Computer simulation of air currents in the space in which the sculpture "Red Polygon" is positioned

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Abstract: The main approach to studying the flow of fluids and their streaming around solid objects is based on combinations of computational and model investigations. However, when designing, it is often difficult to perform a number of model (experimental) investigations, due to the actual cost of designing the model and the specific test conditions. For these reasons, it is often approached to perform simulation optimization through specialized software, which aims at obtaining a more complete image of the stream, which involves calculation and analysis in the field of speeds and pressures.

The tasks of this particular research focus on the determination of the air current field, in a space in which a kinetic art object is placed. Its main aesthetic function is based on movement in the designated space, which of course depends on the influence of airflow.

For this purpose, a modern approach towards determining the airflow field is selected using the Flow simulation module, which is an integral part of the SolidWorks software package. These simulations in a virtual environment are performed on the developed 3D numerical model of the sculpture "Red Polygon" in scale 1:1. This particular artwork is owned by the Museum of Contemporary Art in Skopje and is the author's work by world famous sculptor Alexander Calder.

The main goal of these analyses is to clearly present how the airflow and the sculpture themselves interact in the space, whereby we would be able to explain and predict its dynamic behaviour. On the basis of the obtained data, we contribute specifically to the demystification of the spatial functioning of this type of artwork.

Keywords: kinetic sculptures, mechanics of fluids, aerodynamics.

Introduction

The first kinetic sculptures/ “mobiles” of the famous American sculptor Alexander Calder, who were mechanically moved, will emerge in 1932. What will encourage him to start making “mobiles” will be his visit to the studio of Mondrian. He himself in an interview said: “(...) I was impressed by the few colored rectangles that Mondrian had on the wall. Soon after, I made some mobiles ... Mondrian claimed that his images are faster than my mobiles...”[1]

By combining motion, color and playing in a traditionally static medium, Calder redefined the sculpture of *what it is*, to *what it can be*. At first glance, many of his kinetic sculptures/ mobiles seem simple, but after further examination, it is clear that their extraordinarily balanced designs are made with exceptional expertise and precision. From the featherweight ease of metal shapes, bound with serial (rhythmic) connections, there is an aura of mutual conjugation that arises between the segments that shape the mobiles. For each segment in the mobiles, Calder establishes a general course of movement, determining their position and focus, balanced in a perfect balance, and then let them have the air forces ruling in the space in which they are set (interior / exterior) to determine their dance.

Formulated theoretical knowledge of Calder's kinetic sculptures/ mobiles are not defined solely through artistic and aesthetic and philosophical thought, that is, they have parameters that give an opportunity for an empirical interpretation. Calder, who is a mechanical engineer by himself, was influenced by the ideas, which are rejecting the already well-known grounded scientific

[1] Gvozdanović, N., Lj. Grigorijević, Likovne sveske 3-4, Univerzitet umetnosti u Beogradu, Beograd, 1996, p. 164.

interpretations and understanding of space and time. His dynamical installations that are based on the movement are seeking for the "fourth dimension", but only and only in the field of sculpture.

Calder uses the mechanics and its methods as means to achieve his aesthetic goal. This author, through kinematism, unites science and art in one, giving a visible clear access to what is unlimited inspiration for him - the universe. By its nature of existence in space and time, his kinetic sculptures/ mobiles offer simplicity that points to the possibility of making interesting analyzes and deduced scientific conclusions about the transcription of an idea, certainly in the concrete case of the sculpture in motion and its spatial existence.

In this research, the air environment and its peculiarities are of particular importance, since kinetic sculptures exist in it. The mechanical influence of the aerospace on kinetic sculptures plays a significant role for their spatial function. It is a series of phenomena studied by fluid mechanics arising from the interaction of the environment and the solid object.

The first phenomenon that is important is the force of the pressure, which acts on any object immersed in fluid, whether it moves or not, the force of pressure always has the direction of action that is opposite to the gravitational force.

