Electric Sport Scale - Keith Shaw - Model Builder - July 1987

edited and commented on by Ken Myers,
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Scale aircraft are many times depicted as overweight, under-powered models of marginal performance. Such is also the view held by the uninformed of electric-powered aircraft. Why would anyone want to pursue electric scale aircraft, seemingly the combination of two evils?

Actually, there are several advantages electric power has over conventional model engines. The first is absolutely reliable, reproducible, controllable power (especially with today's efficient MOSFET speed controllers). Confidence in your power system can dramatically improve your confidence in flying and low altitude aerobatics. Electric motors are very easy to gear down, allowing near-scale size props for efficient thrust over those "fat" scale fuselages. Twins (and multi-engines) are trivial to do, and benefit from identical thrust with no chance of one engine out problems. Motors can fit into the sleekest of cowls while the Ni-Cad pack is in the fuselage. There is very little vibration so the most fragile scale details remain in place, and since there is no "goo" to clean off, the finish lasts forever (even flat camouflage).

I will be concentrating on the unique considerations of the electric power system, not on the general problems of structure and aerodynamics. Those are common to all phases of modeling, and extensively covered elsewhere. **What follows is *my* recipe for designing electric sport scale aircraft.**

(1) Choose the type of aircraft that fits your flying style and skills. If you don't think you can handle a full-blown .60 glow-powered Me-109, now is not the time to build an electric one! I build my planes to handle any air load and aerobatic contortions at very little additional weight, but landings and takeoffs need to be done with care. It is senseless to try to build crash protection into an electric airplane (or a glow-powered one, for that matter), as it will only increase the weight, air loads and impact forces. Build light and carefully, and practice flying with an aircraft that fits your skills. Unfortunately no scale glow kits, that I know of, convert well to electric. They will fly, but not with the performance of their glow counterparts. You'll end up with a J-3 Cub with the glide of a Sherman Tank.

(2) After obtaining a good three-view, choose a size for your dream plane, then calculate the wing area, wing span, length, fuselage cross sections, wheel size and scale prop diameter.

(3) Choose a wing loading that will be appropriate for the design type and size. Slow-flying planes, such as, WWI or 1920 - 1930 light planes (Cub, Taylorcraft, etc.), use a 14 - 18 oz./sq. ft. wing loading, but for fighters and aerobatic types, a 20-25 oz./sq. ft. loading is more appropriate. Small planes (less than 400 sq. in.) should use the lower wing loadings for their type. Select a good airfoil; my all-around favorite is the real Clark Y, as it has good load-lifting characteristics, reasonably low drag, and surprisingly good inverted performance. My Spitfire, deHavilland Comet, and Gee Bee use the Clark Y. For fast aerobatic types the NACA 2412 and 2410 work well.

From the calculated wing area and chosen wing loading, we can estimate the flying weight.

Flying weight (oz.) = wing loading (oz./sq. ft.) x wing area (sq. ft.).

(4) There are rule of thumb estimates for horsepower (watts); the first two are from Bob Kopski, electric columnist for Model Aviation, the rest are from my experience and observations. Please note the "watts" refer to **input power** at the motor (volts x amperes). Our motors are just electrical power to mechanical power converters with typical efficiency of 75%. All horsepower estimates are relative to the weight of the airplane in pounds (#).

Power to hold level flight = wing loading (oz./sq. ft.) times the pounds. (*Example: 18 oz./sq. ft. wing loading with a total weight of 3 lbs. means that the plane should hold level flight with 18 x 3 = 54 watts **input power**. km)*

Power to take off from the ground = 30 to 50 watts per pound. (*Example: A 3 lb. plane would require between 30 x 3 = 90 watts and 50 x 3 = 150 watts of **input power**. km*)

Power for sport aerobatics = 40 to 60 watts per pound (loops, rolls, Cuban eights, stall turn, spin). (*Example: A 3 lb. plane would require between 40 x 3 = 120 watts and 60 x 3 = 180 watts of **input power**. km*)

Power for good aerobatics = 70 to 100 watts per pound (outsides, knife edge, vertical rolls, turnaround pattern). (*Example: A 3 lb. plane would require between 70 x 3 = 210 watts and 100 x 3 = 300 watts of **input power**. km*)

Needless to say, these values are approximate, suitable to most reasonably clean monoplane designs. Biplanes, planes with full rigging, or heavily under-cambered airfoils are going to have much more drag and take more power to hold level flight. With respect to takeoff, long grass, tricycle gear, small wheels, and high wing loadings will require higher power.

