technology and Ocean Engineering, Shipbuilding Institute, Admiral Makarov National University of Shipbuilding (NUOS), Nikolaev, UKRAINE**

**** Valeriy ZAYTSEV, Docent, Doctor of Technical Sciences, Deputy Director of Science, Design Bureau IMT, LLC, Nikolaev, UKRAINE**

***** Dmytro ZAYTSEV, Docent, Candidate of Technical Sciences, Deputy Director of Design, Design Bureau IMT, LLC, Nikolaev, UKRAINE**

******Victoria LUKASHOVA, assistant, Dept. of Marine Technology and Ocean Engineering, Shipbuilding Institute, Admiral Makarov National University of Shipbuilding (NUOS), Nikolaev, UKRAINE**

is determined by the shape parameters of the flexible skirt, air pressure, and the presence of diaphragms that reduce the likelihood of the BFS being pulled under the hovercraft's hull.

Despite the fact that hovercraft have been in use for several decades and there is a significant amount of literature related to the theory of such vessels and the practice of their design, a number of unresolved issues remain concerning these vessels. Various methodologies, theories, and publications [1-4] exist, allowing for the calculation and design of various complexes and systems for hovercraft, ultimately leading to the creation of vessels that perform successfully in operation. However, questions regarding the pulling of the bow flexible skirt under the hull of the hovercraft remain unresolved.

In this regard, the purpose of this study is to determine the shape parameters of the BFS without diaphragms in hovercraft and its stress-strain state after transitioning to side-slip mode over still water, which affects the pulling of the single-layer receiver with removable elements, without BFS diaphragms, under the hovercraft's hull.

NARRATION

he study addresses the problem of accounting for the phenomenon of the flexible skirt (FS) of the bow flexible skirt being pulled under the hull of the vessel when determining the stress-strain state (SSS) of its receiver without diaphragms (Figure 1) and without considering the size of the air duct cutouts (pressure jump along the inner line $\boldsymbol{K_1}$ of the BFS internal section of the flexible receiver), as shown in Figure 2. The external view of the hovercraft "ACV-70" (designed by "Design Bureau IMT") is shown in Figure 3, while the direction of the external pulling force acting on its BFS during forward motion over still water in operational mode is shown in Figure 4.

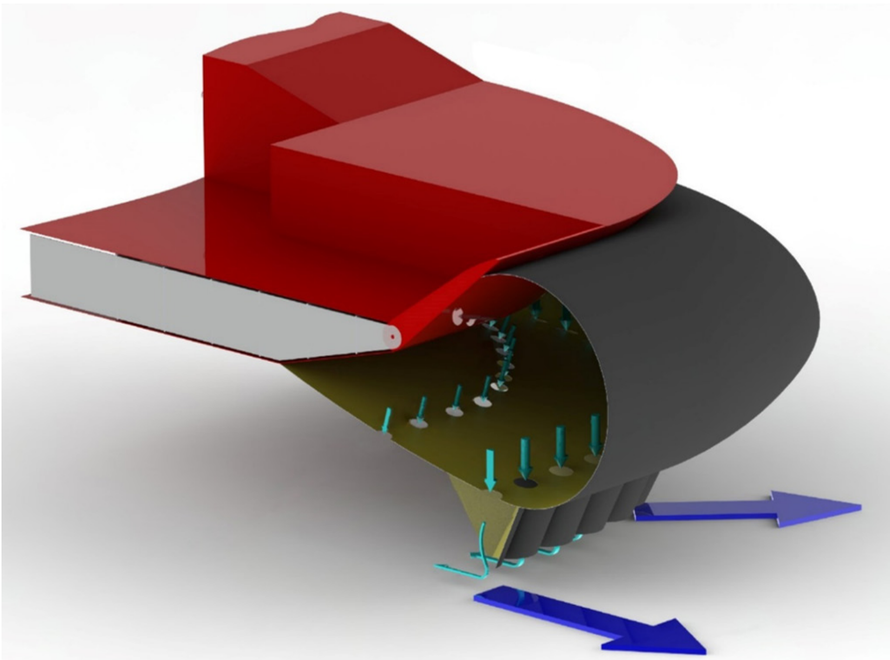

Figure 1.
Bow flexible skirt of hovercraft "ACV-70"

The shell of the BFS receiver is studied (see Figure 2), which consists of three sections DK_2, K_2K_1 and K_1A made of isotropic, non-stretchable, and absolutely flexible material. Between these sections is the horizontal part K_1K_2, to which the removable element (RE) is attached.

