A Bit of Theory.

I know that it is not unusual for me to include theoretical content in this column, but this month I want to introduce a principle which may be useful for all flyers who use LiPo power packs. I have some experimental justification for the proposal, but I have to admit that it also depends upon a certain amount of interpretation on my part, i.e. it is a least partly hypothetical. It stems from what is a well-appreciated fact in the commercial world; a manufacturers/retailers' claims for their products are more often the result of over-enthusiastic marketing than of independent testing. In the case of Lithium polymer batteries the most obvious example is the specified maximum continuous discharge rate in multiples of C. The average modeller might assume that for a range of similar capacity/size/weight packs, that with the highest discharge rate specified would be the best, but I hope to prove that this is not always true.

Modellers are well aware of the relationship between current drawn from a pack and its performance. They know that discharging a pack at 5C (which means 10 amps for a 2000mAh pack) will allow it to hold an average voltage of around 3.7 volts per cell for a discharge period of a little under 12 minutes (60 minutes/5). If we increase the current to 15C (30 amps) we might expect a lower voltage (say 3.5 volts) for less than 4 minutes. What is not so obvious is why the manufacturer's specification sets an upper current limit, and the explanation for this involves two factors. One is the voltage drop as the current increases. If this gets too great the voltage falls below the theoretical limit of 3 volts per cell which is not good for the pack. The other is in terms of temperature. The internal resistance of the cell determines how much energy is released within the cell during discharge. This energy increases as the current draw increases (proportional to the square of the current) and manifests itself as heat in the pack, i.e. the pack temperature rises which again is not good for the pack. At higher current draws the two effects combine to reduce both the performance of the pack (in terms of power output below the theoretical) and, often more importantly, the life of the pack. The extent of the temperature rise depends upon several additional factors such as pack size (i.e. mass/surface area ratio), construction format, cooling, etc., but it is always a factor.

What this theory means, in basic terms, is that running a pack at a higher current can reduce both its efficiency and its life. Testing of LiPo packs at increasing current and plotting the voltage through the discharge shows that there is a neat indicator of what might be considered a transition from optimum usage (high efficiency, maximised life) to below optimum. Graph 1 shows a typical set of curves for such tests and you will see that curve 4 has a distinct difference to the first three. Here the high initial current suppresses the voltage even further than for the previous curves, but then the voltage begins to recover. The temperature rise in this situation is great enough to reduce the internal resistance of the cells and the voltage rises proportionately. In terms of power output this is good, but only at the expense of reduced pack life, and if this is important to the modeller it should be avoided.

Testing actual Packs.

I decided to verify the analysis by comparative testing of three packs. They were all of the same size at 2250mAh, all 3S, but they were rated 2 at 20C and 1 at 25C maximum continuous discharge. I was not comparing performance so I decided to avoid embarrassment by calling them A, B, and C. The packs were not brand new but had only been subjected to some previous bench testing. Temperature is a major factor in this analysis so I made sure that all the packs were allowed to stabilize at an ambient temperature of 20 degrees C before each test discharge. The tests were simple discharge from full at constant current keeping a record of the voltage of the pack from start to finish of the discharge. I chose to use 5C (11 amps), 10C (22 amps), and 20C (44 amps) as the test currents and Graph 2 shows a set of three curves for pack A plotted on the same basis as Graph 1. Whilst I was examining this graph I realised that assessing the shape of the curves could be improved by manipulation of the plot. I therefore reduced the vertical voltage axis so that it started above zero, and normalised the time axis by expressing time values as a percentage of the total time of discharge for each test so that all the curves now cover the full width of the plot. Note that since the discharge is at constant current this axis also represents percentage of pack capacity. Graph 2 was then replotted as Graph 3 on this basis.

