PEAK OF FLIGHT NEWSLETTER

ISSUE 583 / SEPT 27TH 2022

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MOTOR OPTIONS FOR CLUSTERED ROCKETS

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PEAK OF FLIGHT

Motor Options for Clustered Rockets

By Rick DesFosses

Have you ever wondered how many choices you have when setting up a cluster of 2,3, or even more motors in your rocket? The short answer is “a lot”. But being rocketeers, we tend to want a more specific answer than that. There should be no surprise here, but we are going to have to do some math to answer this question. In *Peak of Flight* Newsletter #262 (https://www.apogeerockets.com/education/downloads/Newsletter262.pdf), there is a fantastic article on Mathematics in Amateur Rocketry which covers a host of rocketry related math. It does not however, address the calculations necessary to answer our cluster choice question. That math involves Combinations and Permutations.

Combination and permutation are how we represent a group of objects (rocket motors) from a larger set (all appropriately sized motors) and represent them in a subset (cluster). In a permutation, the order of the item selected matters – that is, a specific motor has to go into a specific spot in the cluster. In a combination, the order does not matter - we can put any of our selected motors into any spot in the cluster.

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Another consideration is whether or not we will allow repetition in our permutations and combinations as these change the math. For our purpose, ask yourself “Do I want to use the same motor type in multiple places”?

Differences between Permutations and Combinations

Permutation	Combination
Arranging numbers, colors, letters.	Selecting food, clothes, or team members.
Picking team positions – 1st base, Pitcher, Shortstop – from a group.	Picking three people to be on your team
Choose your two favorite colors in order.	Choose any two colors
Selecting 1st, 2nd, and 3rd place winners.	Selecting three winners from a group

To answer our cluster question, we have four distinct situations to consider…

1. ***Permutation with repetition*** – I need a specific motor in a specific mount, and I can use the same motor type multiple times.

2. ***Permutation without repetition*** – I need a specific motor in a specific mount, and I cannot use a specific motor type more than once.

3. ***Combination without repetition*** – It doesn’t matter which mount I put which motor in, but I will only use a particular motor type once.

4. ***Combination with repetition*** - It doesn’t matter which mount I put which motor in, and I can use the same motor type multiple times.

Let’s take a look at each.

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You can subscribe to receive this e-zine FREE at the Apogee Components website www.ApogeeComponents.com, or by clicking the link here Newsletter Sign-Up

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Permutations with Repetition

When a thing has ***n*** different types, we have ***n*** different choices each time.

Example: if we have 5 unique motors to choose from (***n***=5), and we want to set up a cluster of 3, the permutations would be… n x n x n (n multiplied 3 times) or 5 x 5 x 5 = 125.

If we change the number of motors in the cluster, we are choosing ***r*** of something that has ***n*** different types, so the permutations would be… n x n x …(r times).

This means there are **n** possibilities for the first choice, THEN there are **n** possibilities for the second choice, and so on. The proper mathematical notation would be n x n x …(r times) = $\mathbf{n^r}$ where **n** is the number of things to choose from and we choose **r** of them.

Let's put this to the test. If we have a rocket with a two-motor cluster, and we have three different motors to choose from, our formula of n^r – where n=the number of motors to choose from and r=the number of motors in the cluster – becomes $r^n=3^2=9$ possible configurations.

Available Motors: A8-3, B4-4, and C6-5

Mount #1	Mount #2
A8-3	A8-3
A8-3	B4-4
A8-3	C6-5
B4-4	A8-3
B4-4	B4-4
B4-4	C6-5
C6-5	A8-3
C6-5	B4-4
C6-5	C6-5

Permutations without Repetition

In this case, we have to reduce the number of available choices each time because once we've used the motor, it is no longer available to us.

How many ways can we arrange a penny, a nickel, a dime, and a quarter? The first time we choose one, we have 4 choices, next we have 3, then 2, then 1. The total permutations are 4 x 3 x 2 x 1 = 24. But what if we only want to choose 2 coins? Then the permutations would be 4 x 3=12.

Mathematically, this is known as the factorial function and is noted with an exclamation point (**!**). It simply means to multiply a series of descending numbers.

