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Degree project

Adding storage to an unmanned aerial vehicle

Without compromising the flight mechanics

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Abstract

The Swedish Sea Rescue Services (SRSS) has developed an Unmanned Arial Vehicle (UAV) which they use for search and rescue missions. The SRSS wants to upgrade this UAV to also be able to fly and drop with a package. By designing according to the model of designing by HH van den Kroonenberg [2]. The main functions for the package is that it needs to be able to carry at least 300 gram and be 900x900x25 millimetres big. After designing 3 concepts, one main concept is chosen and produced as a Solidworks model. This package and the joint to hold the package have been designed and have been calculated to be able to withstand the stresses during flight. The stresses include the weight of the package as well as the aerodynamic drag. With a safety factor of 1.5. Also a finite element simulation is done to check the main stresses, this simulation shows that the critical beam will not be able to hold. It is recommended that a more dense EPP is used or the beam will be redesigned. Also an engineer specialized in aerodynamics is recommended to take a look at the results to be fully secure.

Keywords: Designing, aerodynamics, simulations, flight, mechanical engineering

Summary

The Swedish Sea Rescue Services (SRSS) has developed a Unmanned Arial Vehicle (UAV) which they use for search and rescue missions. A Canadian company wants to know if they can use the same UAV to drop medicine for people living far away from civilization. This would benefit the environment because otherwise a helicopter would be used.
So in this thesis a research and development of a package will be done which needs to fit underneath the UAV. This package needs to be able to contain 300 gram and have a size of at least 900x900x25 mm and it will be made out of Expanded polypropylene (EPP) .
The development of the system has been done through the designing method of HH van den Kroonenberg [2]. Together with the SRSS a few functions are set up. The most important being that the package and joint should weigh as little as possible and it should be easy to produce.
With an morphological overview, three concepts are made. These were put in a table with scores based on how well they met the functions from the SRSS. From here the final concept is chosen and is made in Solidworks. This concept has an electric hook. The joint is slid onto the body of the UAV. The slide over the body is supported by a beam which hold the slides the slides on their spot and carries the hook. The slide is chosen because it is easy to put on and off, also it is cheap to produce and lightweight. The double hook concept will grab the package After this a finite element simulation is done to check if the beam will not collapse under the stress from the gravity and the aerodynamic drag it will have during flight. The maximum allowed stress is 0.4 MPa for EPP. The maximum principal stress is 0,53 MPa so the beam is unsafe to use. This means that it is recommended that or a more dense EPP is used or the critical beam needs to be redesigned.

Preface

I always had an interest in aerodynamics and flight. When I came across this assignment it immediately grabbed my attention. In a talk with Emil we discussed my knowledge about UAV's and flight. During the designing and calculation I was always really motivated to get the best result.

I want to thank Izudin, Emil, Martin, Ruud, Roderik and Filip for their help and critique

Philip Jan Grolleman

Växjö, 23 May 2022

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1. Introduction

1.1. Background

Figure 1 SRSS flag

The Swedish Sea Rescue Society[1] (in Swedish: Sjöräddningssällskapet) is a Swedish company which purpose is to help people in need. This non-profit organisation is specialized in rescuing people from sea. SSRS carries out more than 70% of all emergency calls in Sweden and its territorial waters. [5]. According to their own website[2] they have 260 modern rescue vessels and with that in mind their goal is to depart to an alarm within 15 minutes or less. The crew who is able to meet this goal are volunteer rescue members which train several times a month. They do this part time, next to their normal job. There are around 2400 volunteer rescue members who are available at any point in time. The funding is all based on memberships and donations, there is no government support.

If a ship is in danger or has mechanical problems. It is important to know the location of the vessel. To locate the ship flares used to be shot in the air. Very famous is the scene in the film The titanic[3], in this scene the crew shoots flares in the air. This was for the rescue ship to locate them. These days large ships have GPS onboard. But smaller boats do not always have this. If a ship would come in distress, for example an electrical fire happens, which do not let the captain send out a distress signal via radio. The captain will call the SRSS, and the captain should know where he roughly is. The SRSS will send a unmanned aerial vehicle (UAV) to the location. This UAV is controlled by an operator from land. And will look for the vessel in distress. After visually locating the vessel (with a build-in camera) and assessing the situation, either a helicopter with supplies or a rescue vessel will come to aid.
This UAV has been developed previously to assist the SSRS in their work of search and rescue missions. See figure below. The UAV is powered by an eletric motor and batterys. With a wingspan of 1 meter and 700 gram of mass (including batteries) it is very light. The UAV is made out of EPP, more on that in the next paragraph.

[1] https://www.sjoraddning.se/information-english
[2] https://www.sjoraddning.se/information-english
[3] https://en.wikipedia.org/wiki/Titanic_(1997_film)

The UAV is made in a flying V shape. This means it can not hover like most common UAVs, for example DJI quadcopter drones[4]. The benefit is that it is faster and is more efficient in flight then most other UAVs.

Figure 2 UAV used by the SRSS

EPP

Expanded polypropylene (EPP) is a versatile foam based material. It is used for the UAV because of its high strength to weight ratio [7]. For processing normal plastic injection molding can be used. This is benneficial because it helps freedom during designing.

A Canadian company which helps delivering medical equipment to people who live in remote areas asked if it was possible to use the UAV to deliver emergency medical equipment. In practise this would look like this:
A person needs emergency medical help. When they call help, a helicopter will come to bring a small package with emergency medicine. This takes time; a helicopter pilot needs to start the helicopter and the helicopter uses a lot of fuel which is bad for the environment. Because of this the Canadians wanted to know if it would be an option to use the UAV made by the SRSS and modify it to their situation. If it is possible then it costs a lot less money and it might be faster as well.

