# Warbirds at 1:100 Scale – Part 1
## Supermarine Spitfire
1:100 Scale, 4.4" Wingspan
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4-Channels, fixed landing gear


Steerable tailwheel


Scale 4-bladed propeller


4.4" (11 cm) wingspan

This is the first of two related papers describing the design and construction of very small scale models of warbirds. In this paper the design and construction of a 1:100 scale Spitfire is described. It was inspired by a two-channel plane of similar design by Robert Guillot. Apart from the battery everything in this plane was built from scratch by the author. It has a four-channel Rabbit receiver, using the four channels for elevator, rudder, ailerons and throttle. The design and all the graphics were done using Adobe Illustrator. Construction is from Durabatics foam in three pieces. The fuselage and fin are from one piece, the wing from a second, and the horizontal stab from the third.

Flying weight is 1.7 grams (1/16 oz). It uses a single phase brushless motor based on a 3mm OD x 2mm magnet in a direct drive configuration. The battery is a single cell 10 mAh lipo that fits inside the fuselage. The plane also has rotating wheels on removable landing gear and a steerable 1/8" diameter tailwheel, which provide good ground handling and nice straight take-offs.

**Trim**

The wing is secured with a tab and a magnet, so it pops off easily. There are two versions of the wing for this plane, with and without ailerons. Initial flight testing was done with the non-aileron version. First attempts to fly it from a hand launch resulted in an uncontrollable left roll into the floor. It seems the combination of small scale and the four-bladed prop results in a strong torque reaction. Modifications to give 6 degrees right- and down-thrust, a significant bend of the fin to give lots of right rudder, and judicious twisting of the wings fixed the problem. It now can be taxied around on the floor and does beautifully straight roll outs and takeoffs. It flies fast, but is very smooth and easy to control, at least in left turns. Right rudder turns are a little tricky. After giving right rudder there is a slight delay after which it rolls in to the right unless you quickly react with opposite rudder. Once in a right turn it will happily fly around in circles. Later flights have all been done with the aileron version of the wing. It flies much the same as under rudder-elevator control, but now much faster aileron-elevator turns can be made, and it is well-behaved in both right and left aileron-elevator turns.

Apart from being a very small scale plane it has a number of features that I believe are novel, or at least unusual in a plane of this size. I would be surprised if none of these has been done before, but not to my knowledge.

**Propeller**

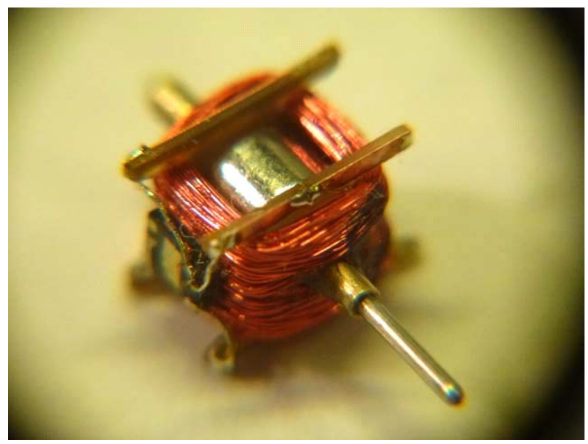
Starting at the front is the 4-bladed prop - I've not seen one on a brushless motor at this scale before. It is made of two almost identical 2-bladed props. One of the props has a raised section at the center to go up and over the other prop. This allows all four blades of the finished prop to be co-planar. The individual 2-bladed props are made from impregnated carbon fiber cloth heat-shrunk to a Delrin mold that was machined on a CNC mill. A whole series of props with varying parameters was made and dynamically tested with the target motor using a turntable. The prop finally chosen has a diameter of 1.1" and a pitch of 0.88". It is very close to 1:100 scale of the 4-bladed props used on some versions of Spitfires.

**Single Phase Brushless Motor**

Much has been said about these wonderful little motors on the RCGroups forum "Brushless Motors in the mg Range". Shagrug described a neat way of building these motors by winding them around the magnet on a pair of formers already mounted on bearings on the shaft. Each former had two pieces of carbon rod attached to hold the wire in place. This makes it much easier to build the motors. You can make the coil wrap the magnet so closely that you would not be able to get it out of the coil afterwards if you pulled the shaft out. I took this idea and developed H-shaped formers that are much easier to make (on a CNC mill) and are made of PC board material with two conducting traces on each former. The four traces provide places to solder the two ends of the coil, the power supply, and the control chip connections. The pictures below show a batch of formers and a finished motor. The magnet is 3mm diameter x 2mm long. The shaft is 0.020" steel hypo tubing.

