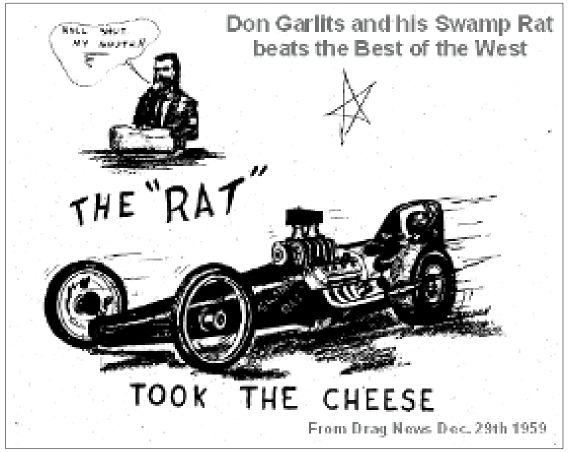
<u>ENGINEERING A SUCCESSFUL ELECTRIC LMR</u>

or; ***"Big Daddy Garlits and the Fat Pipes"***

by Dave Harding



In the late 50’s the pinnacle in the new sport of Drag Racing lay in the West Coast, or so they thought. The rumored performance of a Floridian named Don Garlits was discounted as hype. So when Garlits came to Bakersfield and beat the best of the West things changed.

How did Garlits do it? Well I am sure there were many reasons but one that is pertinent to our sport is he that he used one-inch diameter fuel feed lines (hidden in the frame rails, like all good “speed secrets”). You see, Garlits recognized that if you must burn a gallon of fuel in ten seconds then the supply must feed that much and this meant “fat pipes”. In drag racing you burn as much fuel as the motor can take in ten seconds. In LMR you must burn all the available battery energy in 90 seconds. Both need “fat pipes” to feed the motor/engine.

The well-engineered Limited Motor Run (LMR) model, will draw significant currents to “exhaust” the battery during the climb and this can’t happen unless you use battery cells with this capability. Sanyo calls these cells High Current or Fast Charge cells and they are built with low internal resistance (low resistance = high flows). There are relatively few such cells so when you begin to plan your new LMR for the 2006 rules you need to think about which cells and how many of them make up the battery. In 2006 the total battery weight can be a maximum of 25% of the total model weight. Note; for 2008 and on the battery rules have changed to include alternate chemistries and a smaller energy allowance per pound of model weight. See the new rules. However, the principles described here still apply.

The next step is to pick a motor, gearbox and propeller to match this battery. But the key is the battery.

In practice you don’t want to completely drain the battery for two reasons, first if you do, the last portion of the motor run will be at a markedly reduced power as the battery voltage drops towards the end, and the second is if you use a BEC ESC so your flight receiver and servos run from the power battery, you had better leave some for the glide! Now, if we say that you will drain 90% of the battery you can calculate the current required to do so. The cell capacity is usually expressed in milliamp hours and the first thing to do is convert this to amp minutes by multiplying by 60 and dividing by 1000. This is the current to completely deplete the cell in one minute. Now, to achieve our target current take this number and divide by 1.5 to make it a 90 second level, then multiply by 0.9 to allow for the 10% residue. You now have the target design current for this cell. I have done these calculations for a selection of the candidate Sanyo cells and show it in the table below.

Cell Model	Size	Volts	Capacity milli Amp hour (mAh)	Dia. inches	Height inches	Weight oz.	Approximate Energy Density	Current to Effectively Deplete ~Amps
N-500 AR	2/3A	1.2V	500	.670"	1.100"	0.63	794	18
N-800 AR	A	1.2V	800	.670"	1.909"	1.11	721	29
CP-1300 SCR	2/3 Sub-C	1.2V	1100	.910"	1.032"	1.16	948	40
CP-1700 SCR	4/5 Sub-C	1.2V	1700	.910"	1.340"	1.53	1111	61
RC-2000	Sub-C	1.2V	2000	.910"	1.690"	2.00	1000	72
CP-2400 SCR	Sub-C	1.2V	2400	.910"	1.690"	2.09	1148	86

Table 1 High Current NiCad Cells

Can this current be sustained with these cells? I believe they can, but I can’t promise you that they will. Other forms of competition drive these cells to much higher current levels, but not for such a long time. Regardless, I believe this is a good starting point, but I don’t guarantee it.

