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ISA 321

Final Project

**Cost Optimization for a Model Rocket**

The American Rocketry Challenge is a competition held each year, with nearly 5,000 students from all levels of education competing to see who can build the best rocket. Students competing in the challenge are tasked with utilizing engineering skills to build a model rocket that satisfies the rules of the competition, with the ultimate goal of launching the rocket as high as possible and returning a payload safely back to Earth. This payload consists of an egg that must remain intact with no cracks when landing back onto the ground. As a team, we decided to take on the financial side of this challenge, by building a rocket that is as cheap as possible. Our group has decided to minimize cost because many schools in the US that may be competing in this challenge have very tight budgets that need to be followed, so there may not be large amounts of resources to devote to STEM challenges. Our model is based on NASA’s components of a model rocket, which can be seen below in the appendix (Appendix 1). For each of these components, our group researched and found two compatible parts that often differed in their cost and weight (Research link and component included in Appendix 4). Each cost comes directly from the page where the product was listed. Weight also comes from these pages, however, every supplier did not include their weight, so weights that could not be found are based on similar Amazon products where weights are listed or from other places of research that are labeled in Appendix 4. It is important to consider weight as a constraint for this problem, because a rocket that is too heavy will not be able to get off of the ground, and therefore will not be able to complete the challenge. Another constraint for this problem includes making sure that each of these components was present in the rocket. Without one of these components such as a nose cone for the payload, the rocket would not be able to secure the egg, making it not optimal for the project. After making this model, we decided to expand to include the shipping cost from each supplier where the products are from. This will give us a more accurate look at the total cost of our model rocket. The corresponding constraint for this would be that we have to add shipping costs when a product from that supplier is chosen. Throughout the remainder of this report, we will dive deeper into the model that we have created to minimize the cost of the rocket, the constraints associated with the model, how the model was solved and tested, and the model's applications in this challenge.

**Formulating the mathematical model**

Our overall purpose for formulating this model is to create the cheapest rocket possible to participate in the American Rocketry Challenge. As mentioned in the previous section, our group researched 2 alternative products that can be used for each component of a model rocket as recognized by NASA. Whether to include each of these products was a decision for our model to make. There are 9 necessary components for a model rocket and 2 alternative products for each component, creating 18 decisions for our model (Appendix 2). Whether to include or not to include the component is a binary decision, so each of these decisions (x’s in the model below) is to be considered binary. Many of these products are only available online and therefore have an associated shipping cost along with the cost of buying the product. Whether to purchase an item from a certain supplier, and therefore pay the associated shipping cost was another binary decision (Appendix 3). The products come from a total of 5 different suppliers and are reflected as “y” variables in our model.

Along with the model, there are various constraints that the model must operate in. Some of these constraints have been quickly mentioned in the first section of this analysis, but we will cover them in more detail in this section. The first constraint in our model has to do with the weight of the overall rocket. Each product has an associated weight, and if that product is used, its weight will contribute to the overall weight of the rocket. Each of our chosen engines can lift only a maximum of 8 ounces for takeoff, so the weight of the rocket must remain under this to be competitive. In this constraint, there is also an unseen constant as the American Rocketry Challenge requires an egg to be contained within the rocket. Large eggs weigh on average about 2 ounces, so the other parts of the rocket must remain under 6 ounces to be able to take off (Appendix 4 for engine specifications). Our next set of constraints mentions that only one of the two products chosen for each component of the model rocket can be included. This is a necessary constraint because the model is minimizing cost, therefore it would be cheapest not to include any products in the rocket. However, without one component, the launch of the rocket and completion of the challenge are not possible. For example, if the rocket did not have an engine, it would not be able to take off. The engine is an expensive component, so it is not likely to be included in the model if we do not force one to be included. Another constraint that is included in the model has to do with making sure that shipping costs are added. This constraint has the supplier on the right side of the constraint multiplied by the number of products chosen from that supplier with the products on the right side of the equation. To convert these constraints to standard form, we had to subtract this supply variable from the right side of the equation to place it on the left side of the constraint. If the shipping node is not opened, then none of the products from that supplier can be included in the model. Our final constraint that is included in the model is binary. Because all of our decisions are “yes/no” decisions effectively, it is necessary that a binary structure is used where 1 equals “yes” and 0 equals “no”.

