Warbirds at 1:100 Scale – Part 2
P-51 Mustang, 8 Channel Radio

Actually 1:96 Scale, 4.6” Wingspan

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5 inch wide glasses

Flaps full down

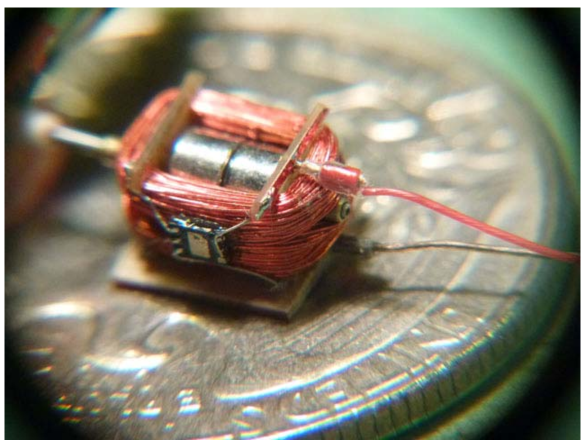
Clean underside

Best Micro Aircraft at NEAT 2013

This is the second of two related papers describing the design and construction of very small scale models of warbirds. In Part 1 details were given of a 1:100 scale Spitfire using a 4 channel Rabbit receiver controlling the standard throttle, rudder, elevator and ailerons. In Part 2 the design and construction of a 1:96 scale P-51 Mustang is described. It was also inspired by a two-channel plane of similar design by Robert Guillot, and started with his design files, scaled down. This plane includes almost all of the features of the Spitfire, but uses an 8 channel Rabbit receiver to extend the set of controls beyond the standard four, to include flaps, retracts, operable navigation lights and cannons. Again, apart from the battery everything in this plane was built from scratch by the author.

The one feature not carried over from the Spitfire is the propeller. Inefficencies in the scale-profile four-bladed propeller defied all attempts to produce enough thrust to fly the plane. Therefore a two-bladed propeller is used for flying, based on a more modern high-efficiency design using a Larrabee profile.

Flying weight is 2.9 grams (1/10 oz), which is significantly heavier than the Spitfire, hence the different scale factor to give about 8% more wing area. It also uses a single phase brushless motor but a double magnet measuring 3mm OD x 4mm and with a 6.5 ohm winding. I call it the “Merlin”. This motor represents a further development over the one in the Spitfire in that it integrates the plugs into the end formers PC board. The battery is a single cell 20 mAh lipo that fits inside the fuselage.



The “Merlin” motor plugged in

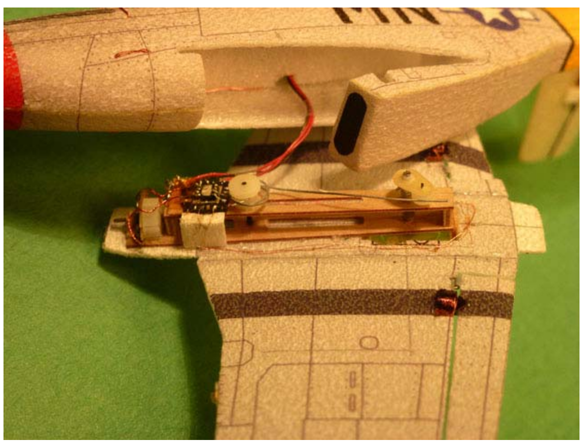
Retracts

By far the most difficult part of this plane was the retracts. The size and weight restrictions meant that the retracts had to be designed from scratch specially for this plane. Relative to control surfaces, retracts require high forces. They need to incorporate devices for locking the wheels in both up and down positions. Since the retracts may stay in either the up or down position for extended periods of time, the mechanism must require no power in order to stay in either of these positions. Finally, we want as much of the mechanism as possible to be housed inside the fuselage.

