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## DESIGN AND CONSTRUCTION OF AN EXPERIMENTAL TEST RIG FOR TESTING SEGMENTS SIMILAR TO THOSE FOUND IN AIR-CUSHION VEHICLE

BY

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**Abstract.** The lift system of an air-cushion vehicle is the essential component that defines this means of transportation. Currently, the most used flexible skirts as part of such a system are the segmented flexible skirt and the bag and finger skirt. The present work it highlights step by step the design and construction of an experimental test rig as well as 4 segment modules that will be tested later. The experimental test rig is a small open circuit wind tunnel with major modification, adapted to test the mentioned segment modules. Each module contains 3 equal-sized segments and 4 separation walls. The inclination angle of the segments differs from one module to another. These angles are as follows: 45°, 60°, 75° and 90°. The test section contains a mobile horizontal plate with which the running surface is simulated and air clearance height can be adjusted through spacers.

**Keywords:** air-cushion vehicle, lift system, experimental test rig, wind tunnel, segment modules.

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## 1. Introduction

Air-cushion vehicles are means of transportation that are not currently as well known as cars, trains, trucks, airplanes, and the list goes on. These vehicles operate based on an air cushion that is located under the hull and are mainly used today for military, commercial, recreational, and rescue & medical aid purposes (British Hovercraft Company; Griffon Hoverwork). Also, these vehicles can run on various surfaces such as: water, soil, snow, ice, sand etc. which makes them unique in the world.

Air-cushion vehicles consist of three main systems: lift system, steering system and thrust system (Pavăl *et al.*, 2020). This research focuses only on the aerodynamic study of the lift system for air-cushion vehicles and therefore only aspects regarding this system will be presented below.

The main component of this system is represented by the flexible skirt which is mounted on the vehicle's hull and which has the main role of retaining a sufficient amount of air under the hull. Due to this, these vehicles are named as such. It should also be mentioned that the concept of the flexible skirt was invented by Latimer Needham in 1958, a concept that led to the acceleration of the development of this type of vehicle (Yun and Bliault, 2000).

The main component of lift system is the skirt. Over time various types of flexible skirts have appeared such: Bertin skirt, Peri-cell skirt, Trunked skirt, Convoluted skirt, Loop/bag skirt, Jetted skirt, Bag and finger skirt and Segmented skirt (Carrillo Vilchis *et al.*, 2006; Pavăl *et al.*, 2020).

Regarding the last two types of flexible skirts listed (bag and finger skirt and segmented skirt), these are the most widely used at present. Also, the bag and finger skirt is considered the most advanced and updated of all the skirts mentioned above (Chung and Jung, 2004).

The main research found in the specialized literature regarding experimental test rigs used for testing flexible skirts are presented below.

A first relevant study was carried out by Davenport (April 1961) where he builds an experimental test rig (Fig. 1a) with which he carried out a series of experimental tests on simple-plenum-chamber within ground proximity. The research had as its main goal the study of lift augmentation due to the modification of geometric parameters such as: the depth of the interior cavity, the ratio between the inlet and outlet area and the geometric configuration of the inlet (1, 2 or 4 inlets). About the tested models it can be said that several types of aluminum skirts were made that had cylindrical shapes and these were attached to circular plates made of plywood (Davenport, 1961).

Another important study is that conducted by Burgess in November 1965 in which he presents a method for reducing data on air-cushion vehicle fan performance. The experimental models (one without flexible skirt with edge jets inwardly inclined at 30° to the horizontal and one with flexible skirt with edge jets inclined at an average 52° to the horizontal) that were tested were

represented by the Britten-Norman CC2 hovercraft in half at 1/3 scale where for different values of air clearance height and weights. The following parameters were measured: fan power, volume flow, and fan rpm. The experimental test rig used by the author can be seen in Fig. 1b (Burgess, 1965).