**The Model**

S := {(1, 2), (3, 4), (5, 6), (7, 8), (9, 10), (11, 12), (13, 14), (15, 16), (17, 18)}

**MIN** 0.59x1 + 1.21x2 + 8.48x3 + 5.99x4 + 11.14x5 + 8.10x6 + 9.62x7 + 6.99x8 + 5.99x9 + 7.24x10 + 13.69x11 + 10.99x12 + 9.99x13 + 11.9x14 + 10.99x15 + 9.36x16 + 6.99x17 + 12.99x18 + 7.99y1 + 1.59y2 + 4.99y3 + 3.99y4 + 7.95y5

**ST** 0.02x1 + 0.02x2 + 0.21x3 + 0.3x4 + 0.13x5 + 0.5x6 + 0.02x7 + 0.07x8 + 0.15x9 + 0.17x10 + 0.7x11 + 0.75x12 + 1.92x13 + 1.6x14 + 1x15 + 1.2x16 + 1.22x17 + 1.22x18  <= 6

x1 + x2 = 1

x3 + x4 = 1

x5 + x6 = 1

x7 + x8 = 1

x9 + x10 = 1

x11 + x12 = 1

x13 + x14 = 1

x15 + x16 = 1

x17 + x18 = 1

(x1 - x16 ) - 2y1 <= 0

(x2 + x6 + x8 + x9 + x12 + x13 + x18)- 7y2 <= 0

(x3 + x4 + x5 + x7 + x10 + x14 + x15)- 7y3 <= 0

x11  - y4 <= 0

x17  - y5 <= 0

xi , yj >= 0 ∀ i Ɛ I, ∀ j Ɛ J

xi , yj Ɛ {0,1} ∀ i Ɛ I, ∀ j Ɛ J

**Generalized Model**

xi + xj = 1, ∀ (i, j) ∈ S

(x1 - x16 ) - M1y1 <= 0

(x2 + x6 + x8 + x9 + x12 + x13 + x18)- M2y2 <= 0

(x3 + x4 + x5 + x7 + x10 + x14 + x15)- M3y3 <= 0

x11  - M4y4 <= 0

x17  - M5y5 <= 0

xi , yj >= 0 ∀ i Ɛ I, ∀ j Ɛ J

xi , yj Ɛ {0,1} ∀ i Ɛ I, ∀ j Ɛ J

S := { {1,2}, {3,4}, {5,6}, {7,8}, {9,10}, {11,12}, {13,14}, {15,16}, {17,18} }

M1 = 2

M2 = 7

M3 = 7

M4 = 1

M5 = 1

**Develop a computer-based procedure for deriving solutions to the problem from Excel**

We decided to use Microsoft Excel to calculate and best optimize our model due to its accessibility and ease of use for replication of this experiment. Using Excel’s cell structure, we first laid out the name of the variable representing each part across row 1, then the corresponding price of each part in the cell below across row 2. This first row of variable cells is used strictly for visual purposes and for ease of inputting information down the line. The information in row 2 will be referenced later on in the model to check whether or not the price of each part has been minimized to best optimize our objective function. We will refer to this section of the Excel file as the ***C Transpose***from here on out.

Next, we want to convert the constraints from the mathematical model to be able to be read by the computer. Let’s take a look at the first constraint regarding the weight of each part: 0.02x1 + 0.02x2 + 0.21x3 + … + 1.22x18 <= 6. For this constraint, we lay the related coefficients out under the same columns as the initial C Transpose variables (i.e. 0.02 goes in the same column as x1, 0.55 goes in the same column as x18, etc. for every variable in the constraint). Note that this weight constraint only applies for x1 through x18, and as such, the cells under the y variable columns are blank because there are no weights associated with the cost of delivery (coefficients of 0). In the columns following the last variable, y5, we will put the matching equality or inequality in congruence with each constraint, and the limiting number in the column following, in this case <= and 6 respectively. We can go ahead and fill in the necessary coefficients under the corresponding variable cells for each constraint with this same logic. For the next set of constraints, we regulate the number of products that serve the same purpose (ex. We can't have two engines). These constraints are listed above and follow the structure x1 + x2 = 1. We then proceed to label the corresponding cells for each remaining constraint. The cells containing the coefficients matching each variable are known as the ***A Matrix***, whereas the cells containing the values that the variables are bound to are known as the ***B Matrix*** (values on the right side of the constraints).

