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The Design of the Payload System of an Aircraft

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The Design of a Payload System for an Aircraft

Ryan Cooper

Department of Mechanical Engineering

Honors Research Project

Submitted to

The Williams Honors College
The University of Akron

Approved:

Date:
Honors Project Sponsor (signed)

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Reader (signed) Solomon Whitmire	
Reader (printed) Solomon B. Whitmire	

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The Design of a Payload System for an Aircraft

Ryan Cooper

Advisor: Dr. Manigandan Kannan

Readers: Dr. Gregory N Morscher and Solomon B. Whitmire

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1.0 Introduction

The Zips Aero Design Team competes in the American Institute of Aeronautics and Astronautics Design, Build, Fly competition. For this year's competition, teams are required to deliver boxes referred to as vaccine vial packages and syringes.

During one of the flight missions the vaccine vial packages must be deliver one per lap of the course without tripping one of the 25 G force sensors. The same system must also be able to hold 10 times more syringes than the number of packages carried [2].

The project team opted for a ramp system for the payload delivery system. The project team learned about the deficiencies in the original design and improved in a further iteration. After taking the aircraft and payload system to competition, some challenges were presented that were unknown before the event, but the project team was able to work through them to get the system to work as intended.

2.0 Design

The University of Akron Zips Aero Design team gave the project team the requirements of the system and the project team was responsible to ensure that it met those requirements and integrated well into the aircraft. The requirements given to the project team was that the deployment system had to be capable of carrying and delivering three vaccine vial packages, that must be capable of carrying at least 30 syringes, and that it must be light and able to be quickly deployed.

2.1 Design Procedure

The project team brainstormed multiple ideas to carry the packages and be able to deploy them. Three main ideas were looked at during the brainstorming process, a ramp, an elevator, and a drop mechanism as seen in figure 1 below.

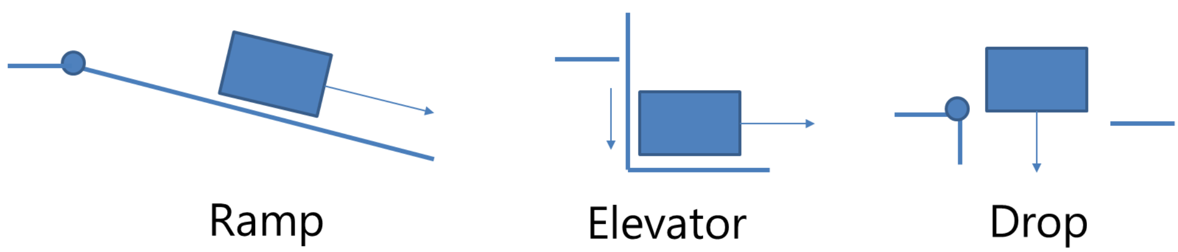

Figure 1: Conceptual Ideas

The system needed to be reliable to so that it would work every time the aero team wanted to use it during the competition. Keeping this in mind, the project team wanted to reduce complexity in the system so that there would be less things that could cause the system to fail. Because of this and the weight requirement the elevator idea was deemed to be inadequate for the payload system. After the 25 G force sensors were attained, the payload project team tested them on the vial packages by dropping the packages from set heights. From this testing it was found that the drop mechanism would be infeasible since it was such a short height.

The ramp design was chosen for the payload system. For an aircraft, the center of gravity should be around 25% of the length of the chord behind the leading edge of the wing. The payload system had to keep this in mind while designing the deployment mechanism since as the packages were deployed, they would shift the center of gravity of the aircraft too much and cause the aircraft to become unstable. The project team also had to ensure that the center of gravity should not shift too far in either direction with respect to the width of the aircraft.

There were multiple ideas of how to orient the ramp to allow the packages to be deployed without shifting the center of gravity of the aircraft too much in any direction. One was to orient them along the length of the aircraft in front of each other from the nose to the tail. This would cause the center of gravity to shift forward and backward but would allow for a smaller system. Another idea was to line them along the width of the aircraft. This would prevent the center of gravity form shifting too much forward and backwards on the aircraft, but would require a larger fuselage cross section, and therefore more drag on the aircraft. A third pattern to orient the boxes would be to create a grid pattern which mix the benefits and detractors of both ideas. Ultimately with the amount of the packages required by the design team, the packages were chosen to be oriented along the length of the aircraft. This was determined since the center of gravity would not shift too significantly as the packages were deployed with only three packages.