Shortly after (February 1966), Lester and Kiernan conducted a series of static experimental tests with the aim of identifying an efficient shape of the flexible skirt intended for a peripheral jet hovercraft, these being part of the research program at R & D.E. Cardington. The peripheral jet hovercraft was the Britten-Norman Cushioncraft CC-2, a hovercraft belonging to the Naval Air Department at R.A.E. Bedford. A sketch of the experimental test rig used can be seen in Fig. 1c, a test rig on which various forms of extensions were tested such as cylindrical skirts with or without tapered nozzle, with nozzle inclined at different angles and variable widths, as well as skirts made of various types of materials (Lester and Kiernan, 1966).

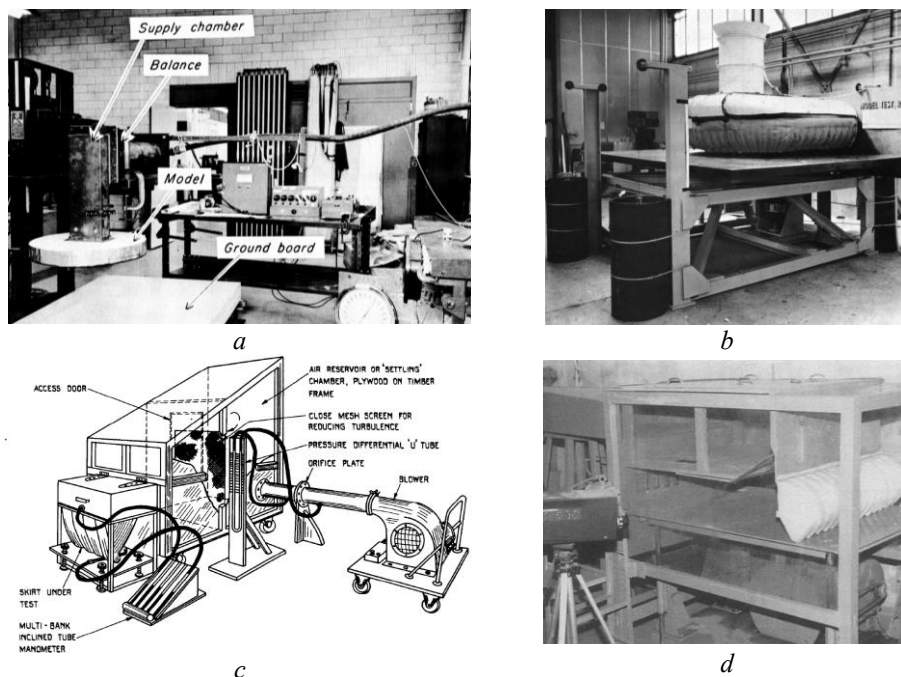


Fig. 1 – The experimental test rigs used by the mentioned authors and by the MARIC where: a – Davenport's test rig (Davenport, 1961), b – Burgess's test rig (Burgess, 1965), c – Lester and Kiernan's test rig (Lester and Kiernan, 1966), d – the small test rig used by MARIC (Yun and Bliault, 2000).

In 1974, the Marine Design and Research Institute of China, known by the acronym MARIC, conducted a series of experimental tests on two-dimensional flexible skirts on rigid surfaces. Unlike the previously mentioned authors, this institute created 2 experimental test rigs (one small with box

dimensions of 1050x700x1000 mm - Fig.1d and one large with box dimensions of 4400x2230x3350 mm) through which one aimed to perform a qualitative analysis and the other to perform a quantitative analysis (Yun and Bliault, 2000).

## 2. Description of the MF-TA2 wind tunnel

The Department of Fluid Mechanics, Fluid Machinery and Fluid Power Systems within “Gheorghe Asachi” Technical University of Iași includes a laboratory hall in which there are 4 aerodynamic wind tunnels that can be classified under the categories of small and medium-size tunnels. These tunnels are called MF-TA1, MF-TA2, MF-TA3 and MF-TA4.

After a thorough analysis of the particularities of each individual tunnel, it was decided to modify the MF-TA2 wind tunnel in such a way as to fulfil the required research theme. The main argument in choosing the MF-TA2 wind tunnel was the fact that it is the only one that allows reaching overpressures of 2kPa per discharge (Pavăl, 2024).

The most important feature of MF-TA2 is that this tunnel is a two-dimensional with an open circuit that draws and reflows air outside the laboratory enclosure. A sketch showing the top view of this tunnel is illustrated in Fig. 2 where each component is mentioned (Pavăl, 2024).