Packs B and C were tested to the same pattern and these results are plotted in Graphs 4 and 5. When you look at Graphs 3, 4, and 5, you will see two factors which indicate the quality of the pack. The first is the general voltage levels throughout the discharge curves. The higher this is, the lower is the internal resistance of the pack and, as with all batteries, a low internal resistance means a better pack. You can see that, on this basis, packs A and C are much better than pack B. The second factor is the suppression and recovery of the voltage which was shown originally in curve 4 of Graph 1, and you can see that this is not present in any of the curves for pack A, is present in the 20C curve for pack C, and is very pronounced in the 20C curve for pack B. On the basis of this part of the analysis, for discharge currents in the 45 amp area, pack A would have a long cyclic life, pack C would have a lesser one, and pack B would have a short one. Any increase in loads would simply exacerbate this effect.

Using the Principle.

My analysis of this testing leads me to suggest that the highest discharge curve which DOES NOT indicate the voltage suppression/thermal recovery is the maximum discharge rate you should use if you are concerned with extending the life of your Lithium batteries to a maximum, and it is often MUCH LOWER than the manufacturer's specified maximum rate. In the case of the three packs I tested I can extrapolate that the maximum life ratings for pack A would be more than 20C (say 22C) where this manufacturer specifies 20C, for B would be around 13C where the manufacturer specifies 20C, and for C would be around 18C where the manufacturer specifies 25C. In an ideal world I would be able to suggest a way for the modeller to determine this maximum life rating, but my testing is a fairly long-winded process and needs at least some specialised equipment. I doubt that it is a viable procedure for the average modeller.