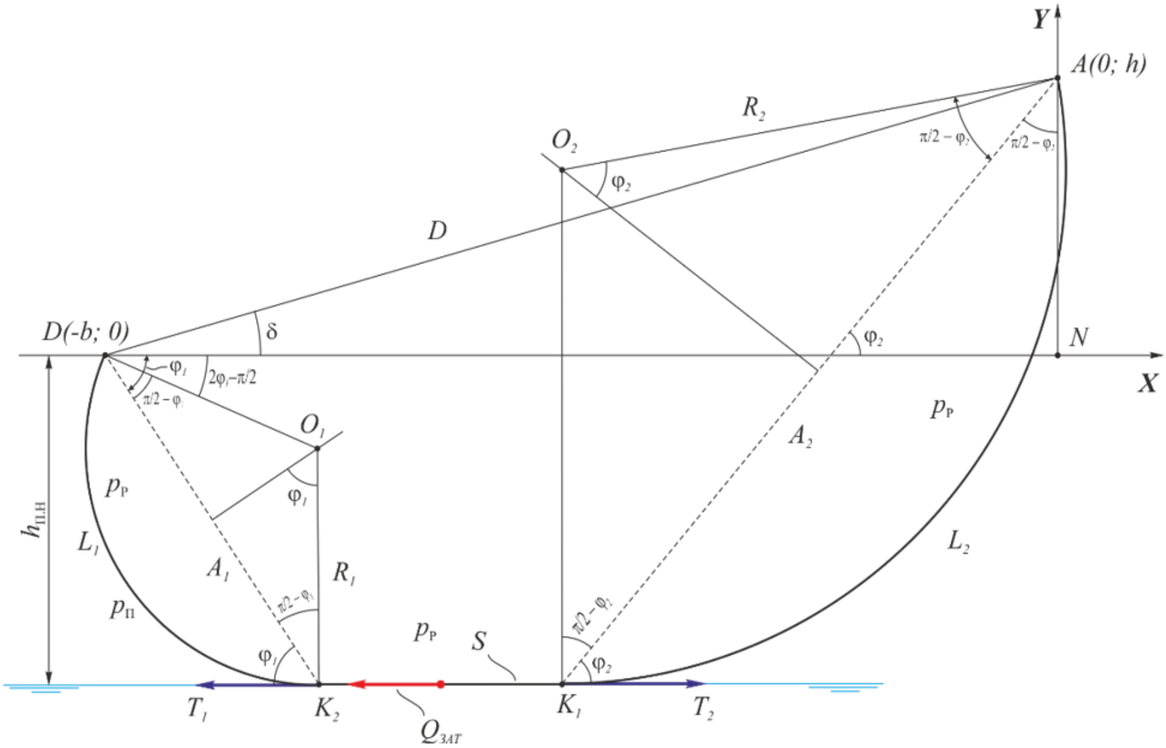

Figure 2.
Diagram of forces (calculation scheme) acting on the flexible receiver of the BFS during hovercraft movement over still water after the transition mode

Figure 3.
External view of hovercraft “ACV-70” (Design Bureau IMT project)