The 2008 rules battery rules revision allows batteries of any chemistry. LiPoly batteries are becoming popular and indeed can be used in LMR, but you must be particularly aware of the limitations of the battery you choose as LiPoly batteries can be ruined in one flight where the current and temperature limits are exceeded. Indeed, should you use a BEC controller, where radio current is provided from the power battery you risk loss of control should you exceed the battery limits. LiPoly battery vendors nowadays specify the current limits in terms of the C rating for continuous operation and for short bursts.. One C is the current at which the battery would be depleted in one hour. Ten C depletes the battery in one tenth of an hour; six minutes. Twenty C depletes it in three minutes. Our 1 1/2 minute motor run in LMR is NOT a short term loading so you must choose a battery with a continuous rating of 40C! Such LiPoly batteries are not available at the time of this writing; September 2007. NiMh high quality, low internal impedance batteries are available however, but the same provisos are applicable. A lighter battery will get hotter than a heavier one with the same internal impedance.

But wait, now you have a good cell and plan on a current level to deplete it, you still have to ensure that the rest of the system will not clog up the works. You must use low loss connectors and wire appropriate to the current level. For all but the lowest current level you should use one of the high quality low-loss connectors such as Anderson Powerpole, Dean’s, Astroflight Zero Loss or the gold plated 4mm bullet connectors favored in Europe. The wires should be at least 16 gauge for the lowest current and 14, 13, and 12 gauge for currents between 25 and 90 amps and as short as possible. Of course you should also minimize the number of connections in your system. Most people who fly high power systems solder the ESC to the motor and do not use a power switch or fuse. These high power systems have the potential to cause major harm if abused so it is important to ensure the battery is connected only when you are ready to fly and disconnected immediately after. Think of Fusing the Bomb!

The next step is to select a size; wing area, for your model. From this calculate the all-up-weight to achieve the desired wing loading, then the allowable battery weight. This leads you to examine the alternatives for cell type and number.

		Pack Weight ~ Ounces - 5% assembly allowance								
	# Cells	4	5	6	7	8	9	10	11	12
Cell Model	Weight oz.									
N-500 AR	0.63	2.6	3.3	4.0	4.6	5.3	6.0	6.6	7.3	7.9
N-800 AR	1.11	4.7	5.8	7.0	8.2	9.3	10.5	11.7	12.8	14.0
CP-1300 SCR	1.16	4.9	6.1	7.3	8.5	9.7	11.0	12.2	13.4	14.6
CP-1700 SCR	1.53	6.4	8.0	9.6	11.2	12.9	14.5	16.1	17.7	19.3
RC-2000	2.00	8.4	10.5	12.6	14.7	16.8	18.9	21.0	23.1	25.2
CP-2400 SCR	2.09	8.8	11.0	13.2	15.4	17.6	19.8	21.9	24.1	26.3

Table 2 Battery Pack Weights

The rule states that weights will be rounded to the nearest ounce, so for example, if you want to continue to fly with the old 8.6 ounce 7 x 800 AR cell pack you round it up to 9 ounces then the model must weigh 36 ounces or more with less than 648 sq inches wing area (If you can make up the pack with wires and connectors for less than this you may have an 8 ounce pack and a 32 ounce airplane). This pack works up to 29 amps.

On the other hand, maybe you want to build a much larger or smaller model. The process begins the same way by selecting the wing area/model size then calculating the model all-up-weight and the battery weight allowance.

For example a 68 ounce model will need a pack that weighs 17 ounces and the wing area must be less than 1224 square inches. The table 3 indicates the possible combinations of cells for such a battery.