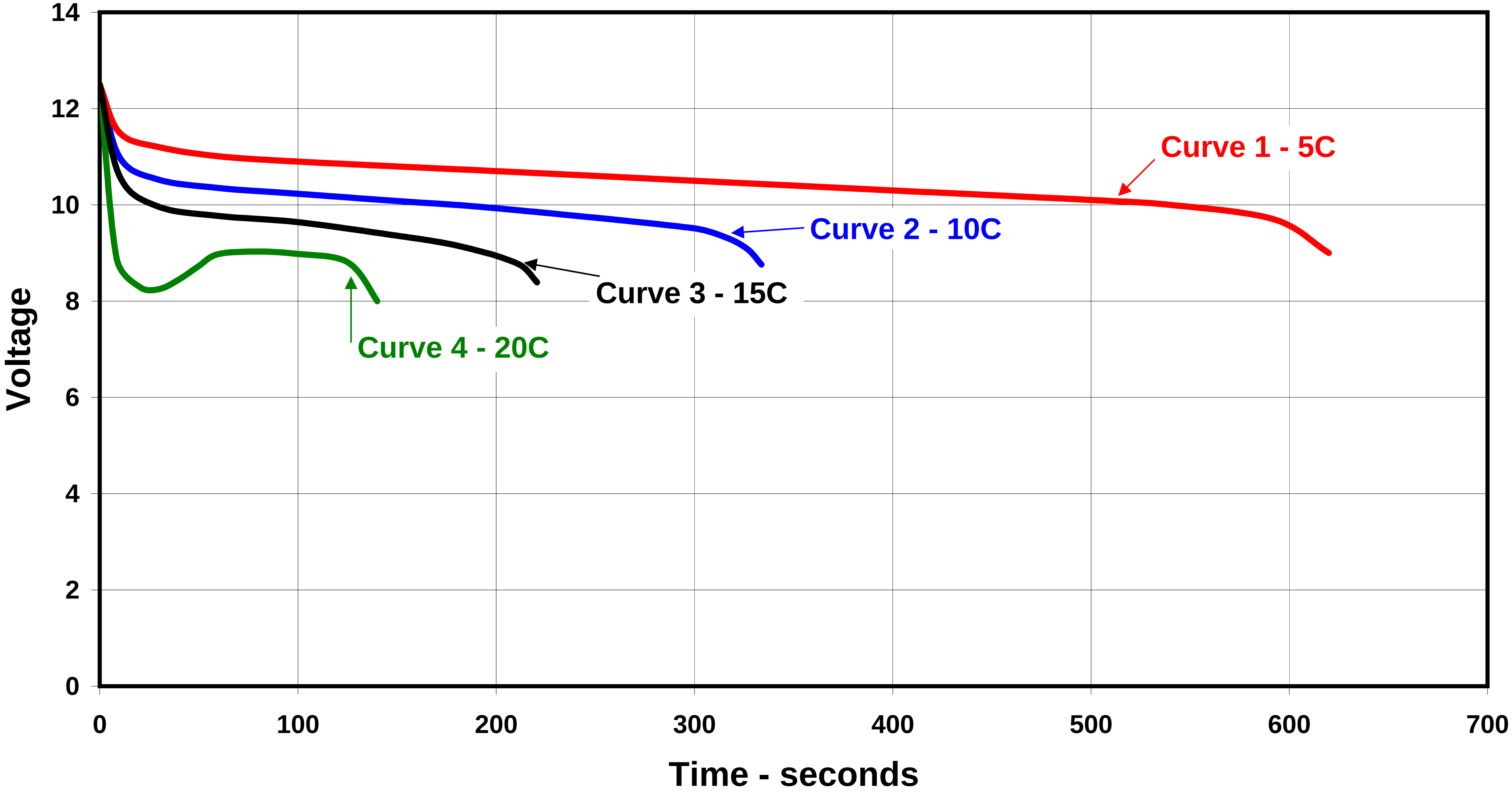
What I can suggest, if you are more concerned with the life of your batteries than with extreme model performance, is a check you could apply to complete models or power trains with the only extra equipment being a Wattmeter or equivalent. If this is fitted between the battery pack and the controller then it allows you to observe the pack voltage changes during a full throttle run (with the usual safety requirements regarding restraint and the propeller arc). If a fully charged pack at ambient temperature is fitted and a test run started at full throttle, observation of the wattmeter (acting as a voltmeter) will show the initial very rapid drop of the voltage until it first stabilises. The higher this first value the better but it is what happens next which is critical. If the voltage holds steady before commencing a gradual decrease your pack is being used under loadings which will allow its life to be maximised. If the initial voltage is lower than you would expect, and begins to increase after a few seconds until it reaches a new, higher, stable value (as in Graph 1, curve 4), then you are effectively overloading the pack and reducing its life. This test is fairly quick to do, as you only need to partially discharge the pack. The changes in voltage that you need to observe occur right at the beginning of the discharge so you will be able to observe the critical features in less than half of the full discharge.

