



TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Department of Electrical Power and
Mechatronics

Grasping System for Drone Landing

Drooni fikseerimissüsteem

MASTER THESIS

Student: Vladislav Kudriavtsev

Student code: 184737EV/187457MAHM

Supervisor: Mart Tamre, EE - Department of Electrical
Power Engineering and Mechatronics

Tallinn, 2019

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

"....." 2019

Author:

This is in accordance with terms and requirements

"....." 2019

Supervisor:

Accepted for defence

".....".....2019.

Chairman of theses defence commission:

/name and signature/

THESIS TASK

Student: Vladislav Kudriavtsev 184737EV/187457MAHM

Study programme, MAHM02/13 - Mechatronics

main speciality:

Supervisor(s): Professor Mart Tamre, +372 5120982

Consultants

Thesis topic:

(in English) Grasping System for Drone Landing

(in Estonian) Drooni fikseerimissüsteem

Thesis main objectives

Design of drone landing system for robotic arm

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Analogues overview	8.03.2019
2.	SolidWorks model composition	5.04.2019
3.	Components selection	18.04.19
4.	Simulation in SolidWorks	7.05.19
5.	Final report	20.05.19

Language: English

Deadline for submission of thesis: "21" May 2019

Student: Vladislav Kudriavtsev "....."2019

Supervisor: Mart Tamre "....."2019

Consultant: "....."2019

Table of Contents

LIST OF ABBREVIATIONS.....	3
PREFACE	4
INTRODUCTION	5
1. ANALOGUE REVIEW	6
1.1 Analogues.....	6
1.1.1 Magnet gripper on the robotic arm	6
1.1.2 Autonomous recharging and docking for multirotors.....	7
1.1.3 Automatic landing/charging quadcopter.....	7
1.2 Analogues in other areas	9
1.2.1 Probe-and-drogue Aerial refueling	9
1.2.2 International Berthing and Docking Mechanism	10
1.2.3 System for docking and internal transfer	10
1.3 Analog analysis	11
2. DRONE FOR LANDING SYSTEM	13
2.1 WINGCOPTER 178.....	13
2.2 VTOL.....	14
3. DESING PROCESS.....	15
3.1 Concept	15
3.2 First prototype.....	16
3.2.1 Top module	17
3.2.2 Bottom module	18
3.3 Final prototype	20
3.3.1 Bottom module.....	21
3.3.2 Top module	24
3.4 Convergence check	26

3.5 Grasp.....	29
3.6 Length of stick	31
4. MATERIALS	33
5. SELECTION OF ELECTRONIC COMPONENTS	36
5.1 Electromagnet	36
5.2 Rangefinder	36
5.3 Motor for stick.....	37
5.4 Control device	38
5.5 Power Supply.....	39
6. SIMULATIONS.....	41
6.1 Simulation with plastic details.....	42
6.2 Simulation with aluminum beams.....	45
6.3 Simulation analysis	46
6.4 Weight of second prototype	47
7. FURTHER WORK.....	48
8. SUMMARY	50
REFERENCES	51
APPENDICES.....	53

LIST OF ABBREVIATIONS

OpenCV – Open Source Computer Vision Library

RDS – Russian Docking System

SSVP - System for docking and internal transfer (Russian: Система стыковки и внутреннего перехода)

VTOL – Vertical Take-Off and Landing

3D printer – Three-Dimensional printer

PLA - Polylactide

ABS – Acrylonitrile Butadiene Styrene

FDM – Fused Deposition Modeling

PREFACE

I would like to thank the Department of Mechatronics at ITMO University and the Department of Mechatronics at the Technical University for the opportunity to participate in the double degree educational program. Also, I would like to thank my leaders Yuri Monakhov and Mart Tamre for their leadership during the writing of this dissertation, as well as my friends and family, who supported me in the process of studying.

INTRODUCTION

At present, mechatronics and robotics are developing in very fast steps. It becomes easier to use, cheaper and more diverse than ten years ago. Drones are used in many fields of activity, such as cinema, terrain research, observation and transportation of goods. They can be programmed and operate autonomously or be controlled with the remote. However, quite an important moment in the work of a drone is a takeoff and landing.

Due to different weather conditions or landscape features, difficulties may arise during landing, since damage to the quadcopter may occur. For example, it may be necessary to land on a moving surface. Under these landings will be necessary to fix the drone on the surface so that it not flew or slipped off on the surface, I was not blown away by the wind. To solve this problem we need to use the platform, which will be a landing surface for the drone, as well as to keep it from falling.

I've reviewed several different types of drones docking station, which exist at the moment, and considered different types of connection that are used in other areas but perform a similar function to fixture.

Since a large number of drones, and it is impossible to create a universal device for all, we must choose a specific and create for him.

Drone Wingcopter 178 was selected to create a landing system. However, if you make small adjustments to the design and size, we can use this approach for a large number of drones that use the principle of vertical takeoff and landing.

Most of this work has been done using SolidWorks 2018 and MatLab 2018b

The main idea of the project is to use a mechanical arm, a special end effector to grab the drone and use the camera to correctly move the arm to the flying drone. In addition, we can use a mobile platform, with the help of which, the drone will not need to come close to the robot and look for where to land, but only to stop next to it. The main goal of the work is to design an effector that will grab the quadcopter, to be as universal as possible for most drones, and not difficult to adapt to other drones.

Once we have formed the idea, it is necessary to search for analogues not only in the subject area but also various other variants of connections in flight.

1. ANALOGUE REVIEW

1.1 Analogues

This chapter provides the analogue docking stations that exist or are under development. Most often, this is non-professional or university projects.

1.1.1 Magnet gripper on the robotic arm

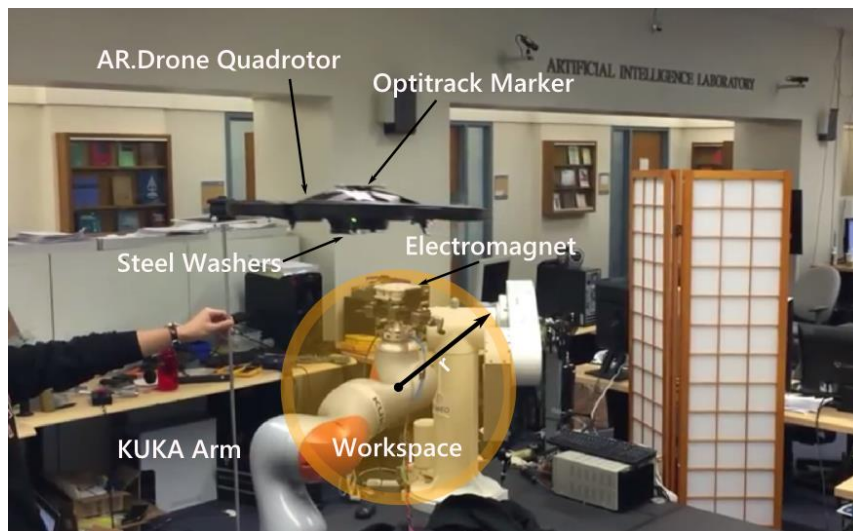


Figure 1.1 Robotic arm with magnet gripper [1]

This project is developed at Stanford University. It consists of the robotic arm KUKA, a quadcopter and four cameras, which were located above the quadcopter and observed its location. As a device that was enough quadcopter used electromagnet. And on the quadcopter were installed metal plates that can be magnetized.

The idea was that the cameras fixed the location of the quadcopter, and the robotic arm moved in such a way that the magnet was always under the quadcopter. After that, when end effector has approached the drone, the magnet turns on and the landing occurs and the drone turns off.

In this work, the robotic arm works in automatic mode, the drone is controlled manually.

1.1.2 Autonomous recharging and docking for multirotors

The project has a slightly different purpose, but from it we can identify some features that may be needed when designing a new sample.

Initially, this project involves an autonomous station, which will charge the batteries, serve for takeoff and landing. However, there is a solution to it that can be useful in the project. It uses a cylinder with a cone-shaped hole with springs. A cone is mounted on the quadcopter, which should go into the hole. According to the author, this has repeatedly saved his quadcopter from damage. This element can help in ensuring the correct location of the drone on the surface. After that, it can be fixed and it will not cause any problems and breakdowns.

This drone uses RGB camera that finds the station and determines the coordinates.

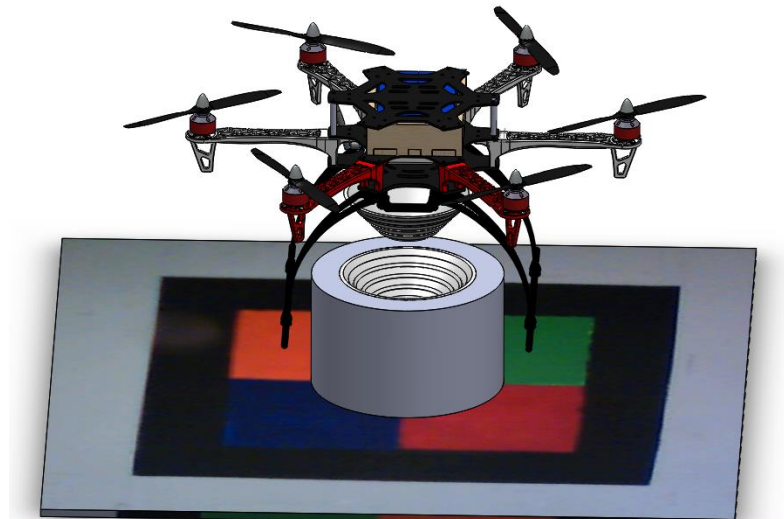


Figure 1.2 Drone with dockstation [2]

1.1.3 Automatic landing/charging quadcopter

Project is going to the drone, which can land and charge from the docking station. Charging takes place with the help of wireless charging on one of the beams of the frame, and on all the other metal plates are fixed. At the docking station, there is also wireless charging and 3 electromagnets that will hold a quadcopter on the racks.

Search for a place to land occurs with the camera and OpenCV. Then, when the drone is very close to the platform, the cross on the platform will assist the fine alignment. A proximity sensor on the

platform will activate the three electromagnets and the wireless charging circuit. This will smoothly force the landing and alignment. When the wireless charging process is done, the electromagnets release the drone, allowing the next takeoff.



Figure 1.3 Quadcopter and station [3]

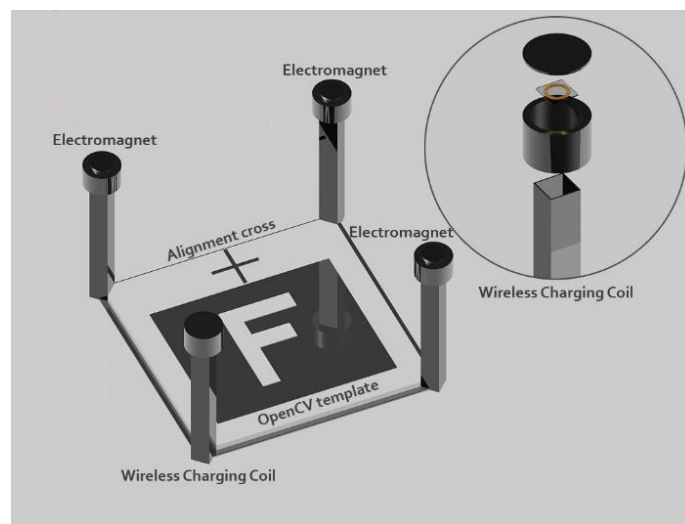


Figure 1.4 Landing/Charging Station [3]

1.2 Analogues in other areas

1.2.1 Probe-and-drogue Aerial refueling

The system consists of a "probe" and "drogue", which must be connected. This mount will allow you to start the "connection" with a small error, and then reduce the deviation when approaching. Refueling is carried out in the following way. The connection is made by an electromagnetic lock. At the end of the refueling, the pilot of the refueling aircraft simply reduces the speed, and the cone is disconnected from the rod when the tension force exceeds the electromagnet force.