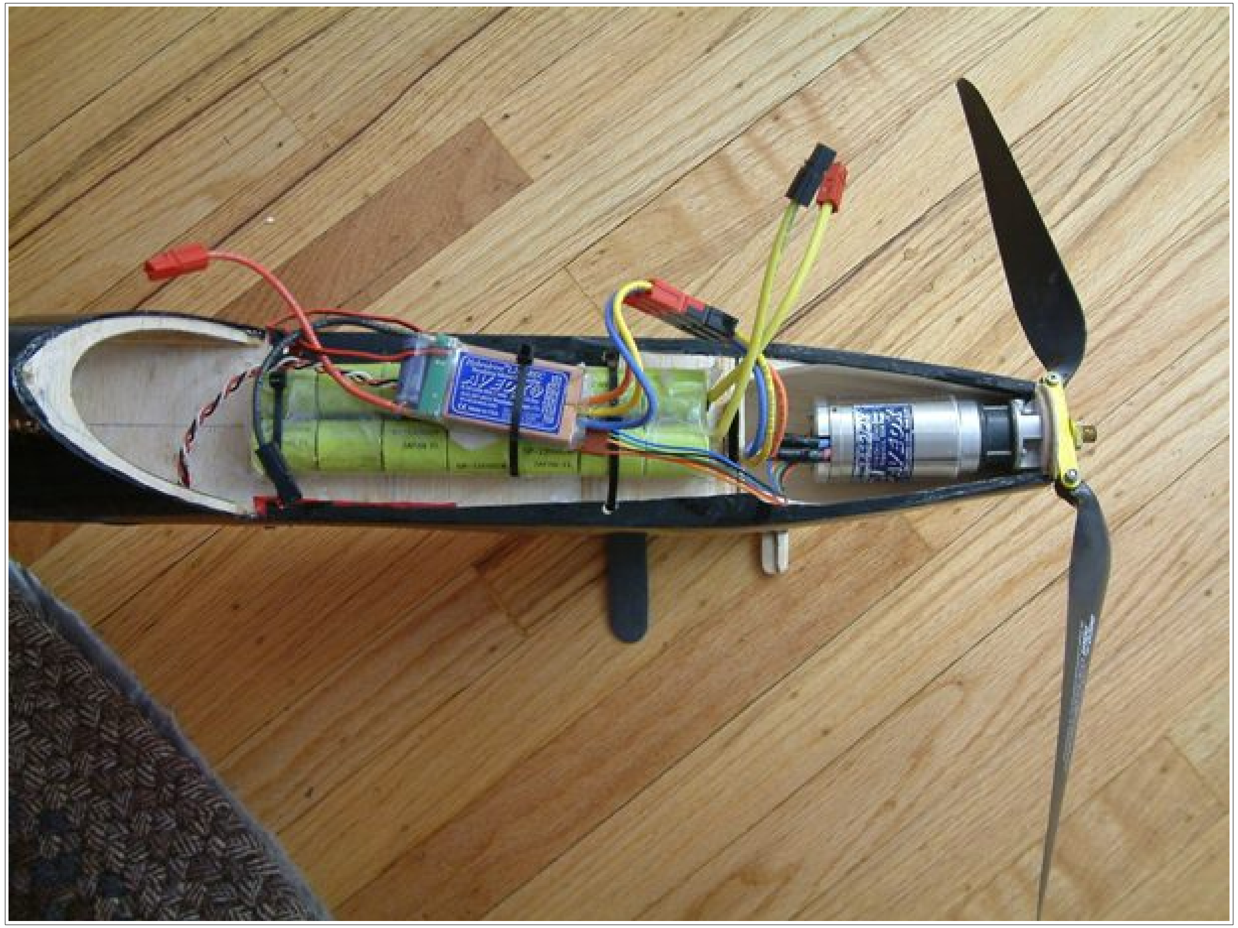
Cell Type	Cell Number	Volts	Weight	Current
CP-1300 SCR	14	16.8	16.3	40
CP-1700 SCR	10	12	16.1	61
RC-2000	8	9.6	16.8	72
CP-2400 SCR	7	8.4	15.4	86

Table 3 Alternate 17 ounce Battery Packs

Sometimes the best battery is slightly heavier than your initial allowance as you can add another cell, or select a better cell. In this case it is probably better to increase your model size a little to accommodate the slightly heavier pack.

Now you must select a motor that can handle the current and voltage. You get this information from catalogs or vendors. Motor limits are the maximum temperature (although this is sometimes inferred by a maximum power in watts) and the armature rpm.

Having selected a motor you must then select a gearbox and propeller that allows that motor to pull the desired current. Electric motors are very different from our glow, ignition or diesel engines. With an electric motor the bigger the prop the more power you will draw, or at least, the motor will try to, but you will eventually overloaded it and “let the smoke out”. Watch those limits!



This power unit; Aveox 1412/2Y with the Robbe 3.7:1 planetary gearbox, a 17x11 Aeronaut prop, an Aveox ESC and Battery of 14 Sanyo CP1300 cells is going in my new 108 inch 1150 sq inch Stardust Special.

Motocalc is an ideal computer program that allows you to easily do these calculations. It includes a library of motors, cells and propellers allowing you to examine the widest range of options. It also has a wizard that allows you to define your needs then it suggests motors, gearboxes, props and batteries. In addition to motor current and propeller thrust it will calculate the expected rate of climb for your model and from that you may estimate the altitude gained in the 90 seconds. Of course, it won't tell you if the model is still in sight!