After setting up the A Matrix, B Matrix, and C Transpose, we will begin to construct a second row containing the same variables as before, this time intending to use these as changing or ***Decision Variables*** (23 in total including 18 binary “x” variables and 5 binary “y” variables). For this step, all that is needed to do to set up these decision variables is the =SUM() command, and then select all rows for the corresponding variable. By doing this for each variable, we are allowing a future command to be able to manipulate the values, as well as connecting them to the constraints associated with the variables.

The next step in creating this optimization model is to create the constraint cells that will also be able to be modified in the final calculation. These will be the first columns where the alignment is not as important as the steps before. To make it the easiest to set up, start on column B below the existing cells and copy and paste the equalities and inequalities as well as the values from the B Matrix. With the leftover space in column A, we will use the =SUMPRODUCT() command, selecting first the C Transpose row and locking it in with $s in Excel, then selecting the corresponding row in the A Matrix that goes with the constraint. For example, in the first modifiable variable cell, we’d select the values in the C Transpose, lock them in, and then select the row with the weight constraints. We could then use Excel’s autofill feature to drag down the first cell to the rest of the constraint cells.

For the final step, we will be calculating the ***Objective Value*** of the model. In any previously untouched cell, we can add in the =SUMPRODUCT() function once more, this time selecting the numerical values from the C Transpose as well as the modifiable decision variable cells. Note that this function can only work if the two selected values are the same length, which is not a problem in our case. Once this value is inputted, we can use the Solver add-in found in the Data tab (see below for installation instructions) and plug in the values that we have laid out in the previous steps. This is the step for which we prepared the modifiable variable and constraint cells, and should be inputted accordingly into the pop-up window. Make sure that the “Make unconstrained variables non-negative” is checked, and that the “Select a solving method:” prompt is set to Simplex LP. Once completed, an objective value should be returned, and in our case, the lowest price that the rocket could be built for was $79.82.

If you do not have the solver add-in installed already, go to File -> Options -> Add-ins then go to Manage at the bottom of the pop-up and select Add-ins from the drop-down menu, then finally, check the box for the solver add-in.

**Testing the Model**

Our objective function aims to minimize the cost of our model rocket while ensuring lift-off is still possible. This model holds three assumptions:

1. The egg's weight will always be 2 oz.
2. Each engine (x17 and x18) will emit 8 oz of lift weight.
3. Prices of components will remain consistent.

Our model's primary components are weight and cost. Our model generally demonstrates that lighter materials/components are typically more expensive than heavy ones. This is a result of how the experiment was designed. A rocket's main objective is to take off, which is easier to do with lighter components.

After running our model, we received an optimal objective value of $79.82. This model rocket weighs 5.93 oz ensuring it will be able to take off. The components chosen are as follows:

* x2 - Estee’s Rockets Launch Lug
* x4 -Amazon Parachute
* x6 -Estee’s Rockets Nose Cone
* x8 -Estee’s Rockets Shock Cord
* x9 -Estee’s Rockets Recovery Wadding
* x12 -Estee’s Rockets Engine Mount
* x13 -Estee’s Rockets Body Tube
* x15 -Amazon Fins
* x18 -Estee’s Rockets Solid Rocket Engine

These products are from 2 different suppliers whose shipping costs have been added to the model. These suppliers are:

* y2 - Estees
* y3 -Amazon

We believe this is a reasonable solution based on the data provided. The model passes all constraints and would be able to lift off of the ground while securing the 2oz egg. As for the constraints, we saw all constraints from the second set of constraints dictating that only 1 of each type of product can be included were binding, although we expected to see this as those constraints had equal signs, forcing them to be binding. Our weight constraint was not binding, although it was close to the right-hand side of the constraint. The model is sensitive to a change in the right-hand side of the weight constraint as we will discuss further in the remainder of this section when we decided to change this value. As for the supplier constraint, where we force the shipping cost to be included if a product from that supplier is included in the model, we saw some binding and some non-binding constraints. In this section of constraints, the constraints including y1, y4, and y5 were binding, although no products from these suppliers were included in the model. The constraint in this section including y2 was binding, as all products from Estees were included in the model. Supplier y3 was the only non-binding constraint in this section as only 2 of 7 products from this supplier were included in the model.

Next, we will move on to testing. We tested our model in 3 ways: increasing shipping costs, increasing the cost of components, and decreasing the capacity for the engine (right-hand side of the weight constraint). During these tests, we saw many results that we would expect to see.

