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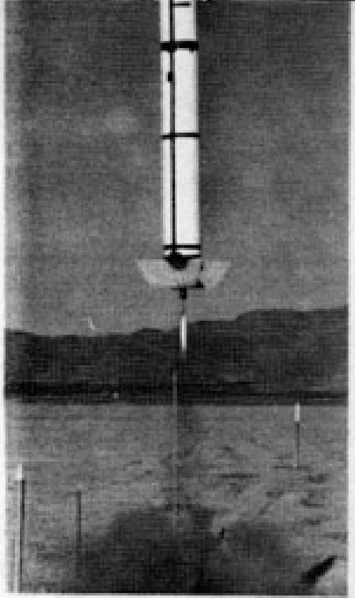
OCTOBER 1981

CALIFORNIA ROCKETRY

QUARTERLY



MOTORS OF THE 80's PART 3

GEODESIC DATA SEDUCTION

ACE INFORMATION REPORTS

SPORT PLANS

RADIO CONTROL BG PLAN

ASTROCAM 110 REVIEW

PHOTO PAGES!!

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CALIFORNIA ROCKETRY
QUARTERLY

THE MAGAZINE BY AND FOR MODEL ROCKETEERS FROM AROUND THE WORLD

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OCTOBER 1981

PUBLIC NOTICE

NEW SUBSCRIPTION RATES

Four issues of California Rocketry will be delivered to your door for only $7.50 for a full year. The increased rates go toward more advanced printing and room for future expansion.

Assuming CRm to be a worthy cause, tax deductible donations are cheerfully accepted.

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· · · Effective October 1 · · ·

NEXT ISSUE (Jan 1982)
Aerobee 170 scale data
Estes and Centuri product updates
ACE new product announcements
NARWIN-3 contest info
Christmas rocketry wishbook
PHOTO PAGES!!

Cover Photo

TOP PHOTO BY JIM TUCCI

This astrocam 110 photo shows the edge of Mile Square park, the site of NARAM-20. Note the tennis courts and baseball diamond. The Astrocam 110 is reviewed this quarter on page 5.

BOTTOM PHOTO BY LORI WICK

Another lift-off photo of this 10.5 foot model shows the clean burn of the Plasmajet G60-3. This model is constructed of a central tube, foam rings, wood stringers, and a paper covering. It has flown successfully four times in a row. Lori got some great shots this time.

COVER PHOTO SUBMISSIONS

California Rocketry magazine is currently seeking excellent model rocket photos suitable for our cover. Photos should be at least 5" x 7" and preferably 8" x 10" or larger, B&W or color.

FEATURE ARTICLE

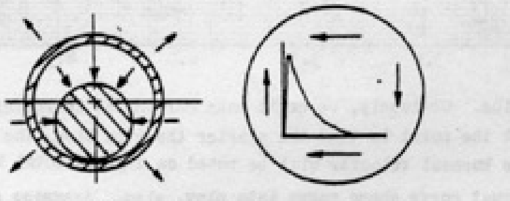
Trends in High-Power Model Rocket Motor Design for the 80's

By Gary Rosenfield

part 3 performance optimization

First off, I would like to correct a few items in the wake of part 2 of this series. I mentioned it in my manuscript but for some reason it never appeared in print. The F.S.I. Thunderbolt was the only commercially available model rocket motor using a plastic composite propellant fashioned in a grain geometry other than a restricted core burner. The Thunderbolt (no longer available) used a hexagonal center port about 1/2 inch across.

Figure 1.



I apologize for not mentioning one other important grain design that has come upon the model rocket scene recently. I'm talking about the RogerJet, the most significant model rocket motor development since the Rock-a-chute. This innovation, pioneered by Roger Johnson of Palo Alto, Ca., consists of a free standing grain epoxied inside a fiberglass case. The propellant burns in a totally regressive manner (see fig. 1). Using this technology, Roger was able to produce the world's largest 'D' engine, a full 1.125" OD x 5.00" long. Maximum thrust with this configuration occurs while the rocket is still on the launcher. This accounts for the extremely quick lift off that is characteristic of RogerJet propelled rocket vehicles.

Finally, in reference to the grain design shown in figure 2 of the last article, the text should have read

"With an L/D ratio of 1.75 and ..."

instead of "1". Using this design, a L/D of one results in a regressive trace.