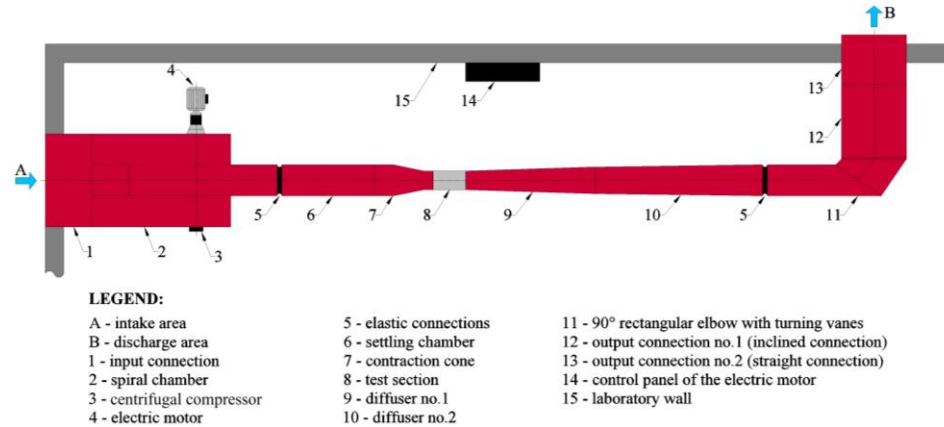


Fig. 2 – Main components of the MF-TA2 wind tunnel (adapted from Pavăl, 2024).

In addition to the components presented, an aerodynamic balance can also be found with 3 components with which it is possible to indirectly measure: lift force, drag force and moment for a chosen aerodynamic profile (Popescu, 2006).

Also related to the MF-TA2 wind tunnel, it can also be mentioned that the aerodynamic characteristics of self-aspirated blades were studied on it around the 2000s. The classic NACA 0012 profile with a partially permeable

extrados was tested, a profile that has an aerodynamic chord of 71 mm, a wingspan of 140 mm and a perforated plate with a number of 54 holes with a diameter of 1 mm. At the same time, in the test section an air speed reaching 84.5 m/s was obtained (Popescu, 2002; Popescu, 2006).

Regarding the components shown in Fig. 2, it can be said that component no. 3 is the most important because it is the only one that generates flow in the entire experimental installation. This is represented by the centrifugal compressor that was part of the Klimov RD-45 turbojet engine. As for characteristics, this component has a bilateral intake with 9 discharge ports and the nominal speed it can reach is 11200 rpm. Given that this centrifugal compressor is connected to the electric motor through a shaft, the maximum nominal speed it can reach is equal to the nominal speed of the electric motor (the nominal speed of the electric motor is 1420 rpm) (Pavăl, 2024).

### 3. Design and execution of new components

Starting from the tunnel configuration presented above, the first step was to remove the components that are not useful for the present study, namely: contraction cone, test section, diffuser no.1, and control panel of the electric motor. Regarding the last-mentioned element, this was an old electrical panel that was replaced with one equipped with a Schneider ATS22D62Q parametrizable soft-starter.

Therefore, Fig. 3 shows the tunnel at the time of starting the design and construction of the new experimental test rig that would meet the requirements of the chosen research topic.



Fig. 3 – The MF-TA2 wind tunnel after removing the mentioned components (Pavăl, 2024).

After accomplishing that, a survey was made with the characteristic dimensions of the settling chamber, diffuser no. 2 as well as the distance between the two components. Based on this survey, the design was started. Consequently, Fig. 4 presents the main diagram mentioning all the stages that led to the completion of the experimental test rig.

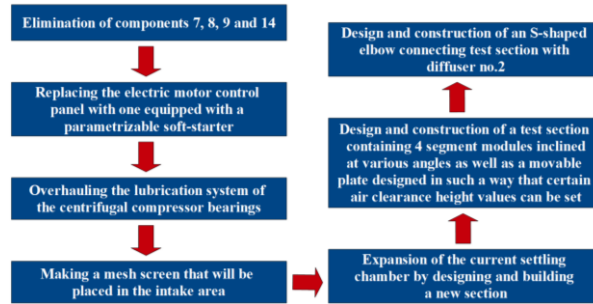


Fig. 4 – The main diagram containing all the stages of the construction of the experimental test rig.

