Matei TOMA

THE DESIGN OF A CATAPULT MACHINE

Abstract: *This article will present the elements of the external structure of the catapulting machine, together with the catapulting mechanism and the operating principle of the whole assembly. In addition to these aspects, the paper will also contain notions related to materials or mechanics used. All these details combated lead to the complete definition of the analyzed product.*

Key words: *design, catapult, structure, geometry, principle, operation, assembly, system.*

1. INTRODUCTION

The product around which this article is made is a catapulting machine. This type of vehicle means a ground-guided device that has in its arsenal, as its main method of attack, a projectile catapult system. The design of the car tends to appeal to the appearance of a scorpion [1]. The main topics analyzed in this paper are the design of the external structure of the catapulting machine, the catapulting mechanism associated with it and the operating principle of the finished product [2]. The external structure and the catapulting system, together with the basic structure already analyzed, form a whole, which denotes the complete form of the product in question.

As a field of use, the catapulting machine will be used both in missions to recognize or shoot down a training target, as well as in direct battles with other such machines. This implies that the exterior structure is designed so that, in addition to acquiring a custom design, it plays an important role in the offensive and defensive level of the car. In other words, the exterior structure must have a special geometry and some dedicated features meant to protect the basic structure and interior elements, but also to give the car the ability to damage other vehicles [3]. This category of structural elements includes: wheel guards, front mask and central housing.

In other words, the included catapult system benefits from a projectile trajectory variation mechanism, based on changing the position of the launch threshold. This movement is done in accordance with the planar rotation of the camera with which the catapulting machine is equipped. In this case, the camera is used simultaneously to transmit the image in real time, and to adjust the launch trajectory, playing a target role.

2. DESIGN OF STRUCTURAL ELEMENTS AND MECHANICAL SYSTEMS

2.1 Description of the software program used

After sketches or drawings have been made beforehand, the pieces must be drawn in a three-dimensional form. This is possible by using a specialized design program. For the current project it was decided to use the software program called CATIA V5. With the help of this program the geometries of the pieces could evolve from the concept stage to the concrete one. In addition to the development of 3D models, the allocation of material was also made with the help of this program. Thus, each piece was assigned a material, which led to both changes in textures and colors, as well as the allocation of specific properties, such as density, modulus of elasticity, yield strength, etc. Also with the help of this program, assemblies of parts can be created, by applying some constraints between the component parts.

The program also includes other useful functions or workbenches, but nevertheless the level of complexity of the interface is very high. In other words, CATIA is a good software but requires user experience. Otherwise, the program becomes very difficult to use and thus unusable.

2.2 Design and description of the exterior structure

As previously stated, the final design of a piece is based on a concept often outlined on the sheet. This principle was followed in this case as well [4].

The first element combated is the front mask of the vehicle. The original concept provided that this mask and the front wheel guards were different parts. It was later decided to merge them into a larger mask. The main reason for this decision was the space. In the case of the primary idea, of being different parts, the lack of space greatly constrained the grip on the basic structure and the turning of the wheels. In the case of three separate parts (two guards and a mask) and the large number of movable parts in that area, the structures allocated to the wheels would not have benefited from a proper mounting on one of the fixed components associated with the front axle. Moreover, there was a risk that the wheel guard would block the maximum stroke of the wheel when cornering. Also in terms of disadvantages for this initial variant is the faulty sizing of the mask. It should have been much narrower and the geometry would have suffered. A final impediment is the integrity of the assembly. Dividing into several pieces leads to a decrease in the strength of the assembly, which is totally undesirable. In Figure 1 and Figure 2 you can see the separate concepts of the two types of structures initially sketched.