When the capacity for the engine was reduced, the model opted to go for materials that had less weight. Because often these materials are more expensive, the cost of the rocket went up when the maximum lift weight of the rocket engine was changed. However, we could not lower this constraint too much, or else our model would not be able to find a feasible solution due to the minimum weight of all materials being above the right-hand side of the constraint.

If we were to reduce the shipping cost, we would want to see the optimal price for the rocket decrease. We decided to change the shipping cost to 0 for smaller suppliers, to give them more of a shot for their products to be included in the model. When we did this, we got the result that we expected, with the objective value dropping to $74.20. However, we only saw 1 product choice change with the engine being supplied now by Hobby Lobby rather than Estees because the price was significantly different. This change is not as dramatic as expected, but overall it did make the objective value cheaper, which is something we expected to see after lowering shipping costs for 3 out of 5 suppliers.

Finally, we decided to change the prices of some of the products in the model. For these changes, we decided to increase the price for every product included in the original model by 2 dollars. After these changes, we expected to see an increase in the overall objective value, which is what we saw with the optimal value jumping to $96.08. However, in conjunction with this, we also expected to see some variables not included in the original model to be included in this model due to the relative attractiveness of their price now. We saw this phenomenon, but only with 2 variables (x9, x14), which was a smaller number than originally thought. Additionally, we noticed that x9 had the same supplier as its alternative product, and x14’s alternative product was from Estees. The common theme for both of these selections is that those suppliers already had a high amount of products being shipped from both of those, so no additional shipping costs were added.

These tests are all included on different sheets of our final Excel document.

**Model Application, Insights**

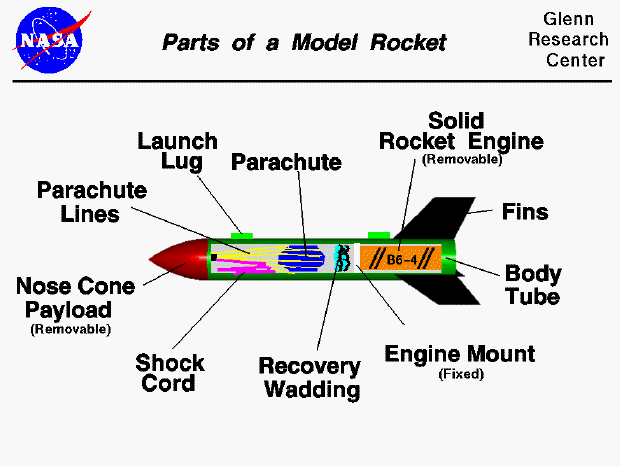
The objective of this model is to help those competing in the American Rocketry Challenge create the cheapest rocket possible to not stress school budgets that are often very limited in the United States. We feel as though this model is very useful for this objective. Those using the model can run the model and discover which parts are optimal and should be included in the rocket. From there, users can follow the links provided in the appendix for the products and purchase the materials that were used in the model.

After viewing the output of the model we have noticed many factors that contributed to which final products were chosen. First, products from smaller suppliers were often cheaper, but they were not chosen often since they did not offer a wide variety of products included in the model. Due to this, the cost of shipping for just one item rather than paying a larger supplier that can ship many items at once made those products less economical for the consumer. Next, suppliers that had second-hand products were often more expensive than companies that specialized in those products. As a result, companies such as Estes (which produces model rocket parts) were chosen more often than companies such as Amazon. In addition to this, buying from one supplier and only paying shipping once seemed to be most advantageous in terms of price, so if a company had one product chosen they often had multiple products chosen. Furthermore, cheaper products were often heavier. This means that a cheaper rocket may take off, but to minimize cost the performance of the rocket may suffer. However, given our weight constraint, it will at least take off and get an increase in elevation, and therefore be able to be used in the challenge.

There are potential limitations to this model. For example, prices particularly on Amazon have high variability, which could make the model inaccurate in a short time. Additionally, for some suppliers, shipping costs may change depending on the size of the products. For this project, we stuck to a fixed shipping cost which is accurate with some companies, however, if many items are added to an order the shipping costs could increase. Another limitation of this model is that the weight of adhesives is not included in the model, as this was very hard to estimate as a constant in the model and the overall weight may be so small that it is negligible. Estimating the uncertain shipping costs, product costs, and adhesive weights could have been done by using a stochastic model (which this model could theoretically become a linear model). However, this model could have become very complicated very fast with a combination of scenarios for all of these variables. The model could also be extended to include constraints for the height of the rocket by utilizing the specific details of the engine listed in (Appendix 5). These details such as maximum thrust could be used to make sure the rocket goes up to a desired height. Our model strived to create a cheap rocket rather than one that had specific performance requirements, so this was not included in our model.