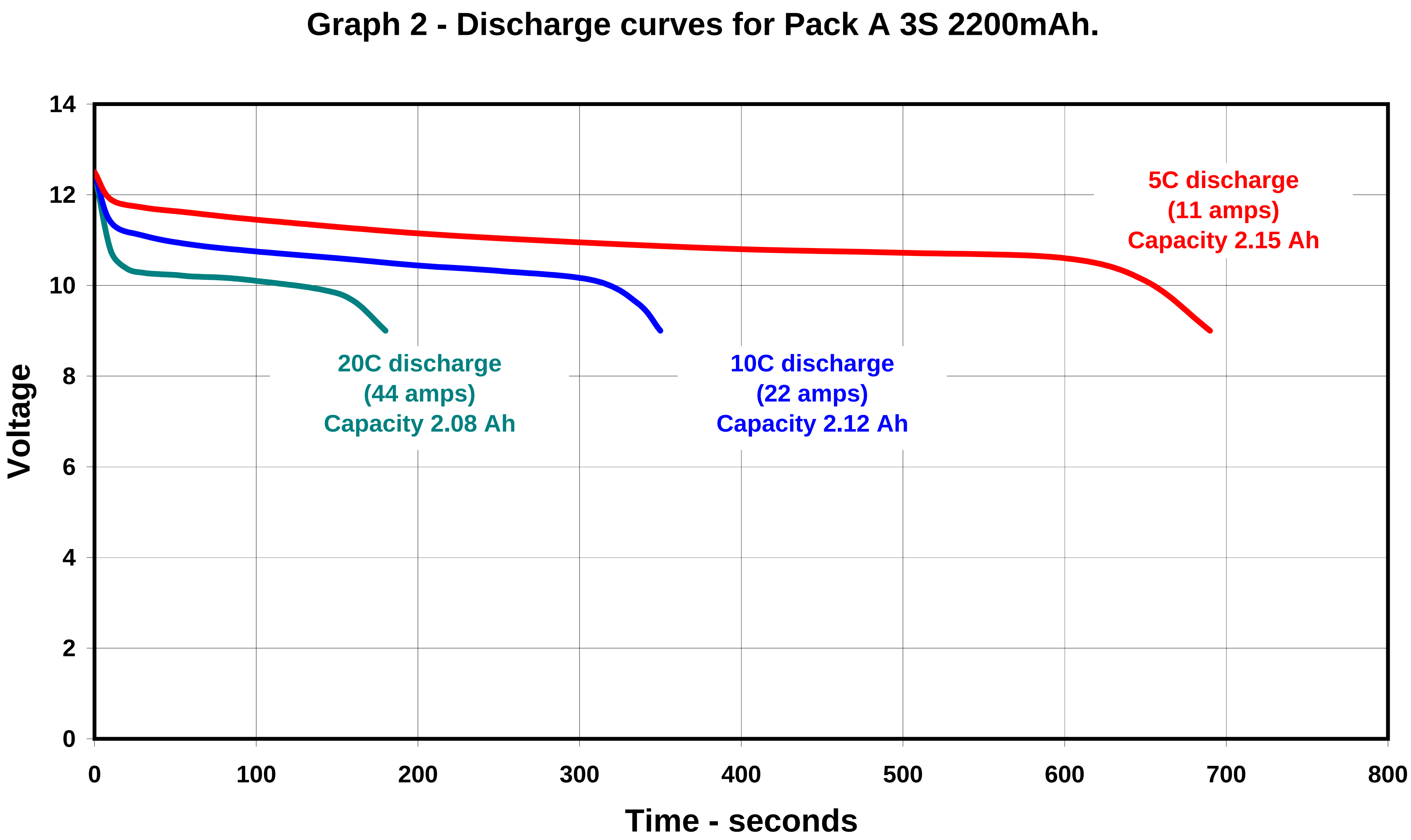
If the check puts you into the second category then there is something that you can do about it. The simplest thing is to reduce the propeller size (not applicable to EDF however). This will reduce the current draw, increase pack voltage, and allow the discharge curve to move above the transition point. It may need some re-testing to check that the smaller propeller has had sufficient effect on the discharge, and, of course, the model performance will also be reduced. The other approach is to change the pack, either to a better manufacturer whose products perform better (as with pack A), or to a larger capacity pack (of the same series count). It may not be obvious why this would help but remember that you will be pulling approximately the same current and that this current will be a lower C value since pack C is higher.