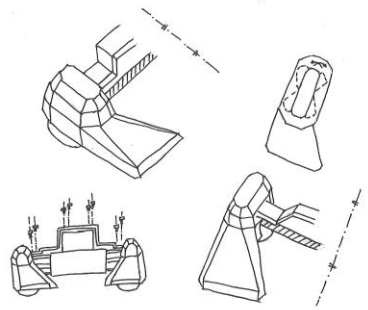

Figure 1 Initial sketch of the front wheel guards

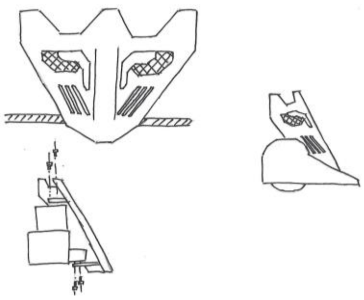

Figure 2 Initial sketch of the front mask

All these disadvantages have been removed, as already mentioned, by replacing them with a single piece: a wider front mask. This mask is designed to cover both the engine and servomechanism together with the other components of the steering system, as well as the two wheels in a very large proportion. The front of the wheels is completely protected, while the side has a vulnerable area. However, the wing of the mask keeps almost anybody away from that area. The only way to reach the tire is by a side hit, with the help of a longer, narrow and sharp body. This type of attack is very unlikely to be performed, and in conclusion, the mask in question is the most optimal solution. The design of this first part of the exterior structure is presented in Figure 3. It can be noticed the evolution of the design compared to the initial sketches. This difference is made primarily by the use of a complex geometry based on curved surfaces.

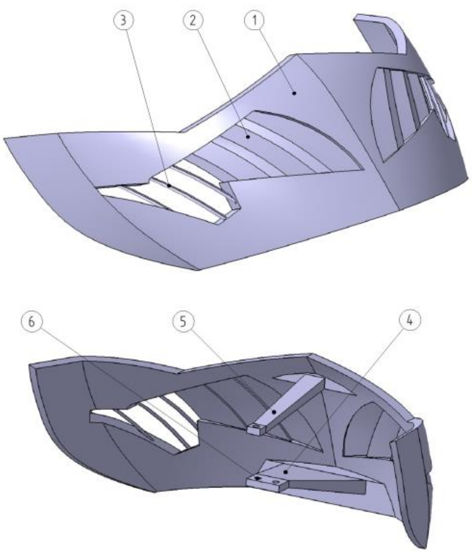

Figure 3 Front mask design

It is observed that the mask consists of a symmetrical profiled body (1), two rows of three semi-overlapping slats (2) and two other series of three curved cylindrical grids (3). The body benefits from an inclination towards the ground plane, which gives the masks an offensive character through the ability to overturn an object on impact with it. The accessories (2) and (3) have, in addition to the visual role of adapting the design to the image of a scorpion, a technical importance. Specifically, by placing these slats and gratings in place of a continuous and uniform body, the mass of the piece decreases. This is very important because firstly: any extra mass requires extra power, which implies increased consumption; and secondly: a mass in front of the axle produces a force moment which can lead to the problem of overturning the car at some blows. The order of placement of the elements is not random, because the slats have a higher level of protection from the bars. As the motor and the actuator are placed centrally, the highest protection (made by the body itself) is needed in that area. Located further to the side are the moving elements, which are protected by the slats, and located at the most extreme are the wheels, in front of which are the bars. In any case, regardless of the zone on the mask, the level of protection remains very high.

There are two supports on the back of the mask: the lower one (4) and the upper one (5). They have the role of fixing the structural element to the machine by a screw based removable grip. The lower support is fixed on the sill in face of the front engine housing (through which passes the steering rod that connects the two wheel bushes together), and the upper one on the top of the servomechanism housing. In this way the front mask is properly fixed by means of the three through-holes (6) for M4 screws, leaving the areas where the wheels perform the cornering movement to be free.

The next element that is part of the exterior structure of the vehicle is the set of guards for the rear wheels. As well in this case it started from a sketched concept, later improved from a geometric point of view. The primary design is highlighted in Figure 4. The differences from the final model consist in the geometry used to make the piece and the fastening method chosen. The use of a common fastening system, as in the original concept, implies the lack of a concentricity on the shaft spindle housings. The new type of grip brings the enormous advantage of a correct, concentric fastening. In case of opting for a common grip, there is a risk of collinearity deviations, and thus there may be friction or even radial run-out.

