Find A Rocket Motor's Max. Lift-off Weight

Developing a useful criteria for how much weathercoocking is too excessive.

By Tim Van Milligan

A lot of the articles I write are a result of a question that I get from other modelers. This one comes from Pat Riepl:

"Is there any place that gives a general chart that tells the amount of weight a rocket engine can lift? I would like to do some scratch building of rockets and would like to get a general idea."

The quick answer is that there isn't a general chart that is useful in all situations. The amount of weight a rocket can safely lift is dependent on a lot of things. I'll try to explain some of the factors.

Factors that affect the Max Lift-Off Weight

The two most important factors are the size of the rocket (it's diameter), and its drag coefficient. These two parameters directly affect the overall "DRAG" force acting on the rocket. As the rocket gets bigger, or it has lots of extra garbage hanging off it, it gets draggy, and doesn't fly as high.

Besides weight, the drag force acting on the model determines how high the rocket flies. But if the model does fly high enough and the delay time is right, the recovery device will deploy to bring the model safely to the ground.

There are still some other factors that will determine how high the rockets flies. One of them is the wind at liftoff. Some rockets will weathercock into the wind more than others. A rocket that weathercocks (turns into the wind), will not fly as high as if there were no wind -- all other things being equal.

Weathercocking is affected by the strength of the wind, and the speed of the rocket as it leaves the launch pad. A rocket that travels faster is less effected by wind than one that travels slower. To a lesser extent, the moment of inertia of the rocket also plays a roll in how the rocket responds to the wind. This is difficult to explain, but the moment of inertia is dependent on the shape of the rocket, and its distribution of mass along the length of the model. A rocket with a high moment of inertia is harder for the wind to deflect than a rocket with a low moment of inertia.

Another factor is the length of the launch rod. This will determine how fast the rocket leaves the launch pad. If the rocket is traveling faster when it leaves the launcher, it will be less affected by the wind.

Basically, what we're asking here is what is the maximum weight the motor can lift (given the drag and wind forces acting on the rocket) and still fly high enough for the recovery system to safely deploy?

To get back to the original question, you can probably see why there are no charts that cover all the various conditions that might occur. You'd need a chart for each: diameter rocket, drag coefficient, launch rod length, wind speed, and moment of inertia.

Fortunately there is a better way to determine the maximum lift weight for each motor/rocket combination. That is with a program like RockSim. You can download the free demo version from our web site at:
http://www.apogeerockets.com/rocksim.asp

In RockSim, what you'll do is: design the rocket, place a motor in it, and select a delay. After defining the launch conditions (elevation, wind speed, etc.), you'll launch it, and see how it flies. If you want to know if the rocket can accept more weight (such as a heavy payload), you can quickly put a "mass object" into the design. Then fly the simulation again.

This is the best way to determine the best motor for your rocket. It is far more accurate and therefore "safer" than any engine chart.

But what criteria should we use to judge whether or not a flight is safe, or somehow "better." This will determine the maximum weight that we can use with the rocket and motor we've chosen.

I've seen 5 different methods for determining Maximum Recommended Lift-Off Weight (MRLOW) of a rocket motor. They all seem to work OK. So I'll let you decide for yourself which method you'd like to use.

MRLOW Method 1

Probably the oldest guideline I've come across is a simple one. It is to divide the maximum thrust of the motor by 4. The advantage of this procedure, and the next one is that you can somewhat predict the maximum lift-off mass prior to running any simulations.

MRLOW Method 2

Method 2, from Bob Dahlquist, is similar to the first method. But this time, you don't use the maximum thrust. You use the average thrust produced during the first part of the burn -- while the rocket is still accelerating on the launch rod. Once you know this, the max lift-off weight is at least 10 times less than this average initial thrust.

The procedure for finding this maximum lift-off mass can be found in Bob's article called "Wind Caused Instability" at: http://www.apogeerockets.com/education/instability.asp

In the next three methods, you'll need to perform multiple simulations to find the maximum lift-off weight. That is, you per-
form a simulation, and if it works, you add more weight. Then continue this routine until you reach the point where the simulation fails.

_MRLow Method 3_

If you follow the discussions on r.m.r. you'll recognize method number 3. It is posted by long-time modeler Leonard Fehskens. In this method, the maximum liftoff mass is determined by the minimum lift-off velocity. Basically, the rocket must leave the launch rod with sufficient speed for stable flight.

This method is easy to perform using a program like RockSim; because it will compute the liftoff speed as the rocket clears the launcher. It compares it to the minimum lift-off speed input by the user. If it does not meet the minimum speed, the program will automatically tell you something is wrong (see the detailed flight report for the simulation as shown in Figure 1).