Conversely, taildraggers, large wheels, short grass, and light wing loading will require less power.

(5) Since the "fuel tank" capacity is fixed at 1.2 Ah to 1.7 Ah (or whatever size Ni-Cad you choose to use), higher current consumption (higher horsepower) will cause shorter flights. **Maximum current drain occurs when the plane is standing still (static drain). As the plane accelerates, the prop unloads, the rpm increases, and the current decreases.** How much the prop unloads depends on how clean and efficient the plane is. Fat fuselages, high wing loading, heavily cambered airfoils, biplanes, etc. will have shorter motor runs. The following is table relating static current drain to approximate motor run.

	Static Motor Run	Static Motor Run	Static Motor Run
Static Current (amps)	1.7 Ah Ni-Cads	1.4 Ah Ni-Cads	1.0 Ah Ni-Cads
15	6.8 min	5.6 min	4.0 min
17.5	5.8 min	4.8 min	3.4 min
20	5.1 min	4.2 min	3.0 min
22.5	4.5 min	3.7 min	2.7 min
25	4.1 min	3.4 min	2.4 min
27.5	3.7 min	3.1 min	2.2 min
30	3.4 min	2.8 min	2.0 min

(***Note:*** *The above chart is not the same one used in the original article. This chart was created by Ken Myers, April 1995, to reflect current battery size use in these types of aircraft. These times represent static (on the ground running) times and can easily be doubled in the air with the unloading of the prop and the use of a good high rate speed controller such as the Jomar SM-4 km*).

In addition, the maximum current capacity of the motor must be considered. For the long motor runs that are common in sport scale, 15 amps is about maximum for ferrite motors, while cobalt motors can go up to 20 to 30 amps, depending on size. For short motor runs (less than one minute), many cobalt motors can stand 40 to 60 amps! I typically use a 20 amp static load for my scale planes; this gives me 4.5 to 5.5 minutes of good performance, or 7 to 10 minutes of just cruising around the sky.

(6) Ni-Cads deliver about 1 volt per cell to the motor under the current loads we use, so we can predict the number of cells required. I highly recommend Sanyo SCRC, SCR and AR cells; don't bother with "off brand" or cheap Ni-Cads, they won't cut it. (*Extended Cell Capacity Cells, such as the Sanyo SCE won't work for this application either.* km)

Number of cells = total power (watts in Step 4) over static current drain (amps in Step 5). (*Example: 3 lb. plane requiring 180 watts for sport aerobatics; 180 watts divided by 20 amps = 9 cells. km*)

This will indicate which power system would be required; for 6 to 8 cells use an 05 (*90 - 150 watt motor km*); 10 to 14 cells on a 15 (*200 - 280 watt motor km*); 12 - 16 cells on a 25 (*240 - 500 watt motor km*); 16 - 20 cells on a 40 (*320 - 600 watt motor km*); 20 to 32 cells and up on the 60-size motors (*400 - 1000 watts km*) and 32 - 36 cells on the 90-size motors (1000 - 1400 watts km). If you come up with a power system you don't own and don't want to buy, go back to Step 2 and try again.

(7) For clean, fast aerobatic designs, you can use direct drive, but for slow to medium speed aircraft, or planes with large cross section fuselages, use a gear drive for the benefit of the larger thrust disk. Once the power system is chosen, weigh it or look it up in the manufacturer's literature.

(8) Estimate the airframe weight by subtracting the radio and power system from the total weight. Be reasonable; don't expect to fly a .40 powered, 6-pound Spitfire on micro-servos! They're okay for small or slow flying planes, but there is every bit of the airloads on the servos and airframe as if there was a "noise maker" powering it. Receiver battery packs should be 225 mAh for 05 to 15-size planes, 450 mAh for 25 to 40-size.

(9) Now comes the big question - can you build your machine at this weight? This means strong, lightweight structures; very little plywood or block balsa (unless it is hollowed out) and very little sheeting. If you are going for an all out "solid surface finish" on a fighter, you will probably be overweight. A partially sheeted wing and fuselage with stringers will give you 90% of the flavor of your subject at substantial weight savings.

(10) The last step is matching the correct propeller to your airplane. Mount your power system on a test stand having the capability to measure amperage (0 - 30 amps or higher); (I think Davey Systems offers a usable one) and rpm (digital tachs work great with electrics due to stable rpm). Check out a variety of props, and select those that come close to your design static current draw (see Step 5).