For refueling with a hose-cone, the tanker aircraft is equipped with one or more overhead refueling units located at the maximum possible distance from each other. The filling station is equipped with a flexible drogue with a length of more than twenty meters. At the end of the drogue there is a so-called cone.

The fueled aircraft, in turn, is equipped with a receiving bar, which, in order to improve the aerodynamics of the device, can be made retractable into the body.



Figure 1.5 Probe-and-drogue system in aerial refueling [4]

1.2.2 International Berthing and Docking Mechanism

The next analogue is the European androgynous low collision docking system, which allows large and small spacecraft to dock in active and passive modes. The international active-passive docking mechanism allows docking of spacecraft in both active and passive modes, fulfilling the role of a berth.

The docking mechanism consists of a Soft Grip System. The soft grip system can control the start of docking with the help of 6 servo brackets. The position of the docking ring with 6 degrees of freedom is controlled through the brackets. This facilitates the process of leveling the platform during capture. In this case, the entire system can provide docking devices with a very large weight. Mechanical latches hold soft grip.



Figure 1.6 International Berthing and Docking Mechanism [5]

1.2.3 System for docking and internal transfer

The docking and internal transition system is a standard for docking modules used on Soviet and Russian spacecraft. It is sometimes called the RDS. It has been used on all versions of Soyuz spacecraft, and Progress ships and on all Soviet and Russian space stations.

It consists of two components: active probe and passive berth. The probe enters the cone, then its end is gripped with a soft snap catch and retracts to ensure alignment. The alignment is done with electric motors that pull in the dipstick. Thereafter, 8 locks provide rigid fastening which does not allow to disconnect the two objects.

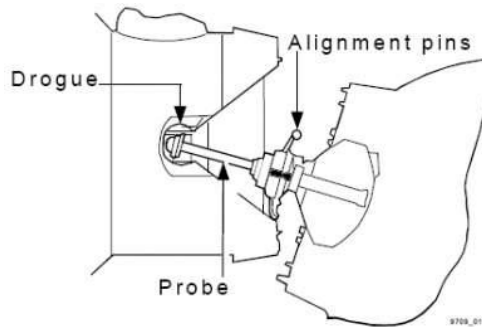


Figure 1.7 Probe-and-drogue system in RDS [6]



Figure 1.8 RDS system, probe [7]

1.3 Analog analysis

Considering the given analogs, it is possible to draw conclusions from all, on the basis of which it is possible to begin development. As we can see, in two of the three analogues, magnets are used to fasten the drone to the platform. This will be the easiest way to fix the drone without resorting to mechanical arrangements and excessive exposure to damage.

On the first analogue, we can see that in their implementation of the project, the drone lands on the electromagnet very accurately. His accuracy is due to the fact that several cameras are watching his position, which completely monitor his movements, and mechanical arm is already adjusting. This avoids large errors in location. However, this method does not suit us, because here the emphasis is no longer programming the behavior of the drone and the industrial arm based on the

movement of the drone. This type of landing assistance is highly dependent on the accuracy of the location of the cameras, which makes it difficult to install this analogue in other rooms. But you can see that the drone can fly up to the landing surface with a huge navigation error, as the hand and the cameras are responsible for the location.

In the second analogue, a very interesting approach was seen. It uses a similar mechanism to the probe and cone system for precise landing. However, in this case, the maximum landing error will be the inner radius of the cone, since this will be the maximum value by which the drone can deviate and land. It is worth considering that the legs do not get caught on the cone with a maximum deviation.

The third analog is quite specific, since the landing of a drone on such a station must be very accurate. If there is a small error when navigating the drone to the docking station, the drone will not be able to land on the surface. However, this station is very well suited not for landing, but on the contrary, for the take-off of the drone, as it will hold until you need to release or there is no need for it. In addition, in this analogue, the author decided to add wireless charging, which significantly enhances the functionality of this docking station. Otherwise, its functionality is only to keep the drone, and the main problem in landing is the accuracy of the landing of the drone itself. The system will not allow the drone to sit down when turning around the axis.

Considering analogs in other areas, it can be noted that the method used in the second analogue is extremely similar to the probe-drogue system. This method is very convenient when docking in a small error, he is due to the structure will reduce the deviation in landing.

We note that the IBDM system is much more difficult to use and design. However, for the drone it will not only be too expensive to implement, but also deprived of the special need to use a similar mechanism. The new system for assistance in landing should be the simplest, less prone to wear and damage. The IBDM system is not suitable for such parameters, so it will be necessary to abandon this analogue in the Aircraft Refueling Systems and RDC.

2. DRONE FOR LANDING SYSTEM

2.1 Wingcopter 178



Figure 2.1 Wingcopter 178 [8]

This quadcopter is a unique drone of its kind. It is a drone plane. It takes off and sits on the VTOL system. However, it can fly like a real airplane. For this, he changes the position of his engines. Due to its design, the drone has advantages both in drones and aircraft. For takeoff and landing, he does not need a runway. In addition, it can achieve high airspeed and be used to deliver small loads over long distances.

Table 2.1 Wingcopter 178 technical specifications

External dimensions	1780 mm*1321 mm*522 mm
Flight time	120 minutes (Fixed Wing mode)
Range	100 km (Fixed Wing mode)
Altitude	5000 m
Speed	0- 50 km/h (Multicopter mode) 40-130 km/h (Fixed Wing mode)
Wind resistant	15 m/s

Rate of climb	Up to 6 m/s
Weight	7.2 kg (with battery)
Payload	2 kg
Drive	Electric
Flight modes	Manual/autonomous GPS navigation/return home function
Takeoff/landing	VTOL
Construction	Composite(fiberglass and carbon fiber)

2.2 VTOL

A vertical take-off and landing (VTOL) aircraft can fly, take off and land vertically. This classification can include various types of aircraft, including fixed wing aircraft, helicopters and different types of drones.

At the present time VTOL is quite common among flying vehicles. Initially, this type of take-off and landing was used for military aircraft. However, VTOL required a sufficiently high qualification and skill on the part of the pilot, since This is a rather complicated process. In addition, the aircraft had a high fuel consumption during takeoff and landing. Other representatives of the aircraft are helicopters. On the basis of them were created classic drones, which are used in the modern world everywhere [9].

Due to the fact that the drone lands vertically, for it you can create a special platform or mechanism to which it can attach at the end of the flight. Since our drone, to which the module is being created, even though it flies like an airplane, it can land vertically. Therefore, it is possible to consider all types of platforms and docking stations designed for drones as analogues.

3. DESING PROCESS

3.1 Concept

After searching for analogues, and analysis, a basic concept was formed, which became the initial stage in development.

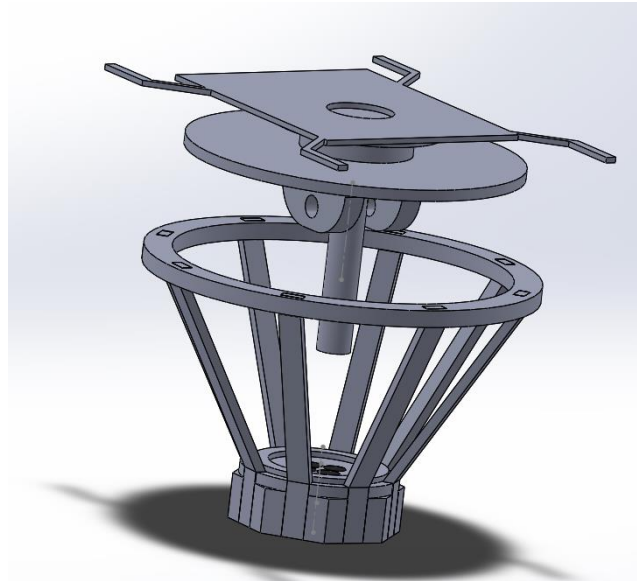


Figure 3.1 Concept of top and bottom module

The basis was the principle of probe-drogue, which is used on Russian spacecraft and one of the possible options for refueling the aircraft during the flight. The whole system consists of 2 modules, one of which is fixed on the drone, and the second will be the landing module. The second module can be used not only as an end effector, but also a separate docking station, which can be put on the ground or fixed anywhere.

The main idea is that the drone, when it will fly up to the landing site, will have a maximum error of 100mm, which means that the internal diameter must not be less than the specified error. During landing, the drone should be lowered, and the stick to slide on the inside of the cone, while maintaining a horizontal position. Thus, at the time of the final landing, the drone will be exactly in the right place and will be fixed. After that, the station must grab the drone in order to lock it in one place so that it will not be blown away or slid off while moving the industrial arm.

For further development, it was necessary to take several points into account when creating the model:

1. When landing, there should be no engagement between the legs of the drone and the lower module.
2. Landing should not depend on the rotation of the drone
3. Installation must withstand the mass of the drone with batteries.
4. A damper is needed that will soften the fit and prevent friction of parts, which can lead to their destruction.
5. The design should be simple and without moving parts.

3.2 First prototype

After that, as the idea and concept was formed, the next step was to create a prototype. It should show the main problems in the design and show the disadvantages that need to be removed.

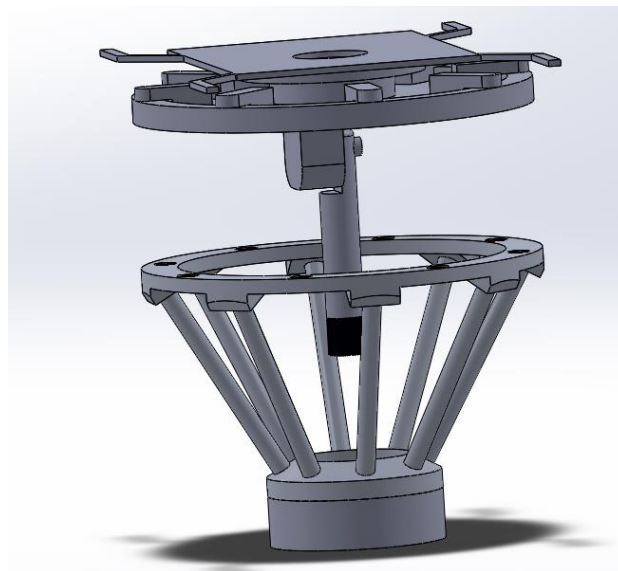


Figure 3.2 First prototype of top and bottom module

All the advantages and disadvantages of the prototype, which were found after the first prototype was formed, should be analyzed. It is not much different from the concept, but it served as a visual

model of what needs to be changed in the final version, what mistakes can arise and what should be changed.