Before proceeding to the detailed description, to analyse the flow in the air clearance height area, it was decided to use Laser Doppler Anemometer (LDA). To perform measurements with this instrument, a system must first be created through which droplets seeding is introduced using Flow Tracker 700 CE equipment and 2 Kaeser SK 22 screw compressors (Pavăl, 2024). The mentioned equipment is found in the department's laboratory. That being said, the design and construction of each component is presented in detail below.

### 3.1. Design and construction of the mesh screen located in the intake area

As can be seen in Fig. 2, the wind tunnel draws air from outside the laboratory enclosure. Regarding the outside, there is vegetation in the intake area and to prevent the centrifugal compressor from drawing some of it into the test section, it was decided to create this mesh screen. This component is characterized by the fact that it consists of 2 galvanized nets made of 0.8 mm thick wire with a mesh size of 13x13 mm. These nets are fixed in a wooden frame, thus creating the mesh screen. At the same time, in order to intervene quickly and easily in the intake area, a wooden framework was also made that was mounted in the wall of the laboratory hall and to which the mesh screen is attached (Pavăl, 2024). A series of representative image from the construction of this component can be seen in Fig. 5.



Fig. 5 – Images from various stages of mesh screen construction: *a* – wooden framework, *b* – mesh screen.

### 3.2. Design and construction of settling chamber no.2

The first main component of the experimental test rig is represented by settling chamber no.2. Regarding the chosen construction solution, starting from the output dimensions of settling chamber no.1, a welded frame made of angle steel with dimensions of 30x30x3 mm was chosen. The walls of this chamber were made of multilayer plywood, BFU 100 glued, their thickness being 6.3 mm which is equivalent to 1/4". As a result, Fig. 6 shows two views of the entire assembly of the initial settling chamber no. 2.

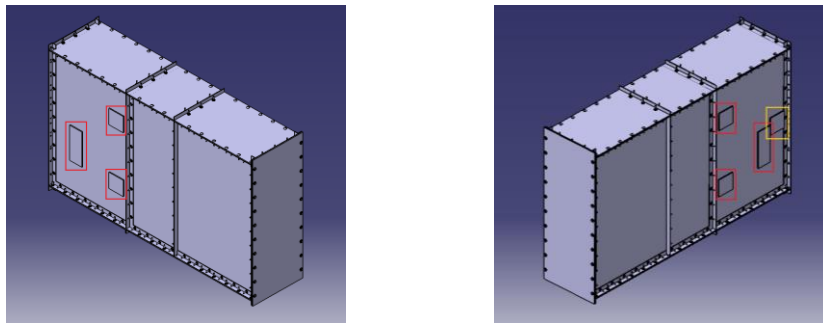


Fig. 6 – Isometric views of the initial settling chamber no. 2 (figure on the left - adapted from Pavăl, 2024).

As can be seen in this figure, on both sides of this component there are small pieces of multilayer plywood (those highlighted with red borders) on which a piping system will be mounted that will later be connected to 2 Flow Tracker 700 CE atomizers. A single pressure tap has also been mounted on the side wall (highlighted with the yellow border). Regarding overall dimensions, this component has the following dimensions: length=1645.3 mm, width=404 mm and height=1035 mm. Fig. 7 shows two images from the construction of this chamber.



Fig. 7 – Images from the construction of the initial settling chamber no. 2 (figure on the right - Pavăl, 2024).

After the entire construction was completed and mounted on the wind tunnel, the next step was to conduct an experiment whose main purpose was to trace the characteristics of the centrifugal compressor. This is of major importance because according to this characteristic the next component called test section will be designed.