The main drawback of these first three methods is that none of them take into account the delay of the motor. For example, they don't differentiate between a D12-3 and a D12-7. But we should all know that the shorter delay can (and should) be used in higher weight rockets. The next two methods do take into account the delay of the motor.

**MRLOW Method 4**

The fourth method I've used many times. It has been around a long, long time. You've probably used it too. It is the brute force computer simulation method. Basically, you perform the computer simulation and see if the rocket is still going up when the ejection charge fires. If it the rocket is still traveling upward, you add some weight and repeat the simulation. This continues until the rocket deploys at or within one second of apogee. It can take numerous simulations if you didn't pick a good starting point. But eventually, by running enough simulations, you'll get an answer.

The drawback to this is that it does not take into account the speed at which the rocket leaves the launcher. On low thrust rockets, it could very well be traveling below the minimum safe speed when it leaves the launcher. This becomes a major concern if there is any wind in the simulation. Then the rocket will weathercock, and could actually go horizontal.

This is where RockSim really comes in handy. You can add wind to the simulation, and still perform this brute-force method. With wind, we know the rocket is going to weathercock, and therefore shorten the delay required. Eventually, we'll find the maximum weight the motor can lift in the rocket for the particular delay.

**MRLOW Method 5**

The fifth and final method is another brute-force procedure, and is basically similar to the forth method. But this time, we're given some additional guidelines.

The guidelines will define what is a safe flight.

Long-time rocketeer; Trip Barber, came up with a simple analytical criteria for evaluating potential safety of a motor/rocket combination. He was attempting to find out if motor manufacturers were giving good guidelines in their Maximum Recommended Lift-Off Weights. The procedure comes from his report: "REPORT TO THE CHAIMAN, NAR STANARDS & TESTING COMITTEE ON A SAFETY ANALYSIS OF MANUFACTURERS' RECOMMENDED LIFTOFF WIEIGHTS FOR MODEL ROCKETS," By Trip Barber, NAR 4322 (January 9, 1996).

In his report, he defines two safety guidelines:

First:

"Ejection Altitude as a percentage of apogee altitude. Rockets which go 'over the top' and fall to below about 50% of apogee or 10 meters of altitude (whichever is lower) before ejecting are too heavy or too draggy for the
motor/delay combination used." ... "Rockets ejecting prior to reaching peak altitude could possibly lift a heavier rocket, if weathercocking is not a problem."

Second:

"Weathercocking as a function of windspeed. The elevation angle from the launcher to which the rocket flies by apogee depends on the ratio of its early thrust (not necessarily average thrust) to its weight. Underpowered models move at low velocities and weathercock more severely in wind than those with a thrust-weight ratio sufficient to give them an adequate velocity at launcher exit. Rockets which weathercock to apogee elevation angles below 70 degrees (as measured from the horizontal) in a 10 mph wind, or rockets that "prang" with ground impact prior to ejection in a 20 mph wind, probably have an MRLOW that is too high."

The first guideline is pretty obvious. If you perform your simulation, and the rocket flies past apogee (peak altitude) and descends more than 10 meters prior to deploying its recovery device, then the weight of the rocket is too high for that motor/delay combination. The reasoning is probably that if the rocket is coming down fast, it is probably going to strip its parachute; leading to an unsafe condition.

It isn’t obvious, but the second guideline is profound in its meaning. This is the first time that I’ve seen where we’re given criteria to determine how much weathercocking is too excessive.

Trip Barber defines an inverted cone, with the point at the launch site. The half-angle of the cone is 20 degrees.

As long as the apogee point of the trajectory stays within this cone, it is a safe ascent. If it also meets the first criteria, it would be a safe flight.

This method also works very well with dynamic stability features of RockSim. Just run the simulation, and find the range and altitude of the rocket at apogee (not deployment). If the range distance divided by the altitude is less than or equal to 0.363, then the flight falls within Trip’s guideline.

Even though I like this method a lot, I would still keep an eye on the liftoff velocity as the model leaves the launch rod. You’ll find this in the detailed report of the simulation.

**Conclusion**

In conclusion, all of the five methods have their good and bad points. All of them are a little bit subjective. That is, they can be vigorously debated whether or not they are the “end all,” or if their basic assumptions are valid. But they are all better than a guess -- which is what the MRLOW tables supplied by motor manufacturers are likely to be. So pick your favorite method, and use it. Just be able to explain which method you used when you seek permission from the RSO to launch your next rocket.

![Figure 2: The 20° cone can be used to define what is too much weathercocking, and can lead to a procedure for determining the MRLOW for the rocket/motor combination.](image)