3.2.1 Top module

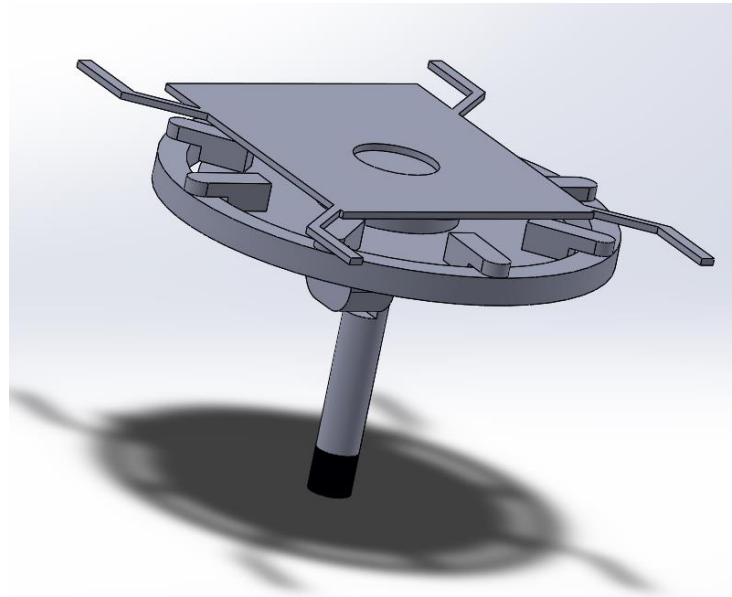


Figure 3.3 First prototype of top module

One of the main drawbacks of this prototype is that it has a fairly large mass, which has a negative impact on the drone's flight with the top of the module. The maximum mass that the drone can lift is 2 kg, then the module, whose mass is close to the maximum, will fly much less time. In addition, if you load the drone with any additional batteries or other payload, then the total mass will exceed the allowable one, which will be a sufficient problem for use.

The next moment was the attachment of the drone to the legs. This is not only a difficult task in order to create a normal mount, but also the fact that the central part will squander heavily and lean on the drone. The drone case is quite light and fragile, due to the fact that it does not have direct contact with the frame in this part. This means that with sufficient load, the case will be forced through, which can lead to breakage.

At first there was an idea that the problem could be solved with a soft layer that would reduce the impact on the case. However, the problem does not disappear and the body will remain supported, only there will be no additional friction, therefore it was necessary to find a new way to solve the problem. In addition, it would be quite difficult to correctly repeat the exact surface of the lower drone case, because the original 3D models are not in the public domain. Even if it were possible to repeat the exact shape of the drone, we would be able to distribute the force over the surface, which would reduce the pressure at each point, it would not solve the problem completely. Also, any damage to the case would make it difficult to use this module, because the load was not evenly distributed and the case was severely flexed, which would give us the destruction of the case.

3.2.2 Bottom module

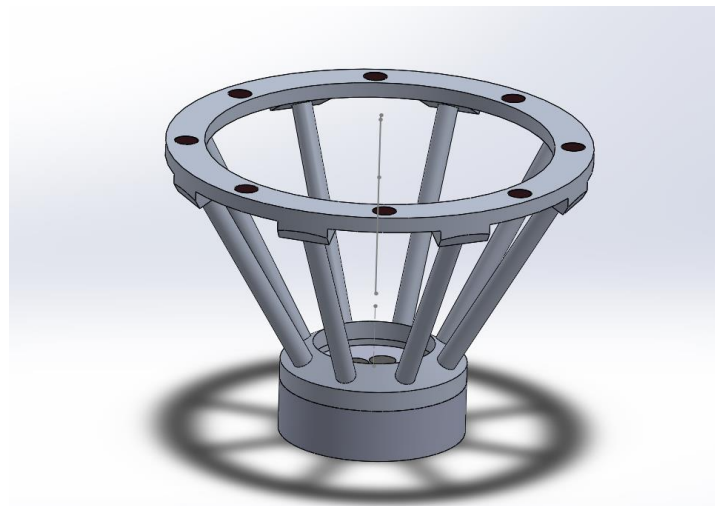


Figure 3.4 First prototype of bottom module.

The bottom module is a cone in the probe-and-drogue system. Since the cone will provide all the support, it is better to do it as a docking station. It is quite massive and its mass will be much higher than the upper module, and due to the fact that the mass of the upper module is limited, it is better to make the heavy part down, and light to fix on the drone.

In the lower module were also found flaws that need to be fix. One of the main disadvantages is the formation of a cone and the connection of the upper ring with the base. Due to the fact that

the tubes are angled, at the slightest mistake with the creation of the design it will be difficult to assemble it without additional interactions with the material. In addition, this design will be much easier to break. Although this design looks pretty nice, however, there is the problem of fasteners, because parts that are at an angle, it is better to mount at a right angle. In this design it is much more difficult to do this, because the entire mounting of the upper and lower parts is at a large angle.

The next problem with this design is that there is no space for any damper that will soften the landing of the drone. For it, it will be necessary either to expand the upper ring, or to make a damper on the upper module, which will give additional weight.

During the analysis of this model, it was noticed that there is no need to reduce the dimensions of the model to the base. It is better to make the design more durable with the least weight.

In this design, the cone was to be formed using plates that were attached to the beams. However, they had such a problem that with a small number of plates, the area available for immersion of the stick was reduced.

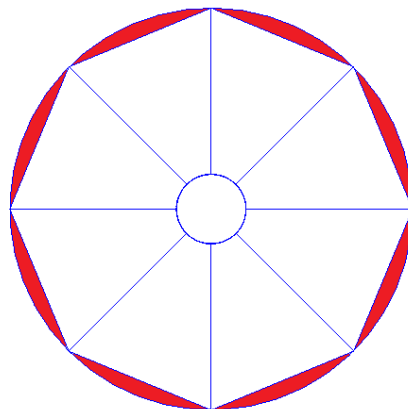


Figure 3.5 Occupied space in a cone.

On the image we can see that when we use the plates, a large area is lost so that the drone can go down there with its probe. This problem can be solved in several ways. The first way is to increase the number of plates, thereby reducing the unused surface. However, this method has one drawback, because additional fasteners for these plates will be needed. The second way is to make the plates rounded, but then the production of these plates will become more complicated. The third way is much more effective than others. It consists in replacing all the plates with a single cone made of rubber or similar material, which will be rolled into a cone and fixed. This will simplify production and reduce the number of fasteners to the body.

3.3 Final prototype

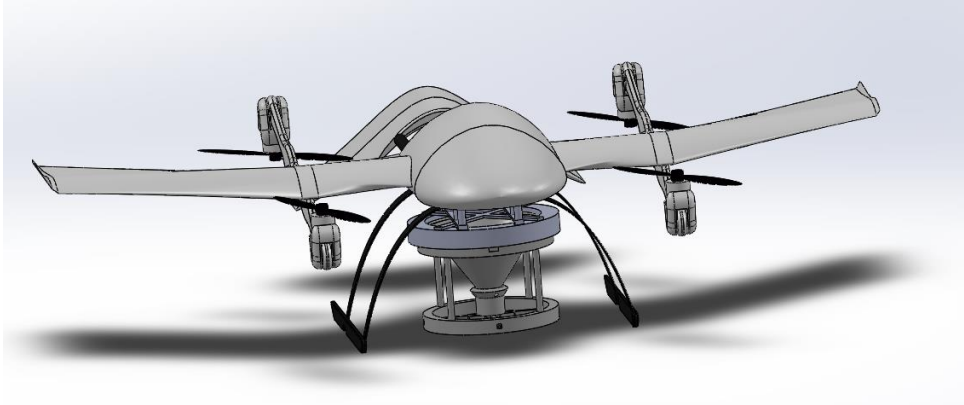


Figure 3.6 Second prototype of two modules with Wingcopter 178

The final version is quite different from the first prototype. It was changed the basic ideas and approaches to the design of some of the details.

Such moments have been changed

- Electromagnets moved to the side
- Added damper
- Changed cone
- Added range finder
- Changed the mount to the drone

In the following sections, we will analyze in full what each module consists of, as well as the main points in the design.

3.3.1 Bottom module

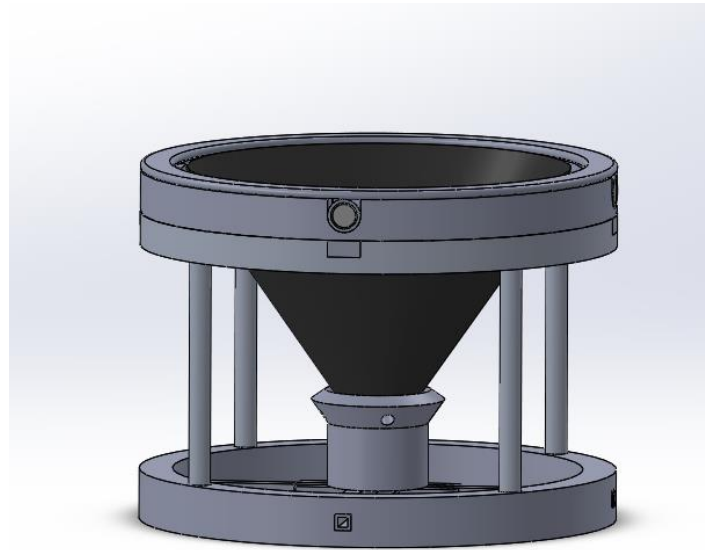


Figure 3.7 Second prototype of bottom module

The bottom module has been completely redesigned. Now it has a simpler and more reliable design, as well as a much simpler assembly and repair. This module can be attached not only to the robotic arm, but also to any other surface. This module cannot serve as an autonomous docking station, since it will require additional power for electromagnets and a rangefinder, which will signal the arrival of a drone.

In comparison with the previous model, the location of electromagnets changed, a damper appeared, the whole frame changed and one more ring was added, and a cone was also changed, which is easier to make and easier to attach. If this is not done, then for sufficient strength it is necessary to make the lower ring too wide, which will complicate production.

The bottom module can be divided into 4 parts:

1. Upper ring
2. Cone
3. Frame
4. Base

The **upper ring** of the module is designed to fit the drone.

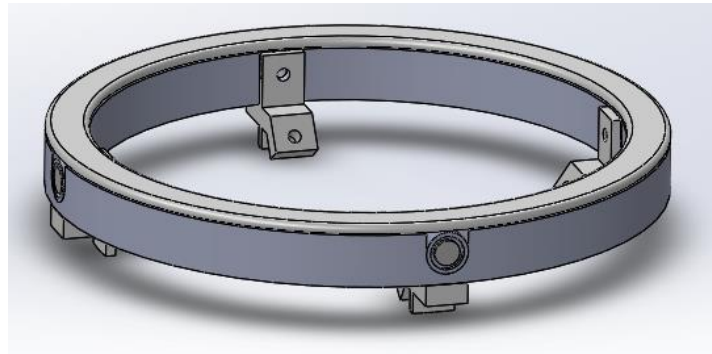


Figure 3.8 The upper ring from bottom module

The initial load will go on it. It is made in the form of a ring, because this form allows you to ignore the drone rotate relative to the horizontal surface and the drone will be able to land irrespective of their position. Magnets are arranged in a circle in the amount of 4 pieces. They will keep the drone for the period of "parking" on the docking station. They will not be designed to hold the drone at any incline, but are only necessary for fixing it in the lower module. If there is no need to hold down the drone in place in the absence of any movement, we can turn off the magnets.

In addition, it is a soft material, in order to create a small damper. This will not only not scratch 2 modules against each other, but also provide a softer landing.

It was decided to change the version of the **cone**, which was made earlier. It is distinguished by the fact that it is now a solid component, which is made of rubber or other similar material. This option will be much more efficient due to the fact that there will be no links or empty space, and also the area of the upper part will be larger due to the fact that it will not be removed by the combined structure.