A request has been made to investigate the possibility to carry a payload of 300 g to also use the current UAV as a delivery UAV. This could for example be to help people who live far away. If they need medicine for an emergency, then it is faster and more cost efficient to send a UAV then a

[4] https://www.dji.com/se/mini-2

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helicopter with its personnel to drop the same package. Start-ups are already doing this with post in parts of Africa.[5]

1.2. Problematization

Adding storage on the current UAV gives rise to problems regarding the:

- Flight mechanics
- Structural stability
- Aerodynamics

These points have to be considered when designing this storage. The main focus for this bachelor thesis will be to design the storage as well as to conduct an analysis of the effect on the structural strength of the joint between the storage and the UAV. Secondary work that can be performed if time allows is to study the flight mechanics and the aerodynamical effect from the storage.

1.3. Goals

The main goal is to develop a storage that can hold 300 g of payload and is able to fit 900x900x25 mm of payload. Also ensure structural stability of the joint between the UAV and the storage. This is a suggestive project because new parts will be developed.

In case of time left there are secondary goals. These are:

- Conduct a flight mechanical analysis of the UAV
- Conduct an aerodynamical analysis of the storage
- Conduct an aerodynamical analysis of the UAV
- Conduct a structural analysis of the UAV with the storage

1.4. Delimitations

This bachelor thesis will only consider the storage as well as the joint between the storage and the UAV from figure 2. No other parts of the UAV shall be studied and no new UAV will be made. The UAV is made out of EPP, the joint and the storage shall be made out of the same material.

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[5] https://knowledge.insead.edu/blog/insead-blog/africas-drone-medical-delivery-service-saves-lives-in-lockdown-14371

1.5. Structure of the document

This document will first explain the background and will flow into the problematization. After that an explanation will be given about the used methods and theory. The rest of the document follows the structure of the book model of designing mentioned [2]. Up next all the requirements will be specified. These requirements will be rewritten in functions. After rewriting this a morphological overview will be made. This will give solutions for the different functions which need to be made.
From these solutions concept will be made. After a brief explanation about the concept a final concept will be chosen together with the supervisor. This final concept should be able to comply with all the requirements. This will be made sure of by different calculations and simulations.

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2. Methodology and implementation

2.1. Theory

The designing of the model will be done with the model of designing by HH van den Kroonenberg [2]. His method is taught to the student at his home university. ISBN is in the references. The book follows four steps. These are:

1. Problem defining phase
   In this phase the engineer makes sure he/she really knows what the problem is. Without this it is impossible the design the best possible solution
2. Method determining phase
   In this phase the engineer determines how the problem can be solved, in which ways is it possible to solve.
3. Choice determining phase
   After determining which choices there are, the best solution is picked.
4. Shaping phase
   After choosing all the best solutions, concepts are made to be validated. The best one is chosen.

More detailed explanation will be given during the designing of the package and joint.

2.2. Method selection

To simulate flight mechanics and aerodynamics computer programs will be used. The student is known with simulating aerodynamics on Solidworks[6]. This will be used to simulate the aerodynamic behaviour of the air around the package and (Stengel, 2004) to optimize that.
Also a Finite Element Methodology will be used. With this method a way of calculating stresses is possible. At last an aerodynamical calculation will be made.

2.3. Research quality and ethics

To keep the quality high, the student will only be looking for information regarding adding weight and aerodynamic shapes. Shapes have a great effect on aerodynamics. When there are less aerodynamic forces the UAV is more efficient. A more efficient UAV means a larger flight range.

[6] https://www.solidworks.com/product/solidworks-flow-simulation

To keep the quality high only books written by engineers who work with UAV design or papers which are peer reviewed are used. This should only give highly reliable and restudy able information. When interviews will be held, they will only be held with people who already worked on or with the UAV. This guarantees a high level of knowledge.
In case of ethics, the SRSS is a company based on volunteers. These volunteers have no interest in cheating or secrecy. The idea is to help people who are in distress.
For the student this is important to help other people and add something good for the world. Also the student is interested in flight and UAV design.

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3. Results

In this chapter the switch from research to design is made. The method used for this is explained in 2.1. First the requirements will be clarified.

3.1. Requirements for the UAV and her package

In this part an explanation will be given about all the functions the joint and package have. Ideally the final concept should have the best solution for all functions. In this degree project the student should focus on the best solution. There is no budget limit or design for manufacturing. The only thing to consider is that it should be able to be milled.

The functions are divided into 3 subcategories. These are:

- Must the function needs to be made
- Variable the function should be made
- Wish it would be nice if this function could be made in the project

The functions for this project are put in a table seen below:

Function	Category
Package size	must
Package weight	must
Package dropping mid-flight	must
Not hard to open	variable
Easy to put the joint on the UAV	wish
Not altering the UAV	wish
Strong enough to handle a safety factor of 1,5	wish

Table 1 Functions for the project

So the final concept of the package should be able to carry 300 gram while being 900x900x25 mm in size. Compared to the size of the UAV it looks roughly like this:

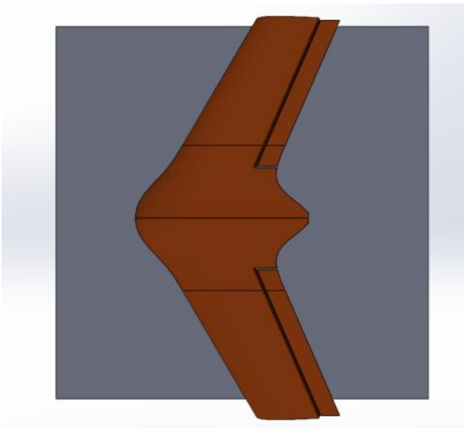

Figure 3 Top view of the size comparison

Also the package should be easy openable. The joint by which it is supported should be able to drop the package mid-flight. The joint should also be carry the package with a safety factor of at least 1.5 while stationary. The supervisor did not want a calculation of the joint strength mid-flight.

The package should also be 10 mm away from the control services on the UAV. Otherwise the air flowing around it is not able to pass, this will make the control services behave like an air brake instead of control the flow of air.