The main equipment used to perform the experiment is shown in Fig. 8. In Fig. 8a, a 3D model of a displacement mechanism containing a Prandtl tube can be seen. This tube has a calibration coefficient of 0.98 and the displacement mechanism consists of the following components: a fine-pitch screw that is rotated using the handwheel on the top, support columns, an indicator element, and a graduated ruler located on the right. This device also includes a protractor with which the tube was positioned perpendicular to the air flow direction. In the lower part, an L-profile was made from chipboard with which this device was attached to the initial settling chamber no. 2. Fig. 8b shows the pressure measurement equipment consisting of six ASHCROFT unidirectional and bidirectional differential pressure transducers. The measurement range is from 160 Pa to 4 KPa where the accuracy is 0.4%. At the same time, these transducers are individually connected to the SWE-73-A digital indicators (Pavăl, 2024).

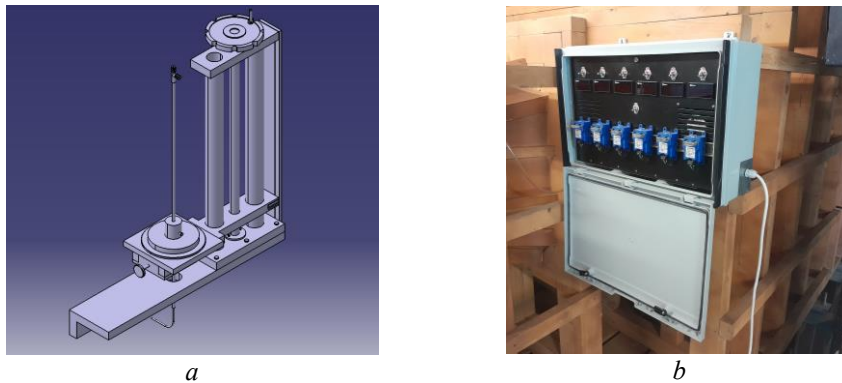


Fig. 8 – The equipment used to carry out the experiment: *a* – Prandtl tube and displacement system, *b* – equipment for measuring pressures.

For this case, the standard method was used which consists of determining the flow rate by local velocity measurements in 10 equal sections. This was achieved by reducing the outlet section using the end plate of the chamber. Two representative images are presented in Fig. 9 where in Fig. 9a a 3D model is illustrated which highlights the working mode while in Fig. 9b the obtained characteristic of the centrifugal compressor is presented. This characteristic was approximated with a 3rd degree polynomial using MATLAB (Pavăl, 2024).

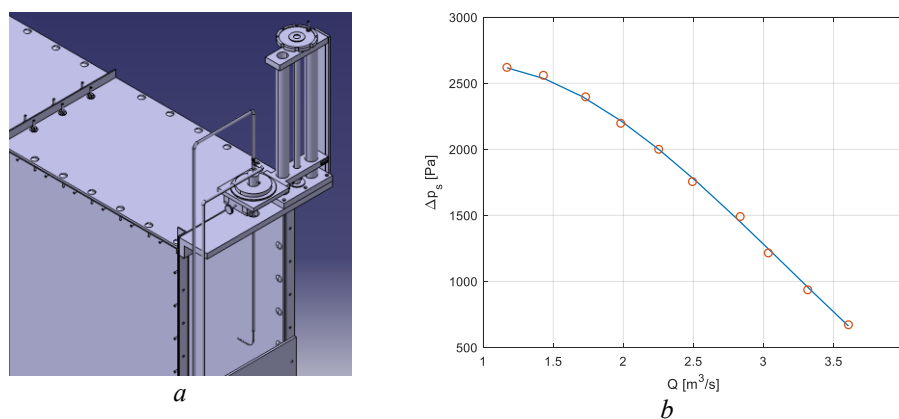


Fig. 9 – Plotting the characteristic of the centrifugal compressor: *a* –suggestive image of the experiment, *b* – characteristic obtained (figure on the right – Pavăl, 2024).

After analyzing the obtained characteristic, it was concluded that this chamber requires modifications / addition of new components. Therefore, Fig. 10 shows a series of images of the settling chamber no. 2 in its final form.