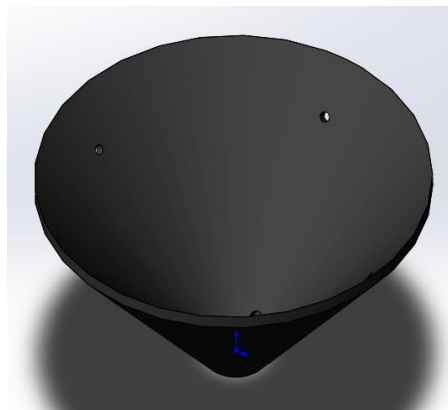


Figure 3.9 Cone from bottom module

The **frame** consists of 3 components, the upper ring, the lower ring and the rays between them. The main load goes to him, because the upper ring rests directly on it and it will already transfer the load to the base.

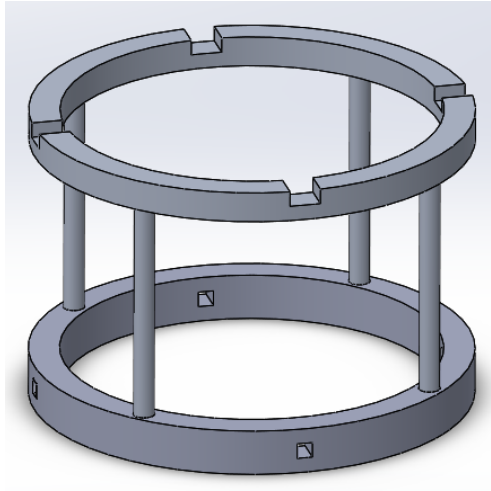


Figure 3.10 Frame from bottom module.

The base is the main component in the module, because it is through it that the frame and the lower part of the cone are connected. In addition, the end effector will be attached to it, which will be connected to the robot arm.

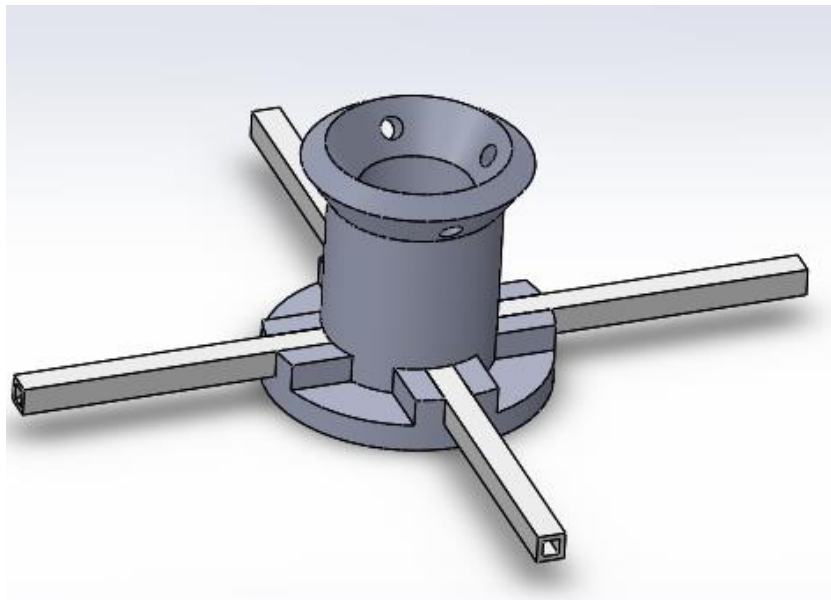


Figure 3.11 The base from bottom module/

3.3.2 Top module

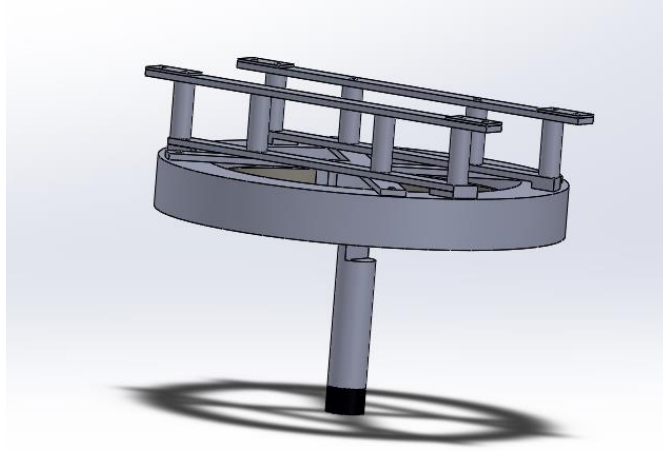


Figure 3.12 The top module

The upper module is made based on the probe, which should fall into the cone and slide along it, in case of deviation from the final location of the drone on the platform.

It can also be divided into several parts:

1. Mount
2. Main ring
3. Stick

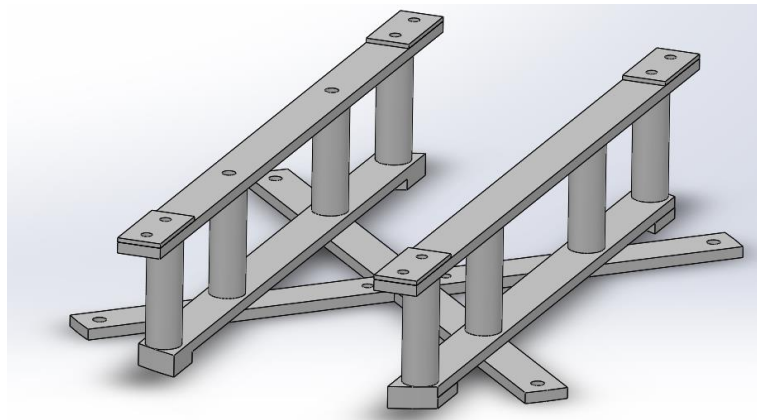


Figure 3.13 The mount from top module

The **mount** is completely redesigned. In order to attach the top module with the drone, there is the only option without damaging the drone case, it is to connect to the base of the legs. The drone has a limited space in the lower part of the case; it is necessary to lower the attachment to the main part of the module below so that neither the ring nor the attachment to it is in contact with the drone case.

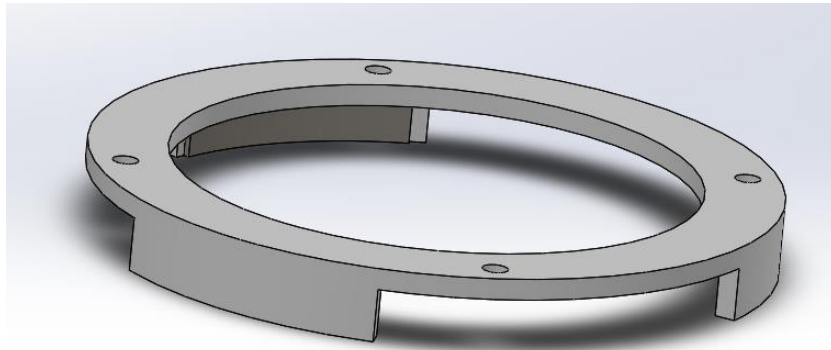


Figure 3.14 The main ring from top module

The **main ring** of the top module is used by the main support when the upper module contacts the docking station. It also contains metal plates that will be magnetised to the side electromagnets of the lower module.

The stick is needed to direct the drone to the desired position. It will slide along the surface of the cone and prevent the diversion of the drone in the opposite direction.

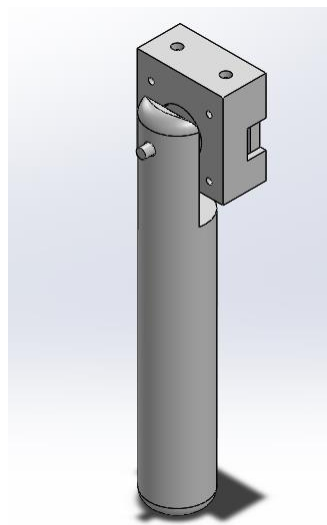


Figure 3.15 The stick from top module

In addition, the stick can be removed during the flight, because He will be absolutely not needed when flying a drone. This function is not necessary, however, there is no need not to do it, because the stick during the flight will create additional resistance to the wind.

3.4 Convergence check

One of the design problems was with the maximum deviation to the sides of the drone. The drone's legs can touch the lower module and interfere with the landing of the drone.

To calculate this, it is necessary to derive an inequality, under which it will be possible to determine whether this construction is suitable or not.

For this situation, I created an inequality that must be observed during the docking of the drone. It uses equations that describe the basic dimensions of the bottom module, stick and legs. With the help of them, it is possible to form an inequality that will show whether this construction will function or not in the extreme positions of the lower module.

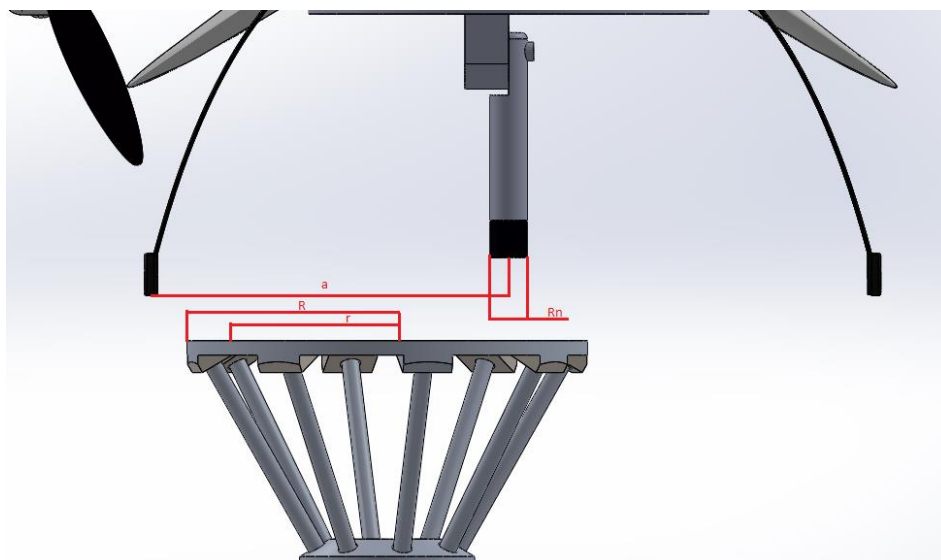


Figure 3.16 Variables on modules

With a maximum error, the condition that the cone fits under the drone will be:

$$a(h) + 130 + Rn(h) > r(h) + R(h) \quad (3.1)$$

Where

a - the distance between the center of the drone and the edge of the leg

Rn - the radius of the stick or another form

r - the inner radius of the cone

R - the outer radius of the cone

h - height

130 - the distance between the center of the drone and the legs.

This is a function that will change as the distance between the drone and the cone decreases, it is necessary to calculate its values.

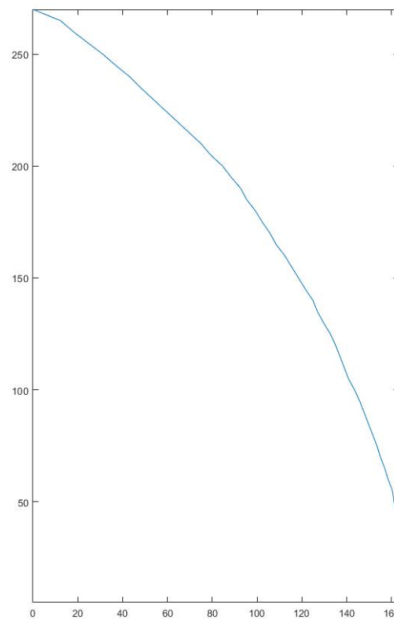


Figure 3.17 Leg plot

If we make an equation from inequality, we can calculate the distance between the legs and the cone.

$$a(h) + Rn(h) - r(h) - R(h) = I(h) \quad (3.2)$$

Where

$l(h)$ - the distance between the legs and the cone.