In-flight Analysis - 110 in Stardust Special LMR Aveox

Motor: Aveox 1412/2Y; 1450rpm/V; 2.7A no-load; 0.018 Ohms.
Battery: Sanyo CP-1300SCR (30C); 14 cells; 1100mAh @ 1.2V; 0.0074 Ohms/cell.
Speed Control: Aveox L260; 0.007 Ohms; High rate.
Drive System: Robbe Aveox 1412/2Y; 17x11 (Pconst=1.18; Tconst=0.95) geared 3.7:1 (Eff=95%).
Airframe: 110 in Stardust Special; 1150sq.in; 74.4oz RTF; 9.3oz/sq.ft; Cd=0.085; Cl=0.96; Clopt=0.96; Clmax=1.34.
Stats: 102 W/lb in; 84 W/lb out; 14mph stall; 17mph opt @ 38% (24:40, 107°F); 17mph level @ 38% (24:40, 107°F); 1490ft/min @ 90°; -129ft/min @ -5.1°.

Sea Level, 29.92inHg, 95°F
100% Throttle

AirSpd (mph)	Drag (oz)	Lift (oz)	Batt Amps	Motor Amps	Motor Volts	Input (W)	Loss (W)	MGbOut (W)	MotGb Ef(%)	Shaft Ef(%)	Motor RPM	Prop RPM	Thrust (oz)	PSpd (mph)	Prop Ef(%)	Total Ef(%)	Time (m:s)
0.0	0.0	0.0	37.5	37.5	12.6	474.7	82.3	392.4	82.7	62.2	17195	4647	91.1	48.4	0.0	0.0	1:46
1.0	0.0	0.3	37.5	37.5	12.6	474.7	82.3	392.4	82.7	62.2	17195	4647	90.1	47.4	2.8	1.8	1:46
2.0	0.1	1.1	37.5	37.5	12.6	474.7	82.3	392.4	82.7	62.2	17195	4647	89.2	46.4	5.6	3.5	1:46
3.0	0.2	2.4	37.5	37.5	12.6	474.9	82.4	392.5	82.7	62.2	17193	4647	88.3	45.4	8.4	5.2	1:45
4.0	0.4	4.3	37.6	37.6	12.6	475.1	82.4	392.7	82.7	62.2	17188	4645	87.4	44.4	11.0	6.9	1:45
5.0	0.6	6.8	37.6	37.6	12.6	475.3	82.4	392.9	82.7	62.2	17183	4644	86.5	43.4	13.7	8.5	1:45
6.0	0.9	9.8	37.6	37.6	12.6	475.5	82.5	393.1	82.7	62.2	17177	4642	85.7	42.4	16.2	10.1	1:45
7.0	1.2	13.3	37.7	37.7	12.6	475.8	82.5	393.3	82.7	62.2	17171	4641	84.8	41.3	18.7	11.6	1:45
8.0	1.5	17.4	37.7	37.7	12.6	476.1	82.6	393.5	82.7	62.1	17165	4639	83.9	40.3	21.2	13.1	1:45
9.0	1.9	22.0	37.7	37.7	12.6	476.4	82.6	393.7	82.7	62.1	17158	4637	83.1	39.3	23.5	14.6	1:45
10.0	2.4	27.1	37.8	37.8	12.6	476.6	82.7	393.9	82.7	62.1	17152	4636	82.2	38.3	25.9	16.1	1:45
11.0	2.9	32.8	37.8	37.8	12.6	476.9	82.7	394.1	82.6	62.1	17147	4634	81.3	37.3	28.1	17.5	1:45
12.0	3.5	39.1	37.8	37.8	12.6	477.1	82.8	394.3	82.6	62.1	17142	4633	80.4	36.3	30.3	18.8	1:45
13.0	4.1	45.8	37.8	37.8	12.6	477.3	82.8	394.4	82.6	62.1	17138	4632	79.5	35.2	32.5	20.2	1:45
14.0	4.7	53.2	37.8	37.8	12.6	477.4	82.8	394.5	82.6	62.1	17135	4631	78.6	34.2	34.6	21.5	1:45
15.0	5.4	61.0	37.9	37.9	12.6	477.5	82.9	394.6	82.6	62.1	17133	4631	77.6	33.2	36.6	22.7	1:45
16.0	6.2	69.4	37.9	37.9	12.6	477.5	82.9	394.6	82.6	62.1	17133	4631	76.7	32.2	38.6	23.9	1:45
17.0	6.9	78.4	37.8	37.8	12.6	477.2	82.8	394.4	82.6	62.1	17140	4632	75.7	31.3	40.4	25.1	1:45

Motor performance calculations take ambient temperature and heating effects into account.