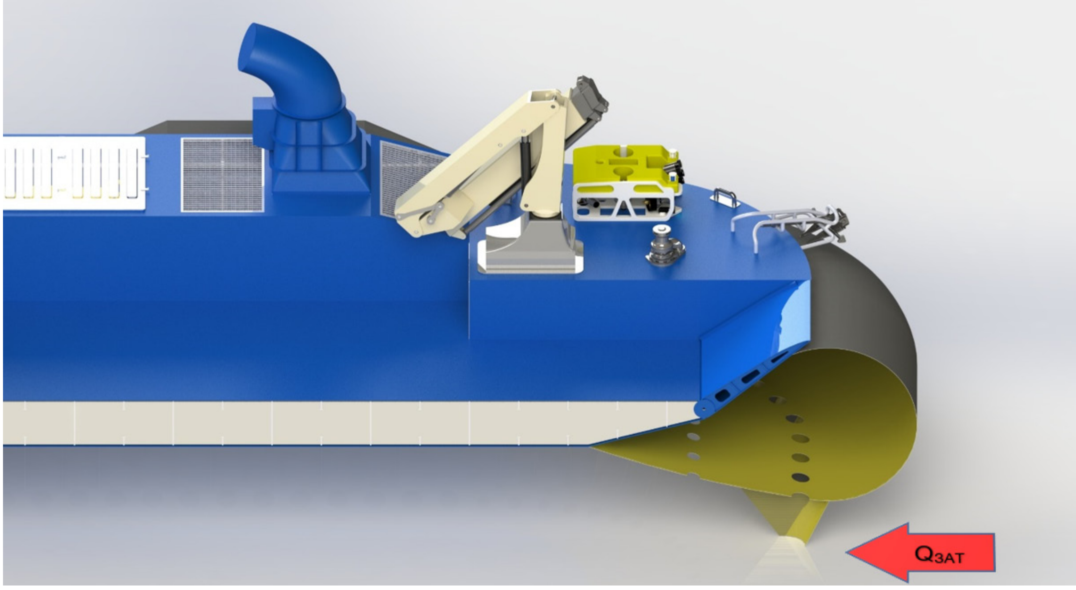

Figure 4.
Direction of pulling forces acting on the bow flexible skirt of hovercraft "ACV-70" during its movement over still water in operational mode after the transition phase

Assumption. During hovercraft movement on the air cushion (AC) after the transition mode, the BFS will slide along the water surface (the attachment section of the RE K_1K_2 will be horizontal and will slide along the water surface). The RE will be pressed under the flexible receiver, and in the calculation scheme, only the shape resistance of the RE $Q_Ф$, located in the water, will be considered. The horizontal element K_1K_2 does not experience longitudinal inclinations or rotations in the horizontal plane. Therefore, the fabric sections of the flexible receiver shell of the BFS will remain cylindrical during operation. There are no normal or tangential forces at the end sections of the flexible skirt shell.

The shell of the flexible receiver is subjected to stepwise air pressure loading. The section AK_1 is loaded by the pressure inside the flexible receiver $p_Р$, the section DK_1 - is loaded by the pressure difference between the air cushion $p_П$ and the receiver $p_Р$, that is, by the pressure $p_Р$ - $p_П$, and the receiver section K_1K_2 - is loaded by the pressure $p_Р$ and the pulling force $Q_{зат}$, applied along the surface of the horizontal section K_1K_2.

Solution of the problem. The shape parameters of the bow receiver, considering its pulling under during the hovercraft's movement over still water, are determined by examining its cross-section after the transition mode (see Figure 2).

In the task of determining the shape parameters of the receiver under the influence of external forces, the following are considered: $p_Р$ - air pressure in the receiver, Pa; $p_П$ - air pressure in the air cushion, Pa; $Q_{зат}$ - resultant pulling force, directed parallel to the horizontal axis NX, N/m.

In addition to pressures and the pulling force, the following are considered as input data: $\boldsymbol{L}$ - length of the flexible receiver's cross-section (FRCS); $\boldsymbol{D}$ - distance between the attachment points of the receiver, m; $\boldsymbol{\alpha_P^0}$ - BFS opening angle (structural angle between the cut of the bow section of the pontoon and the main plane (MP)), degrees (see Figure 5); $\boldsymbol{x_П}$ - abscissa of the air cushion center of gravity in the moving coordinate system, m; $\boldsymbol{L_П}$ - air cushion length, m; $\boldsymbol{\psi}$ - trim angle of the hovercraft «ACV-70» in hover mode, degrees, as a function of the heel angle $\boldsymbol{\theta}$, yaw angle $\boldsymbol{\varphi}$, drift angle $\boldsymbol{\beta}$, heading angle $\boldsymbol{\gamma}$, translational $\vec{V}^T = \begin{pmatrix} V_x & V_y & V_z \end{pmatrix}$ and angular

$$\vec{\omega} = \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$$

velocities of the hovercraft, longitudinal accelerations $\boldsymbol{a_x}$, lateral accelerations $\boldsymbol{a_y}$ and vertical accelerations $\boldsymbol{a_Z}$ of the hovercraft:

$$\psi = f\left(\theta, \varphi, \beta, \gamma, \vec{V}, \vec{\omega}, \vec{a}\right);$$