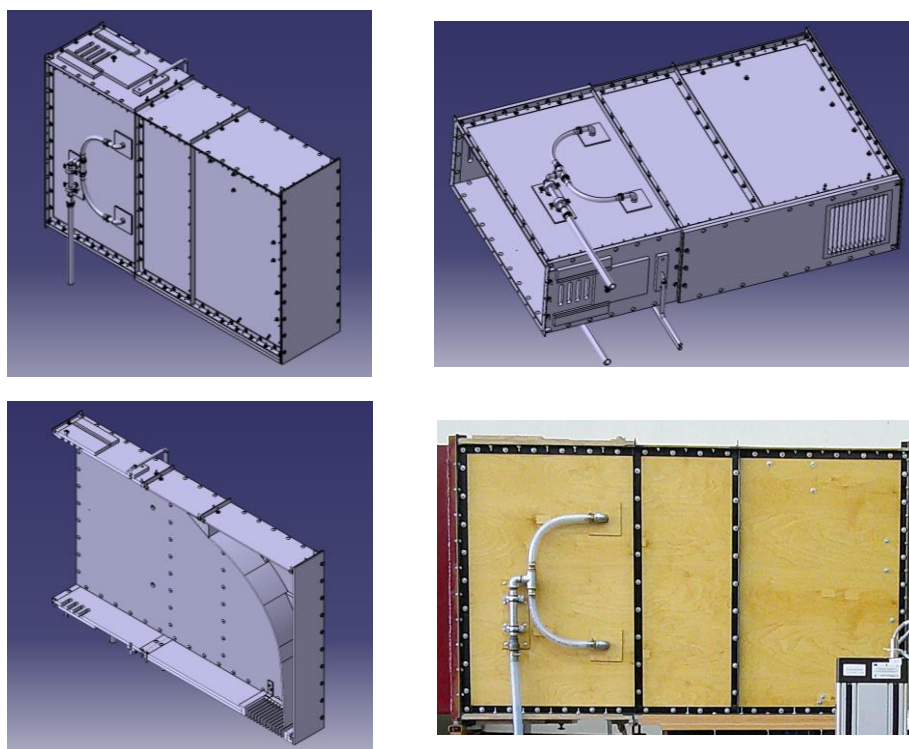


Fig. 10 – The final form of the settling chamber no. 2.

The main components that were made and installed were the following: 2 by-pass flaps that each have 4 holes (a single hole has an approximate size of 125x20 mm) where the main role of the flaps is to control the flow rate in the installation in order to avoid pumping, an inner wall that has the shape of an elbow whose main role is to direct the air flow towards the inlet grille, an inlet grille made of wood that has 12 blades made of 2 mm thick plywood where the main role is to reduce the axial component of the velocity at the entrance to the test section. At the same time, as can be seen in Fig. 10, some existing boards were replaced with boards made of 18 mm thick melamine-coated chipboard (Pavăl, 2024).

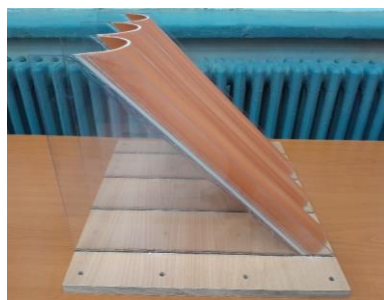
### 3.3. Design and construction of the test section

After the completion of settling chamber no. 2, the most important component of the experimental test rig was designed, which is the test section. Three important factors were considered when this process began, namely:

1. The dimensions and configurations of the modules;
2. The range of values for air clearance height;
3. The maximum possible overall dimensions.

In the first instance, a study was carried out on the geometric dimensions of the segments of the flexible skirt currently used. Following this study, it was found that the sources are limited, the vast majority of which do not have sufficient information to configure and size the segments. Finally, two papers were identified in the specialized literature (Chung and Sullivan, 2000; Sullivan *et al.*, 1994) in which the first paper the ratio between the height and width of the segment is 3.291 while in the second paper the ratio is between 2.954 and 3.2822 (Pavăl, 2024).