If we specify other values, then we can find out the maximum sizes of parameters that can be used.

To simplify the task, a small script was made in MatLab, which would help determine the possible dimensions of the structure, as well as check how the lower module will move relative to the legs and the stick.

The script is quite simple, it only makes graphics that visually resemble the lower module in the section, the legs of the drone and the stick itself.

It is possible to change the angle of inclination of the cone, the length of the stick, relative to the drone, as well as the width and height of the whole lower module. From the functional, there is only an insertion of coordinates, which are responsible for changing the position of the lower module.

Due to the fact that this script is very simple, quickly check a few parameters will be problematic. However, it can be much faster than changing the prototype, because it can take a lot of time.

In addition, the basis of the script can help if you make a similar module to other quadcopters, with other sizes, etc. Equation can also help with this, because the basic idea and approach will not be changed. The script will be an idea in similar other projects.

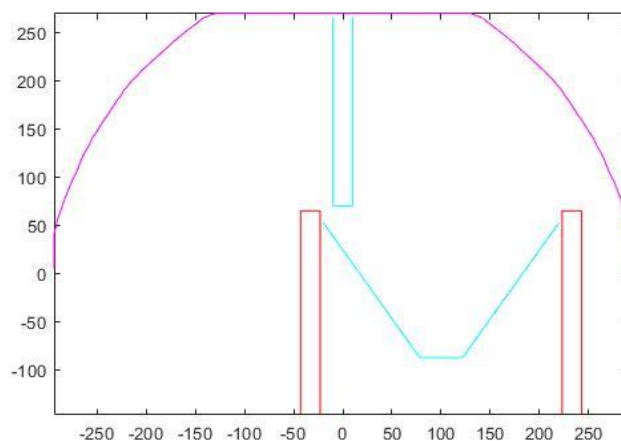


Figure 3.18 Plots in MatLab

3.5 Grasp

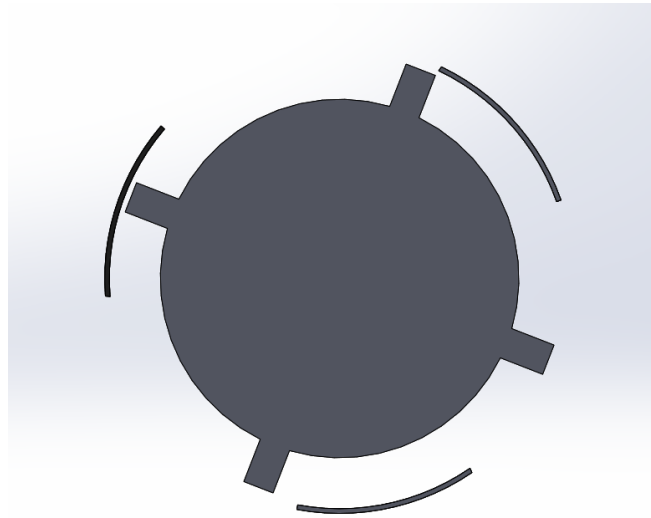


Figure 3.19 Electromagnets and metal strip

Keeping the quadcopter is quite an interesting and difficult moment, which may be necessary in various situations. Since we have a drone can land at the docking station at any possible angle, it is necessary to make it so that at any turn the lower module can be attached to the upper one.

There are 2 options that can be used to solve this problem.

The first option is a mechanical connection, which can be realized with the help of grippers. However, there is a problem that what this grip will be attached to will not be free around the whole circle. Other options will not be too reliable or take a lot of space, which is so small, because we are limited to the legs of the drone and its weight.

The second option is gripper with electromagnets, which will be much easier to use than mechanical grippers. In addition, they take up much less space, which is good for us and have a fairly small weight.

It was decided that it was necessary to use electromagnets that would be able to hold the drone during small shakes.

The main task is how to locate these electromagnets so that they can attract one half of the drone to themselves and not attract the other. This was done with the help of 4 electromagnets and 3 plates, which will be magnetized to the electromagnets.

This option is effective in that they will not attract the opposite magnets, at any turn, but at the same time, at least one will be attracted in any position.

There will be no case when all 3 plates will be attracted to electromagnets. This may be due to the excessive length of the metal plate that will be mounted on the inside of the top module. This case is possible only if one of the plates will stand exactly in the middle of one electromagnet, and the others near the side electromagnets.

The condition to be satisfied can be expressed in the following inequality

$$\frac{\alpha}{2} + \gamma > \frac{\beta}{2} + \theta \quad (3.3)$$

where

α - the length of the arc plate

β - the length of the arc of an electromagnet

γ - the length of the arc between the outermost plates

θ - the length of the arc between the electromagnets

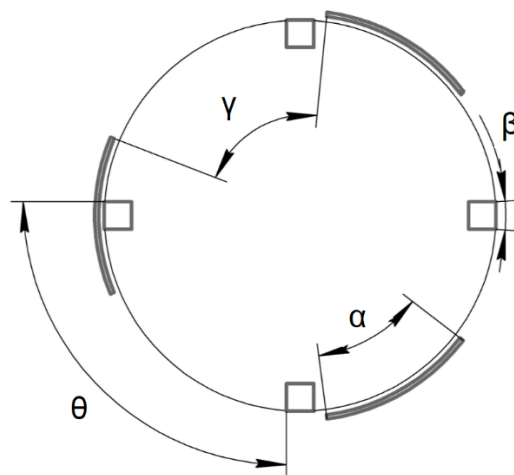


Figure 3.20 Plot of variables

Table 4.1 Variable values

α	45°
β	$8^\circ 2'$
γ	75°
θ	90°

$$\frac{45^\circ}{2} + 75^\circ > \frac{8^\circ 2'}{2} + 90^\circ \quad (3.4)$$

$$25^\circ 30' + 75^\circ > 4^\circ 1' + 90^\circ \quad (3.5)$$

$$100^\circ 30' > 94^\circ 1' \quad (3.6)$$

The inequality is true, which shows us that these parameters for electromagnets and plates are suitable for us, and they will not be able to be simultaneously opposite 3 magnets.

3.6 Length of stick

This parameter is very important, it should be given special attention. If for individual parts size was not so important, because they can vary and are highly independent of each other.

In the upper module, plates are attached to the outer ring, which will magnetise. If the probe is small enough, then there is a high probability that the upper module will incorrectly fall onto the lower one and there will be no fixation. On the other hand, if the stick is large enough, then the upper module will not be able to adhere to the lower module. At this time, the stick will rest on the main part, and thus there will be no contact between the parts that are intended for this. In such a case, the drone will tilt and may turn over the entire structure or fall out of the cone.

Due to the fact that it is planned to add a motor for raising the stick, we need to know not so much the length of the stick itself, so much the maximum distance from the top of the ring to the end of the stick. Having this distance, you can add a stick by subtracting the distance that the fastener takes for that stick.

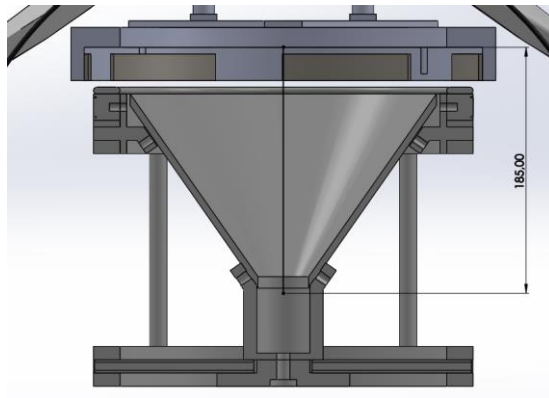


Figure 3.21 Length of stick

On this picture we can see that when the upper cone approaches the lower one by about 5 mm. We need the stick to be completely submerged in a cone. This result suits us, because the probe will not be able to deviate to different directions, and the movement of the drone will be exclusively vertical. Therefore, we conclude that the length of the probe together with the engine must be at least 185mm. In case of contact of the lower module with the upper one, there will be a space of about 15 mm for the stick. Due to this distance, the range finder will not be hit by the drone, and its minimum detectable distance will be lower than the minimum measured.

4. MATERIALS

The drone's payload capacity is small, so we need to choose materials that will be light and fairly durable. In addition, it is worth knowing that in the manufacture of plastic parts, possible shrinkage of the material, which can greatly disrupt the structure. If we deliberately make larger parts, it will take a long time to process the material in order to achieve the required size.

Most of the details can be done with 3D printer, because they are quite small in size and can easily be made in it.

The most common plastics for printing are PLA and ABS. To select them, we need to compare all the advantages and disadvantages [10].

Among the advantages of PLA plastic is that it is non-toxic, does not have a large shrinkage in the volume when creating components, as well as obtaining more detailed and fully ready-to-use objects. However, it is much heavier than other plastics used in FDM.

ABS plastic has advantages in that it is much easier to process. In addition, it is much lighter in weight than PLA plastic. However, it has shrinkage and has a relatively low resistance to direct exposure to the sun. This parameter is very important for us, because the parts we create will be under the direct action of sunlight. Also, the negative point can be considered the fact that ABS plastic is quite toxic in the manufacture of parts from it using a 3D printer.

Table 4.1 Compare PLA and ABS plastics [11] [12]

Material	PLA	ABS
Extrusion temperature	170..180°C	180°C
Flexural strength	55.3MPa	41MPa
Density	1.23-1.25g/cm ³	1.05 g/cm ³
Temperature shrinkage	Low	0.8%

My choice is PLA plastic. From it will be made such components for the lower module, as mounting for the cone below, as well as the part that holds the cone on top and secures the electromagnet in the ring of the lower module.

Because several parts have rather large dimensions, it is worth considering that they will not be possible to print on a simple 3D printer. There is only the option of splitting the part into components and then connecting them. We are implementing this option, but it is worth considering other options for creating the necessary large parts.

For such parts will have to choose other options for production. Because metal components are not only expensive to manufacture, but also heavy, it should also stop on plastics, only molded. Pouring such a plastic into a mold, we can get the shape we need. To select the type of plastic, we also need to compare their parameters to select the best option.

Since there are a lot of molded plastics, one should pay attention to plastics produced by one company but compare their various types of plastics [13] [14].

Table 4.2 Compare different molded plastics [13] [14]

Characteristics	Units	Smooth-Cast 300	Smooth-Cast 305	Smooth-Cast 310	Smooth-Cast Onyx Fast	Smooth-Cast Onyx Slow
Color		White			Black	
Life time, 23°C	Min.	3	7	15-20	2.5	5
Solidification time	h.	0.16	0.5	3-4	0.16-0.25	1.5
Density	g/cm ³	1.05			1.09	
Tensile strength	MPa	20.68			40.27	52.81
Flexural strength	MPa	31.1	27.58		57.09	70.53
Shrinkage	%	2.54	1.65		2.54	3.05

The most interesting type of plastic for us is a smooth cast 305. For larger models, the ring is better to use it. It has much lower shrinkage than other types of plastic.

The parts that will fix the lower module to the drone, as well as the tubes and beams of the lower module, will be made of aluminum profiles. They will be easier to buy than to make themselves. In

the lower module there are more of them, but there is no mandatory reduced mass in it. And in the upper module, these parts are small enough to make a large weight advantage, so you can use them for the greatest structural strength.