ν - kinematic viscosity coefficient, m²/s; $\zeta_{Ш}$ - surface roughness coefficient of the BFS.

Let's write the equilibrium equation for the horizontal section of the BFS element $\boldsymbol{K_1K_2}$, (see Figure 2):

$$-T_1 - Q_{зат} + T_2 = 0;$$
$$Q_{зат} = Q_{тр} + Q_{Ф};$$
$$T_1 = (p_Р - p_П)R_1;$$
$$T_2 = p_Р R_2,$$

where

T_1 - tension in the BFS shell acting on the inner section of the flexible receiver DK_2, N/m;
T_2 - tension in the BFS shell acting on the outer section of the flexible receiver AK_1, N/m;
R_1 - radius of curvature of the inner section of the receiver DK_2, m;
R_2 - radius of curvature of the outer section of the receiver AK_1, m.
$Q_{ТР}$ - friction resistance of the BFS against the water, N/m:

$$Q_{тр} = (\zeta_{ТР} + \zeta_{Ш})\frac{\rho_В \upsilon^2}{2} S;$$

where

S - length of the horizontal section of the BFS element K_1K_2, m;
$\zeta_{ТР}$ - friction coefficient of an equivalent smooth plate

$$\zeta_{ТР} = 0{,}455(\lg\mathrm{Re})^{-2{,}58};$$

Re - Reynolds number

$$\mathrm{Re} = \frac{\upsilon L_С}{\nu};$$

υ - speed of the hovercraft "ACV-70" in hover mode, m/s;
L_C - length of the hovercraft "ACV-70," m;
ν - kinematic viscosity coefficient, m²/s:

$$\nu = 1{,}57 \cdot 10^{-6};$$

$\zeta_{Ш}$ - surface roughness coefficient of the BFS:

$$\zeta_{Ш} = (0{,}5 \ldots 0{,}6) \cdot 10^{-6};$$

$Q_{Ф}$ - shape resistance force of the BFS removable element during hovercraft movement with bow trim when the BFS is pulled under the hull in transition mode, N/m:

$$Q_{Ф} = 0{,}5C_x(\alpha, h_{ЗАТ})\rho_В \upsilon^2 A_{ХАР}\frac{1}{B_П} = 0{,}5C_x(\alpha, h_{ЗАТ})\rho_В \upsilon^2 \frac{h_{ЗАТ}}{\sin\alpha};$$

$$A_{ХАР} = \frac{B_П h_{ЗАТ}}{\sin\alpha};$$

v - forward speed of the hovercraft in hover mode, m/s;
$A_{ХАР}$ - characteristic area of the removable element during the pulling of the bow flexible skirt under the hovercraft hull, m²;
$\rho_В$ - density of seawater, $\rho_В = 1025\ kg/m^3$;
$C_x(\alpha, h_{ЗАТ})$ - shape resistance coefficient along the NX axis, determined by numerical experiments for the real RE structure of the BFS, dependent on the values of α and $h_{ЗАТ}$;

α - angle of inclination of the RE to the water surface, degrees (see Figure 4).