Overall, we feel as though this is a good base model for accomplishing the requirements of the American Rocketry Challenge, especially for schools that are working with a limited budget. Students participating in the challenge can take advantage of this model and feel confident that they will be able to acquire the materials to make a successful rocket. In the future, this model could be extended to factor in the performance of the rocket more as well as prepare for uncertainty in factors including the price of shipping and products in addition to adhesives. These changes would make this model more applicable for real-life scenarios and commercialization of the model.

**Appendix**

1. 

2.

| Component Name | Variable | Cost($) | Weight(oz.) | Supplier |
| --- | --- | --- | --- | --- |
| Launch Lug | x1 | .59 | .02 | y1 |
| Launch Lug | x2 | 1.21 | .02 | y2 |
| Parachute | x3 | 8.48 | .21 | y3 |
| Parachute | x4 | 5.99 | .05 | y3 |
| Nose Cone | x5 | 11.14 | .13 | y3 |
| Nose Cone | x6 | 8.10 | .5 | y2 |
| Shock Cord | x7 | 9.62 | .02 | y3 |
| Shock Cord | x8 | 6.99 | .07 | y3 |
| Recovery Wadding | x9 | 5.99 | .15 | y2 |
| Recovery Wadding | x10 | 7.24 | .17 | y2 |
| Engine Mount | x11 | 11.99 | .7 | y4 |
| Engine Mount | x12 | 10.99 | .75 | y2 |
| Body Tube | x13 | 9.99 | 1.92 | y2 |
| Body Tube | x14 | 11.99 | 1.6 | y3 |
| Fins | x15 | 10.99 | 1 | y3 |
| Fins | x16 | 9.36 | 1.2 | y1 |
| Solid Rocket Engine | x17 | 6.99 | 1.21 | y5 |
| Solid Rocket Engine | x18 | 12.99 | 1.21 | y2 |

3.

| Manufacturer | Transportation Costs |
| --- | --- |
| Apogee Rockets (y1) | 7.99 |
| Estes Rockets (y2) | 1.59 |
| Amazon (y3) | 4.99 |
| E-Rockets (y4) | 3.99 |
| Hobby Lobby (y5) | 7.95 |

4.