The movement of the fluid around the object and the movement of the object through the fluid is treated as an identical phenomenon. In our case, the reference system refers to the resting object, and the movement of the fluid is displayed through its current lines. There are two types of fluid flow around a given object, which are laminar and turbulent. "The laminar movement of the fluid happens when the adjacent layers of the fluid move parallel to each other and do not interfere. This fluid movement occurs when the body speed or flow rate of the fluid is very low. The turbulent motion of the fluid occurs when the adjacent layers interfere and create vortices“.[2] We will try to present these types of currents through the flow lines and current fields on the sculpture "The Red Range". For this operation we will have to use a computer simulation.

When the flow of the fluid around the object is at a higher speed - the strength of the resistance of the fluid increases. The resistance force depends on the density of the fluid, the surface of the cross-section of the object and the speed at which the object is subjected.

The coefficient of aerodynamics is a dimensionless parameter, which depends solely on the shape of the object. In different objects of different shape, the resistance of the fluid is different. The smallest resistance is observed in elongated drop shaped bodies, in which the body's length is four to five times greater than the thickness. In this type of objects, turbulences, that is, the vortices that occur behind the body are minimal, which is a factor plus for reducing the resistance of the fluid.

Measurements performed on the sculpture Red Polygon

This research was done on a sample of the kinetic sculpture by this author under the title "Red Polygon", which is owned by the Museum of Contemporary Art in Skopje. This sculptural work in the form of a hanging mobile with all its grace in spatial operation is essentially a perfectly balanced installation. During the standstill phase and the absence of external influences caused by air currents, the whole composition of this sculpture lies in a vertical plane. Its segments are composed of metal plates and steel wire, with thirteen levels of their welding, which are carefully balanced in a semi-open kinematic chain.

Through this sculpture, the author tries to present incidental movements, which in spite of their naturalness have their own particular and somewhat controlled form. The air currents that contribute to the movement of the components of the sculpture "Red Polygon" are in the focus of this research.

For the needs of my research research, in the premises of the gallery of the Museum of Contemporary Art in Skopje, in the presence of a responsible person (curator), detailed measurements were carried out on all dimensions of the sculpture. More precisely, the dimensions of the plates, the length of the wires connecting them, and their thickness were measured. The weight of the sculpture,

[2] Туфекчиевски А., Биомеханика, ФФК, Скопје, 2003, p. 248

as well as the weight of its elements, could not be measured, because it was placed in an exhibition space and its parts can not be dissociated. All measured lengths are accurate to 1.0mm, while the measured thicknesses are accurate to 0.1mm. The plates, which are 14 in number as elements of the sculpture, are made of sheet metal, which are painted with automotive paint without varnishing. The wires that are tightly bonded with the plates, on the other side end with a joint system, made of steel for their greater toughness.

Computer simulation of air currents in the space in which the sculpture "Red Polygon" is positioned

The main approach while studying the flow of fluids and their perforation around solid objects is based on combinations of computational and model investigations. However, when designing, it is often difficult to perform a number of model (experimental) trials, due to the actual cost of designing the model and the specific test conditions. If we want to do simulation optimization we need to create a broad database obtained as a result of comprehensive, but extensive calculations and analyzes. On the other hand, relatively fast computers with affordable prices and the development of specialized software, lead to the emergence and rapid development of an applied branch of fluid mechanics, or more precisely fluctuation of fluids - Computational Fluid Dynamics (CFD). With the help of this branch, it was made possible to perform some (until now) truly elusive solutions that demanded too much accrual time and other support.

The task of this research is to focus on the determination of the air current field in the space in which the “Red Polygon” sculpture is placed, as well as the impact of the air velocity on the dynamic behavior (motion, balance) of the sculpture. For this purpose, a modern approach for determining the flow is selected using the simplified module for CFD simulations (Flow simulation module), which is an integral part of the SolidWorks software package.

All of this was simulated in a virtual environment - software where on a three dimensional models several analyzes we made, that will clearly show how the air and the sculpture interact in space.