PERFORMANCE OPTIMIZATION

What does that mean, anyway? There are lots of performance factors like velocity, altitude, minimum drag, payload lifting capability, coast time (coast time?!?), etc. In this article I want to deal with the performance factors that the motor or motor designer is capable of influencing. These factors are controlled by a) Design envelope b) burn time c) thrust curve shape and d) motor weight and mass fraction.

The design envelope is simply the shape or package the motor fits or is described by. Since our model rockets are subject to air drag, and that drag is directly proportional to the frontal area of the model, it is desireable that the motor be as small a diameter as possible. Also, most rocketeers like to use motors of a "standard" diameter to allow them maximum flying versatility. Today's standard motor sizes include the 18mm x 70mm (Estes 'A-C' size) and the 24mm x 70mm (Estes 'D' size). It is possible to fit a composite propellant 'D' into a 'C' sized case with little difficulty. The old Enerjet D21 is an example (although it was a little long at 3.0"). It is possible to fit a full 'E' performance into a 'D' sized case, as Composite Dynamics has done with their E20 motor. The Crown E45 is 'D' diameter, but is 3.25" long. The early Enerjet 'F' motors used a 1.125" diameter case, 5" long, but the only manufacturer currently making motors of this diameter is Crown. It will probably remain a standard size for some specialty model rocket motors and for 'G-I' class professional type rocket motors. Composite Dynamics is the only company currently marketing an 'F' motor in the 'D' diameter case. It is about 4.6" long and will fit any Estes 'D' rocket as long as the engine block is removed (although it's thrust level is too high for some of these rockets). It is possible to fit 40ns ('E') into a 'C' sized case of sufficient length, likewise for 80ns ('F' - boy would that be a long motor!). But manufacturing economics and buyer preferences for exact replacement motors will probably keep the 'E' and 'F' in their current configurations, except for some specialty and contest applications. I have yet to see a new 'C' size 'D' make it's debut on the market.

Model rocket velocity and/or altitude performance is governed largely by the motor burn time. In the absence of air, a model rocket's burnout velocity is given by the equasion:

Gravity x Specific Impulse x (Natural Log of the Mass Ratio) - (Gravity x Burn Time) or

$gI_{sp}(\ln MR) - (gT_b)$ for short.

The mass ratio is simply the loaded weight divided by the burnout weight.

Let's take a look at the theoretical performance of a hypothetical model rocket:

Outside dia.	1.0"
Total impulse	80ns
Burn time	1.0 sec.
Total wgt.	.20 lb.
Propellant wgt.	.0925 lb.

The values for the total weight and propellant weight are what I consider state-of-the-art limits to highest perfor-