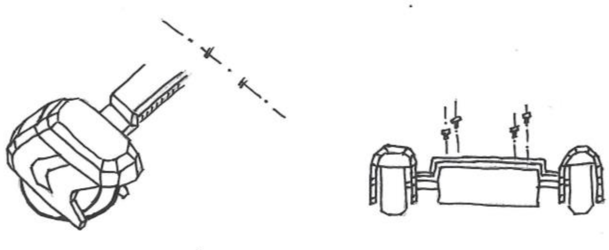

Figure 4 Initial sketch of the rear wheel guards

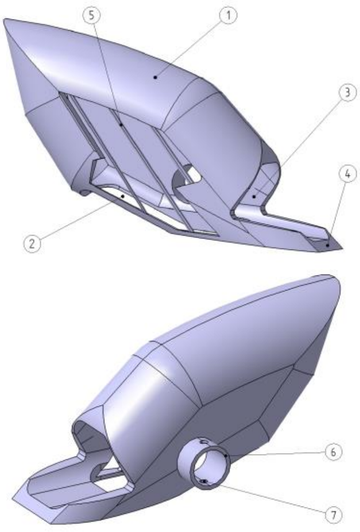

Figure 5 Rear wheel guards design

As in the case of the mask, the rear guards have undergone a design reassessment. Curved and elongated surfaces plus a few new elements have been added to the existing model, while the typical features of a scorpion have been improved. The new design was intended to be in line with that of the front mask, using some of the geometric concepts and internal elements found in it.

Figure 5 shows the final design of these guards assigned to the wheels on the rear axle. The body of a piece is broadly composed of an elongated curvilinear contour (1) and the cutouts (2) and (3), respectively. The latter serve as space for the wheel. In the context in which the rear wheels have a fixed trajectory (do not turn), there is no question of obstructing them. Following the cut-out (3), the ramp (4) is created, which has the role of removing possible bodies that may stand in the way of the wheels. The inclined, sharp plane located on the ramp's end leads to damage or overturning related to the bodies with which the guard comes into contact.

For reasons of reducing the mass of the object, a third cutout is made, strengthened and stiffened by the three bars (5). As can be seen, this concept is similar to the portion of grids in the case of the front mask. The idea of the appearance of this cutout is taken from the initial concept, to abstractly induce the impression of two scorpion legs. However, the overall shape is modified, aiming for a longer and sharper one. The primary functionality of this cutout is to allow access to the wheel fixing coupling on the spindle (made by a screw that passes through the center of the rim). This is very important because the assembly consisting of the wheel and the guard can only be mounted or dismounted simultaneously.

On the inside of the guard is the bushing (6) which is placed concentrically on the spindle housing. Two through-holes (7) for M4 screws are drilled in the sleeve for fixing the wheel guard. The last part that completes the external structure of the catapulting machine is the central housing. This is the largest and most important piece of protection. The housing is intended to shelter all the car's electronics, along with the engines, plus the catapult system.

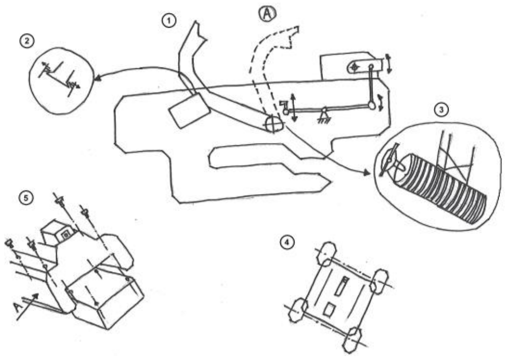

Figure 6 Initial sketch of the central housing and the catapult system

Obviously, if any of these components were to fail, the functionality of the entire product would be jeopardized. The final design of this component follows, in a very high percentage, the concept originally outlined. One of the differences is made by adding elements related to the appeal of a scorpion's features. Thus, the upper part of the final model benefits from a repetitive structure that mimics the back of the arachnid. Figure 6 shows the concept of the central housing together with the catapulting system. Minor changes are also made to the side wing of the piece. One last aspect that differs is the placement of the camera, which for protection reasons has been inserted inside the case. The fastening method remained the same, being ensured by four screws that are fastened to the basic structure of the machine (more precisely by the four corners of the central body).