During the competition, each individual package needed to be remotely deployed individually. To solve this challenge multiple ideas were looked at to allow the packages to be deployed while constraining the other packages. One design was to split the ramp into multiple sections, where the packages would be constrained by the internal structure of the aircraft while in the up position, but as its section of the ramp was allowed to lower the package would be allowed to slide out of the aircraft. When the next package needed to be deployed, the next section of the ramp would be unlocked and would allow both the previous section(s) and the current section to be lowered and the next package deployed. A second option for the package deployment mechanism was to create a solid ramp with servo motors or some other actuator that would prevent the packages from being able to slide until activated. The last package activation system considered was a conveyor system that would push the packages to a ramp then gravity would cause them to slide down the ramp. The conveyor system was determined to be too complex to work consistently on an aircraft that would be jostled around by flight and handling on the ground. The project team was trying to reduce weight of the system and adding a large number of servos to the ramp would be too heavy for the second option. Therefore, the team chose the multistage ramp.

To move the ramp up and down, the project team decided on a motor with a worm gearbox. This meant that the string attached to the ramp could only turn when the motor was activated and would stay in place without stress on the motor other times during flight. It also allowed for the use of a smaller motor since the gearing would increase the motors torque. The motor sizing was based off the following equation:

$$\tau = F_T r G_w G_m \qquad (1)$$

In this equation the torque required for the motor is τ, F_T is the force required to lift the ramp, and r is the radius of the spool. G_w and G_m are the gear ratio of the worm gear and motor respectively. This can be derived from the basic torque equation $\tau = Fd$ [1].

With the size required for the ramp system, the payload bay was large enough to fit the required number of syringes with extra. They would be held in place using the ramp as a door, each other, and the walls of the fuselage as to prevent shifting.

2.2 Design Details

The ramp was made of balsa wood, Polytetrafluoroethylene (PTFE), and plywood in 3 sections. The packages rest on top of ¼ inch balsa wood stringers coted in PTFE. And between two stingers that act as bumpers to keep the package on the ramp. As the package goes down each subsequent ramp, the bottom stringers get lower, and the side bumpers get wider so that the packages will not get stuck while going down the ramp. The first ramp gives the box and extra 1/8 inch from the side bumpers to allow for it to slide easily, each subsequent ramp gets 1/16th inch wider and lower.

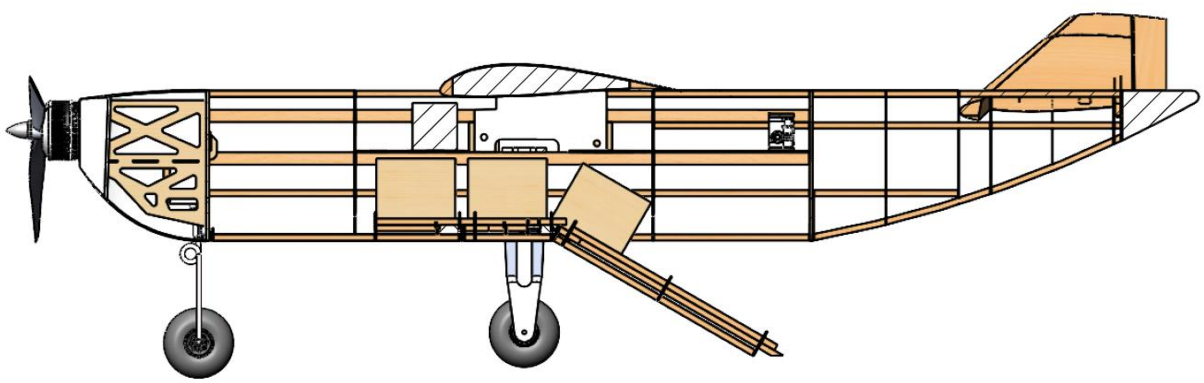

Figure 2: Vaccine Vial Package Configuration

The ramps were made of laser cut plywood framers that the balsa stingers would be adhered together. After the ramps sections were assembled, the PTFE would be applied. The nylon block for the locking mechanism was machined on a mill, then attached to each section. The ramps were covered on the bottom with MonoKote covering film to reduce aerodynamic drag and create a barrier between the inside and outside of the aircraft. The ramps were attached together and to the fuselage using small brass hinges. The assembled system can be seen in figure 2 above.