When designing a flying object the centre of gravity of the object is really important. Combined with the centre of lift it will tell a lot on how the object will behave mid-flight. See Figure 4. In order to not disturb too much on the flight mechanics, it is better to have the centre of gravity from the package as close as possible to the centre of gravity of the UAV. There is dimension in which the centre of gravity should be.

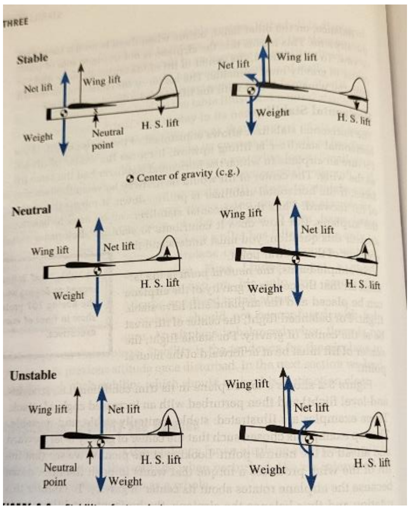

Figure 4 Center of gravity. Courtesy of Understanding Flight [1]

As seen in Figure 4 above, the package is a lot longer than the UAV while roughly the same width. With basic aerodynamic knowledge it is visible that this might give some lift on its own, this will create a whole new way of flying the UAV when the package is attached. To make sure what the effects of this might be, more is needed to know about aerodynamics. A preliminary gave one answer:
If the angle of attack is to large, the flow of air over a small thin aerofoil is separated.
This means that if the nose of the UAV is going up to a certain angle the airflow over the package will be blocked. Visualized in the figure below.

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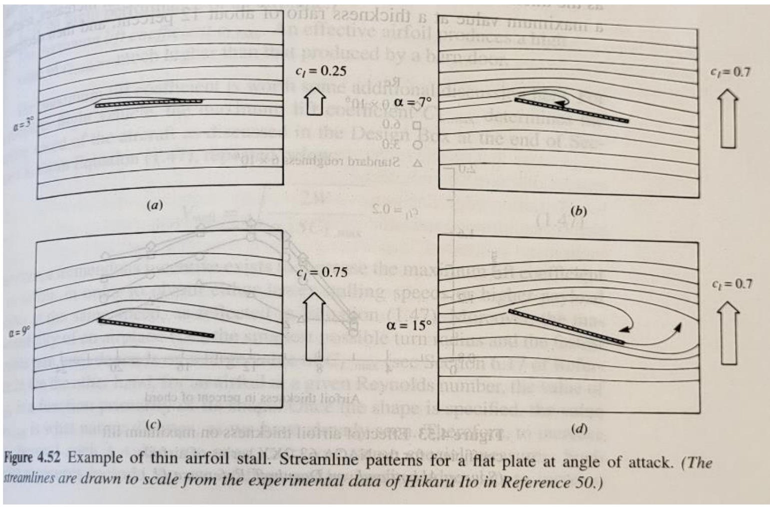

Figure 5 airflow over a thin plate, courtesy of fundamentals of aerodynamics see more in the reference list

3.2. Morphological overview

To make the best concept with all the functional requirements a morphological overview is made. The idea is that for every function different solutions are thought of. After writing these down and briefly explaining them, multiple concepts will be chosen with one of the

	1	2	3	4	5
connection between the joint and the UAV	bolt nut connection	pin hole connection	big slide over the surfaces	glue	electro magnets
opening and closing of the package	magnets	pinlock with a hatch (like the cheap bathroom door locks)	plastic lock (like a computer mouse)	turnable lock with hatch	
package to the joint with regarding to mid air release	electro magnets	pneamatic release	electric actuators	electric turnable hook	

Table 2 Morphological overview

solutions for each function.

3.3. Concept design

Make a few concepts and choose the best one. These concepts should contain a function for all problems. Also will be explained how each concept should work and a sketch will be made how they possible roughly could look like. The concept which gets chosen to be finalized can than still be changed in shape if that would be beneficial.

3.3.1. Concept A

Bolt nut connection – magnets - electric hook

In this concept it is chosen to have a bolt nut connection with magnets to open and close the package. Also it will have an electric turn able hook. Because these options are all quite heavy this will be the heavy concept.

In order to make the bolt nut connection possible a small metallic part is necessary in order to be able to carry a nut. The downside is that that will be heavy and it needs to be able to handle the environment without corroding. For example rain.
Also it is necessary to drill at least one hole (maybe more depending on the calculations) in the UAV.

The solution of magnets to open the package are a simple solution. These magnets require no power. To open a package it requires a bit more strength and a small hole to place your fingers in order to open the package. But there is no need for a hatch.

The electric hook is holding the package in its place. If it would turn 90 degrees for example the aerodynamic drag will push the package back. This will cause the package to fall. To make this working a small turning motor is necessary.

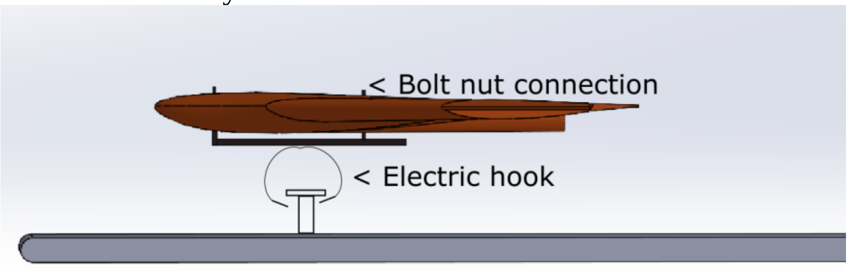

Figure 6 Concept A sketch

3.3.2. Concept B

Big slide – pinlock – electro magnets

This concept is based on ease of use. By choosing to have a big slide of the surface of the UAV together with a pinlock to open and electro magnets to let go of the package mid-air. The idea of the slide is that during flight the aerodynamic drag will force the package to move “back”. So if a slide would be slid over the front side of the UAV than the aerodynamic drag will force it to not move. This is not a solid solution, so a lot of calculations with regards to crosswinds and stall scenarios need to be made.