The 3D model assigned to the central housing is illustrated in Figure 7. The piece is composed of a base body (1) which has included on the top a series of five scales (2) that increase the strength of the object. The defense wing (3) is profiled in the style of the other components presented so far (having the same properties), and compared to the initial concept has an addition: a sharp blade (4) with offensive character. In the scales on the outside, a channel (5) is practiced long, wide and deep enough to include the catapulting system. The front enclosure (7) is used to place the camera. This enclosure ends with a triangular cutout on the front of the case to uncover the camera lens. Also in the front part is practiced a longitudinal channel (8), which has the role of making room for the insertion of the upper support of the protective mask (element 5 in Figure 3).

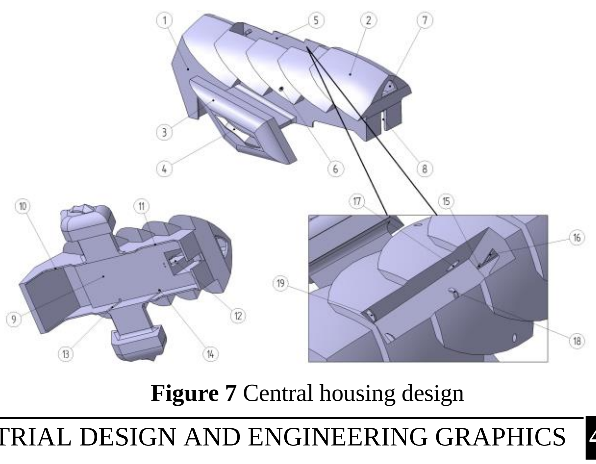

Figure 7 Central housing design

Inside the housing is the enclosure (9) which covers all the internal elements of the catapulting machine. On the other hand, on the sides of the housing are provided the sills (10) and (11) which are located next to the axles. Their role is to avoid unwanted contact between the center housing and the axles housing during a damping process. The predisposition to this event is due to the fact that this housing is mounted on the moving part of the machine (the part that undergoes position changes due to the suspension system), while the rest of the components of the external structure are mounted to the fixed parts (elements attached directly to the axle housings).

Following the enclosure (7), a channel (12) is cut where the lever and the threshold of the catapult direction adjustment system will be mounted. This channel is a special profiled one. The ditch (15) allows the sill to be placed at the required position, while the groove (16) guides the sill on a rectilinear transverse path. The figure also shows the channels (13) that center the housing on the basic structure of the machine, followed by the four M4 threaded holes (14). Inside the channel (5) can be identified: the two electrically operated locking pawl (19) which hold the catapult arm armed and release it to order, the two bearings hole (17) in which ball bearings for d=6 are inserted and a hook (18) from which one of the ends of the tensioned rope is attached. Last but not least, there are two full holes (6) on either side of the channel (5). They help to compress the catapult shaft spindles. In this way, the spring-based spindles are compressed inside the central shaft and so it can be disassembled between the two bearings.

2.3 Design and description of the catapult system

With the completion of the external housings and guards, having already designed the basic skeleton together with the engines, the damping system and the steering system, the finished product lacks the last two components: the mechanical catapult system and the electrical one base of the microprocessor. The next step in this paper is to design the catapult system, which also includes the trajectory variation mechanism. The concept of this system has already been captured in Figure 6, in representations (1), (2) and (3). For a more concise analysis, the whole system is divided into two subcategories: the catapulting mechanism and the trajectory adjustment one.

The subsystem which strictly ensures the catapulting of a projectile consists largely of an arm provided at one end with a shaft and at the other with a cup (1). In order for the arm to store energy, a pre-tensioned elastic cable is wrapped on its shaft, according to the detail (3). When the arm is fully armed, the cable tension increases even more. The arming is ensured by the locking pawl (2), which is also presented in the concrete model from Figure 7, element (19). The launch trajectory adjustment subsystem is also conceptually available in Figure 6, being located in front of the arm. This mechanism consists of a transversely moving threshold, a lever and the camera. The laws of motion of the components are described with arrows in the same image. Based on these concepts, the complete model of the catapult system was created and illustrated in Figure 8.