A locking mechanism was created using laser cut plywood, servos, and steel wire. The lock was made of steel wire that would slide into the nylon blocks of the ramp to prevent the ramp from moving. The lock was moved by servo motors which would move the lock between three separate positions; unlocked, fully locked, and half locked. The unlocked position can be seen below in figure 3.

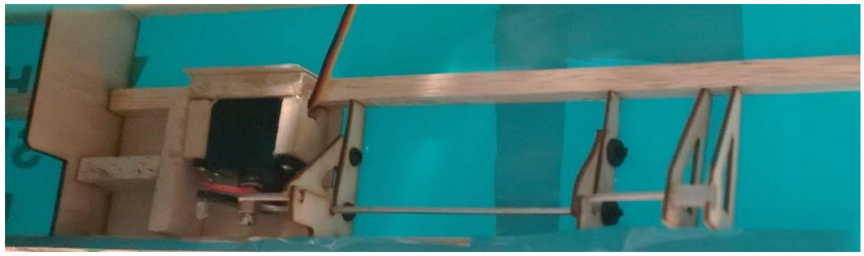

Figure 3: Ramp Locking Mechanism

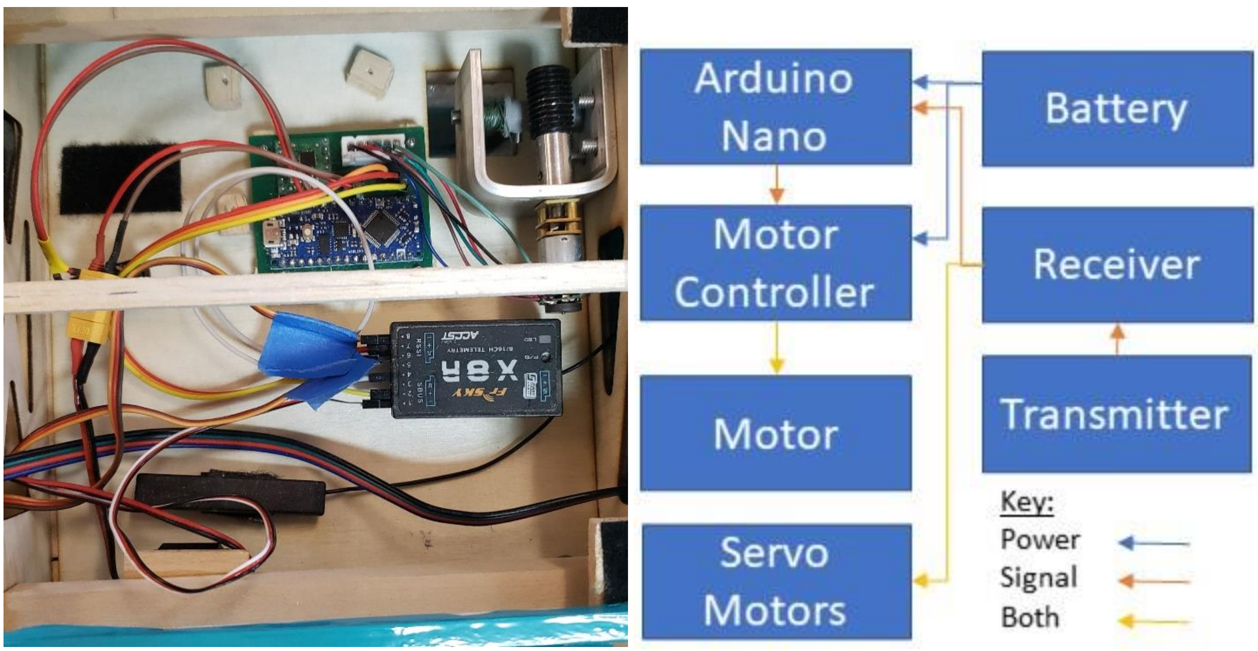

Figure 4: Payload Electronics System and Diagram

The movement of the ramp was controlled by a motor attached to a gearbox that would raise and lower the ramp when given the signal by the radio transmitter. The specific control of the motor and servos can be seen in figure 4. The Arduino, motor controller, and the wires for the stand-alone electronics were all attached to a custom-made circuit board. The code on the Arduino caused the motor to turn in a direction that would lower the ramp when the stick of the transmitter would go down and raise it when it would go up. The switches on the transmitter controlled the servo motors.

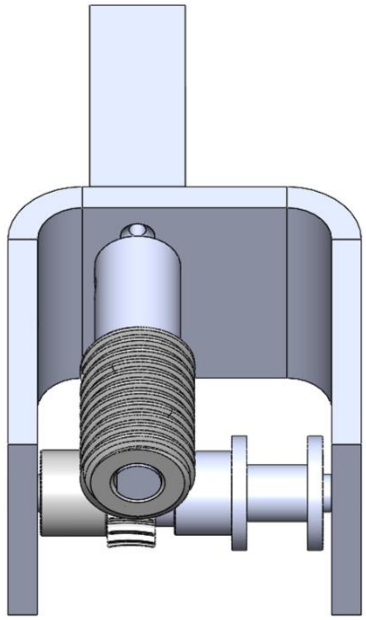

Figure 5: Gearbox

The gear box used a N20 motor with a 5:1 gear ratio. The worm gear had a 20:1 gear ratio. The spool was about .25 inch in radius. Using the equation 1 it created about 10 ounces of force on the ramp. The gear box was made of 6061 aluminum that was drilled with the necessary holes then bent to shape, as seen in figure 5. The spool and gear are attached to a stainless-steel