- 4! = 4 × 3 × 2 × 1 = 24
- 7! = 7 × 6 × 5 × 4 × 3 × 2 × 1 = 5,040
- 1! = 1

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The formula for this is written as:

$$\frac{n!}{(n-r)!} = \frac{4!}{(4-2)!} = \frac{24}{2!} = \frac{24}{2} = 12$$

where n is the number of things to choose from (available motors) and we choose r of them, no repetition and order matters.

So in our 5 motors / 3 cluster example from above, it would look like this…

$$\frac{5!}{(5-3)!} = \frac{5!}{2!} = \frac{120}{2} = 60$$

Which is the same as 5 x 4 x 3 = 60.

Combinations without Repetition

This is how the lottery works. The numbers are drawn one at a time and if we have them all, regardless of the order, we win.

Let's revisit the coins from above. We know we had 24 permutations with 4 coins. With 3 coins we would have 6 (3! = 3 x 2 x 1 = 6)

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Order Matters	Order Doesn't Mater
1 2 3	1 2 3
1 3 2	
2 1 3	
2 3 1	
3 1 2	
3 2 1	

Since we know the number of ways n things can be placed in order (n!), we can adjust our permutations formula to reduce it by how many ways the objects could be in order (because we aren't interested in their order anymore).

This formula would be written as:

$$\frac{n!}{(n-r)!} \times \frac{1}{r!} = \frac{n!}{r!(n-r)!}$$

So in our 5 motors / 3 cluster example from above, it would look like this…

$$\frac{5!}{(5-3)!} \times \frac{1}{3!} = \frac{5!}{3!(2)!} = \frac{120}{6(2)} = \frac{120}{12} = 10$$

Which is the same as:

$$\frac{5x4x3}{3x2x1} = \frac{60}{6} = 10$$

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Combinations with Repetition

This is the most difficult to explain. In our 5 motor / 3 cluster example. there are n=5 things to choose from and we choose r=3 of them, order does not matter, and we can repeat. While I do not have a simple way of explaining it, the formula for this works out to be…

$$\frac{(r+n-1)!}{r!(n-1)!}$$

Or

$$\frac{(3+5-1)!}{3!(5-1)!}=\frac{7!}{3!4!}=\frac{5040}{6x24}=\frac{5040}{144}=35$$

There are 35 ways to have 3 motors from a 5-motor selection.

We have just worked out the 4 variations of order and repeats being allowed that we need to deal with. Here are the formulas…

	Repeats Allowed	No Repeats Allowed
Permutations (order matters)	n^r	$\frac{n!}{(n-r)!}$
Combinations (order does not matter)	$\frac{(r+n-1)!}{r!(n-1)!}$	$\frac{n!}{r!(n-r)!}$

Where n is the number of motors to choose from and r is the number of motor mounts in the rocket.

Using what we now know about calculating permutations and combinations, let's determine how many simulations RockSim would need to run for the Flamethrower (https://www.apogeerockets.com/Model-Rocket-Kits/Skill-Level-4-Model-Rocket-Kits/Flamethrower), a 2 cluster rocket that takes 24mm motors.

There are currently 69 24mm motors on the Apogee site for sale. So n=69 and r=2 for this rocket

	Repeats Allowed	No Repeats Allowed
Permutations (order matters)	n^r=4,761	$\frac{n!}{(n-r)!}$= 4,692
Combinations (order does not matter)	$\frac{(r+n-1)!}{r!(n-1)!}$ = 2,415	$\frac{n!}{r!(n-r)!}$= 2,346

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If the rocket was a cluster of 4 motors, the numbers would look like this… n=69 and r=4.