A pinlock idea is based on a “door bolt” see figure below.

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[8] door bolt

This is an easy to use idea and it quite cheap solution. The material needs to be able to withstand the environment which could make it less cheap.

At last to drop the package it would be with electro magnets. This will benefit a quick setup. Because the package only needs a small magnetic piece of material inside. Once the operator wants to drop the package it only needs to stop feeding the magnets energy.
The downside is that the magnets always require energy. This will decrease the flight time more than the other solutions. But the benefit of this is that the package does not need to be on rails which the other solutions need to have. The magnets need to be strong enough to overcome the aerodynamic drag from the package while flying at 35 m/s. (126 km/h)

The sensors on the UAV, which are necessary to control the plane, are probably not interfered by magnets with their magnetic field. But if this concept is going to be finalized, this need be made sure.

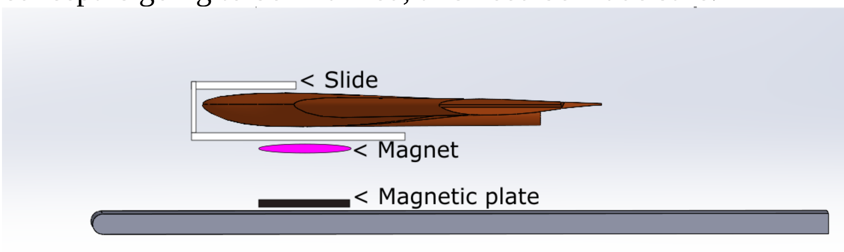

Figure 7 Concept B sketch

3.3.3. Concept C

Pinhole connection - Turn able lock - Electric actuators

This concept is between ease of use and weight. To use a pinhole connection. This is possible with EPP because EPP is a sturdy material.

The turn able lock is not that much different than the pinlock from concept B.
The electric actuators are a heavy duty solution. These are usually heavier than the other options but the UAV has a cruise speed of 35 m/s. When the operator decides to drop the package. The electric actuators move out of the way. This will make sure the aerodynamic drag will push the package away and it will fall.

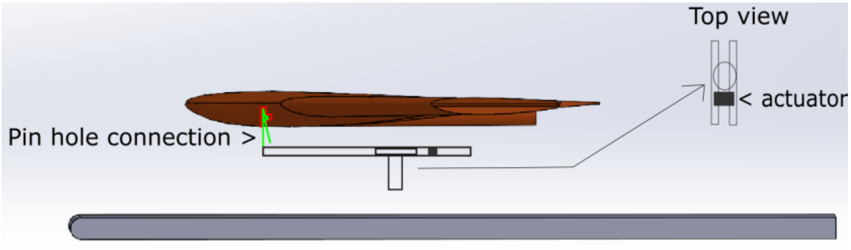

Figure 8 Concept C sketch

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3.4. Deciding the final concept

To pick the best concept a method is necessary. This method is called the weight factor method. It works by giving a weight on functions in a selection table, for example it is important that the UAV is as light as possible.
So on a scale from 1 – 4 this would be a 4. The concepts will then be graded. If they are light they will also get a 4 for lightness. This would mean 4 x 4 = 16 for lightness which is also the maximum score.
The weight of all the requirements are given by supervisor which is in compliance with the SRSS.

The selections the concept will be subjected to are:

- As light as possible 4
- Ease of manufacturing 3
- Ease of use 1
- Not consuming much electrical energy 2
- Cheap 4
- Not altering the UAV 3

With all concepts graded and put in a table it looks like this:

Requirements	Importance	Concept A	grade x weight factor	Concept B	grade x wei	Concept C	grade x weight factor	Ideal	grade x weight factor
as light as possible	4	1	4	3	12	3	12	4	16
ease of manufacturing	3	2	6	3	9	4	12	4	12
ease of use	1	3	3	4	4	3	3	4	4
not consuming much electrical energy	2	4	8	2	4	3	6	4	8
cheap	4	3	12	2	8	2	8	4	16
not altering the UAV	3	1	3	4	12	2	6	4	12
total		14	36	18	49	17	47	24	68
total %			52,9		72,1		69,1		100,0

Table 3 Weight factor table

The red 2 in Table 3 is unsure because it is unsure how much energy electrical magnets use while they are powered.
In consultation with the SRSS it is chosen that concept B will be further developed but instead the electric magnets, the electric hook will be used. The final concept will be a slide over the top of the UAV and a pinlock to open and close the package. With an electric hook.

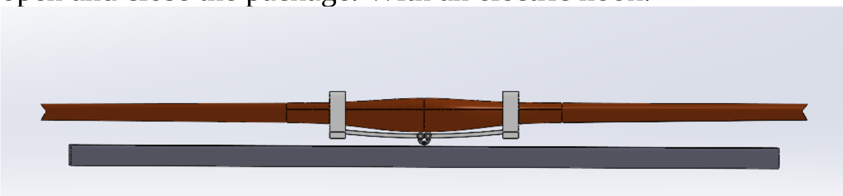

Figure 9 final prototype front view

The picture above shows how the final prototype looks like in Solidworks. This front view shows the package in grey and in white the slide. The big hook will be explained later more in detail. The slide is clear from the UAV his control services, also the nose of the UAV is bigger so the slides cannot slide in the horizontal view. When the prototype will be made, then it will become clear if the friction is big enough during flight. If this is not the case, the SRSS can still add Velcro strips to increase friction.