Geometric relationships for the bow receiver of the BFS:

$$D\cos\delta = A_1\cos\varphi_1 + S + A_2\cos\varphi_2;$$
$$D\sin\delta = A_2\sin\varphi_2 - A_1\sin\varphi_1;$$
$$A_1 = 2R_1\sin\varphi_1;$$
$$A_2 = 2R_2\sin\varphi_2;$$
$$L = L_1 + L_2 + S;$$
$$L_1 = R_1(2\varphi_1);$$
$$L_2 = R_2(2\varphi_2);$$
$$h_{\text{П.Н}} = h_{\text{ГО.0}} - \left(\frac{L_{\text{П}}}{2} + x_{\text{П}} - D\cos\delta\right)\tan\psi;$$
$$h_{\text{П.Н}} = R_1\left(1 + \sin\left(2\varphi_1 - \frac{\pi}{2}\right)\right).$$

where

A_1 - chord length of the inner section of the receiver DK_2, m;

A_2 - chord length of the outer section of the receiver AK_1, m;

$h_{\text{го.0}}$ - height of the BFS at trim angle $\boldsymbol{\psi} = 0^o$;

δ - angle between the segments ***AD*** and ***ND*** or the rise angle of the outer line of attachment of the BFS to the hovercraft hull relative to the inner attachment line of the BFS;

$$\delta = \alpha_P^0 - \psi;$$

α_P^0 - opening angle of the BFS (structural angle between the cut of the bow section of the pontoon and the main plane (MP)), degrees (see Figure 5):

φ_1 - half of the central angle of the arc of the cross-section of the inner part of the receiver DK_2;

φ_2 - half of the central angle of the arc of the cross-section of the outer part of the receiver AK_1;

L_1 - length of the inner part of the cross-section of the flexible receiver of the BFS, m;

L_2 - length of the outer part of the cross-section of the flexible receiver of the BFS, m;

$h_{\text{П.Н}}$ - height of the air cushion at the inner part of the BFS receiver, m;

$\boldsymbol{x}_{\Pi}$ - abscissa of the center of gravity of the air cushion, m;

$\boldsymbol{L}_{\Pi}$ - length of the air cushion, m;

ψ - trim angle of the hovercraft “ACV-70” in hover mode, degrees.

δ - angle between the segments ***AD*** and ***ND*** or the rise angle of the outer attachment line of the flexible skirt to the hovercraft hull relative to the inner attachment line of the BFS;

$$\delta = \alpha_P^0 - \Theta\ ;$$

α_P^0 - opening angle of the side flexible skirt (structural angle between the cut of the side section of the pontoon and the main plane (MP)), degrees (see Figure 5):

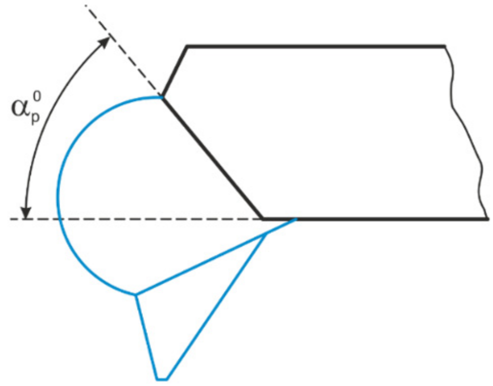

Figure 5.
Opening angle of the BFS

In the system of 14 equations with given values, we have: D, L, δ, $x_П$, $L_П$, ψ, f, $p_П$, $p_Р$, and the unknowns are 14 variables: L_1, L_2, A_1, A_2, S, R_1, R_2, T_1, T_2, $Q_{ЗАТ}$, φ_1, φ_2, $\delta\, h_{П \cdot Н}$.

Coordinates of point K_2 which connects the inner part of the cross-section of the flexible receiver of the BFS with the horizontal section K_1K_2 of the flexible receiver in the *XNY* coordinate system (see Figure 2):

$$X_{K_2} = -b + R_1 \cos\left(2\varphi_1 - \frac{\pi}{2}\right);$$
$$Y_{K_2} = -R_1\left(1 + \sin\left(2\varphi_1 - \frac{\pi}{2}\right)\right),$$

where

b - horizontal projection of the distance between the receiver attachment points $b = ND = D \cos \delta$, m.