As input parameters for the software are the following:

Finite element network - a parameter by which the software is used to limit the geometry of the sculpture to a finite number of elements through which it can calculate the simulation. In this case a network with a finite number of elements equal to **134694** elements was used. The size of the number of finite elements defines the accuracy of the calculation, and depends on the geometry itself and the size of the model under investigation.

The flux of the fluid, in this case air, is not limited, i.e. the simulation itself will detect whether the air flow will be laminar or turbulent. Changes in velocity and air pressure will be examined in the airflow around the sculpture, that is, the impact of the sculpture on the parameters of surrounding air.

Simulations were performed under normal outdoor conditions, respectively:

- **Pressure - 1,01325 bar - atmospheric pressure**
- **Temperature - 20,050 C.**
- **Molecular density - 29.0 kg / kmol**
- **Flow velocity - 3 m/s**

A number of numerical simulations are performed on conditions similar to the conditions of experimental research. The 3D numerical model of the sculpture is made in the scale 1: 1, shown in Figure 1. Given that it is not a matter of large static pressures of air flow in the room (aerotunel-measuring section), only the results for the current image will be displayed through the field of speeds. In this study, all simulations and calculations are performed in a case where the sculpture is in a fixed position (at rest).

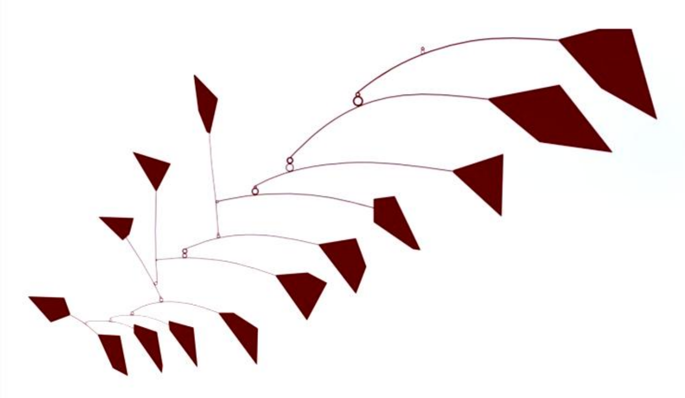

Figure1. – 3D numerical model in SolidWorks

The first simulated representation (Figure 2) shows the results for the field of velocities in the case when the direction of airflow is in the direction normal to the sculpture. It can be noted that the intensity of the speed decreases in the nearby surroundings of the sculpture plates, and the intensity is the smallest around the plates themselves (red colour).

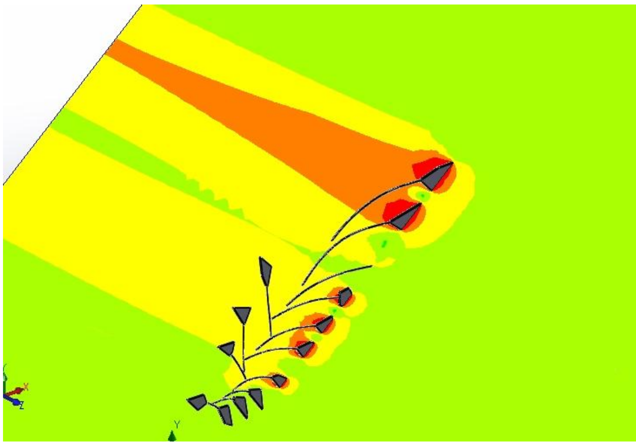

Figure 2. –Current field in the space around the sculpture, in case when it is set normal to the direction of the current

Figure 3 shows the results from the vector field of speeds and the way of streaming the sculpture, at the same position of the sculpture against air currents. The air currents are shown as current fibers that obstruct each plate from the sculpture. It can be noted that due to the non-aerodynamic geometry of the plates, there is the appearance of a stripping off of the current (the boundary layer) and the occurrence of vortices in the back of the plates. These vortices (blue circuits) are more present on larger plates. It is noticeable that after a certain distance from the plates, the flow begins to calm.