Color Key: Propeller Stalled | Stall Speed @ Clmax=1.34 | Level Flight @ Clopt=0.96 | Level Flight @ Cl=0.96

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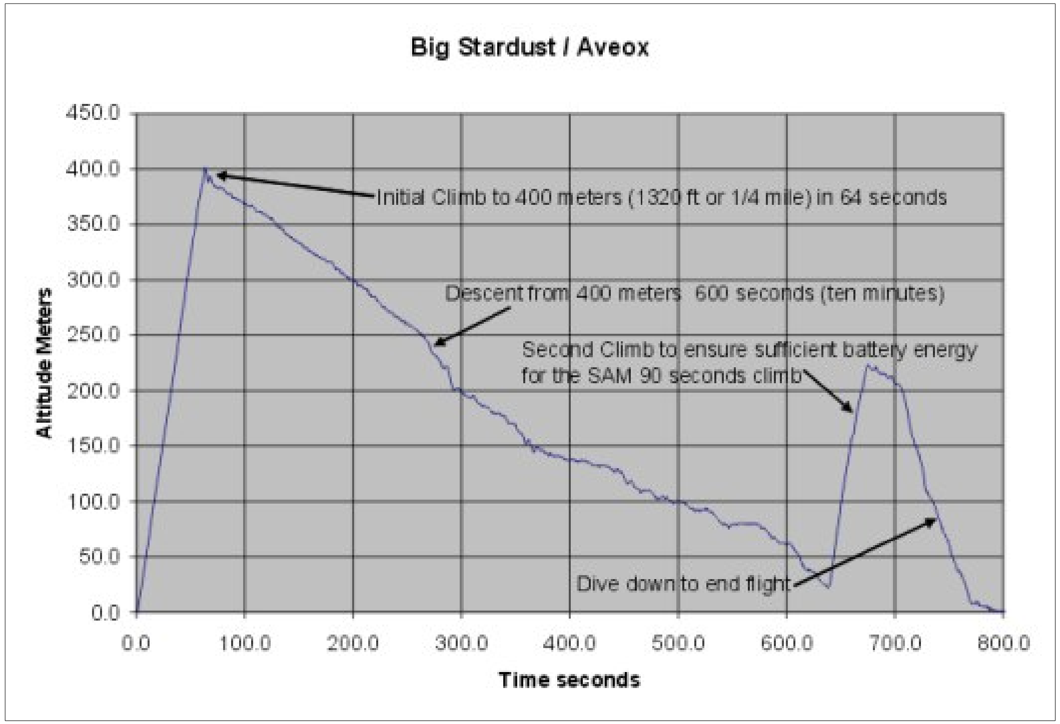
Here is a graph from the measured performance of the 108-inch Stardust Special showing the climb performance. The data was measured by a LoLo Altitude Logger.



Motocalc will also give you an indication of motor heating. This is a major factor in selecting a motor for these high current applications and you should pay attention to the parameter that drives it; the motor efficiency associated with the internal losses (back to Fat Pipes again). Motocalc calculates the input power (volts and amps) for the installation you selected, and it also calculates the motor efficiency at this operating point. Then from these two numbers it calculates the losses, in terms of watts; think about hot light bulbs! This loss is the power that drives the motor temperature and you will find that there is a world of difference between various motors. Table 4 shows some typical powerplant systems that match models of various sizes. Note that they all have about the same performance. See, Steve Roselle proposed a rule that allows the widest choice of models that can compete on an even field.

Battery cell	Number of cells	Battery Weight +5%	Battery Weight Rounded Up***	Model Weight ~ ounces	Model Wing Area ~ sq	Current to Effectively Deplete ~ Amps	Power Input ~Watts	Motor	Gearbox	Prop	Rate of Climb ~ ft/min *
N-500 AR	7	4.6	5	20.0	360	18	126	Mega 16/15/3	4.5:1	13x8	1500**
N-500 AR	9	6.0	6	24.0	432	18	162	Astro 20 803G	3.3 : 1	12x8	1470
CP-1300 SCR	7	8.5	9	36.0	648	40	280	Hacker B40-10S	4:1	13x7	1500
CP-1700 SCR	8	12.9	13	52.0	936	61	488	Neu 1506/1Y	6.7:1	14x7	1550
CP-2400 SCR	7	15.4	16	64.0	1152	86	602	Neu 1506/1.5D	6.7:1	17x9	1500

*** Rule says weights are rounded up to the nearest ounce.
* Note; the rate of climb can be varied by propeller and gear ratio selection, within the battery and motor limits.
** Almost certainly out of sight in 90 seconds

. ***Table 4 Battery, Motor, Gearbox and Propeller Choices for Various Size LMR Models Using 2006 Rules***

So choose carefully before you buy, but in any case make sure you use Fat Pipes and tip your hat to Don Garlits.

Dave Harding