shaft using set screws. The motor was attached then an adapter between the motor shaft and the worm gear was attached between them. The adapter was turned on a lathe and is made of aluminum. The spool was made with additive manufacturing using PLA.

Originally the payload bay was designed to carry 30 syringes with packaging, but after the design was complete the competition committee clarified that the syringes would not be in the packaging. This increased the payload capacity of the bay to be able to carry 50 syringes instead of the original 30. The syringes were held in place by the ramp, the aircraft structure including the covering film, and the lack of space between syringes. The door was held closed using the locking mechanism and a rotating lock attached to the fuselage near the end of the ramp, which allowed the ramp to be closed without using the winch motor, increasing the speed at which the aircraft could be loaded during the ground mission. The aircraft with the syringes can be found in figure 6.

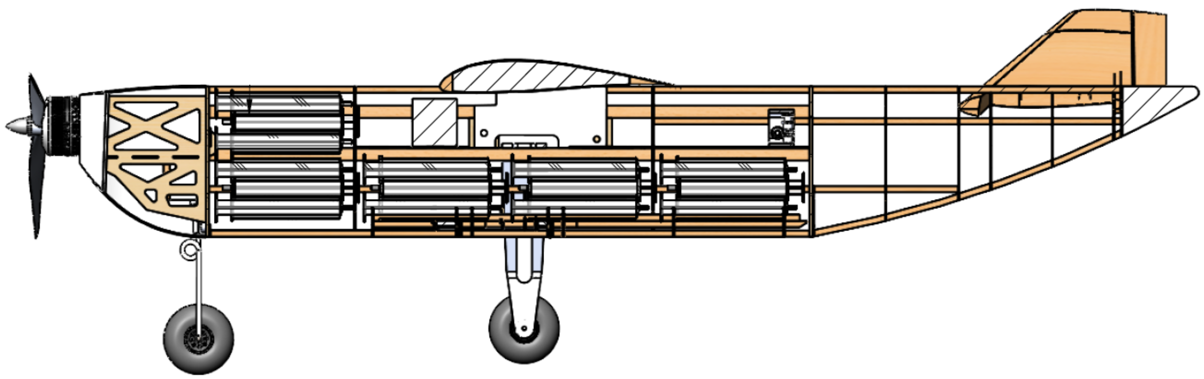

Figure 6: Aircraft with Syringes

3.0 Verification

After the ramps were assembled, they were placed at a height equivalent to what it would be in the aircraft from the ground. The packages were place on the ramp in the down position to ensure that they would slide freely but would not trip the sensor. The initial iteration had problems with the boxes getting stuck on the ramp in the transitions between ramp sections, so the next iteration added an offset between the guides of the ramp sections.