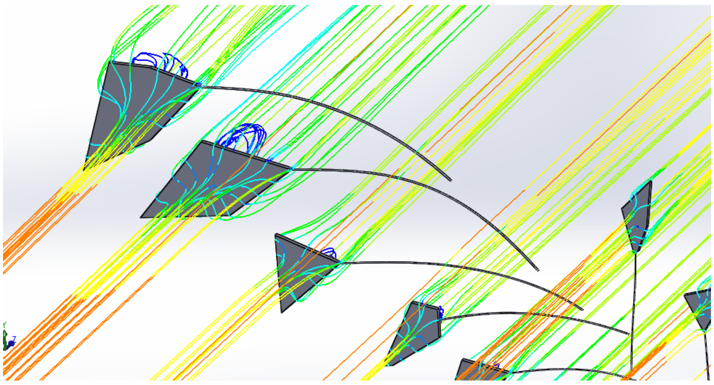

Figure 3. - Vector field of velocities around the sculpture

Figure 4 shows the results of the simulation for the velocity development during the streaming, in the case when the direction of air flow is at an angle of about 45^0 toward to the placement of the sculpture. Here, the development of the speed during the streaming depends on the sculpture itself in a simulated environment. It can be noticed that the speed is reduced during the streaming and that the intensity of the speed reduction is greatest in the sculpture area where the plates have the largest surfaces (larger in size), which at this point of theoretical standstill of the sculpture is quite important for the further action of the sculpture in relation to the air.

It is also important to say that during this placement of the sculpture, the air velocity at just a short distance behind the sculpture already regains its size, and interacts with the outer space in a natural way, with mild changes.

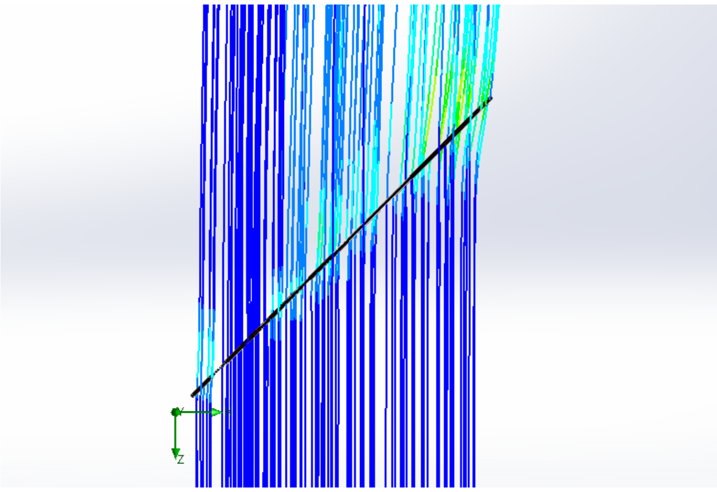

Figure 4. - The development of the speed during the streaming, in the case when the direction of airflow is at an angle of about 45^0 against the placement of the sculpture

With the same placement of the sculpture in relation of the flow in Figure 5 it can be seen more clearly how the flow lines are moving along the sculpture itself and how the change in the speed of the airflow takes place depending on the starting position of each current. The profile of the current is defined by the profile of the plate, which is part of the sculpture. Each current acts separately on the sculpture and contributes to the final result of the change in the current field, as well as to the change in the position of the sculpture itself.