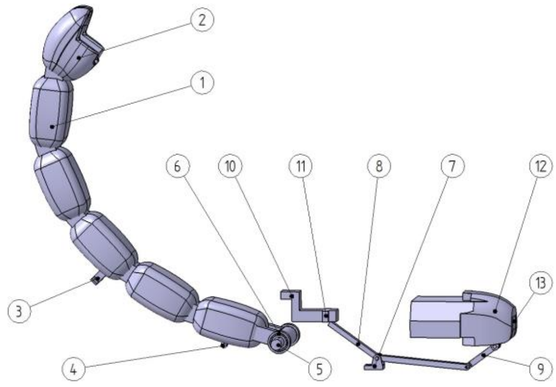

Figure 8 Complete catapult system

The first element in terms of importance is the catapult arm (1). It consists of five identical segments, connected by fixed joints, the arm having a rigid structure. Moreover, it can be noticed that the catapult arm is curved forward. Beside the concordance with the aspectual characteristics of a scorpion, this type of construction also helps to obtain a favourable trajectory of the projectile. Since the range is not a parameter of interest, the coverage given by the curvature of the catapult arm implies a straighter and more grounded trajectory of the projectile (which increases the accuracy) to the detriment of a vaulted one over a longer distance. At the top of this tail is the cup (2). This special segment resembles the other five, but has a larger size and has a place practiced inside, which serves to support the projectile. At the other end is the shaft with the two spindles (5) that enter the bearings (6). The transition between the arm and the shaft has a special feature. It is preferred a mounting based on two parallel rods apart, to the detriment of a single and thicker one.

This is beneficial because the space between the two rods is used to wrap the elastic rope around the shaft. The last features of the arm are: the fixed locking pawl (3), which obviously locks in the electric locking pawl previously analyzed, and the hook (4) to which the other end of the elastic rope is connected, after it has been previously wrapped and pretensioned.

The components of the trajectory adjustment system are described below. The element with which the arm comes into contact and on which the projectile launch trajectory depends is the threshold (10). It has a special profiling (11) at the bottom, which makes the piece slide controlled on a path imposed by the groove (16) from Figure 7. The sill can be brought into the sliding position by inserting it from inside the housing, through the ditch (15) from Figure 7.

Returning to Figure 8, the next element is the lever arm (8), which makes the connection between the threshold and the camera (12). This arm is attached to the joint (7), which is mounted in the machine housing and has a slightly bent shape, made to reduce the size of the mechanism. The reduction of the gauge is not a random fact, but eliminates the risk of interacting undesirably with the front axle servomechanism. At the opposite end from the sill, the arm (8) is articulated with another arm (9). The latter is directly bound to the lens (13) of the camera.

2.4 The operation principle of the trajectory adjustment mechanism

The components of the automatic launch path adjustment system, presented above, are engaged one by one in order to obtain a mechanical assembly. The part that guides the system is the camera lens. It receives a signal from the remote control and can thus perform a rotational movement around the axis. Being articulated by the arm (9), the rotational movement is transformed into a translational movement. By means of the bent arm (8) this translational movement is transposed to the other end of the lever. The proportion in which the translation is transmitted from one end to the other depends on the place where the arm (8) is articulated and the angle at which it is bent.

The free end of the rod, associated with the lever, supports the launching threshold, which is inserted into the corresponding grooves, guiding it transversely. The principle of the catapult is that after unlocking the locking pawl, its arm performs a rotational movement around its own axis, until the moment of reaching the threshold. Figure 9 shows two external cases that denote the principle of adjusting the trajectory of the catapult. In case (A) the camera lens is operated downward at the maximum stroke. This leads to the upward movement of the threshold. By moving the threshold higher, the angle described by the catapult cup between the "armed" position (when the locking pawl has not been released) and the "unloaded" position (when the arm meets the threshold) is increased. Along with the angle, the length of the corresponding arc is also implicitly increased. Thus, the cup travels a greater distance until the moment of launch. Given the curvature of the catapult arm, the arc of the circle will correspond to a value of over 90o. This means that the slope of this curve, at the time of launch, at the point where the cup is, has negative values, ie the projectile will benefit from a slightly decreasing trajectory. At the opposite pole, in case (B), the camera lens is operated upwards at its maximum stroke. This operation causes the threshold to be shifted downwards. Contrary to case (A), the angle and the length of the arc decreases. In these circumstances, being values lower than 90o, the slope will be a positive one, and the projectile will be launched on an increasing trajectory.