For reasonably clean monoplanes, the flight speed can be estimated by:
Speed (mph) = rpm (in thousands) x prop pitch (inches).
(e.g., a 12x6 prop at 7,000 rpm would be 6 (inch pitch) x 7 (thousand rpm) = 42 mph.)

The stall speed of our models depends on the wing loading, airfoil choice and surface contour finish, but fortunately is not a very strong function of any of these. At wing loadings of 14 to 25 oz./sq. ft. and the nominal airfoils used in sport scale, an amazingly reliable stall speed estimate is:
Stall speed (mph) = 3.7 x the sq. root of the wing loading (oz./sq.ft.)

In order to just do a nice inside loop, the plane must enter at twice the stall speed. To do clean inside loops, rolls, and other sport-type aerobatics, three times stall speed is needed. Anything over 4 times the stall speed gives "fighter-type" performance and extended vertical aerobatics.

Another factor to consider is the diameter/pitch ratio of the prop. A 1:1 ratio may be usable for high speed pylon racers, but for scale planes and aerobatic types 1.3:1 (*ie. 6 pitch x 1.3 = 7.8" dia. km*) to 1.7:1 (*ie. 6 pitch x 1.7 = 10.2" dia. km*)are better ratios. For high drag or slow-flying aircraft a 2:1 ratio is more suitable (*ie. 6 pitch x 2 = 12" dia. km*). (*Another way to look at the same thing is pitch to diameter ratio, as Bob Boucher does in the Electric Motor Handbook - ie. 8" dia. x .77 [that is the inverse of 1.3] = 6.16 pitch; 10" dia. x .59 [inverse of 1.7] = 5.9 pitch; 12" dia. x .5 [inverse of 2] = 6 pitch.*

The best overall prop brand seems to be Rev-Up. (*The wood Master Airscrews and wood Master Airscrew electric props have been working very well. km*) For small planes the Cox grey 6/4 and 7/3.5 are very good props. Top Flite props work well in the 8-inch diameter and up sizes. Don't bother with Zinger props below a 14-inch diameter, as their squared-off thick leading and trailing edges are very inefficient at our operating speeds.

The final step is to go out and try all of the props that meet the static current draw, flying speed and diameter/pitch criterion. Usually one of them will give the best compromise of performance vs. duration.

So much for the philosophy and/or theory. **Here are several examples** of very successful electric scale planes that were designed using this technique.

Example 1:

(1) Spitfire Mk. Ia'

(2) Span 61", 670 sq.in. area (4.65 sq.ft.)

(3) Use a Clark Y, at a wing loading of 20 oz./sq.ft. Estimated total weight = (20 oz./sq.ft. x 4.65 sq.ft. = 93 oz. or 5.8 lbs.)

(4) Power to hold level flight = (20 oz./sq.ft. x 5.8 lbs. = 116 watts. Power to take off falls between 30 x 5.8 = 174 watts and 50 x 5.8 = 290 watts (probably 200 watts). Power for fighter performance = 60+ x 5.8 = 348+ watts.

(5) I chose a 20 amp static drain, estimating a nominal 5 minutes of aerobatics from 1.2Ah Ni-Cads.

(6) Number of cells = 350 watts divided by 20 amps = 17.5 cells - so an Astro Flite geared 40 on 18 cells would be a good choice.

(7) Weight of the system (motor, gearbox and Ni-Cads) is 50 oz.

(8) Airframe weight = 93 - 50 (power system) - 11 (radio) = 32 oz.

(9) This weight was easy to achieve, in fact, I splurged and installed mechanical retracts (about a 4 oz. weight penalty). The structure looks like a giant rubber model with the fuselage built on the half-shell, built up surfaces, with 1/16 sheeting on the top and front of the fuselage to enhance the looks. I did hit the design weight of 5.75 pounds.

(10) I wanted good performance, so a 1.5:1 diameter-to-pitch ratio was sought. A Rev-Up 11x7.5 turns 8500 rpm at about 20 Amps, giving an estimated speed of 60 mph, and a flight speed to stall speed ratio greater than 3.5, so good performance is indicated. Indeed it flies very well, although it seems to take more power than indicated to just hold level flight. I get 4.5 to 5 minutes of continuous aerobatic and full-power straffing passes.

Example 2:

(1) deHavilland Comet DH88 (twin engine 1934 racing plane.)