Based on the data presented above, it was decided to create 4 segment modules with 4 different inclination angles, each module containing 3 segments and the ratio between the height and width of the segment to have the value 3. Therefore, in Fig. 11 the 4 mentioned modules are presented.



a



b

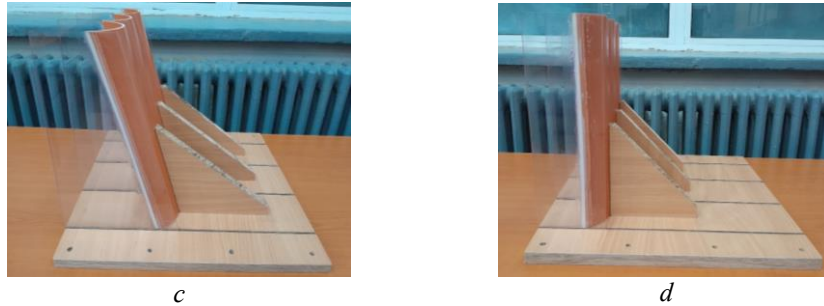


Fig. 11 – The 4 segment modules with the inclination angles:  $a - 45^\circ$ ,  $b - 60^\circ$ ,  $c - 75^\circ$ ,  $d - 90^\circ$  (Pavăl, 2024).

As can be seen in the figure above, the 3 segments were made of SN4 multilayer PVC pipe with a diameter of 110 mm and a thickness of 3.2 mm, the separation walls were made of 4 mm thick transparent solid polycarbonate plate and the fixing plate was made of 18 mm thick melamine chipboard.

In addition, melamine chipboard profiles were installed downstream to fix and stiffen the segments. After the modules were build, the actual construction of the test section followed. Fig. 12 shows two 3D models of this component.

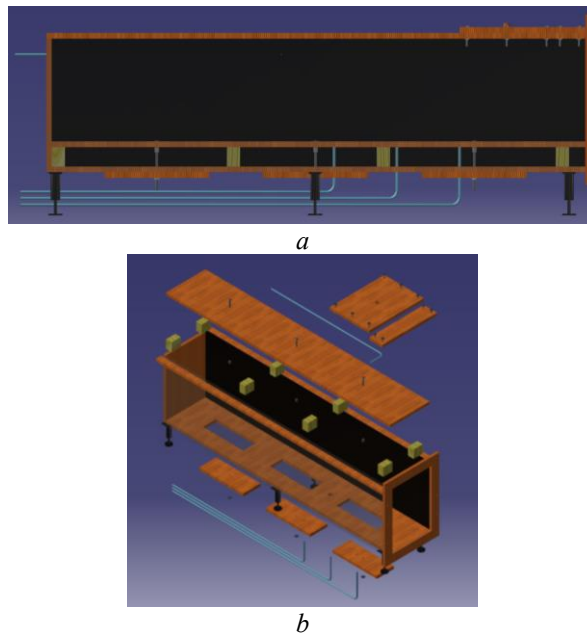


Fig. 12 – Images with test section:  $a$  – final assembly,  $b$  – 3D exploded isometric view

The internal dimensions of the test section are as follows: length=1701 mm, width=300 mm and height=400 mm. Except for the front wall which was

made of 20 mm thick colourless plexiglass plate with a transparency of 92%, all other walls were made of 18 mm thick melamine-coated plywood. The back wall was painted matte black to eliminate reflections of the laser beams towards the experimenter (Pavăl, 2024).

In the bottom wall, to insert spacers necessary to adjust the air clearance height, 3 holes of significant dimensions were made.

The mobile horizontal plate is adjustable using a system made of screws, nuts, and washers and 3 pressure taps were also mounted on it near the exit under the segment, taps that are connected to the hoses. The 3 counter plates fix the mobile plate and ensure a good seal. Also, a pressure tap was installed right at the entrance to the test section on the back wall.

The range of values of the air clearance height parameter for this test section as well as for these segment modules is within 0 – 100 mm. For the experimental tests performed on this test rig, 6 values were chosen for air clearance height, namely: 25, 40, 55, 70, 85 and 100 mm.

Another important aspect is that the plate downstream of the segment module has an orifice created into which a technical glass immersion thermometer is inserted to determine the temperature during the experiment.

In conclusion, it can also be said that this test section has 6 adjustable stainless steel furniture legs. Therefore, in Fig. 13 two images of the real test section are presented (Pavăl, 2024).



Fig. 13 – Images of the test section during construction and during the experiments (figure on left – Pavăl, 2024).