I think I had better give an example of that! Your test indicates that your power train is pulling 40 amps from a 2000mAh pack (a 20C load) and even if the manufacturers rating is 25C max you find that you are getting voltage suppression/recovery. You switch to a 3000mAh pack (with a small weight penalty), find that you are now pulling 42 amps (higher voltages on discharge) which is only 14C and is much better for the life of the pack (also OK for EDF).

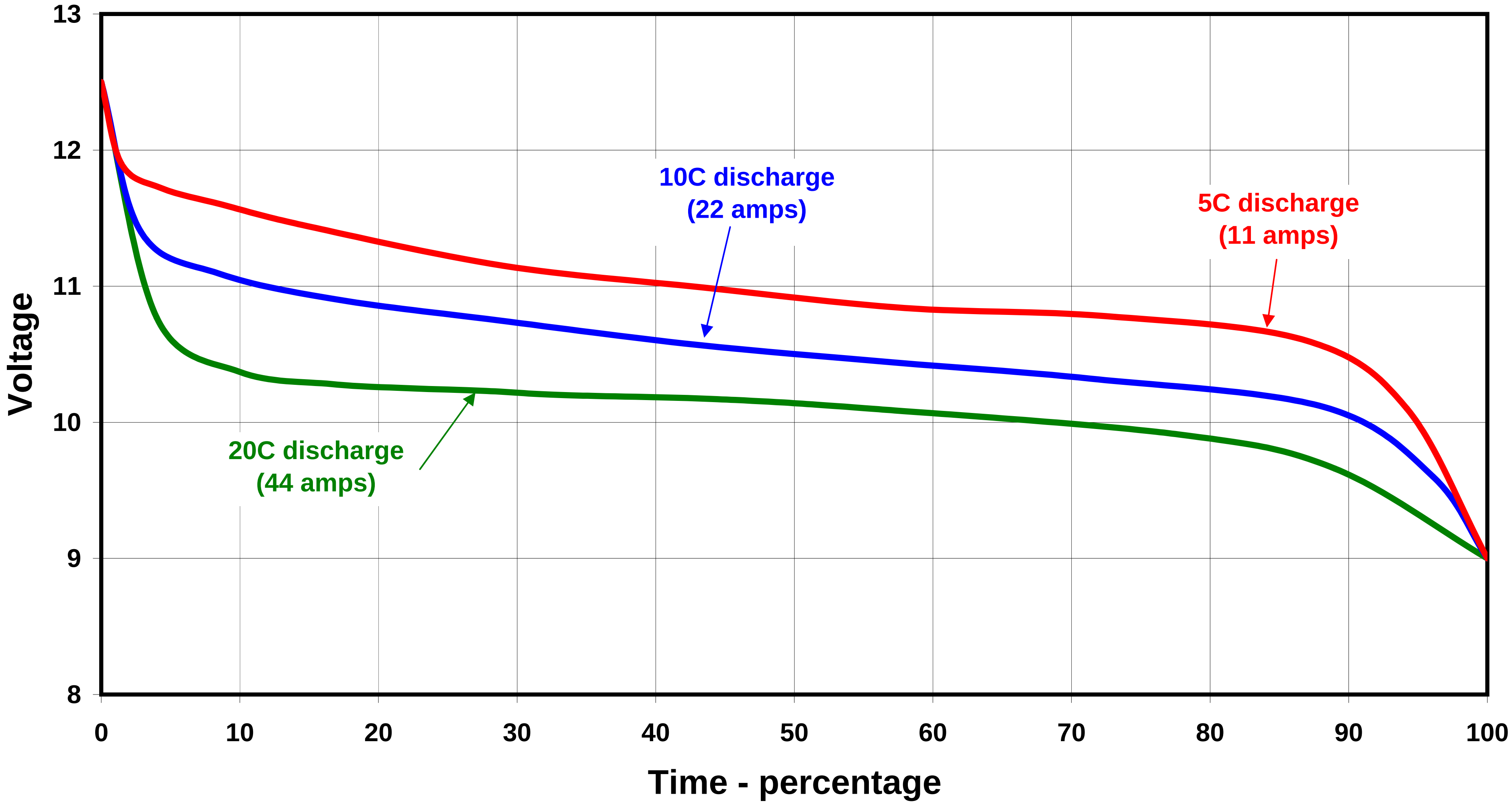
There is one final point to make which is very relevant to the club modeller. The graphs I have used and the testing I suggest are all based upon continuous full-throttle operation, whereas the club flyer uses a lot of part throttle operation in his flights. The full throttle condition can be thought of as a worst-case scenario, but even if you use it occasionally and for short periods in your flights you are risking a reduction in pack life. This kind of damage to a LiPo pack is both accumulative and non-reversible so if your full throttle loading is beyond the transition it will occur each time you use full throttle. I also have to point out that this scenario is certainly not the only way we can reduce the life of our LiPo packs. Unbalanced charging, over-discharging, and physical abuse (aka crashing), are all ways of ending with a dead pack before we expect to, but I believe that this factor is the one that answers the much-repeated question “my pack has been used exactly within specification so why has it lost 30% of its capacity over 30 cycles?”