After assembly of the aircraft and installation of the payload system, the winch motor and locking mechanism were tested. It was found that the supports for the locking mechanism were too tight and needed to be looser to allow for the locks to slide better. During testing, the project team found that the box on the first section of the ramp would start sliding too soon, causing it to fall and trigger one of the sensors. To solve this issue, the project team added a servo motor to the aft most section of the ramp that would prevent the box from sliding until the ramp was fully extended.

During testing, the project team used boxes that were bare wood as was shown in the rules document for the competition. Upon arrival at the competition, the team discovered that the boxes were painted with latex paint. This increased the coefficient of friction between the package and the ramp, causing the package on the foremost ramp to have too much friction to slide from gravity alone. To solve this issue, the project team added silicon-based lubricant to the two foremost sections of the ramp to reduce the friction between the package and the ramp. This allowed the system to work as desired.

At the competition the ramp system worked during the ground mission after the lubricant was added. The ground crew member was able to load the aircraft in a total of two minutes and 18 seconds. During flight mission three, the payload system worked to safely deliver all three packages without any problems. The Aero Team performed two attempts at mission two, for both the syringe containment and loading worked throughout both attempts.

4.0 Costs

Item	Quantity	Per Unit Cost	Total Cost
HS-65 Servos	2	$ 21.67	$ 43.34
HS-40 Servo	1	$ 11.47	$ 11.47
N-20 Motor	1	$ 16.99	$ 16.99
Fishing Line	1	$ 5.99	$ 5.99
1/4 balsa stringers	10	$ 0.75	$ 7.50
1/16 ply	2	$ 11.31	$ 22.62
Aluminum Flat Stock	1	$ 3.03	$ 3.03
Round Aluminum	1	$ 1.68	$ 1.68
Eye bolts	1	$ 7.52	$ 7.52
Nylon Bolts	1	$ 8.31	$ 8.31
Steel rod	2	$ 2.69	$ 5.38
Set Screw	1	$ 3.73	$ 3.73
Hinges	10	$ 1.66	$ 16.60
PTFE	1	$ 20.27	$ 20.27
Plastic Gear	2	$ 10.66	$ 21.32
Worm Gear	1	$ 13.56	$ 13.56
PCB	5	$ 0.78	$ 3.90
Arduino Nano	1	$ 40.00	$ 40.00
Motor Controller	1	$ 16.32	$ 16.32
Engineering Labor	32	$ 30.00	$ 960.00
Manufacturing Labor	32	$ 15.00	$ 480.00
Grand Total			$ 1,709.53

Table 1: Project Costs

The Aero Design Team paid for the supplies and parts needed for the project. Specific costs can be seen in table 1. The labor cost was free as it is a student design team but are estimated values from the average pay of an engineer and manufacturing staff.

5.0 Conclusions

The project team was able to achieve most of the goals that they set out to achieve. They were able to make a system that effectively delivered the Zips Aero Design Team payload, and allowed them to place 10th out of 97 teams in the competition.

The project team found some challenges with getting the packages to consistently slide down the ramp but worked through them with multiple iterations of the system. As in every system, there is further room for improvement, such as a gear box that can also lift the boxes, or a system that can carry more boxes, but the system worked as required.

The project team would like to thank Luke Datsko, Jeremiah Eggleston, and all the other members of the Zips Aero Design Team that assisted the project team in the design and construction of the payload delivery system.

6.0 References

[1] Hibbeler, R. C. *Engineering Mechanics: Dynamics*. 13th ed., Pearson, 2013.

[2] "2021-22 Design, Build, Fly Rules." *American Institute of Aeronautics and Astronautics*, 1 Nov. 2021, https://www.aiaa.org/docs/default-source/uploadedfiles/aiaadbf/dbf-rules-2022.pdf.