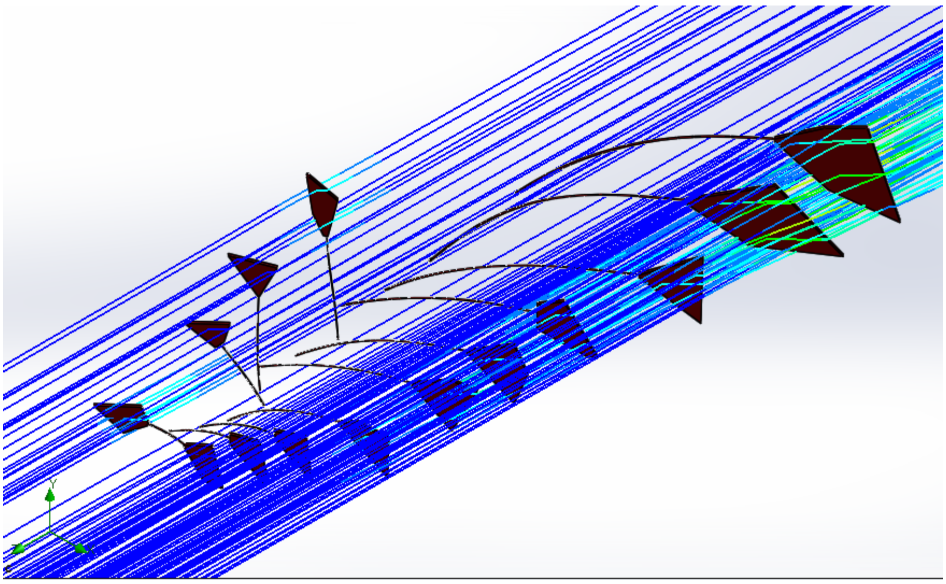

Figure 5. - Vector field of speeds around the sculpture, in the case where the direction of air flow is at an angle of about 45^0 against the placement of the sculpture

In the next simulation, results are presented for the field of velocities in the vertical plane of the current space, in case when the model of the sculpture is placed in the direction of airflow (Figure 6). It can be noted that the intensity of the velocity decreases in the nearby surroundings of the sculpture plates, and the intensity is the smallest around the plates themselves. The most significant changes in the flow velocity occur around the largest and highest plates, which in this case tells us that the highest tiles define this position of the sculpture.

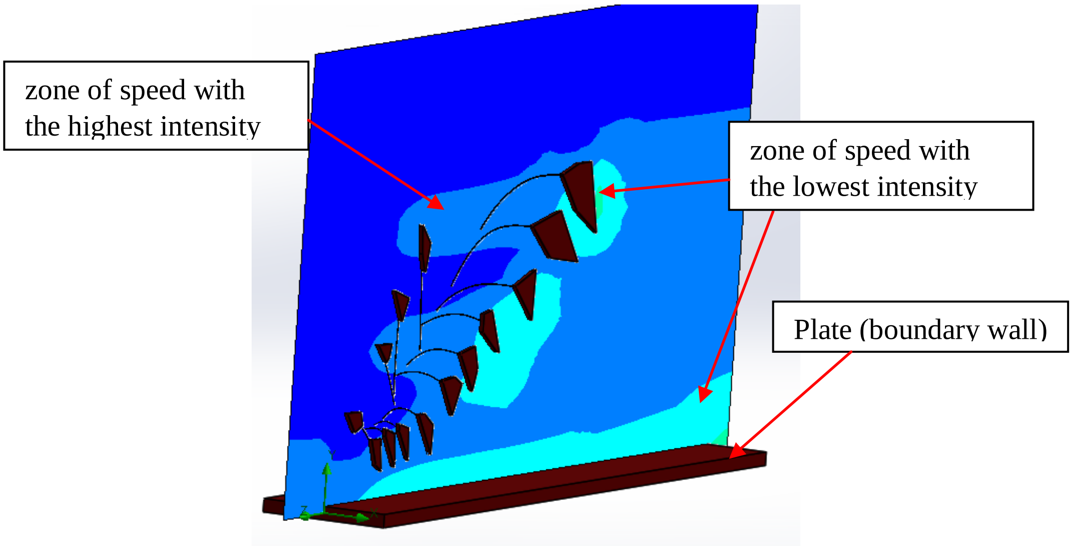

Figure 6. – Current field of velocities in a vertical plane, in the case when the sculpture is set in the direction of the air flow

The movement of the current lines, which are quite specific for this simulation settlement, is identified with the real experiment, in which we used very thin threads to determine the flow lines, placed on a vertical axis in the air tunnel. The arrangement of flows and their trajectory of movement is shown in Figure 8. It can be seen clearly how the flow lines move around each plate and how the speed changes with respect to the initial speed. The speed change is such that a vacuum field is created in the immediate vicinity of the plate and this vacuum field acts negatively on the high velocity in front of the plate and thus creates an equivalent pressure that keeps the entire tile in a collinear direction with the direction of movement of the air.