5. SELECTION OF ELECTRONIC COMPONENTS

5.1 Electromagnet

Electromagnets will be needed for gripping. Our task is not to fix the drone in any position, but only to hold it so that it does not fall out of the system, it is necessary to choose the optimal electromagnets. With this choice, it is worthwhile to consider the relative size and power to choose an electromagnet.



Figure 5.1 Electromagnet UE-2020 [15]

Table 5.1 UE-2020 specifications

Diameter (mm)	Height (mm)	Thread Size (mm)	Thread Depth (mm)	Lead Wire Length (mm)	Rated Voltage (VDC)	Rated Power (W)	Rated Current (A)	Holding Force (N)	Weight (G)
Φ20	20	M6	8	300	12	2.4	0.2	30	20

5.2 Rangefinder

It will serve as a sensor for the landing of the drone. When the sensor measures a small distance between the lower and upper modules, it will give a signal of approximation and electromagnets will work, which will fix the upper and lower modules.

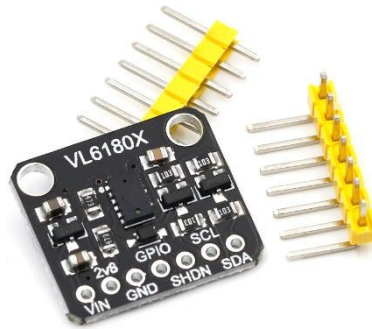


Figure 5.2 Rangefinder VL6180

Table 5.2 Rangefinder specifications [16]

Rated Voltage	3V
Rated Current	300 μ A
Interface	I2C
Range	5-100 mm
Dimensions	25.4*25.4*3
Weight	1.4g

5.3 Motor for stick

This is necessary in order to move the stick during the flight. There will be no need for it to create more resistance to the wind as long as it is not necessary.



Figure 5.3 Stepmotor FL39ST20-0506A [17]

Table 5.3 Stepmotor FL39ST20-0506A specifications [18]

Rated Voltage	12V
Rated Current	0.3A
Resistance	13
Torque force	0.8kg*cm
Weight	0.12kg
Dimensions	39.3 mm * 39.3 mm *20 mm

5.4 Control device

The system uses electrical components that will work only for a certain time, it will be necessary to control them in order to reduce electrical costs and switch on as needed. Due to the fact that we have a small number of elements that need to be managed, a simple arduino uno board is best suited.



Figure 5.4 Arduino Uno [19]

Table 5.4 Arduino Uno specifications

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V

Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz

5.5 Power Supply

In the system there are various components that operate from different voltages. We need to choose a power supply that will convert the voltage to the required one.

$$P = V * I$$

Table 5.5 Bottom module's components required power supply chart

Component's name	Operating voltage, V	Operating current, A	Electrical power, W
Arduino Uno	7-12	0.5	6
VL6180 VL6180X	3	0.1	0.3
4 x UE-2020 DC12V	12	0.2	2.4

We need to convert 220 to 12 volts. The proximity sensor can be connected to the Arduino and receive power from it. Electromagnets and arduino can be powered with 12 volts, therefore it is necessary to choose a converter for these parameters.



Figure 5.5 Power Supply S-25-12 [20]

Table 5.6 Power Supply specifications

Input Voltage	AC 110V-220V +-15%
Output Voltage	DC 12V
Output Current	2 A
Working Temperature	0-40°C
Power	24W
Dimensions	85mm * 57mm * 33mm

6. SIMULATIONS

To test these modules for strength, you must use Solidworks Simulation [21]. With it, you can determine the offset that will occur in the modules, identify deficiencies and, if necessary, correct them.

I do not have a real drone model for which I make modules, but I have it myself. With the help of measurements we can make an approximate model. However, we will not be able to correctly form it by materials and by mass. That is why we need to make a simulation without it, loading the attachment.

According to the technical data, the wingcopter weighs with the entire load of 7.2 kg.

The force that will be applied to the mount will be computed by the equation

$$F = mg \quad (6.1)$$

$$F = 7,2 \text{ kg} * 9.8 \frac{\text{m}}{\text{s}^2} = 70,56\text{N} \quad (6.2)$$

To simulate we take a load equal to 100N, in order to have a small margin.

We make 2 different tests that will use different materials in the design.

1. All parts will be made of PLA plastic and injection molded plastic.
2. Main parts that require great strength will be made from aluminum.

Also, the mass of each module will be calculated. If for the lower module we do not need to reduce it to the minimum possible, then the upper module needs to reduce it. This is due to the fact that the drone has restrictions on the use of useful mass. In addition, if we use additional batteries, the weight of the drone will increase.

In addition, we will consider 2 options for using the lower module.

1. The bottom module will be fixed on the mechanical arm
2. The bottom module will be located on the ground and supported on the lower ring and base.

6.1 Simulation with plastic details

In this section, we will see what happens with the modules if they are made entirely from plastic. The only exception is the cone, which will be made of rubber. Since it does not carry any strength model, it can not be changed.

The first simulation will be done if the bottom module is used on a mechanical arm. With this simulation, the bottom ring will not rest on the ground.

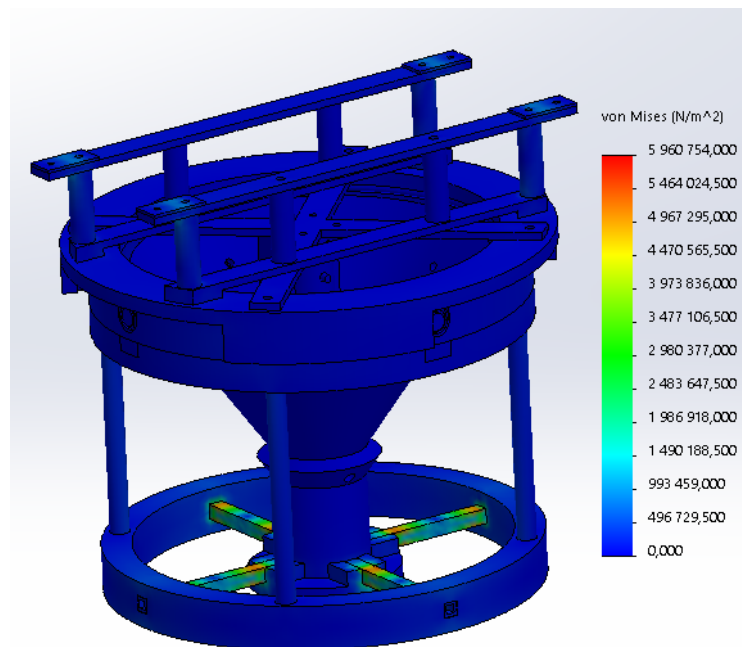


Figure 6.1 Simulation, Stress, First simulation

On the image we can see that the beams that connect the base and the bottom ring of the module experience the greatest load. They have the biggest load of the whole structure, which in some places is about 6 MPa. Bending strength of PLA plastic is much higher, this type of beam is better not to be used, because after a while the beams at the base will become deformed. After that, the beams will break and the module can no longer be used. Also, we can make these beams from injection molded plastic. It is durable enough for this purpose. However, it is better to use for experiments and testing of the module and its various options.

The following image shows the change in location of all parts from the original position. The graph shows that the drawdown is all the details. The maximum deviation value is about 0.9 mm. For the prototype, this option will be very good, but further use of plastic can damage the material and disrupt the entire structure.

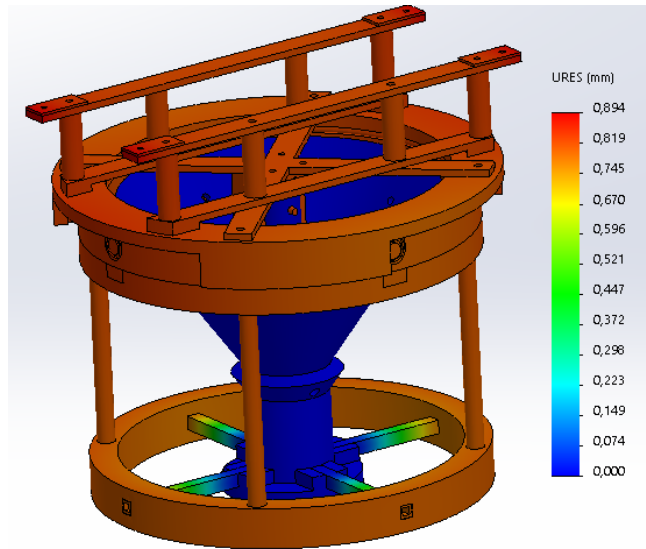


Figure 6.2 Simulation, Displacement, First simulation

The second simulation will be done under the condition that the module will be on a flat surface. In this case, the ring and the base will be on the surface. This will greatly relieve the beams, which will be needed only for fastening and there will be no load.

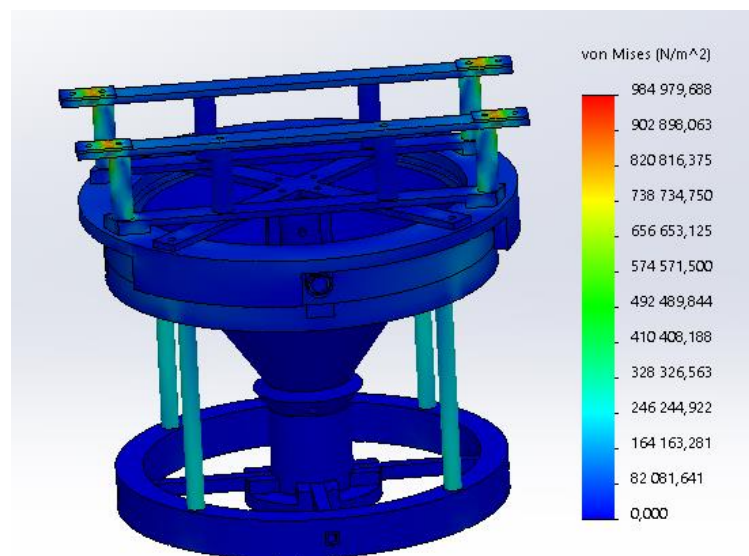


Figure 6.3 Simulation, Stress, Second simulation

We can see that the main load in the structure falls on the beams that connect the rings in the lower module. The load in these beams reaches 400kPa. This value is very small, so they do not need to be made of aluminum. Also, this load will withstand casting plastic. It can be used both for prototypes and for real models. The safety margin is enough for a long time.

Another point that can be noticed is the top plate that attaches to the drone. She is also under pressure. However, it is quite low, although higher than in other places. There is no special need to change it to a more durable material, because the load is small.

In addition, look at details such as the top module ring and the bottom module ring. The load on these details is small. Therefore, there is also no need to change them for another material, which will be both stronger and more expensive.

In the image we can see that displacement is very low. This shows us that when standing on the ring and base, the bottom module will not squander.