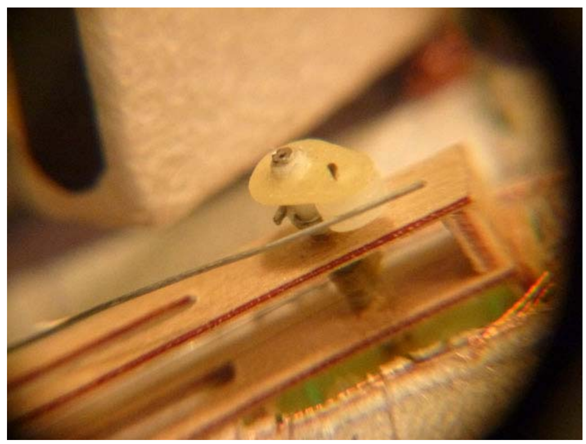
The solution adopted uses 0.001” diameter Nitinol “muscle” wire. Muscle wire has the property that it can be stretched about 5%, then when it is heated above a critical temperature by passing a current through it, it exerts a considerable force in attempting to contract back to its original length. By using two lengths of muscle wire, a pull-pull mechanism can be built, in which the contraction of one wire has the effect of stretching the other, while at the same time actuating the retracts.

Unfortunately this appealingly simple mechanism is fraught with implementation issues when trying to meet the design requirements. One of them is that after stretching one wire by contracting the other, when the current is stopped the contraction recoils about 30%. Therefore a lock is needed to keep the wire fully stretched. Then a second lock is needed to secure the landing gear up or down, so that sharp sideways forces do not result in any forces back on the muscle wire, which could collapse the landing gear.

These requirements were met with a unit that weighs about 400 mg. The muscle wires rotate a 0.030" diameter capstan 90 degrees. The muscle wire recoil is countered by an over-center spring acting on an idler at the end of an arm attached to the capstan.

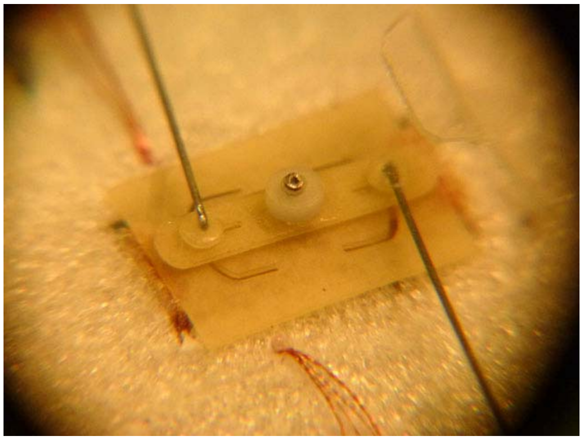


Wing processor and retract mechanism

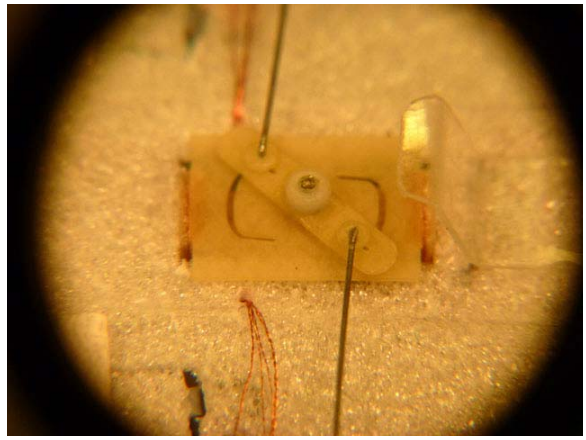


Over-center spring

The capstan drives a two-ended slotted arm which drives two pins in the slots, one for each wheel. Those pins also slide in fixed U-shaped slots that are shaped to reduce the motion of two pushrods to zero for about 15 degrees at each extreme of the rotation. This has the effect of locking the landing gear in the up and down positions.



U-lock slots



Arm position at gear down

When the retracts are activated, a microprocessor on the wing (more below) ramps up the current through the appropriate muscle wire to the maximum value, holds it there for ½ second, then cuts it to zero. The maximum current is about 30mA. It was hoped that this would give a smooth motion to the retracts, but the over-center spring causes the motion to be a little jerky.