Motor end formers



Completed motor

**Motor Starting**

The next trick is to get the motor to start every time without having to blow on the propellor. Some motors start almost every time by themselves, but some have a habit of stopping in one of the two places where it needs help to start again. This problem can be solved by sticking a tiny piece of iron onto the coil opposite the chip. This makes the magnet stop in one of two ideal positions for starting again. If the piece of iron is too large the motor won't run, and a magnet is much too strong. This modification does not affect the performance of the motor at all, as far as I am able to measure.

**Motor Mounting and Replacement**

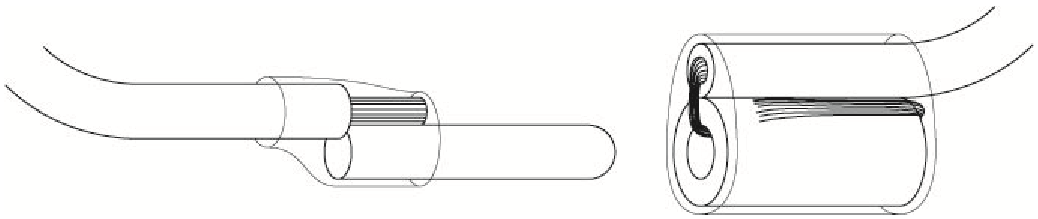
An issue with small planes, especially if you want to experiment with different motors, is how to mount the motor in the plane.  I used to glue the motor to the fuselage, but then removing the motor without wrecking the plane can be difficult.  So, here's a way of mounting the motor that allows it to slide in and snap locked, while still being easy to slide out again.  It's a bit like the bracket on the top of cameras for removable flash units.  The motor is glued to a 1/4" square plate of 1/64" ply, easily done with the motor's formers.  The bracket is made of shrink tube material.  After the plate slides in, a little tab pops up and locks it.  Removing the motor involves depressing the tab with a pin and just sliding the motor out.  The edge of the bracket is outlined with a marker in the picture below so you can see it.

Snap-in motor mount

**Plugs and Sockets**

This leads to the next development – very small plugs and sockets to detatch the motor leads.  Also the wing is removable and the aileron actuators need to be detatched, and the battery needs to be removable.  All the commercial plugs and sockets I can find are too big.  The plugs used on this plane are made of a 0.1" length of 0.010" diameter brass rod soldered to the lead supported with 0.020" ID polyolefin shrink tubing. I use 36 awg multi-strand wire for power leads.  The socket is a 0.1" length of the plastic insulation from 32 awg wire.  The lead wire is stripped, pushed through the insulation then folded back, and the insulated lead wire is also folded against the tubing.  The whole thing is covered with 0.020" polyolefin shrink tubing, see below.  Contact is made by the brass pin being squeezed against the multiple strands inside the plastic insulation tube, see below.  You can see two of them in the picture above of the motor hanging out of the front.

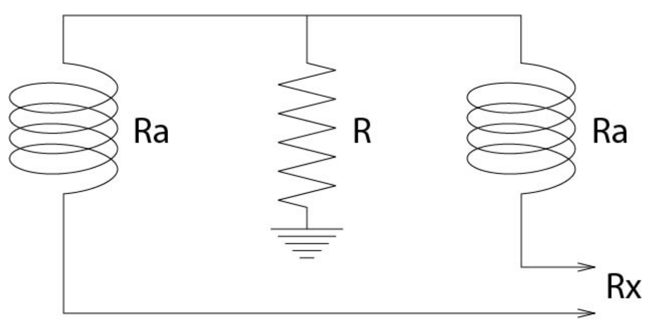
 



Structure of plug and socket

**Ailerons**

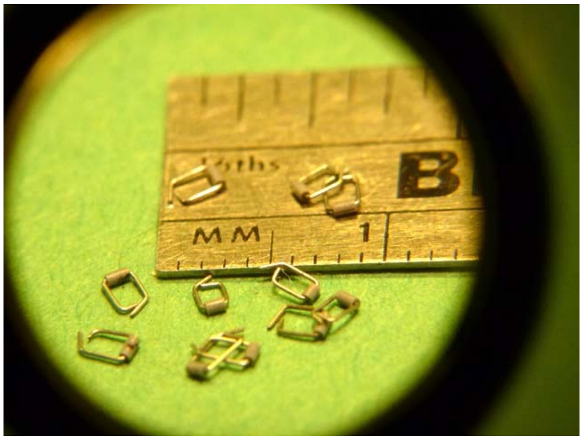
On these small planes I have found you need a lot of differential in the ailerons, or the plane crabs badly to the outside of the turn. In the extreme you can use up-only ailerons. The aileron actuators on the Spitfire are wired in series. If you plug the two free ends into the actuator outputs on the receiver they act as regular up-down ailerons. However, there is a third wire coming from the connection between the two actuators. This can optionally be plugged into a grounded socket in the plane. When the receiver output on one wire goes high, current flows only through the actuator connected to it, and not through the other actuator. This has the effect of neutralizing the downward motion of the ailerons, making them up-only. This is the configuration that has been flown on the Spitfire, and works well, with no adverse yaw tendencies. Further, if you put a suitably chosen resistor in this grounded line you can get differential ailerons with any ratio you like. For example, using a resistor, R, having the same resistance as each actuator, Ra, the current through the actuator connected to the output that stays low will be divided in half, giving 50% aileron differential. This can be handy for experimenting with different amounts of differential.