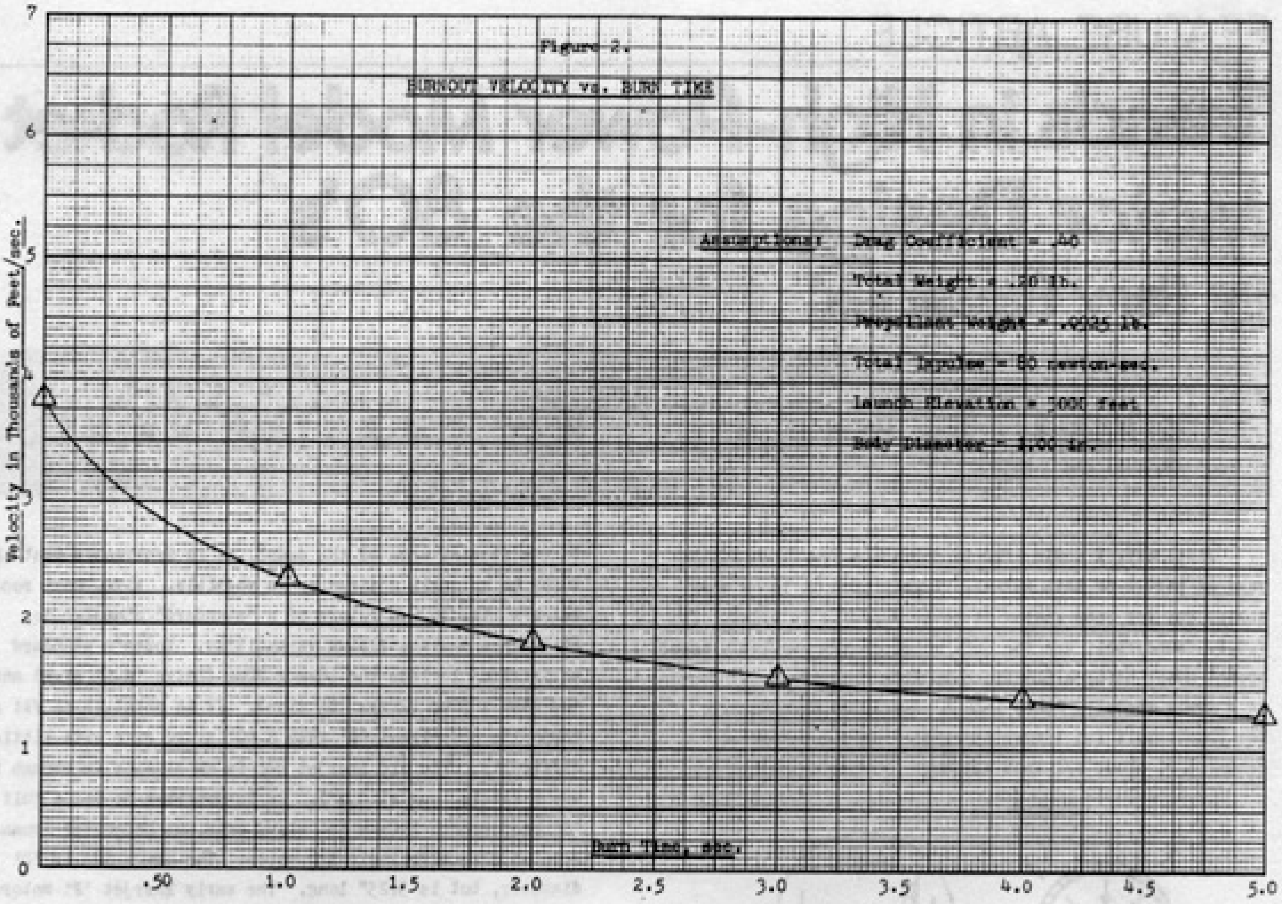


Figure 2.

BURNOUT VELOCITY vs. BURN TIME

mance. That is, current propellants I_{sp}'s dictate the propellant weight of .0925 lb. for 80ns and .20 lbs. is about the lightest possible total weight. Plugging in these values in our equasion, we discover our model is capable of about 3,851 feet per second (2,626 mph). Of course, we don't fly our rockets in a vacuum, and the actual burnout velocity for our model is near 2,390 fps. Interestingly, it is possible to approach the theoretical value, if not reach it exactly, even in the atmosphere.

Drag is found by the equasion:

1/2 x Drag coefficient x Cross sectional area x Air density x Velocity^2 or

$1/2 C_D A \rho V^2$

The drag coefficient is a dimensionless value which basicly describes the shape of the model and it's resistance to the airstream. Air density is in "slugs" (lb/ft^3 / gravity, 32.17 ft/sec^2) and cross sectional area is in square feet.

The answer comes out in pounds force. We'll assign a drag coefficient of .4 to our model (a typical value for a high performance design). Using the parameters given for our hypothetical rocket we come up with a drag value of 38.5 pounds force at the drag free burnout velocity of 3,851 fps. Now notice this. If we decrease the motor burn time (and increase the thrust) so the total impulse remains the same, we still get the same burnout velocity. This is true because neglecting gravity losses (which are very small for 'short' burn times), the burnout velocity is independent of burn time (in a vacuum). See figure 2.

As the burn time of our rocket approaches zero seconds, the thrust approaches infinity. But the maximum drag remains the same! Just as a finite thrust is infinitely larger (in relative terms) than the "drag force" in a perfect vacuum, our thrust becomes "infinitely" larger than the fixed drag value. Obviously, we can't make our thrust infinitely large, but the point is that the shorter the burn time, the higher the burnout velocity will be based on a fixed total impulse. Thrust curve shape comes into play, also. Assuming a fixed burn time, a progressive time thrust curve is desirable for maximum velocity performance. That's because high thrust isn't needed at low velocities where drag forces are low. There is something that should be mentioned here. In the region of about 800-1300 fps (.75 - 1.2 mach) there is a dramatic increase in a rocket's drag coefficient, sometimes going to .8 or more. At velocities greater than this, the drag coefficient decreases, and can be as low as .2 or so depending on the velocity. Presumably this is due to interactions of subsonic and supersonic airflow on the model. In any case, a rocket spending time in this region will exhibit a lower performance than that calculated using a subsonic drag coefficient. However, since the C_D is not an exponential term, an average value may be taken for it (which can be determined experimentally) and applied to the drag equasion.