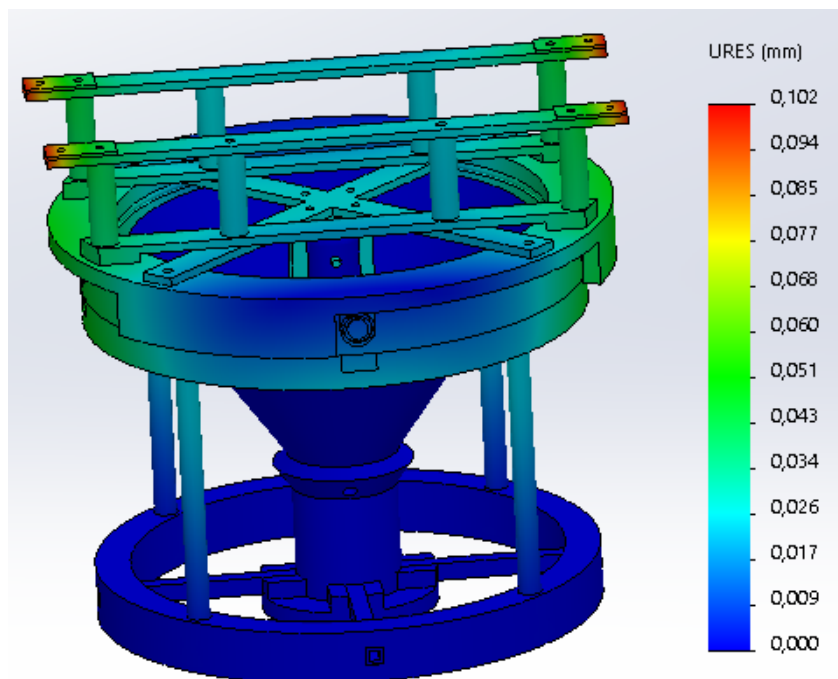


Figure 6.4 Simulation, Displacement, Second simulation

6.2 Simulation with aluminum beams

In this section, we consider another option. The connecting square profiles will be made of aluminum. This will add strength to the structure. Aluminum is much harder, however, these beams will not add much mass. In this section we also consider 2 options. The first option will be when using the mount for the base, and the second option is the base and ring.

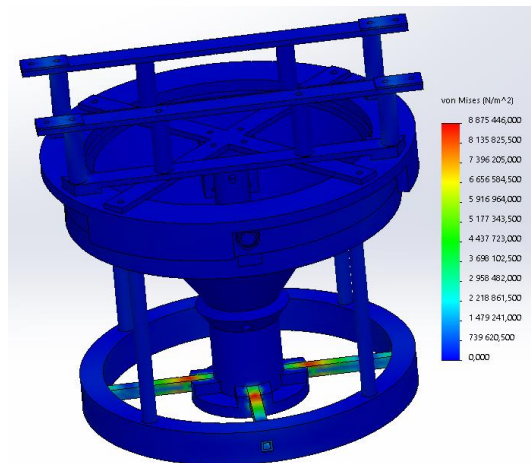


Figure 6.5 Simulation, Stress, Third simulation

On this image you can see that the maximum load will also be on the square profile. However, the flexural strength of aluminum is much higher. That is why it will be much stronger than the same plastic beam. This beam is best used in the working version of the module, since it will be much stronger.

An aluminum beam is best used if the module is mounted on a mechanical arm. Only in this case it will be beneficial to use, due to the fact that the strength will be much higher. Aluminum will be heavier than plastic, however, when using a mechanical arm, it will be necessary to take a large margin on loading capacity so that the engines in the mechanical arm do not work at maximum torque. This difference between plastic and aluminum will be insignificant with those with a mass of a drone and two modules.

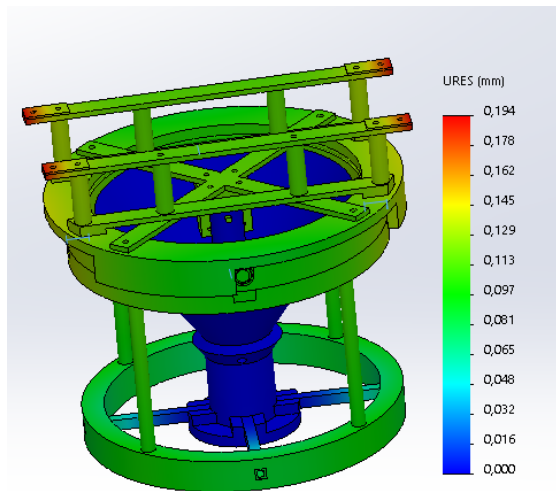


Figure 6.6 Simulation, Displacement, Third simulation

The displacement is only 0.2 mm, which will be considered a very small result. This will not be completely noticeable.

There is no need to carry out the second simulation due to the fact that there will be no deformation of parts when using plastic.

6.3 Simulation analysis

We may notice that in both sections there were good simulations. When using plastic you can see that it is best to use without a mechanical arm. The base and the bottom should be on the surface to distribute the load. In this case, the plastic profiles will only connect the base and fix it exactly in the center of the module. Also, these profiles can be used to create a prototype. These parts will not be designed for a long load, so their use is recommended in such cases.

Aluminum profiles are best used with a working model that will be used frequently. They will withstand the load when using a mechanical arm. It can also be used when mounted on a ring and on the base.

6.4 Weight of second prototype

As a measurable prototype, we take a model that includes aluminum beams, because it will be used on an industrial arm. Therefore, we need to have more strength.

Table 6.1 Total weight of components

Component	Weight
Drone	5.2 kg
Batteries	2 kg
Top module	1.09 kg
Bottom module	2.93 kg
Total	11.22 kg

The approximate mass of all components is 11.22 kg. It turns out that for an industrial hand it is necessary to lift at least 12 kg in order to hold the drone and modules.

7. FURTHER WORK

Further work is planned to take the following steps to improve the work of the drone landing assistance system.

1. Optimize dimensions and materials.

This is necessary for the best work of the modules and the final result. The idea is to reduce the dimensions of the parts, to make them of a more durable material. It will be necessary to reduce the amount of flat packed. For example, you can make steel plates that will keep everything, but their dimensions will be much smaller due to the greatest strength. By exemplary representations, it will resemble a thin skeleton of the whole structure.

2. Create a case for this module

This is necessary in order to improve the aerodynamics of the upper module. If we take wingngcopter 178 as a working drone, it will be necessary to focus more on direct flight due to the characteristics of the quadcopter. It looks like an airplane, but it takes off and lands according to the WTO principle. This is one of the reasons why he should make a body that will only be oriented in one direction. This is due to the fact that most of the time the drone will fly straight. And drones that do not have such features, can fly in different directions. For them it will be important to make a hull that will be streamlined from different sides for better flight.

3. Integrate the legs into the drone module.

This option can be considered in order to eliminate the possibility of hurting the legs on the lower module. In addition, it will allow you to change the size of the legs themselves for each individual drone. This can be done in several ways. The first option is to make the legs retractable. This will allow to remove and lower them only when necessary. In this case, there will be no need to build on them in size. This can increase the work area for planting. The second option is to improve the module so that the drone can sit on it without using its legs. It will also simplify the adaptation of the top module for individual drones.

4. Grab the stick in the bottom of the module.

This function is implemented in the SSVP system for docking to the ISS. In this embodiment, the stick simply falls below the cone, where it cannot deviate strongly to the side. However, in order to avoid problems with the landing, you can realize there a magnetic electromagnet, which will attract the stick and promote the best fit.

5. Add a small parcel box

This addition will be very important, because now the module occupies all free space below and weighs a lot. It is necessary to add the ability to transport small things, which will add additional functionality to the module.

8. SUMMARY

During this work, an overview of the analogs was made. After that, they were analyzed. Based on the analogs and the task, a concept of the system was formed, which was further improved. After the concept, an analysis was made in which flaws were noticed and ideas were formed to improve the design and principle of operation. The next step was to create a prototype that was better than a concept, but needed some work. The final step in working with the model was the creation of a second prototype, which combined all the advantages and ideas of previous models, and could also be ready for testing. All models were made in the program Solidworks CAD software.

After that, electrical components were selected for the latest model. After that, materials were selected and simulated in SolidWorks Simulation. She showed that it is possible to use different materials depending on the principle of work. Further ideas were also formed that could improve this system for later use.

During the work, a prototype was fully formed, which is ready for production and testing under real conditions, during which some strengths and weaknesses can be noticed that were not noticed during the whole work.

REFERENCES

- [1] J. Zhu, "Magnet gripper on the robotic arm," [Online]. Available: <http://stanford.edu/~jackzhu/cs225A/>. [Accessed 30 01 2019].
- [2] G. Durso, "Autonomous recharging and docking for multirotors," [Online]. Available: <https://hackaday.io/project/2759-autonomous-recharging-and-docking-for-multirotors>. [Accessed 29 01 2019].
- [3] C. Rojas, "Fiva Drone: Automatic Landing/Charging Quadcopter," [Online]. Available: <https://hackaday.io/project/10618-fiva-drone-automatic-landingcharging-quadcopter>. [Accessed 30 01 2019].
- [4] L. Dewitte, "The F-16 gets a Conformal Aerial Refueling Tank System (CARTS)," 2 8 2010. [Online]. Available: <http://www.f-16.net/f-16-news-article4163.html>. [Accessed 28 01 2019].
- [5] «Docking systems,» [В Интернете]. Available: <http://www.russianspaceweb.com/docking.html>. [Дата обращения: 02 02 2019].
- [6] "ISS les Docking System," [Online]. Available: https://www.capcomespace.net/dossiers/ISS/docking_system.htm. [Accessed 01 02 2019].
- [7] "International Space Station Imagery," NASA, [Online]. Available: <https://spaceflight.nasa.gov/gallery/images/station/crew-17/html/iss016e035627.html>. [Accessed 02 02 2019].
- [8] "Wingcopter," [Online]. Available: <https://wingcopter.com/>. [Accessed 25 01 2019].
- [9] Y. P. Aditya Intwala, "A Review on Vertical Take Off and Landing (VTOL) Vehicles," [Online]. Available: https://www.researchgate.net/publication/289290148_A_Review_on_Vertical_Take_Off_and_Landing_VTOL_Vehicles. [Accessed 26 01 2019].
- [10] "Расходные материалы для 3D-принтера. Пластики.," [Online]. Available: https://3dtoday.ru/wiki/FDM_materials/. [Accessed 01 05 2019].
- [11] "ABS-пластик для печати на 3D-принтере," 3D Today, [Online]. Available: https://3dtoday.ru/wiki/abs_plastic/. [Accessed 01 05 2019].