The main part of the retract mechanism is mounted on the center section of the wing, inside the fuselage. The slotted arm and U-slots are below the wing, but are hidden in the oil cooler housing that is a defining characteristic of the P-51. This leaves only the pushrods to the landing gear legs visible under the wing.

Landing gear down

Landing gear up

Flaps

The flaps are implemented using magnet and coil actuators, much like the other control surfaces. Two actuators are used, one for each flap, wired in series. The resulting 300 ohms draws a current of about 12 mA to hold the flaps full down. Several mechanisms were considered to avoid this current, but size and weight constraints defeated them. Consequently, flaps should be used only for a brief time while landing under reduced throttle. Slow motion travel of the flaps is currently implemented in the transmitter.

Navigation Lights

The navigation lights are implemented as size 0402 red and green LEDs on the wing tips. They are actuated by a transmitter switch that can switch them on, off, or flashing once a second. The flashing is implemented in the wing microprocessor, described below. The lights are much brighter and with more intense colors than the pictures below show.

Wing tip navigation lights

Cannons firing

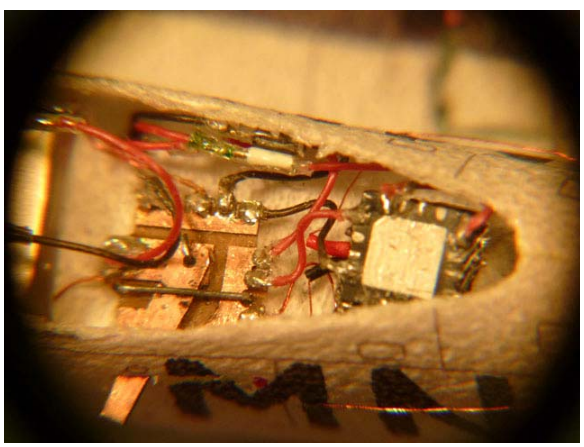
Wing-mounted Cannons

One cannon is mounted on each wing, see above right. Each cannon is just a size 0402 orange LED, flashing 8 times per second while a button on the transmitter is pressed. The flashing is implemented in the wing microprocessor. It proved too difficult to implement a sound generator with sufficent volume on a plane of this size. Instead, appropriate cannon sounds are generated at the transmitter in time with the orange flashes. This can be quite effective, especially if the transmitter is kept some distance from any spectators.

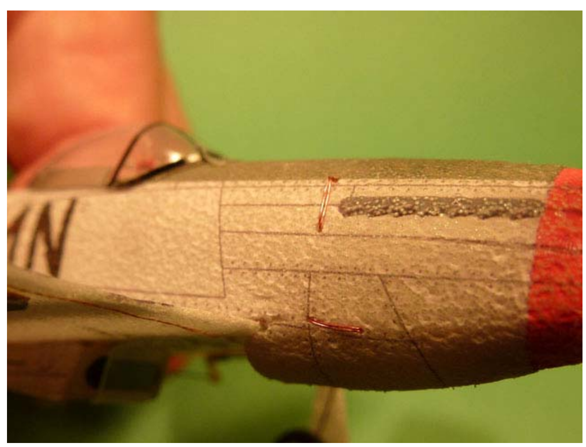
Wiring

One of the biggest issues in a plane of this complexity is handling all of the wiring and inter-connections. Three of the eight channel controls, rudder, elevator and throttle, reside in the fuselage. The other five reside on the wing. The wing is removable to provide access to the retract mechanism and wiring to the other wing functions. If all the functionality had been implemented in the receiver microprocessor the resulting amount of wire and plugs and sockets going to the wing would have been unworkable. Also the receiver microprocessor would have needed to be replaced with a larger one providing more output pins. Instead, a separate microprocessor was installed on the wing. The receiver microprocessor sends all eight digital channel values to the wing microprocessor via an RS-232 serial connection at 50 frames per second. This requires only three wires, which can be disconneted using the same type of micro plugs and sockets described in the earlier article. The wing microprocessor then picks out the five channels that it implements and generates the necessary control signals to the various devices. The wiring and the wing microprocessor can be seen in the picture of the retract mechanism above.