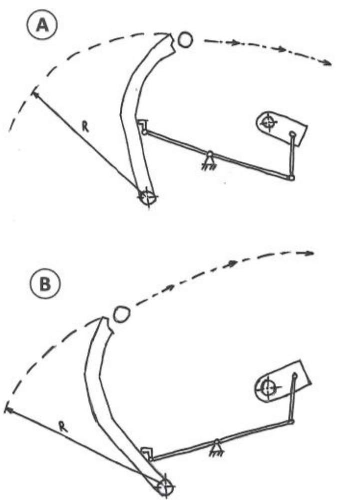

Figure 9 The principle of changing the trajectory

Following this principle, all intermediate positions of the camera lens involve different launch trajectories of the projectile. These trajectories will be associated with slopes between the two extremes resulting from cases (A) and (B). In conclusion, once the camera rotates, the projectile is launched higher or lower. Following calculations and appropriate sizing, a parallel relationship can be obtained between the lens arm (defined as the line between the axis and the joint) and the tangent to the trajectory at launch. In this case, the camera would play the role of target.

2.5 Materials and visual effects

The analyzed product is prone to quite violent and frequent collisions due to its field of use. Analyzing the materials commonly used in such constructions and trying as much as possible to maintain a reasonable maximum mass, it was concluded that the optimal choice consists of using class 6061-T6 aluminium. This material has a very good hardness and a yield strength of around 270 MPa. Also its density is very good, about 2.7 g / cm^3. 6061-T6 aluminium is frequently used in structural frame applications, where strength and low mass are required. In other words, it is chosen that all the elements analyzed in this article be made of this type of aluminium. However, it is specified that both the active part of the sill and the inside of the catapult cup will be lined with a rubber material.

As previously mentioned, the CATIA program offers the possibility to assign a corresponding material to each piece. After this assignment, all parts will acquire a characteristic lustre of aluminium. Moreover, the program also has the option to paint a piece. Thus, the elements that make up the exterior structure will be painted in a metallic purple. The last step is to mount these parts on the basic structure of the machine, in order to obtain a final unitary assembly. Following this procedure, the product acquires the “market” aspect, illustrated in Figure 10.

3. MACHINE OPERATION PRINCIPLE

Once the structural and mechanical assembly has been completed, all that remains to be added is the electrical part.