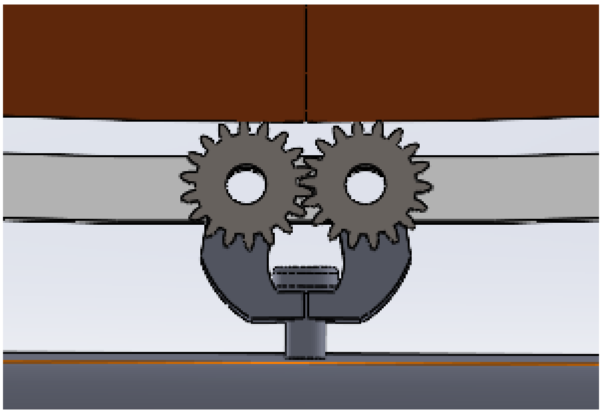

Figure 10 Final prototype zoom in on the hook

To make sure the package swings less during flight everything is made squared instead of round. This will make sure the package is unable to turn mid-flight and should also make it harder to swing.

The opening and closing is not drawn in Solidworks. The real life prototype can be made with an opening as big as the SRSS wants. The pinlock can open and close the package, while being easy to use for the operator.

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3.5. Structural analysis of the final concept

The EPP used in the UAV is EPP with a density of 35 gram / litre. This gives it a strength of 0.4 MPa with a 15% elongation, material data sheet is in appendix III. The E modulus is roughly 2.5 MPa as seen in Figure 11.

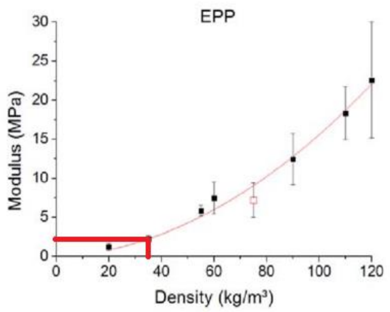

Figure 11 E modulus of EPP [9]

First a calculation will be made regarding material strength, this is a maximum principal stress calculation and will be made by hand. To check if the structure will fail a Solidworks simulation is also made.

In order to analyse the structural strength the white part is considered a beam. With a 1.5 safety factor it will be calculated statically. This calculation is wanted by the SRSS, but this is not good enough for the strength during flight. Because statically it only creates a force in the vertical way resulting from gravity.
Visually the beam looks like Figure 12 in the holes will be a shaft which supports the hooks carrying the package (as seen in Figure 10). In the middle of Figure 15 the X and Y axis are also seen. These will be used in further calculations.

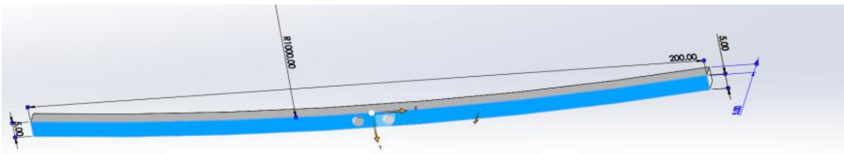

Figure 12 Beam with her dimensions

To calculate if the beam is strong enough, the maximum principal stress will be calculated. The whole explanation of the formulas are in appendix I, here all letters are explained with their respected values.
The known numbers are put in the table below:

dimensions	in mm					maximum able material	
length	200	L	package weight	0,3	kg	σ in N/mm^2	0,4
width	5	b	force per hole	1,4715	N	elongation in %	15
height	5	h				E modulus in N/mm^2	2,5

Table 4 Known numbers beam

Because the package is used during flight a drag calculation will be made. The formula for this is called the drag equition

$$F_{drag} = \frac{1}{2}\rho v^2 C_D A$$

Here in this equation C_d is the drag coefficient which is unitless and for the beam the value of 1.05 has been chosen. In Figure 24 in the appendix is visible that a square has that value.
ρ is the air density in kg/m^3 . v is the speed of the UAV in m/s. And A is the area of the beam in m^2 . The answer is:

F_{drag} = 0,787828 N

The beam will probably fail by structural elastic collapse. This means that by having too much pressure instead of cracking, bending will cause the beam to collapse. Solidworks is able to simulate this well with finite element simulations. The one thing Solidworks is not able to simulate is that EPP is a nonuniform material, this means that it is shaped in bubbles with air between the bubbles. The air is unable to handle forces. Therefore the results of the simulations are not a perfect picture of the results in the real world. But it can still be used, and that is why it is used in this thesis. For the simulations Solidworks 2020 is used.

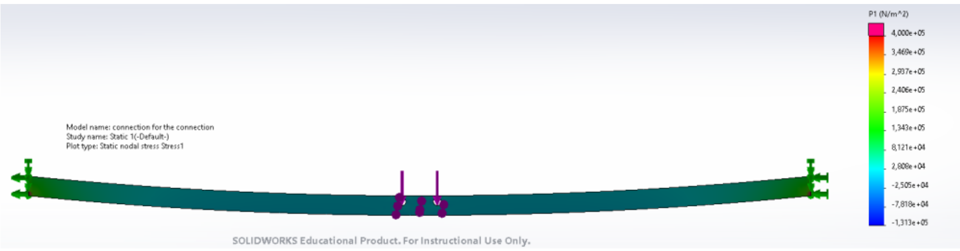

Figure 13 Von Mises stress front view of the carrying beam

In the picture above it is visible that the beam will hold the package. A force of 1.5 N in Y axis is used, and a drag force of 0.8 N in the X axis which would be the aerodynamic drag. The mesh is showed in Figure 23 in appendix I. The deformed result (not realistic) looks like figure below.

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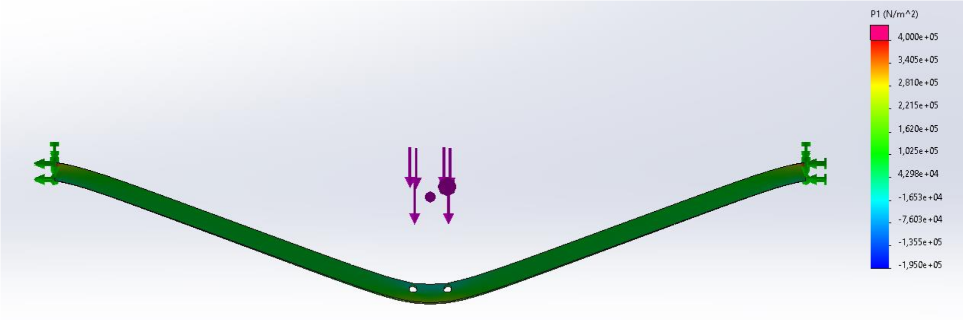

Figure 14 Deformed result of the simulation

According to the results the maximum principal stress is 0,53 MPa as seen in Figure 15. This means that the beam will not hold. A redesign or a more dense EPP would be a sollution.