Another issue with the amount of wiring is the need to connect multiple wires to the same conductor. This is especially true of ground connections. Common solutions include a bank of plugs and sockets (too big and heavy), attempts to solder multiple wires to the same connector, and twisting all the common wires together before soldering. Either of these last two approaches make it very difficult to solder or unsolder a single wire. The solution here uses the main power switch, which is implemented as a lever switch sliding on a PC board base. The PC board was extended to provide 11 terminals, two of them for pre-switch positive, 4 for post-switch positive, and 5 for ground connections. This greatly simplified wiring everything up.



Switch/terminal bank and Rabbit receiver



Charging and external power contacts

Charging and Testing

As on the Spitfire, the P-51 has two conductors on the front upper fuselage connected to the battery terminals, to contact conductors in the charging cradle. This saves having to plug and unplug the battery in the plane to charge it. The P-51 goes a step further by having another pair of conductors on the front lower fuselage connected to the power wires after the switch, to contact a different pair of conductors in the charging cradle, see above right. These provide for using an external power source, like a large single cell lipo, when checking out the plane's functionality, and for giving non-flying demos without discharging the small internal battery.

Transmitter

The transmitter usually used with this plane is shown below. It is a heavily-modified Plantraco AM2 transmitter. Apart from reprogramming it to support the Hip-Hop 900 Mhz frequency hopping radio system, it has four extra switches and a push-button to control all eight channels. It has been enhanced with an LCD screen to provide display of the many extended parameters like 50 model memory, dual rates, expo, various mixes, servo reversing, servo slow motion and range checking. Finally it has an audio module driving a loudspeaker on the back to provide the cannon sounds mentioned earlier. This module is just another microprocessor and FET transistor that generates bursts of pseudo-random noise while the push button is pressed.

Re-engineered Plantraco transmitter

Added speaker

Flying

It took many attempts to get the P-51 to fly. Using experience from the Spitfire, it turned out to be well trimmed right from the start. However, it was underpowered. A progression of motors and propellers was developed, each one improving the length of the powered glide by a little. But it was only by increasing the battery to 20mAH, 20C, and a 6.5 ohm motor turning the fifth generation of a two-bladed propeller, that the little plane achieved sustained flight with less than full throttle. It flies relatively fast, due to the high wing loading, but is quite controllable in the air. Controlled taxiing, nice straight ROGs, firing the canons while airborne, and wheels-down landings with flaps down, followed by taxiing back to the flight line, have all been accomplished. Having the flaps full down does allow it to fly a little slower while staying under control. To achieve stable flight the trick is to allow it a long take-off run to get up to speed, and then flying fast. Hand-launched flights are more consistent than ROGs. It looks great in the air, especially with the navigation lights on and the cannons firing.

Details

Specifications

Scale	1:96
Wingspan	4.6 in (11.7 cm)
Weight	2.9 grams (0.1 oz)
Radio	8 channel Rabbit Receiver, 900 Mhz FHSS
Controls	Ailerons, Elevator, Rudder, Throttle, Flaps, Retracts, Navigation lights, Cannons
Battery	20mAh Lipo
Motor	Single phase, 6.5 ohm, 38 awg
Length of wire in motor	10 ft
Propeller	2-bladed, 1.25” Dia, 0.9 P/D ratio, carbon
Control surface actuators	150 ohm, 0.1” dia, 50 awg
Length of wire in each actuator	14 ft
Retracts	0.001” Nitinol wire, locking

Performance

Airspeed	14 mph
Scale airspeed	1350 mph, Mach 2
Propellor speed	18,000 rpm
Propellor tip speed	67 mph
Main wheels rotation at take off	18,800 rpm

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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