It is important for velocity performance that the total weight of the rocket and the body diameter be as small as possible, and that the mass ratio be as large as possible. That means the use of high energy composite propellant, small diameter, lightweight motor cases, and minimum diameter featherweight rocket shells. Clearly, there is a tradeoff here between minimum weight and sufficient vehicle strength to withstand the forces involved.

Model rocket altitude performance demands a somewhat different set of parameters. For a fixed burn time, the greatest altitude performance does not always result from a minimum rocket weight. In the case of our hypothetical

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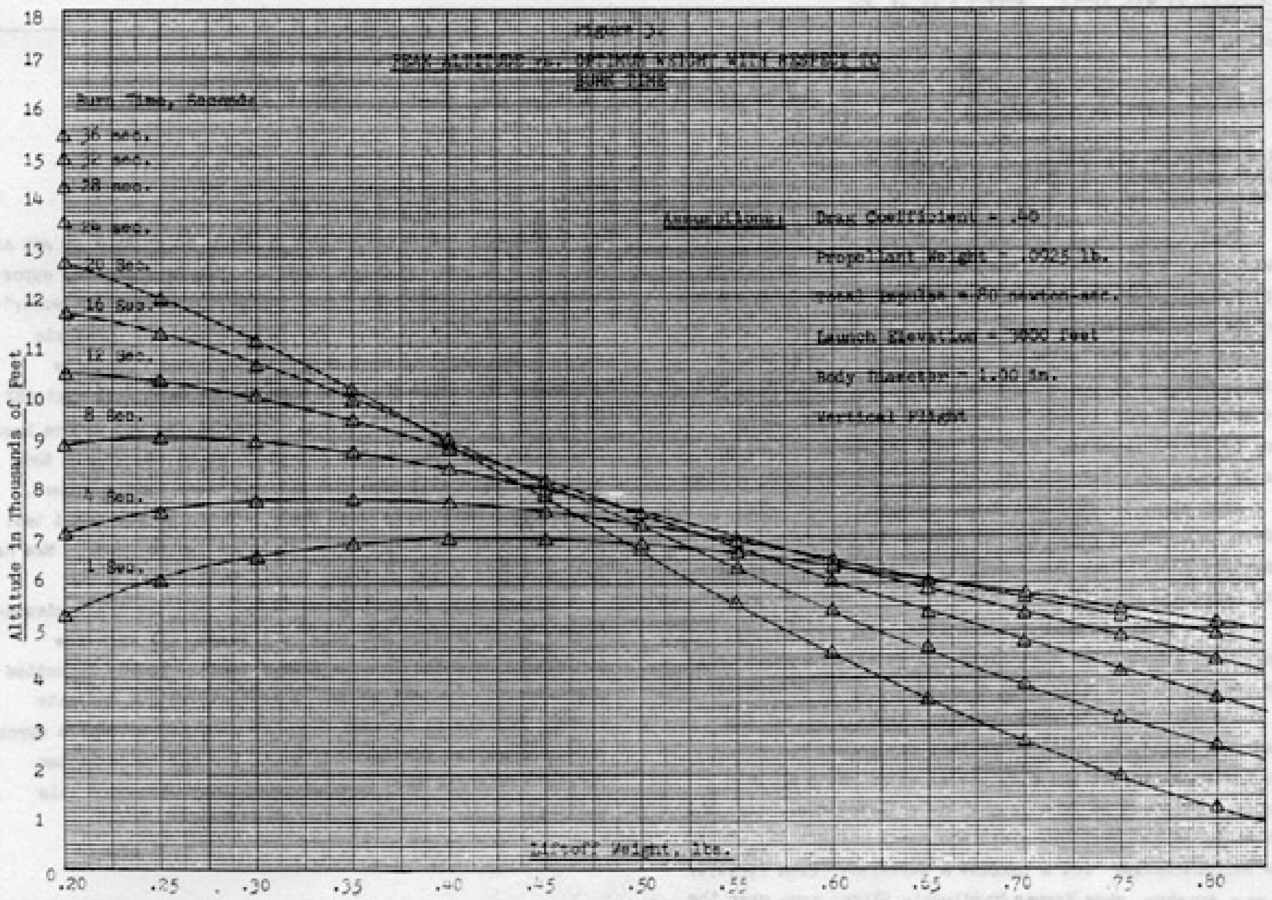
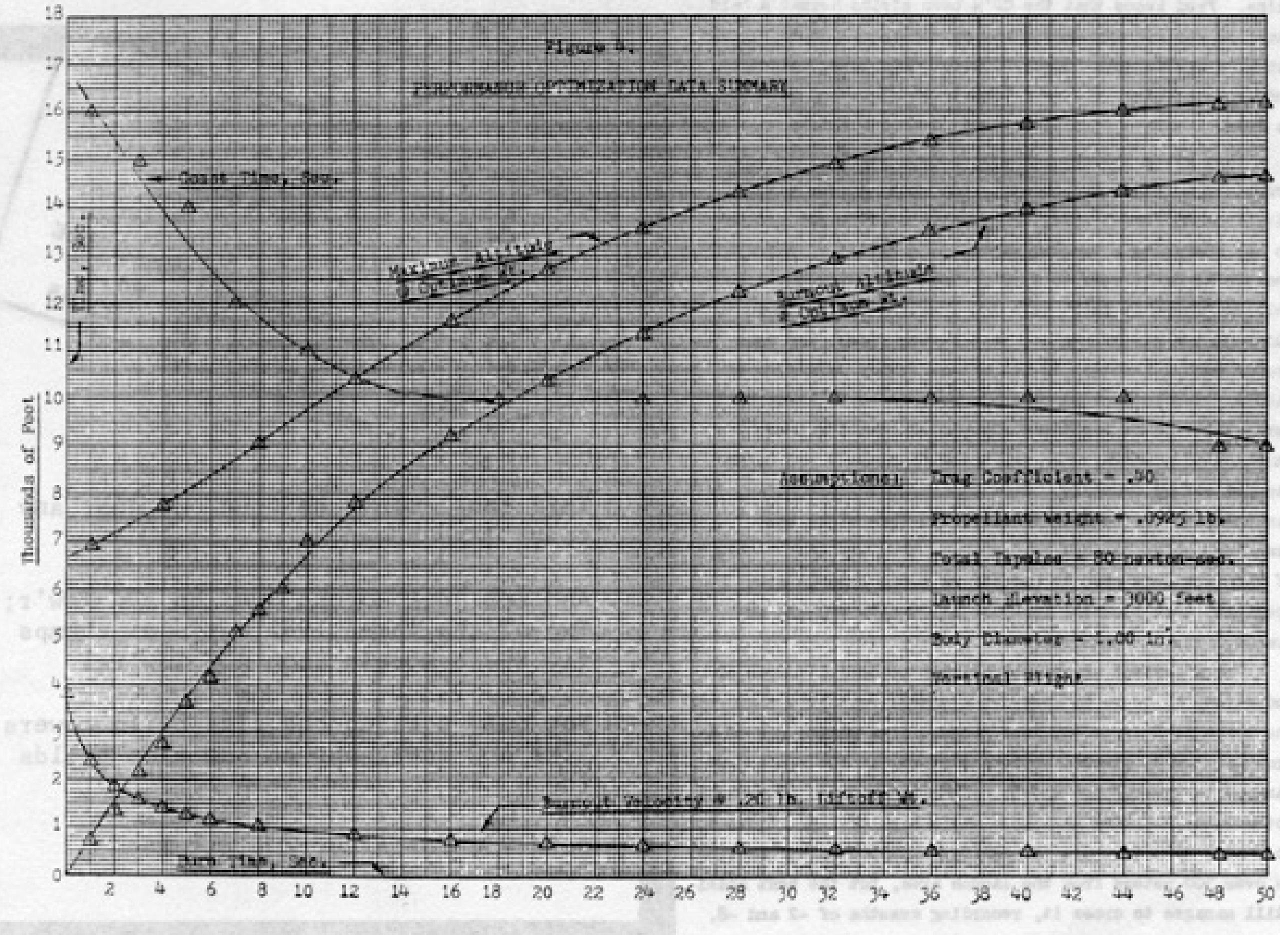
PERFORMANCE OPTIMIZATION CONTINUED FROM PAGE 8