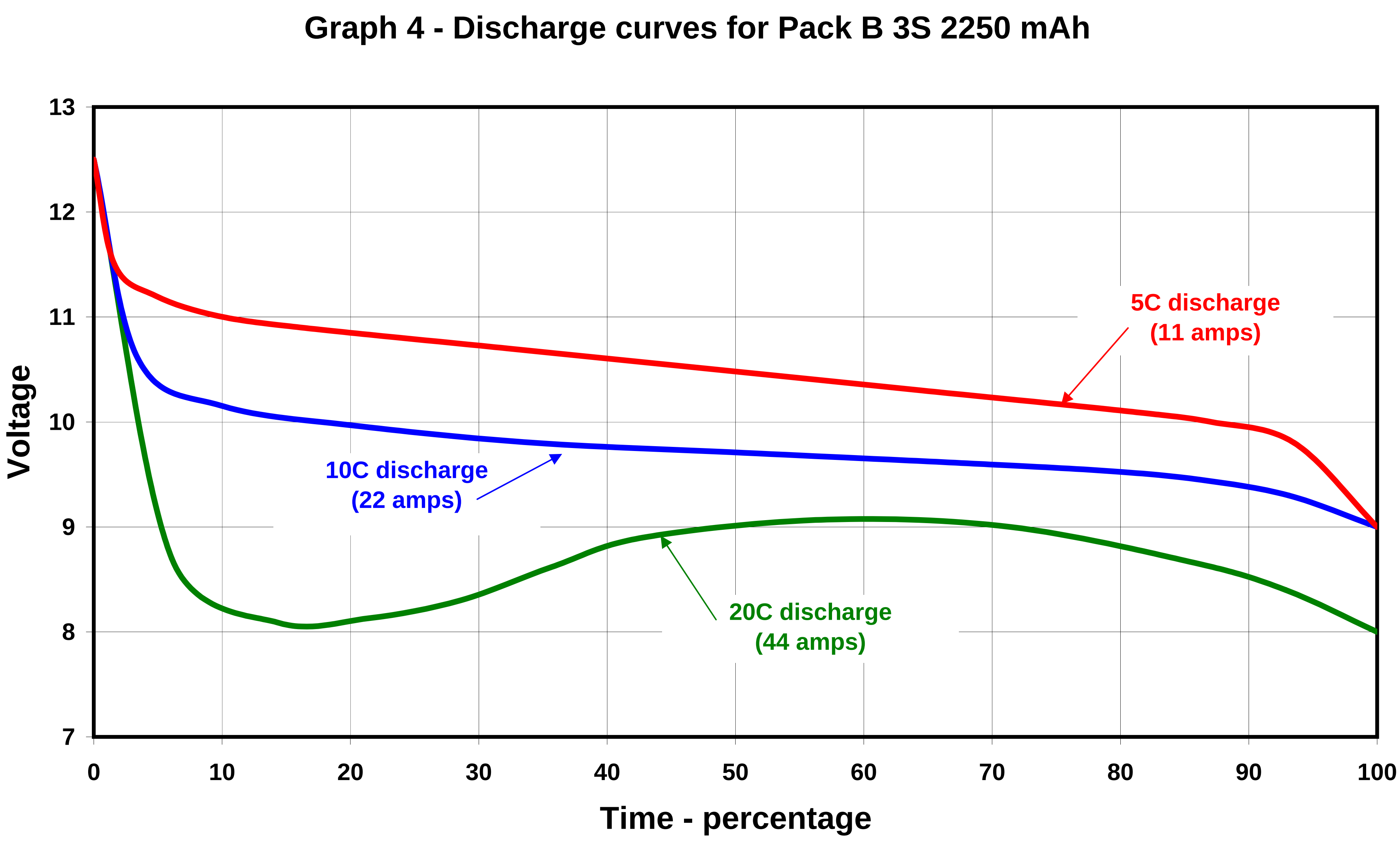
Graph 1 - Discharge of Lithium 3S pack at increasing current.