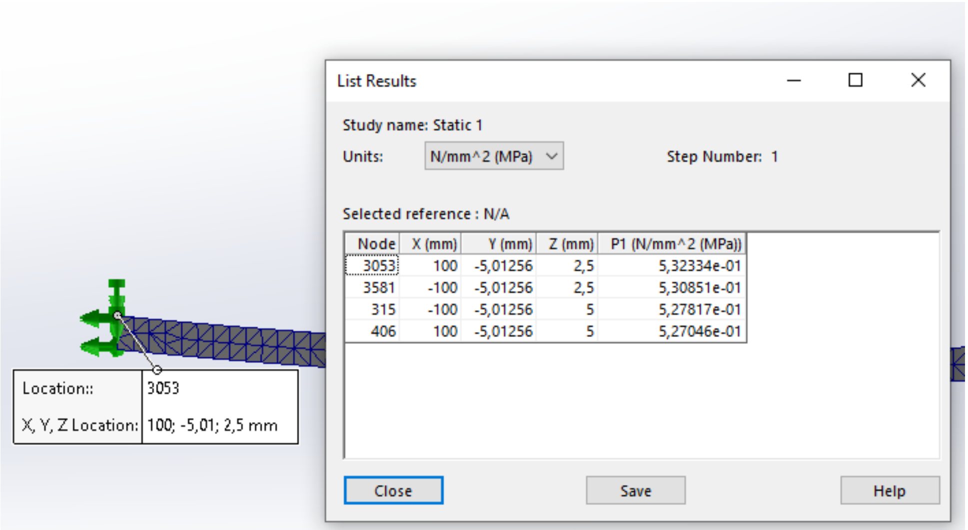

Figure 15 Maximum principal stress according to Solidworks simulation

3.6. Aerodynamical simulations of the final concept

To check how the air flow will behave around the joint, an airflow simulation is done. With Solidworks it is possible to simulate this. With the parameters of flight at 35 m/s the airflow looks like Figure 16

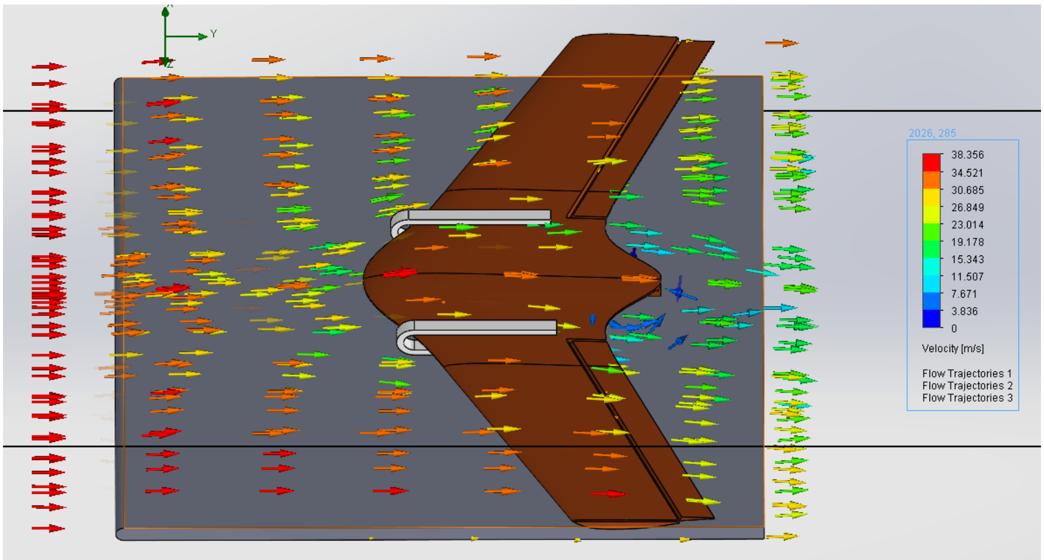

Figure 16 Airflow in flight

The airflow is disrupted at the end of UAV. This is visible by the blue arrows. That they are blue means that their velocity is almost zero.
In Figure 17 below it is visible that the joint does not disrupt as much airflow as the back of the UAV.

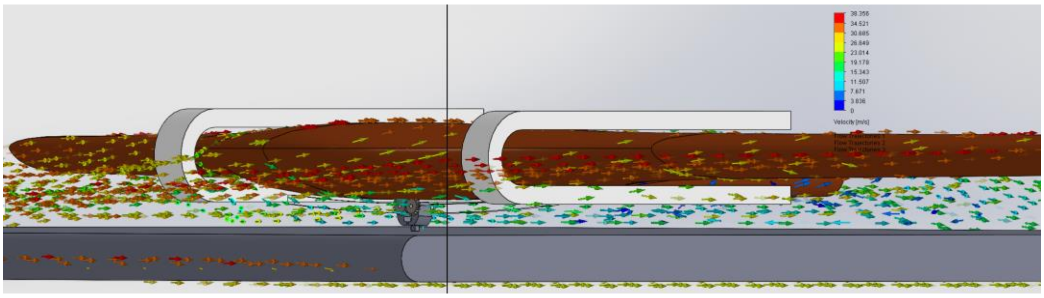

Figure 17 Airflow 45 degree angle

Also is visible in Figure 17 that the package slows the air velocity by 10 m/s.
To compere the results between the UAV with and without the package, a similar simulation is made with only the UAV. As shown in Figure 18 it is visible that the flow on the back is flowing in without much disturbance because the arrows are still flowing the same way and are almost the same colour so there is not much friction.