Figure 10 Final design of the catapult machine

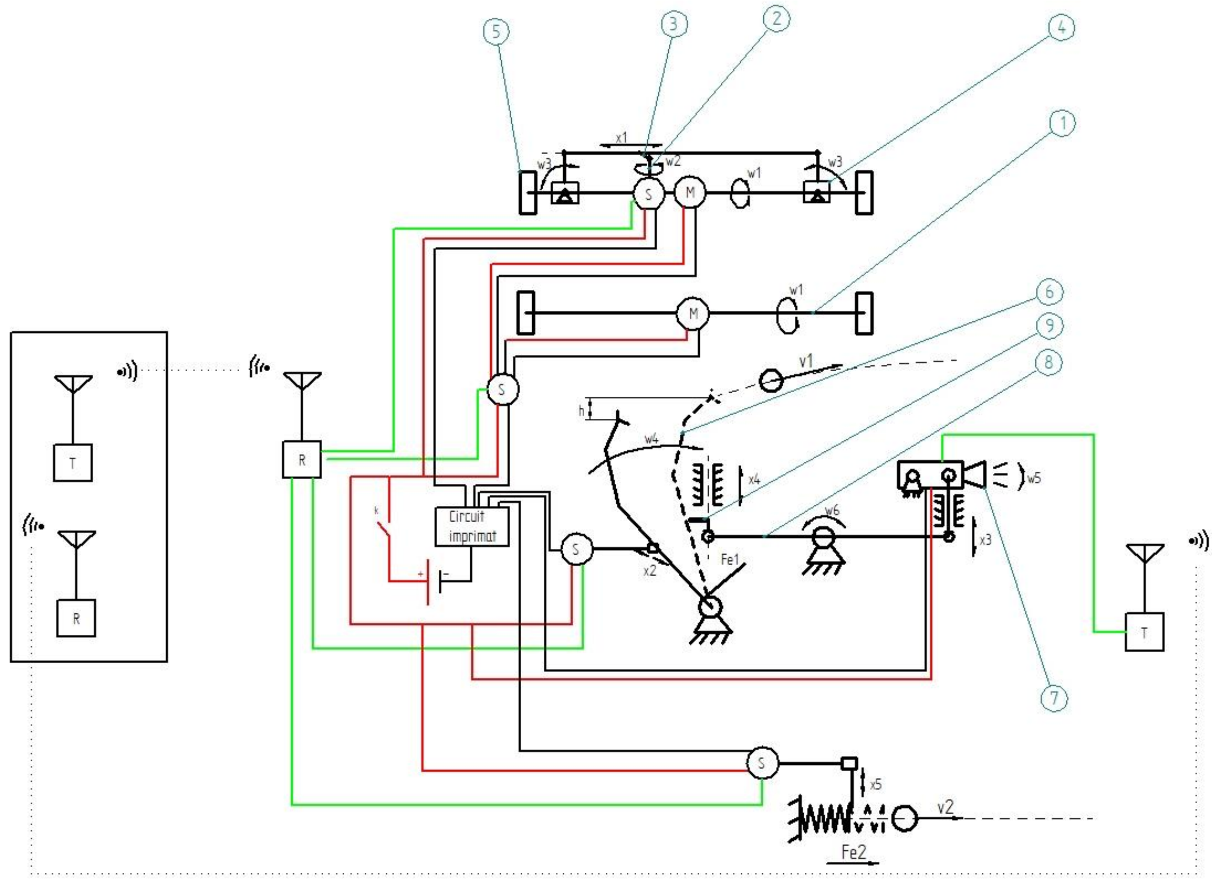

Figure 11 Principle scheme of the catapult machine

It consists largely of a circuit board with microcontroller, batteries, transmitters and receivers. With the implementation of these electrical components, the catapulting machine is finished and fully functional.

For a complete perception of the whole product, its principle scheme is elaborated. The role of such a scheme is to highlight the combination of physical effects and the geometric and material characteristics of the whole assembly. The schematic representation from Figure 11 details the operating principle of the system, equipped in addition to the current version with a secondary launcher based on compressed spring. The more detailed subsystems are the steering one and the catapulting one, as they contain more extensive mechanisms. This image can be interpreted using the legend Table 1. Also based on this figure, you can see all the connections established between the electrical system and the other elements of the catapulting machine.

Table 1

Principle scheme legend

T	Transmitter	**1**	Shaft/ Axle
R	Receiver	**2**	Crank
S	Servo	**3**	Rod
M	Electric motor	**4**	Bearing
k	Switch	**5**	Wheel
x	Displacement	**6**	Catapult arm
v	Velocity	**7**	Video camera
ω	Angular velocity	**8**	Lever system
F_e	Elastic Force	**9**	Threshold

4. CONCLUSIONS

The content of the paper manages to cover all the structural and technical aspects necessary for the design of the catapulting machine. Considering the final design, made without any irregularities or technical deviations, the project achieves a very high level of feasibility. In addition, the scheme of principle developed at the end of the article manages to unite all the concepts in a unitary system, well developed, which ensures the bases of operation of the product.

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Author:

Eng. Matei TOMA, Master student, University Politehnica of Bucharest, Faculty of Aerospace Engineering, Department of Engineering Graphics and Industrial Design, E-mail: toma.nmateiionut@gmail.com