model, a liftoff weight of .40 lbs. is required for maximum altitude. This is what is referred to as "optimum weight". Optimum weight can become minimum weight in certain cases, especially with long motor burn times. In order to explore this area of "optimum burn time versus optimum weight". I recommend a TI-59 calculator/printer with a fairly simple ballistics algorithm.

This program evaluates rocket ballistics during burn with iterative calculations every .10 second, then calculates coast time and peak altitude using a differential equation and displays the results. Decreasing vehicle mass during burn and decreasing air density are taken into account. Since the TI-59 is very slow in operation, the program was modified to display only burnout velocity, burnout altitude, coast time, and peak altitude. After each performance analysis is completed, the calculator adds .05 lb. to the total weight and refigures vehicle performance. When the total weight equals 1.0 lb., the program adds 1.0 second to the burn time and resets the total weight to .20 lbs. Also, the program adds 1.0 second to the burn time whenever the total weight is greater than the thrust, thus saving additional time. Calculations stop when the burn time reaches 50 seconds (an arbitrary limit). Even with automatic programming, it took the TI-59 nearly a week to compile the data shown in figures 2, 3, and 4.

The performance data are in agreement with work done by J. Pat Miller, Ed Brown of Estes Industries, and others. That is, maximum altitude results from a motor with thrust about twice the total rocket weight, assuming a minimum diameter rocket and optimum weight at each burn time.

The program assumptions included a 1.0" body diameter, 80 newton-seconds total impulse, 3000 feet launch elevation (similar to Lucerne Dry Lake, California), vertical flight, and an average drag coefficient of .40. This value is actually low for the shorter burn time data, so those data are somewhat optimistic. As the burnout velocity drops below mach .80, the performance figures come closer to reality.

As you can see, optimum altitude performance of the 1.0 inch diameter, 80ns design is obtained with a burn time in the 48-50 second region. Also, optimum weight for these velocities is simply the lightest weight possible, actually lighter than the motor itself. One can see that motor weight and mass fraction play a large role in determining the performance of long burn rockets. These vehicles spend most of their burn times at a rather constant velocity, so a preferred thrust curve shape would bring the rocket up to this "cruise velocity" rapidly to minimize gravity losses, and drops to a level which maintains this velocity until burnout. Long burn rockets get most of their altitude during the motor burn, and short burn time rockets during the coast period. The long burners win because they trade gravity losses (which are constant) for drag losses (which are velocity related by a square function). The long burners lose only when the gravity losses exceed the drag losses on a fast model, which doesn't happen until the gravity losses are greater than half of the model's acceleration value.

At this point, a few practical considerations are in order. This author's experience has shown that twelve second burn times with rockets of 1.22" diameter and 80ns are about the longest obtainable and still maintain a vertical flight. I assume that the 1.0" diameter vehicles could take a longer burn, possibly as long as 15 seconds. Another thing is that motor case heating problems on the longer burn motors are considerable and the 12-15 second burn may be a practical limit from this aspect also. However, it is obvious that the performances at even these burn times exceed anything obtainable with existing motors, and remain as goals to be achieved in the 80"s and beyond as new techniques and technologies become available. Model rocket performance in general has a long way to go, and hopefully this and other data will encourage developments in this field.

HIGH THRUST VS. DRAG

or How to Cope with the Brick Wall

By Jim Tucci

You have just finished that once in a lifetime model, you know, the twelve foot job that weighs 500 grams. Only one thing stops you from running out to the field and taking the final step. What kind of engine will lift the beast? So you dash down to the nearest hobby shop and proceed to inspect all the engines on the shelf.

Let's see, three D12's will lift it, or how about a couple of F100's. Those F100's really push. So you settle for three F100's and electric matches for ignition and a twenty dollar bill sized hole in your wallet. Off you go to the launch field with your pride and joy under wing. Five, four, three, two, one, liftoff! A large ball of fire erupts from under your rocket. It leaps for the sky, accelerating rapidly, then the rocket stops like it hit a brick wall, the chute opens and you're happy, except your twenty dollars bought you two hundred feet!

Well, there are many ways to send large models to great altitudes. The most commonly used one is clustering as described above. But when one trys to pile on the engines you also pile on weight and drag. The common view is more thrust the higher the rocket goes. This works very well without an atmosphere, however, the Environmental Protection Agency frowns on atmosphere removal. The lay rocketeer, or "nutzee", as they are called by us Florida idiots, believes wholeheartedly in such mystic beliefs; however, the modern alchemists (i.e. Physisists) have discovered the reason behind the "brick wall effect"; Drag! Yes, drag, that mystical pain in the neck one hears much talk about. But, like the weather, no one does anything about it. Well, almost. Drag comes from many factors such as air density, velocity, frontal area, etc. However, most of those we can't control or reduce. The only factors under our control are the model parameters, such as frontal area, surface finish, etc. Velocity can also be controlled.

Now everybody has read (I hope) the mountain of drag literature and knows all about nice finishes, pop lugs, and tower launchers, so I will not go into more of that. Well, that leaves velocity; what can you do about velocity? To get a better idea of what changing velocity can do for you, let's examine our 500 gram beast with the three F100's.