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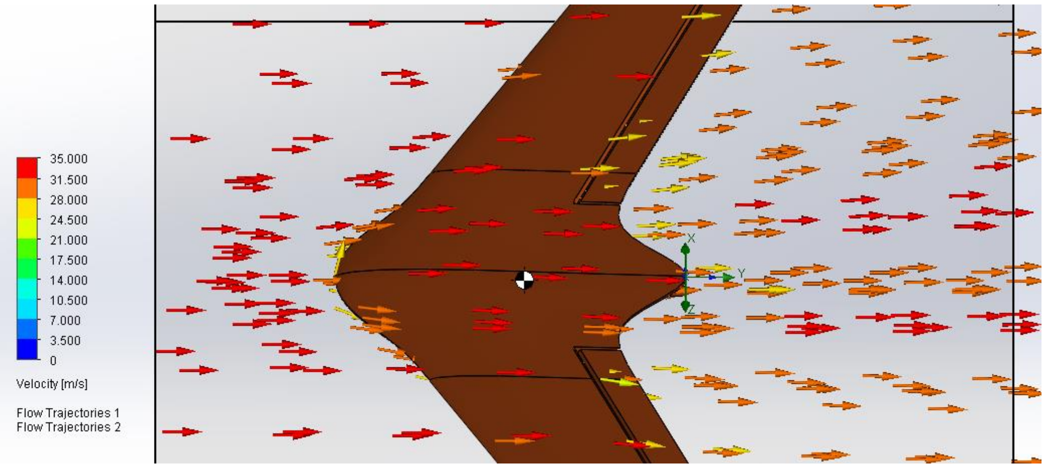

Figure 18 Flow simulation UAV

So back to the original simulation with the package and the joint a close up look reveals a disturbance at the end of the lower end of the big slide. Visible in Figure 19.
What is causing the disturbance is not fully known and will be a recommendation.

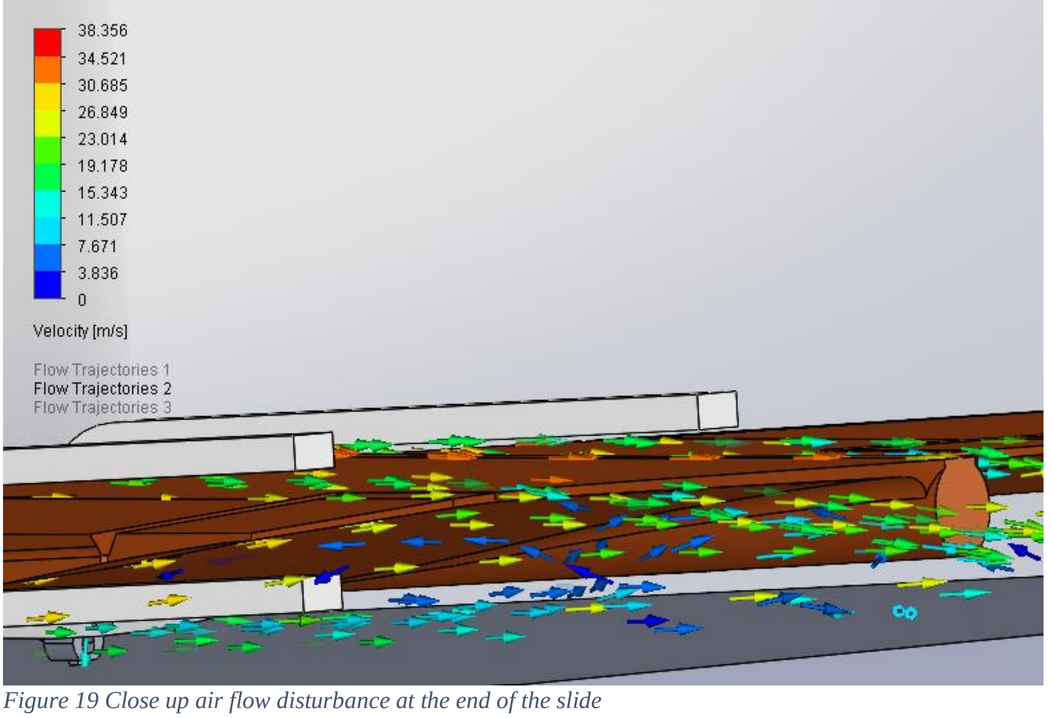

Figure 19 Close up air flow disturbance at the end of the slide

4. Discussion

The discussion is a section that is written more freely. Here the author's own thoughts and opinions are given. It should include a discussion of both the method and the result.

4.1. Methods discussion

The method chosen is more focused on design than on the scientific background. This means that a practical solution was wanted rather than a scientifical solution. The amount of work spend on a practical solutions might be less than the most perfect scientific solution.

Solidworks simulation is as written in 4.5 treating the simulations as a homogeneous material. While it is not. Also it is not fully sure how accurate the results of the flow simulations are. So these are only used as an indication.
There is a lot more to an UAV than only shapes. With more time a study about the whole UAV could be done as well. Maybe the package would be much better in the UAV considering aerodynamic forces.

4.2. Results discussion

The results show a working solution. This might not be the most perfect way, but out of the prototypes showed to the SRSS it was the best one.

The results from the calculation are based on a homogenous material as said in 4.1 but it is not. The results from Solidworks FEM calculations are also a study and based on a model. This is never 100% the real world. When producing the batch of EPP it might be that the batch going to the SRSS is a bit different than expected even though this might be slightly it can still have in impact in material strength.

4.3. Relevance for the society

As told in the background the relevance for society is there. There are companies which already do the same exact thing. But when there multiple companies working on the same solution it will force them to

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come up with the best idea in order to succeed on the market. In this case the market are hospitals and other business who sell medicine.

By using an UAV instead of a helicopter it saves gasoline and it costs less to have pilots ready on standby because the UAV can be launched with the operator sitting at home.