| Variable | Manufacturer | Link |
| --- | --- | --- |
| x1 ⅛” Launch Lug | Apogee Rockets | <https://www.apogeerockets.com/index.php?main_page=product_motor_info&products_id=171> |
| x2 ⅛” Launch Lung | Estes Rockets | <https://estesrockets.com/products/launch-lug-pack?variant=44470373450033&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_medium=ppc&utm_source=adwords&utm_term=&utm_campaign=PM+Space+Fans&hsa_src=x&hsa_kw=&hsa_mt=&hsa_acc=9787008750&hsa_grp=&hsa_ad=&hsa_cam=20786635567&hsa_tgt=&hsa_net=adwords&hsa_ver=3&gad_source=1&gclid=CjwKCAiApaarBhB7EiwAYiMwqnVtHo4tp6XAeJQ5Hpp0-lVbYN70atsr9g-HzylqOmbnObYk-OfkOhoCskkQAvD_BwE> |
| x3 12 inch parachute | Amazon | Cost based off - <https://www.amazon.com/Estes-302264-12-inches-Parachute/dp/B0006N6T6A/ref=sr_1_4?crid=38VZJAO2QHARK&keywords=model+rocket+parachute&qid=1701444570&s=toys-and-games&sprefix=model+rocket+parachute%2Ctoys-and-games%2C118&sr=1-4>  Weight based off -  <https://www.apogeerockets.com/Building-Supplies/Parachutes/Up-to-24in/12in-Printed-Nylon-Parachute> |
| x4 15 inch parachute | Amazon | <https://www.amazon.com/Estes-2265-15-Parachute/dp/B00A4UXATY/ref=sxin_16_pa_sp_search_thematic_sspa?content-id=amzn1.sym.9e5188ef-9cc8-48bb-b834-24761033aedf%3Aamzn1.sym.9e5188ef-9cc8-48bb-b834-24761033aedf&crid=38VZJAO2QHARK&cv_ct_cx=model+rocket+parachute&keywords=model+rocket+parachute&pd_rd_i=B00A4UXATY&pd_rd_r=82fec041-7c0c-444a-b4df-de67143a7701&pd_rd_w=YXxS6&pd_rd_wg=D7scb&pf_rd_p=9e5188ef-9cc8-48bb-b834-24761033aedf&pf_rd_r=WDEB79CDE8H60PEEG2WE&qid=1701444599&s=toys-and-games&sbo=RZvfv%2F%2FHxDF%2BO5021pAnSA%3D%3D&sprefix=model+rocket+parachute%2Ctoys-and-games%2C118&sr=1-1-364cf978-ce2a-480a-9bb0-bdb96faa0f61-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9zZWFyY2hfdGhlbWF0aWM&psc=1>  Weight based off -  <https://www.apogeerockets.com/Building-Supplies/Parachutes/Up-to-24in/12in-Printed-Nylon-Parachute> |
| X5 Nose Cone | Amazon | <https://www.amazon.com/ESTES-303163-NC-55-Cones-ESTT3163/dp/B001BHGJ42?source=ps-sl-shoppingads-lpcontext&ref_=fplfs&psc=1&smid=A15QN6QABYC6HS>  Weight calculated for each nose cone by dividing overall package weight by 4. Package weight also factored in. |
| X6 Nose Cone | Estes Rockets | <https://estesrockets.com/products/nc-55-nose-cone-4-pk?variant=44470371156273&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&srsltid=AfmBOooHhbdVhgMSDwvL_4udx7RUzMYjcxTM_tz4hZCeEgdoOI_6P5Xwv4o>  Weight calculated for each nose cone by dividing overall package weight by 4. Package weight also factored in. |
| x7 | Amazon | <https://www.amazon.com/Estes-302278-Shock-Cords-Mount/dp/B001BHKAQK/ref=asc_df_B001BHKAQK/?tag=hyprod-20&linkCode=df0&hvadid=309875687217&hvpos=&hvnetw=g&hvrand=16893843143016244092&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9015640&hvtargid=pla-567990502696&psc=1&mcid=5b252aacd0cf37a6ac8fd9d4a31cdaa3&gclid=CjwKCAiApaarBhB7EiwAYiMwqsGZ0xOV5J2BXknhynO7q82dAgxdGEuDvkWa3Y8a-bD17ug-e9jNqxoCKZQQAvD_BwE>  Weight expected to be very minimal. Weight from package is small, and is expected to be much smaller for 1 individual shock chord. |
| x8 | Estes Rockets | <https://estesrockets.com/products/shock-cords-mount-pack?variant=44470373482801&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_medium=ppc&utm_source=adwords&utm_term=&utm_campaign=PM+Space+Fans&hsa_src=x&hsa_kw=&hsa_mt=&hsa_acc=9787008750&hsa_grp=&hsa_ad=&hsa_cam=20786635567&hsa_tgt=&hsa_net=adwords&hsa_ver=3&gad_source=1&gclid=CjwKCAiApaarBhB7EiwAYiMwqmPSJorThweUp4OkSjChcJzMkr9v8DGpr83QIFpd-G3s2-3Uu5tfZRoC4igQAvD_BwE>  Weight expected to be very minimal. Weight from package is small, and is expected to be much smaller for 1 individual shock chord. Weight comes from similar amazon product. |