	Repeats Allowed	No Repeats Allowed
Permutations (order matters)	n^r=22,667,121	$\frac{n!}{(n-r)!}$ =20,748,024
Combinations (order does not matter)	$\frac{(r+n-1)!}{r!(n-1)!}$ = 1,028,790	$\frac{n!}{r!(n-r)!}$ = 864,501

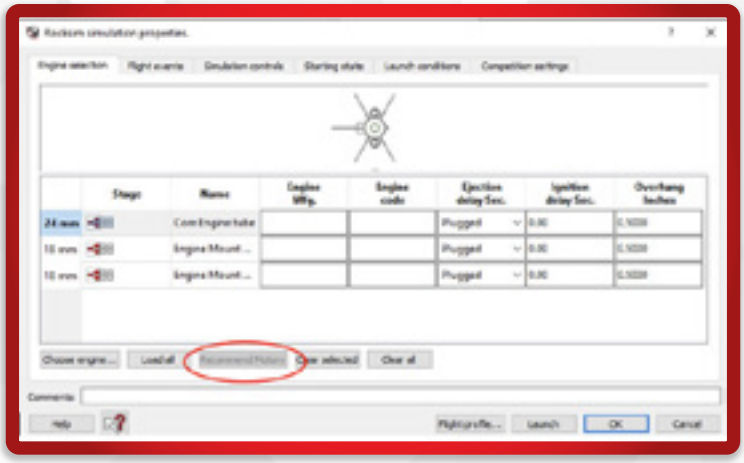

FIGURE 1: APOGEE FLYING MACHINE

One of many great features in RockSim is its ability to recommend motors for your particular rocket. But why is this option greyed out and unavailable when your rocket had multiple motor mounts?

Good question! The answer is simple, yet complicated at the same time. The “simple” answer is “math.” The “complicated” part is… math, the math we just explored above. Sometimes you can have too much of a good thing.

When you ask RockSim to recommend motors, the program does so by running simulations for - get ready for this – EVERY possible motor that can fit in your rocket! Why would that be? Well, RockSim is not going to recommend an unsafe motor, so it needs to evaluate every one to determine which are safe. There are a lot of factors that determine if a flight is safe. Speed off the guide rail, remaining in the weathercocking cone, successful deployment of a recovery device, to name a few.

It’s not that RockSim could not make these calculations, the issue is with the computing power and time needed to accomplish the task. When we went from 2 to 4-24mm motors in a cluster, our repeatable combinations went from approximately 24 hundred to over 1 million. Just imagine (or calculate if you’re up to it), what happens to the numbers when we consider larger clusters, clusters with varying size motors or the ability to use a motor adapter and put a smaller size motor into a particular mount.

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While RockSim will not recommend motors for a cluster rocket, it is essential to determining if your cluster project will fly safely. Whatever combination of motors you load into your simulation, RockSim will do the math, evaluate the results, and provide a visual flight profile as well as all the data it used and the results it obtained. If you are like me, you probably don't want to sit around while that happens several thousand or more times.

So how do you go about choosing motors for your cluster? If you ask a dozen rocketeers, you are likely to get a dozen answers to that question. For me, the number one consideration is safety! I want a combination of motors that will safely and successfully get the rocket into the sky and allow it to be recovered. This is where RockSim and the Flight Visualizer come in. I will use these programs to evaluate the flight for the motors I am thinking of using. If all of my motor mounts are the same diameter, I will typically start by loading all motor mounts with the same motor and then play from there to get the flight profile I desire for the mission at hand. If the motor mounts have different diameters, like the Apogee Flying Machine (https://www.apogeerockets.com/Rocket-Kits/Skill-Level-4-Model-Rocket-Kits/Flying-Machine), I want the larger diameter motor to be able to support the flight should the smaller ones not ignite. I also avoid mixing black powder and composite motors in a cluster. Yes – this can be done but I just don't do it. With the availability of 18mm composite motors, I prefer to keep the propellent type consistent within my clusters.

It is likely that most people reading this who have flown clustered rockets in the past, have done so without calculating the number of motor possibilities. Knowing the number of possibilities will not make your rocket fly any better. However knowledge is power and what is rocketry about if not knowledge…and power. So the next time you are setting up a clustered rocket, do the math and know that you are about to launch flight number 1 of ???.

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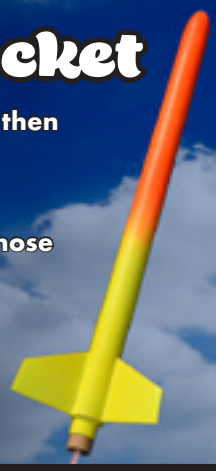
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