(2) 1/6-scale, span: 88 inches, area: 900 square inches (6.25 sq.ft.)

(3) Use a Clark Y, at a wing loading of 20oz./sq.ft. Estimated total weight = (20 oz./sq.ft.) x (6.25 sq.ft.) = 125 oz. = 7.8 pounds.

(4) a.) Power to hold level flight is wing loading times pounds

20 oz./sq.ft. times 7.8 pounds = 156 watts

b.) Power for takeoff is 30 to 50 watts times pounds

30 x 7.8 = 234 watts   50 x 7.8 = 390 watts

(I estimated 250 watts due to tail dragger and larger wheels.)

c.) Power for decent performance 40 to 60 watts times pounds

On the high side; 60 x 7.8 = 468 watts

(5) I chose 20 Amp drain and 1.2 Ah Ni-Cds.

(6) The number of cells that I need = 468 watts (power for decent performance) divided by 20 (my amp draw) = 23.4 (the number of cells). since the Comet is aerodynamically, very clean, I used two direct drive Keller 25/12's wired in series across the 24 cells, so each motor effectively "sees" 12 cells. (*This design now uses two Astro Flight Cobalt 25's km*)

(7) Power system weight is 60 oz.

(8) Airframe weight = 125 oz. (estimated weight) - 60 oz. (power system) - 11 oz. (radio) = 54 oz. airframe weight.

(9) I actually installed Rhom-air retracts (about a 6 oz. penalty) and still came out underweight at 120 oz.

(10) Originally I predicted Rev-Up 9/6 at 9.000 rpm, but the Comet is so clean, I'm now using Rev-Up 9/7 or 9/8. Speed is about 75 mph, and performance is breathtaking! I get 6 minutes of aerobatics and high-speed passes, and at highly reduced power I've made 14 to 16 minute flights, with continuous motor run, no gliding or thermalling. This indicates about 125 watts of power, substantially under the estimated power to hold level flight. I suspect the twin engine efficiency and high aspect ratio wing contribute strongly to this phenomena.

Future Project

(1) Duane Cole's clipped-wing Taylorcraft

(2) 50 inch span, 432 sq.in. (3 sq.ft.)

(3) Use either a Clark Y or NACA 2410. Wing loading 14 oz./sq.ft. Estimated weight = 14 x 3 = 42 oz. or 2.6 pounds.

(4) Power to hold level flight - 14 oz./sq.ft. x 2.6 lbs. = 36.4 watts

(5) Power to take off;

30 x 2.6 = 78 watts to 50 x 2.6 = 130 watts

Power for sport aerobatics (*by KM*)

40 x 2.6 = 104 watts to 60 x 2.6 = 156 watts

Numbers 5 and 6 have been redone by Ken Myers to keep the same format as used above.

20 amp drain for good performance

(6) 156 watts (high power) divided by 20 amps (drain) = 7.8 cells

What Keith actually wrote; Using 7 cells, current is 18.5 amps, so a cobalt geared 05 would be needed. A leisure geared 05 at 16 amps would give 112 watts or 43 watts per pound, still reasonable power for sport aerobatics.

(7) Power system weight = 19 oz. for a geared 05 and seven 1.2 Ah Ni-Cds

(8) Airframe weight = 42 oz. **-** 19 oz (power system) **-** 6 oz. (mini-radio) = 17 oz.

(9) This should be feasible, using a built-up stick structure (ala old timer) covered with Monokote or Micafilm.

(10) Geared 05 systems typically turn an 11/7 at 5800 rpm. With an estimated stall speed of 14 mph, we get a performance ratio of 40 divided by 15 = 2.8, suitable for sport aerobatics.

Well, that's my design philosophy.

Go forth and create your silent Show-stopper. I'd be glad to hear from you about your experiences, Keith Shaw.

Keith Shaw and his incredible flying wing, electric powered, of course. You're only limited by your imagination . . .

Picture 1: page 1 Keith with his electric Spitfire Mk 1A. an excellent flight performer, it has retracts. Powered by an Astro Flight geared 40 cobalt, it has excellent fighter maneuverability and performance.

Picture 2: page 1 The deHavilland Comet cruises on two Keller 25/12 motors which provide fantastic performance power when needed.

Picture 3: page 1 The GeeBee R-1 proves that anything can fly as a successful electric. With a span of 50 inches, a cowl diameter of 10 inches, and wing loading of over 30 ounces per square foot, it demands everything its Astro Flight geared 25 can deliver.