### 3.4. Design and construction of the S-shaped connecting elbow

To connect test section with diffuser no.2, it was necessary to design and build a connecting elbow that would have an S-shaped middle fiber. A first important aspect about this component is that it was designed as a planar diffuser with a linearly increasing cross-section. A series of representative images are shown in Fig. 14 where a 3D model is presented as well as the component made and installed on the wind tunnel (Pavăl, 2024).

Another aspect that should be mentioned is the overall dimensions of this component, which are the following: length=705 mm, width=430 mm and height=1334 mm. Also, the materials used in the construction are represented by 18 mm thick melamine chipboard and 8 mm thick moldable plywood (Pavăl, 2024).

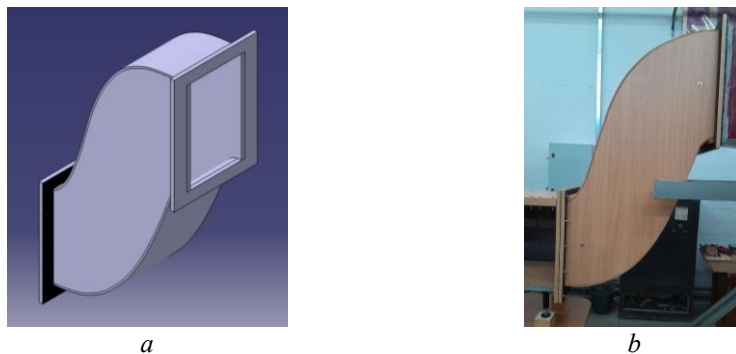


Fig. 14 – Representative images with the connecting elbow: *a* –isometric view of the 3D model, *b* – installed component (figure on the right – Pavăl, 2024).

#### 4. Conclusions

This paper presents in detail all the steps that led to the modification of the MF-TA2 wind tunnel as well as the design and construction of new components with the aim of conducting research on the aerodynamics of the lift system for air-cushion vehicle on this experimental test rig. The main goal was to reproduce as closely as possible the flow around and in the immediate vicinity of the segments.

Another important aspect is the fact that the entire construction was carried out with our own funds and executed within the Department of Fluid Mechanics, Fluid Machinery and Fluid Power Systems within “Gheorghe Asachi” Technical University of Iasi.

Also, after the completion of the entire test rig, a series of experimental tests were carried out using the Laser Doppler Anemometer, test that validated CFD numerical simulations performed using ANSYS. An image from the experiments can be seen in Fig. 15 where the segments inclination angle value is  $60^\circ$  and air clearance height value is 40 mm. Information related to the experimental data obtained as well as the numerical data will be presented in a future paper.

As a final conclusion, this experimental test rig allows testing of different experimental models in different configurations (Pavăl, 2024).



Fig. 15 – Image of the Laser Doppler Anemometer during the experiments (Pavăl, 2024).

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PROIECTAREA ȘI CONSTRUCȚIA UNUI STAND EXPERIMENTAL PENTRU  
TESTAREA DE SEGMENTE ASEMĂNĂTOARE CU CELE ÎNTÂLNITE LA  
AEROGLISOARE

(Rezumat)

Sistemul de sustentație al unui aeroglisor este componenta esențială ce definește acest mijloc de transport. În prezent, cele mai utilizate fuste flexibile ca parte a unui astfel de sistem sunt fusta flexibilă segmentată și fusta de tip pungă și segmente. Lucrarea de față evidențiază pas cu pas proiectarea și construcția unui stand experimental precum și a 4 casete de segmente ce vor fi testate ulterior. Standul experimental este un tunel aerodinamic în circuit deschis de mici dimensiuni cu modificări majore, adaptat pentru a testa casetele de segmente menționate. Fiecare casetă conține 3 segmente de dimensiuni egale și 4 pereți despărțitori. Unghiul de înclinare al segmentelor diferă de la o casetă la alta. Aceste unghiuri sunt următoarele: 45°, 60°, 75° and 90°. Camera de experiențe conține o placă orizontală mobilă cu ajutorul căreia se simulează suprafața de rulare iar garda la sol poate fi ajustată prin intermediul unor distanțiere.