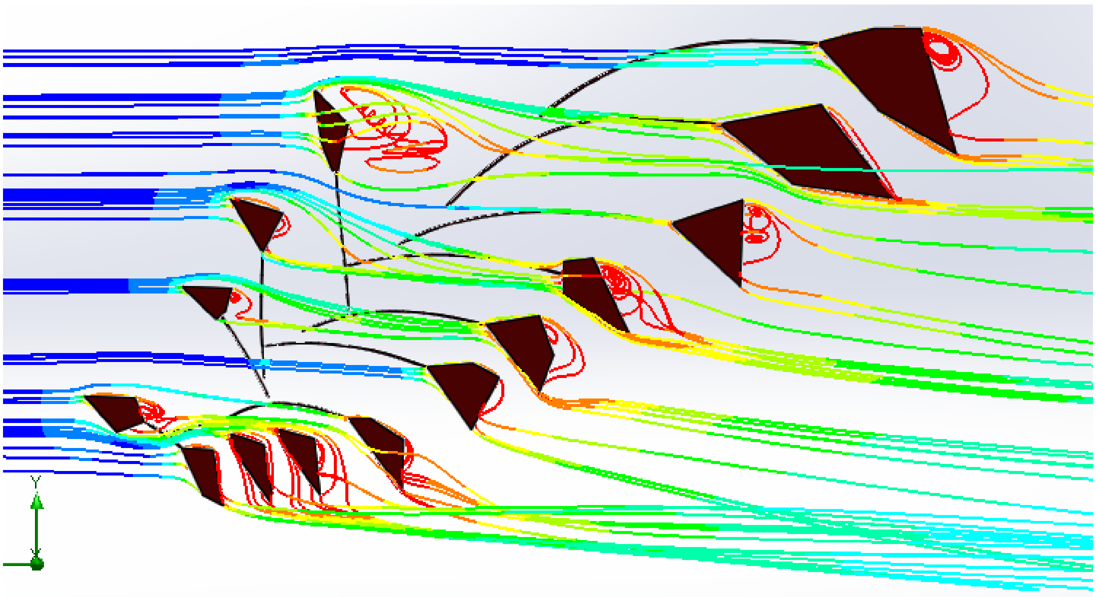

Figure 7. - Arrangement of flows and their trajectory of motion

To perform the next simulations, the sculpture is placed in a semi-enclosed space (semi-closed room) as shown in Figure 8.

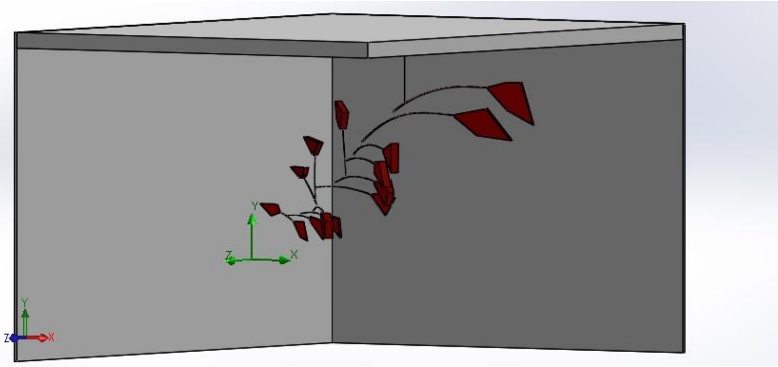

Figure 8. - A model of sculpture placed in a semi-enclosed space

From the airflow simulations in the half-closed room shown in Figure 8, a chaotic and recurrent movement of the air can be observed. Because of this, the sculpture would make undefined movements and rotations similar to those observed in experimental research.