| x9 | Estes Rockets | <https://estesrockets.com/products/recovery-wadding?variant=44470373515569&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_medium=ppc&utm_source=adwords&utm_term=&utm_campaign=PM+Space+Fans&hsa_src=x&hsa_kw=&hsa_mt=&hsa_acc=9787008750&hsa_grp=&hsa_ad=&hsa_cam=20786635567&hsa_tgt=&hsa_net=adwords&hsa_ver=3&gad_source=1&gclid=CjwKCAiApaarBhB7EiwAYiMwqovbo4bWnxXq5KuXaqbN29I0zbgCe9dyf-LuG0Pd1NZgj143DqVF4hoCEm0QAvD_BwE>  Weight estimated from similar amazon product (x10) |
| x10 | Amazon | <https://www.amazon.com/Estes-2274-Recovery-Wadding/dp/B0006NAQ6O/ref=asc_df_B0006NAQ6O/?tag=&linkCode=df0&hvadid=312039856506&hvpos=&hvnetw=g&hvrand=14928249603605504368&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9015640&hvtargid=pla-459080525234&mcid=668fb824eba13488ba38a7aa424bbf91&ref=&adgrpid=68991967824&gclid=CjwKCAiApaarBhB7EiwAYiMwqkl_KYutbNMdl7eZyU2s2gIRyWEyCMAFL9UK0nCV_JCE7J-_LTpByxoC9W8QAvD_BwE&th=1> |
| x11 | E-Rockets | <https://www.erockets.biz/estes-flying-model-rocket-part-d-e-engine-mount-kit-est-3159/?setCurrencyId=1&sku=EST%203159> (Shipping = 3.99).  Weight based off of - <https://www.skylighter.com/blogs/how-to-make-fireworks/how-to-make-estes-model-rocket-engines#:~:text=The%20total%20weight%20of%20the,the%20weight%20of%20the%20mount>  Webpage mentions an average weight for engine mounts at about .8 oz. . |
| x12 | Estes Rockets | <https://estesrockets.com/products/bt-80-29mm-engine-mount-kit?variant=45993653633329&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_medium=ppc&utm_source=adwords&utm_term=&utm_campaign=PM-STEM_Spark+Joy&hsa_src=x&hsa_kw=&hsa_mt=&hsa_acc=9787008750&hsa_grp=&hsa_ad=&hsa_cam=20819261687&hsa_tgt=&hsa_net=adwords&hsa_ver=3&gad_source=1&gclid=CjwKCAiApaarBhB7EiwAYiMwqlMcNxt2kmlnaDKqIeqhE8cKndqcW3m2j0RmaHTCxMREVeu8B_A0qhoCcEkQAvD_BwE>  Weight based off of - <https://www.skylighter.com/blogs/how-to-make-fireworks/how-to-make-estes-model-rocket-engines#:~:text=The%20total%20weight%20of%20the,the%20weight%20of%20the%20mount>.  Webpage mentions an average weight for engine mounts at about .8 oz. |
| x13 | Estes rockets | <https://estesrockets.com/products/bt-60-body-tube?variant=44470371647793&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&srsltid=AfmBOopwGlmDk_Ph0nqBJcsT2QSbwZHkdKH9k89Afi3dXv-rKLF0I3MssaQ&com_cvv=d30042528f072ba8a22b19c81250437cd47a2f30330f0ed03551c4efdaf3409e>  Weight estimated using - <https://www.rocketryforum.com/threads/weight-of-3d-printed-body-tubes.172184/>  Webpage mentions a range of 20-80g (.7 to 2.8 ounces) |
| x14 | Amazon | <https://www.amazon.com/ESTES-303089-BT-60-Tubes-ESTT3089/dp/B001AIT05W?source=ps-sl-shoppingads-lpcontext&ref_=fplfs&psc=1&smid=A1YLD6DK9B7ZV6>  Weight estimated using - <https://www.rocketryforum.com/threads/weight-of-3d-printed-body-tubes.172184/>  Webpage mentions a range of 20-80g (.7 to 2.8 ounces) |
| x15 | Amazon | <https://www.amazon.com/StratoFins-Screw-Water-Rocket-Fins/dp/B00BA3K0WY/ref=asc_df_B00BA3K0WY/?tag=hyprod-20&linkCode=df0&hvadid=312136795426&hvpos=&hvnetw=g&hvrand=11204068158373755851&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9015640&hvtargid=pla-525357981003&psc=1&mcid=ab2e0238914b3793b909f07121290ef2&gclid=CjwKCAiA9ourBhAVEiwA3L5RFqHwj_EfN_0qWbm1mbsyVAe3vcHy5lGNXPCQe-Mdd7awdVa1nKJYohoCHbUQAvD_BwE>  Amazon weight deemed to be accurate. |
| x16 | Apogee Rockets | <https://www.apogeerockets.com/Building_Supplies/Rocket_Fins/Rising_Star_Fins>  Weight listed |
| x17 | Hobby Lobby | <https://www.hobbylobby.com/Crafts-Hobbies/Hobbies-Collecting/Rockets/B6-4-Model-Rocket-Engines/p/21233?gad_source=4&gclid=CjwKCAiApaarBhB7EiwAYiMwqvt1FHtdc5o1OYygGmBV5WDp0oO1_o9Hp8cmBj7YcumN2lN8MucmQBoCfhwQAvD_BwE>  Weight and output based on appendix 5 as well as x18. |
| x18 | Estes Rocket | <https://estesrockets.com/products/c5-3-engines>  Weight included and specifics listed in appendix 5. |

5. 