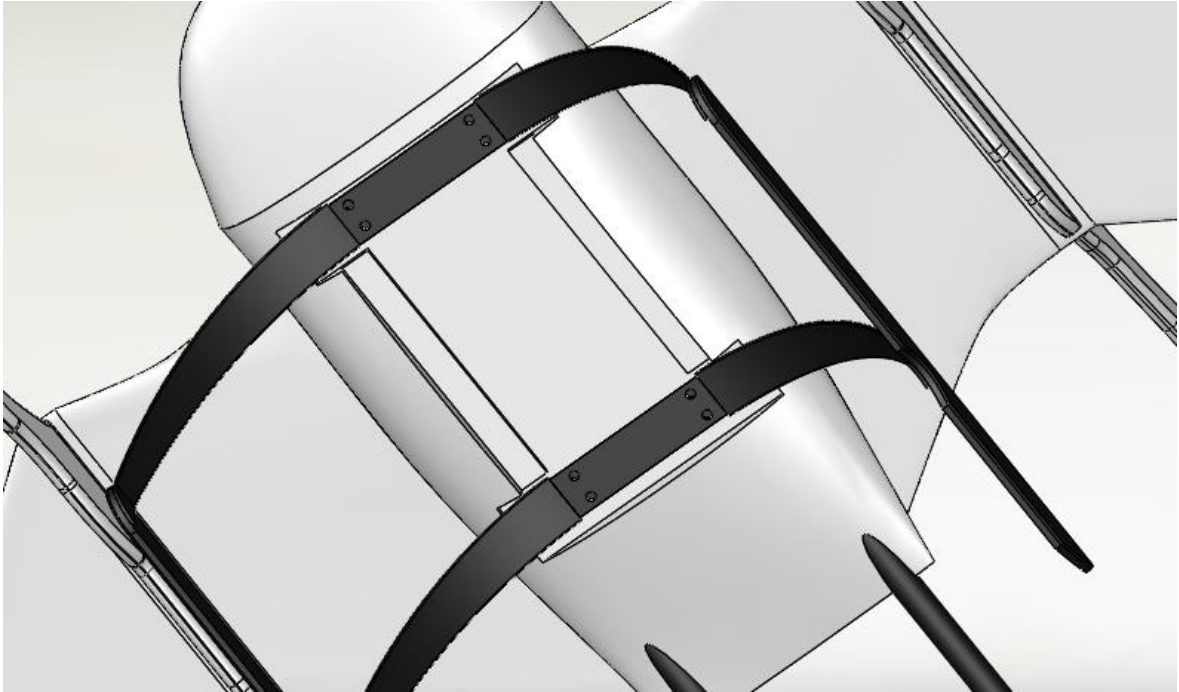
- [12] "PLA-пластик для печати на 3D-принтере," [Online]. Available: https://3dtoday.ru/wiki/pla_plastic/. [Accessed 01 05 2019].
- [13] "Smooth-Cast Onyx Slow," [Online]. Available: <https://www.lenkapenka.ru/smooth-cast-onyx-slow-chernyj-zhidkij-plastik-poliuretanovyj.html>. [Accessed 01 05 2019].
- [14] "Smooth-Cast 305," [Online]. Available: <https://www.lenkapenka.ru/smooth-cast-305-belyj-zhidkij-plastik-poliuretanovyj.html>. [Accessed 01 05 2019].
- [15] "UE-TECH DC12V 6.6LB/3.0KG Lifting Magnet Electromagnet Solenoid Lift Holding UE-2020-12VDC," [Online]. Available: <https://www.amazon.com/UE-TECH-Lifting-Electromagnet-Solenoid-UE-2020-12VDC/dp/B0177893XM>. [Accessed 10 04 2019].
- [16] "Adafruit VL6180X Time of Flight Distance Ranging Sensor (VL6180)," Adafruit, [Online]. Available: <https://www.adafruit.com/product/3316>. [Accessed 13 04 2019].
- [17] "Шаговые двигатели серии FL35ST и FL39ST," [Online]. Available: <https://electroprivod.ru/fl39st.htm>. [Accessed 06 04 2019].
- [18] "Шаговые электродвигатели серии FL39ST," [Online]. Available: http://www.zetek.ru/products/servo_technology_and_servo_drive/stepper_motors/step_fl/step_fl39st/. [Accessed 06 04 2019].
- [19] "ARDUINO UNO REV3," Arduino, [Online]. Available: <https://store.arduino.cc/arduino-uno-rev3>. [Accessed 16 04 2019].
- [20] "(S-25-12) AC to DC Power 25w," [Online]. Available: <https://ru.aliexpress.com/item/553599356.html>. [Accessed 14 04 2019].
- [21] "Lesson Five: Simulation," [Online]. Available: <https://www.solidworks.com/sw/resources/getting-started-simulation-and-analysis-tools.htm>. [Accessed 28 04 2019].

APPENDICES

Appendix 1 – MatLab Script for plots

```
y=[];
x=[163.46 163.46 163.46 163.46 163.46 163.46 163.46 163.46 162.69 161.12
160.38 158.46 156.92 155 153.46 151.53 149.61 147.69 145.76 143.46 140.76
138.84 136.92 135 132.69 129.61 126.92 124.91 121.53 118.46 115.38 112.3
108.46 105.76 102.3 99.23 95.38 92.69 88.46 84.61 79.23 75 69.61 64.23
58.84 53.46 48.07 43.07 36.92 31.15 24.61 18.07 12.3 0];
R=160;
H=200;
HV=200;
XS=0;
YS=100;
for i=1:54
    y(i)=i*5;
    x1(i)=x(i)+130;
    x2(i)=-x(i)-130
    %stick
    xst1(i)=15;
    yst(i)=54*5-185/54*i;
    xst2(i)=-15;
    %cone
    xc(i)=20+H/54*i*tan(35/180*3.14)-XS;
    yc(i)=50+150/54*i-YS;
    xc1(i)=-20-H/54*i*tan(35/180*3.14)-XS;
    yc1(i)=+50+150/54*i-YS;
    %base
    xb1(i)=R-XS;
    yb1(i)=HV/54*i-YS;
    xb2(i)=-R-XS;
    yb2(i)=HV/54*i-YS;
end

plot(x1,y,x2,y,xst1,yst,xst2,yst,xc,yc,xc1,yc1,xb1,yb1,xb2,yb2);
axis('image')
```

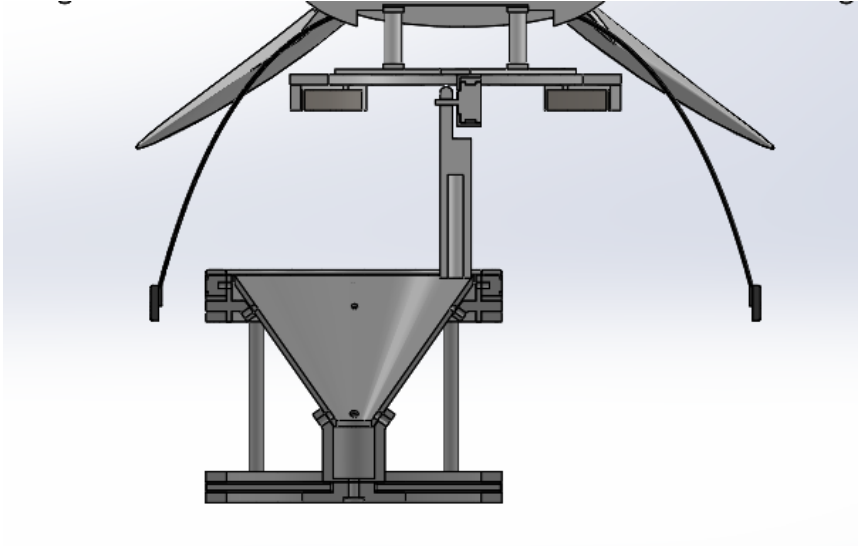


Figure: Start landing from the most distant position

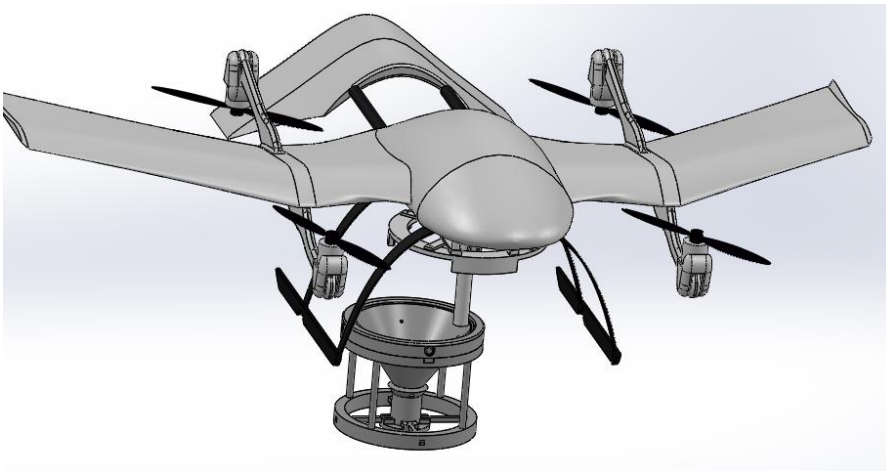


Figure: Start landing from the most distant position

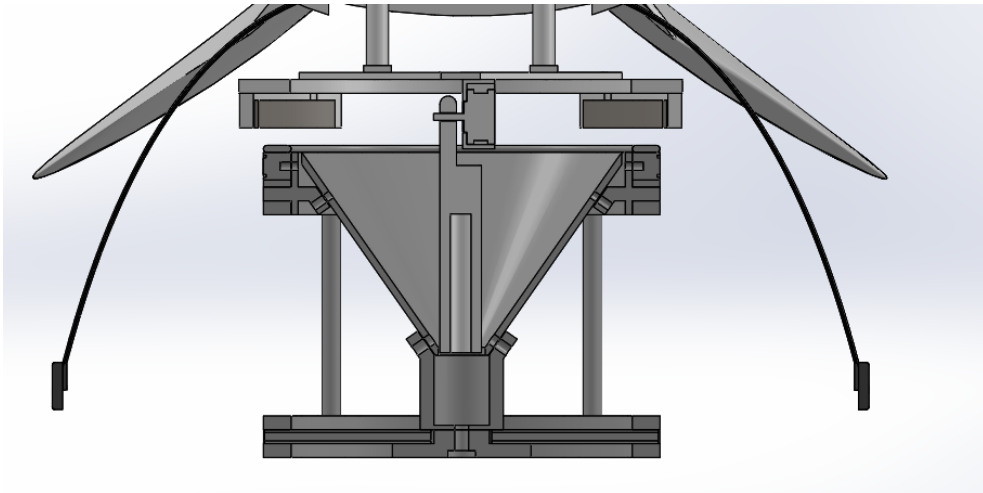


Figure: Mid landing

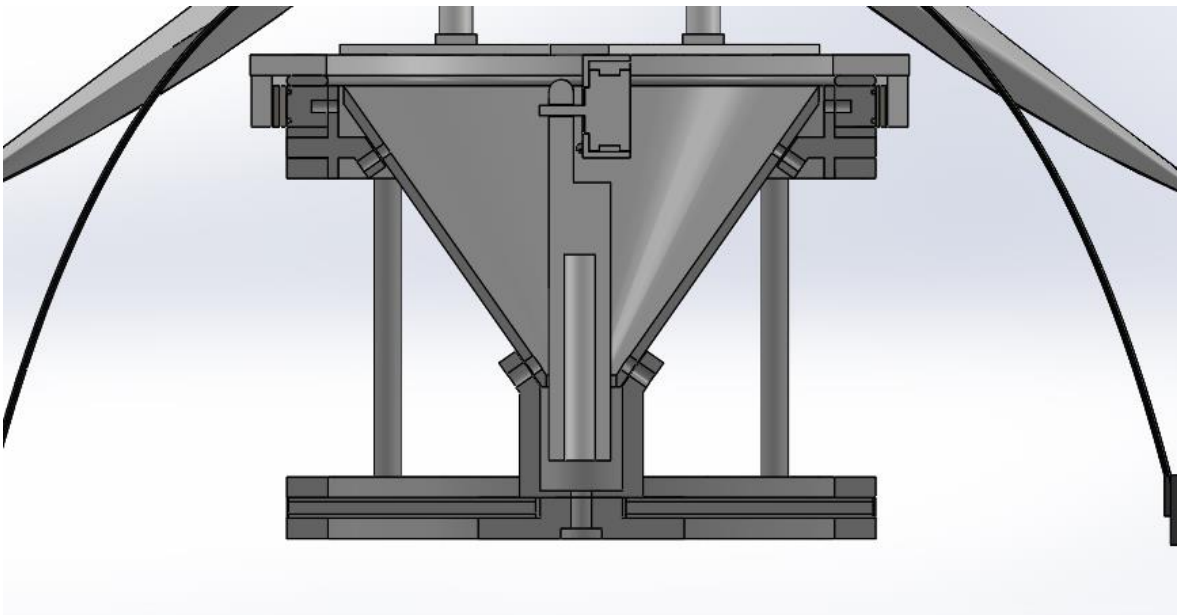


Figure: Finish landing