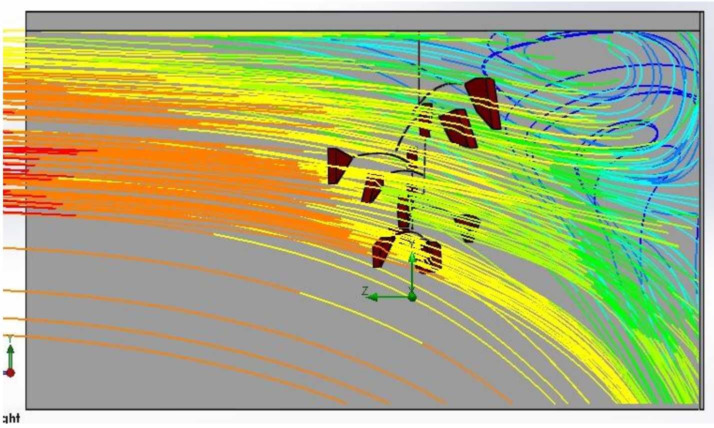

Figure 8. - Air flow around the sculpture in a half-closed room

From the previously mentioned in these simulations, it can be seen that the precise prediction of the behavior of the sculpture depending on the current parameters and conditions, i.e. the initial (speed, pressure) and boundary (space, walls, constraints) conditions can be a difficult task, and even the leading specialized technique in the field of fluid dynamics (CFD) is used.

Conclusion

The computer simulations made in the Flow simulation module, which is an integral part of the SolidWorks software package, serve to clarify the current space by displaying a visible current image around the entire sculpture. The graphic representations of this simulation could be compared and supported by experimental investigations of the effect of air currents on the sculpture "Red Polygon".

The first simulation made by placing the sculpture at right angle to the direction of the air currents, refers to the first moment of the beginning of the flow, just before the start of the movement of the sculpture. From this, it can be noticed that the intensity of the flow velocity decreases in the nearby surroundings of the sculpture plates. The intensity of velocity is the smallest around the largest surfaces, indicating that the influence of air currents on the sculpture is greatest in those parts (plates).

This would lead them to move forward and dictate the direction of rotation and the setting of the sculpture. Also with this simulation, we visually get the currents and their streaming around the sculpture, as well as the vortices that are created.

The second simulation was made in such a way that the sculpture was placed at an angle of 45 degrees from the direction of the air currents. It also refers to the first moment of starting the flow, just before the start of the movement of the sculpture. As in the previous simulation, here as well,it can be noted that the speed is reduced during the displacement of the sculpture and that the intensity of the speed reduction is greatest in the sculpture area where the plates have the largest surfaces, which shows that the impact of air currents on the sculpture is the largest of those parts.

In the third simulation, the sculpture was placed in the direction of the movement of air currents, that is, the position that the sculpture strives to keep while exposed to air flow from a certain direction. From this simulation we learn that the intensity of the flow velocity slightly decreases (slows down) over the plates with a larger surface, while in other cases the decrease in velocity is insignificant, which points to us that the plates with a larger surface define this position that occupies the sculpture.

The last type of simulation was done in order to show us the flow lines when placing the sculpture in a part of the half-closed room. From the graphic results it is clearly seen that there is a chaotic and recurrent movement of the air, which would lead to movements of sculptures that would be hardly predictable.

We can conclude that the author could not only intuitively act in the accomplishment of his goal, i.e. the construction of this kind of artwork. The question of the technique of making, in whose principles the fluid mechanics is obviously involved, is essential for the artist's activity.

The seemingly simple mobile "Red Polygon", with its entire aesthetic attraction in the spatial existence, is in essence a very complex construction, in which on the one hand we have a structure with well-defined statics and balance of elements, and on the other hand the possibility for different movements of segments, certainly influenced by external influences of air currents. No matter how much it seems natural, inarticulate or free, the movement of the mobile through its rotations in the structural segments is very well conceived, with great precision in the placement of the elements.

Therefore, from the previously analyzed, we can see that in the creation of this work, Calder simultaneously paid attention to the visual and aesthetic part of the presented visualization, as well as to the process of producing the works, in which he as a mechanical engineer directly used his knowledge for the mechanics of fluids.

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