5. Conclusions and recommendations

The goals from chapter 1 are rewritten here with the their answer.

The primary goals are:
Develop a storage that can hold a mass of 300 g and that can fit 900x900x25 mm of payload. This is proven in chapter 4. The structural analysis of the joint between the storage and the UAV with a safety factor of 1.5 is not successfully made. The maximum principle stress according to Solidworks FEA simulations is to high for the material. Therefore a redesign or a denser EPP is recommended.
After the main goals an aerodynamical analysis of the storage is Conducted. According to Solidworks 2020 flow simulation the storage decreases air velocity by 10 m/s. also an aerodynamical analysis of the UAV is Conducted with the results being shown in Figure 18

As told in chapter 4 aerodynamics is the most important part of designing a package. With this information a package is created with an aerodynamic body.

The biggest recommendation is to let someone with knowledge about aerodynamics check the results. Because the package is so big with regards to the UAV, on level flight it will probably be flyable, but how it behaves with crosswinds or a different angle of attack is a guess.

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APPENDIX I: formula explanations

dimensions	in mm					maximum able material	
length	200	L	package weight	0,3	kg	σ in N/mm^2	0,4
width	5	b	force per hole	1,4715	N	elongation in %	15
height	5	h				E modulus in N/mm^2	2,5
moment of inertia		52,1	mm^4	$I = \frac{1}{12} b * h^3$			
shear stress							
0,08829	τ=the shear stress			$\tau = \frac{V y' A'}{It}$			
	V=force						
1,25	y^'=distance of the centre of gravity to the neutral line						
12,5	A^'=area of the part above the centre of gravity						
5	t=width overall						
normal force			$\sigma_n = \frac{F}{A}$				
0,05886	σ	N/mm^2					

Figure 20 Calculations part 1 basic shear stress and normal force

maximum principal strength						
σ ave	0,02943	N/mm^2	$\sigma\ ave = \frac{\sigma x + \sigma y}{2}$			
σx = 0						
+	0,122496	N/mm^2	$\sigma 1{,}2 = \sigma\ ave \pm \sqrt{\left(\frac{\sigma x - \sigma y}{2}\right)^2 + \tau^2}$			
-	-0,06364	N/mm^2				
max principal strenght with safety factor						
0,183744	N/mm^2					

Figure 21 Calculations part 2 maximum principal stress

	drag calculations		
	$F_{drag} = \frac{1}{2} \rho v^2 C_D A$		
	0,787828	N	
ρ =	1,225	air density	kg/m^3

Figure 22 Calculations part 3 drag calculations

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APPENDIX II : Figures

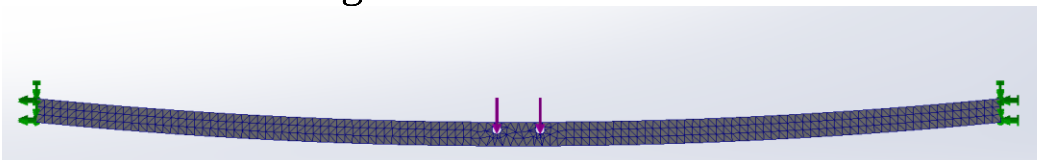

Figure 23 Mesh beam

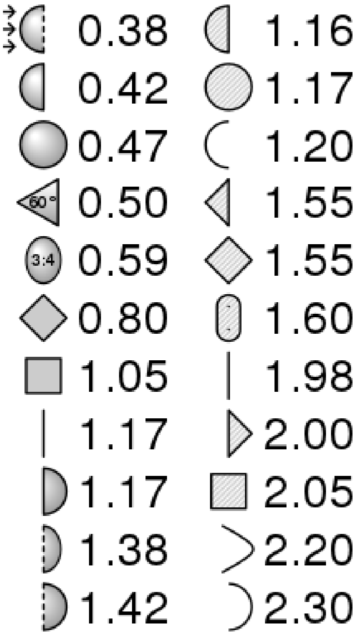

Figure 24 Drag indicator [6]

APPENDIX III : Material data sheet EPP

EXPANDED POLYPROPYLENE (EPP)

TECHNICAL DATA SHEET— FROM 20 G/L TO 90 G/L

Physical Properties	Testing Method	Unit	20	30	45	60	67	82	90
Compressive Strength 25% Strain 50% Strain 75% Strain	ASTM D3575	MPa	0,10 0,16 0,31	0,16 0,23 0,44	0,28 0,37 0,76	0,39 0,50 1,07	0,45 0,59 1,26	0,60 0,80 1,78	0,69 0,93 2,08
Compression Set	ASTM D3575	%	14	12	12	11	11	10	10
Tensile Strength	ASTM D3575	MPa	0,26	0,38	0,46	0,62	0,71	0,87	0,97
Tensile Elongation	ASTM D3575	%	15	15	14	14	13	13	12
Tear Strength	ASTM D3575	KN/m	1,74	2,13	2,73	3,25	3,51	4,07	4,35
Flexural Strength	ASTM D790	MPa	0,21	0,38	0,54	0,72	0,86	1,08	1,16
Flexural Modulus	-	MPa	9,8	11,6	14,5	19,0	22,2	28,9	31,1
Coefficient of Linear Thermal Expansion 20°C to –40°C 20°C to 80°C	ASTM D696	mm/mm/°C·10^{-5}	6,8 10,8	5,9 10,2	5,5 9,8	4,3 8,7	4,1 7,9	3,9 7,5	3,7 6,8
Water Absorption	ASTM C272	gms/cc·10^{-3}	10,4	8,1	6,2	5,1	4,5	4,2	3,5
Flammability	FMVSS 302	<100 mm/min.	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Chemical Resistance (Auto fuels, fluids, solvents)	Various	1hr exposure	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Data for JSP International ARPRO® White Material (7000 Series) and Black Material (5000 Series). Typical Values Shown.									

Figure 25 Material data sheet EPP [11]

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