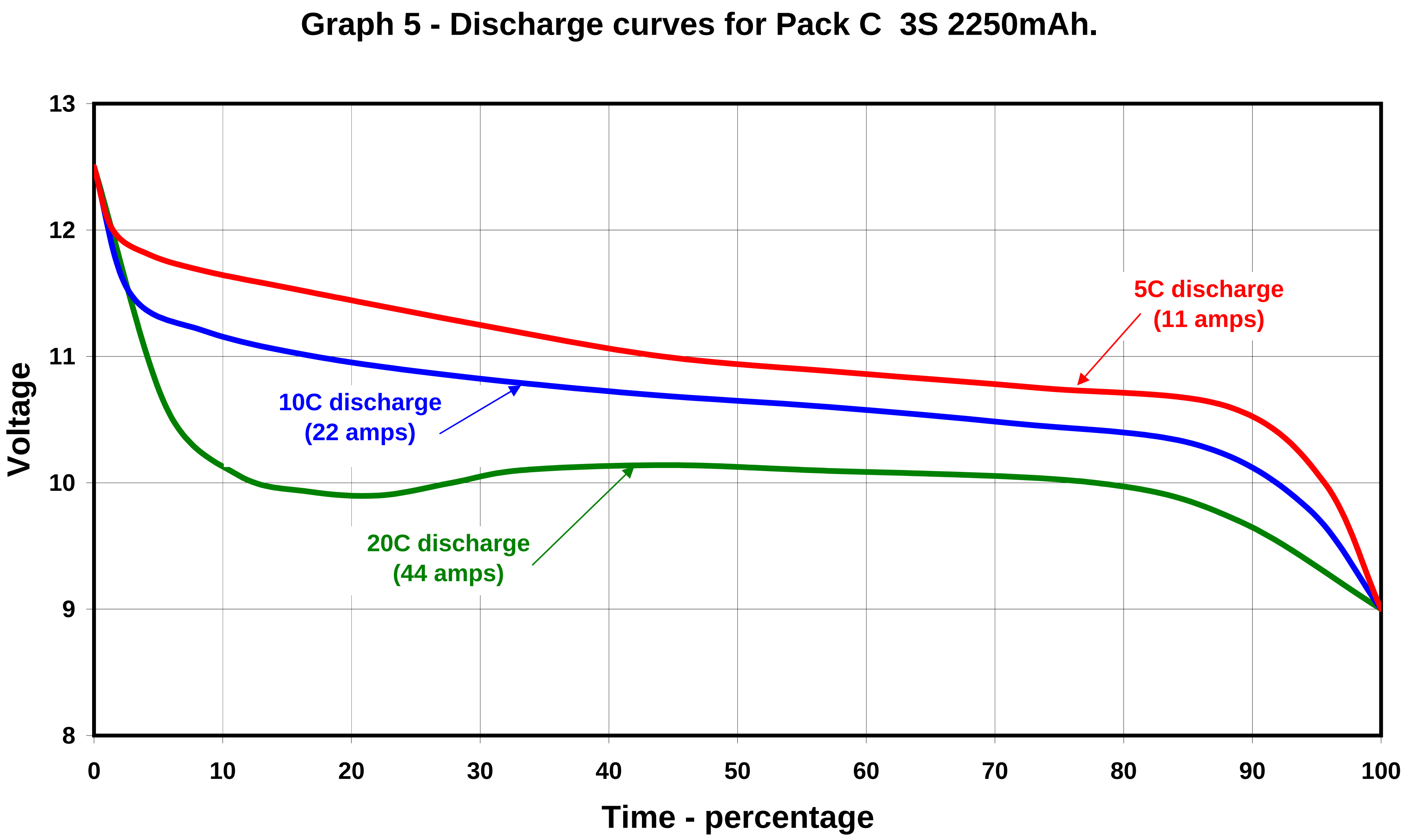



Graph 2 - Discharge curves for Pack A 3S 2200mAh.
Voltage
Time - seconds
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
5C discharge
(11 amps)
Capacity 2.15 Ah
10C discharge
(22 amps)
Capacity 2.12 Ah
20C discharge
(44 amps)
Capacity 2.08 Ah

Graph 3 - Discharge curves for Pack A 3S 2250mAh.




Graph 4 - Discharge curves for Pack B 3S 2250 mAh
Voltage
13
12
11
10
9
8
7
0
10
20
30
40
50
60
70
80
90
100
Time - percentage
5C discharge
(11 amps)
10C discharge
(22 amps)
20C discharge
(44 amps)


Graph 5 - Discharge curves for Pack C 3S 2250mAh.
13
12
11
10
9
8
0
10
20
30
40
50
60
70
80
90
100
Voltage
Time - percentage
5C discharge
(11 amps)
10C discharge
(22 amps)
20C discharge
(44 amps)