Coordinates of point K_1 where the outer part of the cross-section of the flexible receiver of the BFS connects with the horizontal section K_1K_2 of the flexible receiver in the *XNY* coordinate system (see Figure 2):

$$X_{K_1} = -b + S + R_1 \cos\left(2\varphi_1 - \frac{\pi}{2}\right);$$
$$Y_{K_1} = -R_1\left(1 + \sin\left(2\varphi_1 - \frac{\pi}{2}\right)\right).$$

Coordinates of the center of curvature 0_1 of the inner part of the cross-section of the flexible receiver of the BFS in the *XNY* coordinate system (see Figure 2):

$$X_{O_1} = -b + R_1 \cos\left(2\varphi_1 - \frac{\pi}{2}\right);$$
$$Y_{O_1} = -R_1 \sin\left(2\varphi_1 - \frac{\pi}{2}\right).$$

Coordinates of the center of curvature 0_2 of the outer part of the cross-section of the flexible receiver of the BFS in the *XNY* coordinate system (see Figure 2):

$$X_{O_2} = -b + S + R_1 \cos\left(2\varphi_1 - \frac{\pi}{2}\right);$$
$$Y_{O_2} = R_2 - h_{П.Н}.$$

CONCLUSIONS

The described methodology for creating a mathematical model allows for the study of the pulling of the bow flexible skirt under the hull of amphibious air cushion vehicles during straight-course movement in operational mode over still water after the transition phase. Additionally, it enables simulation modeling of this process for hovercraft with six degrees of freedom, which will reduce the costs of designing and constructing the lead hovercraft with accurately predicted seakeeping and operational characteristics.

REFERENCES

[1] З а й ц е в, Д.В. Исследование процесса затягивания носового гибкого ограждения без диафрагмы при эксплуатации судна на воздушной подушке на тихой воде / Зайцев Д.В., Зайцев В.В. // Зб. наук. праць НУК. - Миколаїв: НУК, -2008. - № 5 (422). - С. 37-41.

[2] З а й ц е в, Д.В. Расчет гибкого ограждения с учетом его затягивания в режиме движения судна на воздушной подушке / Зайцев Д.В. // Зб. наук. праць НУК. - Миколаїв: НУК, -2006. - № 4 (409). - С. 32-40.

[3] D m y t r o Zaytsev, Volodymyr Zaytsev, Pentscho Pentschev. Design Methods of Small Hovercrafts // Black sea 2014: Twelfth international conference on marine sciences and technologies. - Varna, Bulgaria: Varna Scientific and Technical Unions- Varna, - 2014. - P 107-108.

[4] L i a n g Yun. Theory and design of air cushion craft / Liang Yun, Alan Bliault - London: Yun and A. Bliault, 2000. - 632 p.

---

[1] Z a y t s e v, D.V., Zaytsev, V.V., «Issledovanie protsessa zatyagivaniya nosovogo gibkogo ograzhdeniya bez diafragmy pri ekspluatatsii sudna na vozdushnoy podushke na tikhoy vode,» (in Russian), *Zb. Nauk. Prats NUK*, no. 5 (422), pp. 37-41, 2008.

[2] Z a y t s e v, D.V., «Raschet gibkogo ograzhdeniya s uchetom ego zatyagivaniya v rezhime dvizheniya sudna na vozdushnoy podushke,» (in Russian), *Zb. Nauk. Prats NUK*, no. 4 (409), pp. 32-40, 2006.

[3] Z a y t s e v, D., Zaytsev, V., Pentschev, P., "Design methods of small hovercrafts," in *Proc. 12th Int. Conf. Marine Sci. Technol. Black Sea 2014*, Varna, Bulgaria, 2014, pp. 107-108.

[4] Y u n, L., Bliault, A., *Theory and Design of Air Cushion Craft*. Oxford, U.K.: Butterworth-Heinemann, 2000, 632 pp.

VARNA SCIENTIFIC AND TECHNICAL UNIONS

SEVENTEENTH INTERNATIONAL CONFERENCE ON MARINE SCIENCES AND TECHNOLOGIES

Correction by LARGO CITY Ltd. - DOBRICH
Computer layout by Donika Sarkoleva-Zlateva
Total print: 30, Format 60/84/8

LARGO CITY Ltd. - DOBRICH
DESIGN, PRE-PRESS AND PRINTING

ISSN 1314 - 0957