Down aileron / Up aileron = R / (Ra + R)

**Control Surface Hinges**

I have used thin plastic hinges with some success, but I find them very fiddly, and difficult to adjust the springiness.  They can also be rather fragile, which is bad for a steerable tailwheel where the hinge on the rudder has to support the rear of the plane. The Spitfire uses proper hinges made from a rectangle of 0.008" nickel wire and a 1mm length of 0.4mm plastic tube.  The wire is glued into a slot in the fixed surface, and the moving surface is glued to the tube.  They weigh just 1.6mg each and are virtually friction free.  Here is a batch of them, and one installed on an aileron.




Control surface hinges

Installed hinge and centering spring

**Control Surface Centering**

Having achieved virtually frictionless hinges we now need a way to provide spring centering.  I like magnetic centering for the surfaces, but have had some difficulty with in-surface actuators with the control surface distorting over time because of the constant pull of the centering magnet.  I found a paintbrush with very fine, tapered nylon bristles that are quite springy.  One of these goes through an edge-wise hole in the control surface and into the fixed surface.  By adjusting how far it is pushed in, the amount of maximum deflection can be tested and adjusted to just where it is wanted.  Then a dot of glue where the bristle exits the control surface locks it in.  You can see one sticking out the back of the aileron in the picture above.

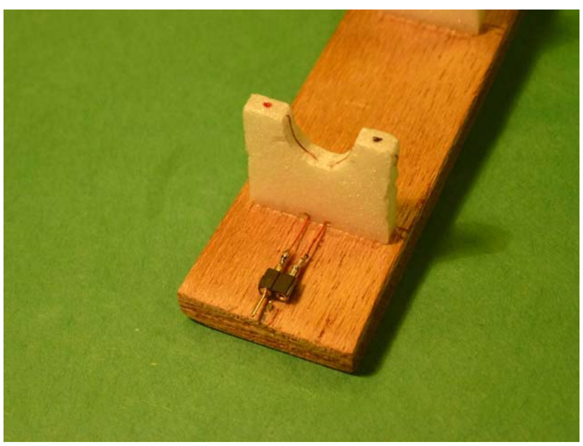
**Battery Issues**

The battery is connected internally through a plug and socket, but it is not convenient to turn power on and off using those connectors.  Therefore there is a lever switch built into the plane, with the top of the lever protruding above the fuselage just in front of the canopy, see below.  It is quite easy to operate with a thumbnail or fingernail.

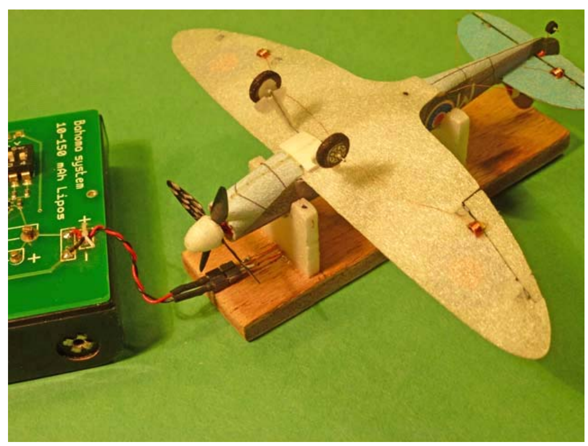
 

Power switch and charging conductor

The other battery-related issue is in charging the battery. Again, the socketed battery can be removed for charging, but that is difficult in the field, and disturbs the wiring to the ailerons. Instead the battery terminals are brought out to the outside of the fuselage as short lengths of 38 awg copper wire. One of them is visible immediately behind the exhausts in the picture above. These make contact with conductors embedded in the work cradle shown below. Charging involves just placing the plane onto the work cradle and plugging it into the charger.



Charging and work cradle



Charging

That completes the "novel" features of this plane. It has now successfully completed numerous flights, with taxiing out, ROGs, landings, and taxiing back, and really is fun to fly.

**Acknowledements**

To Robert Guillot for talking me into building scale airplanes and showing the way to making scale aircraft at this size.  Thanks go to Matt Keennon for introducing me to the delights and challenges of muscle wire, and for use of the gym in Simi Valley.  Thanks, also, to the Blacksheep Squadron for putting up with my pesky RC planes at their indoor meetings in Burbank.  Richard Cox gave me much good advice about electronic issues. Also to Brian Daniels for many stimulating and encouraging discussions.

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