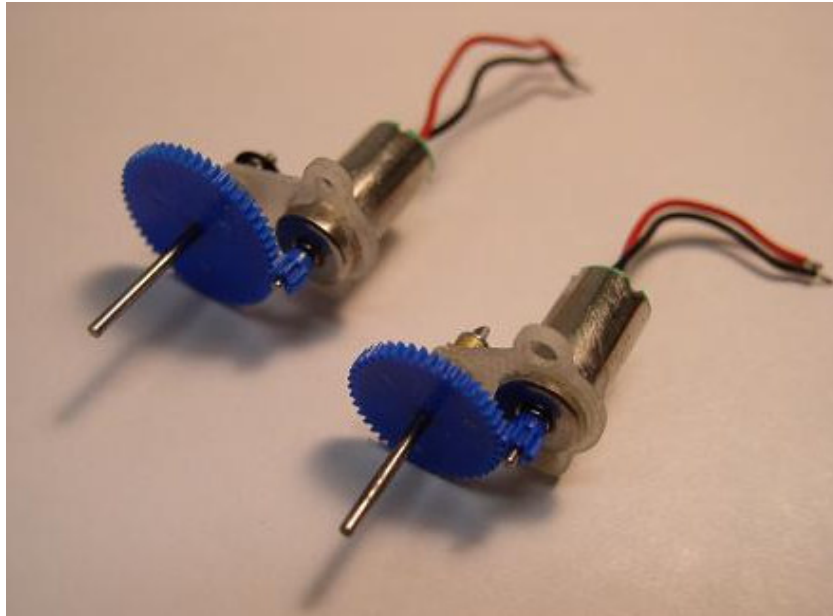


Falcon Models PU03 & PU04 Pager-Motor Propulsion Sets

By Gordon Johnson

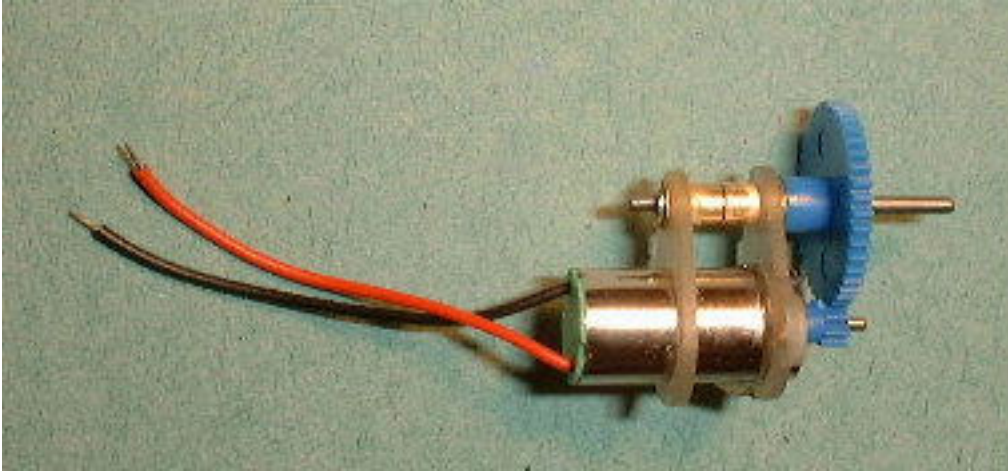


In the fall of 2003 Falcon Models introduced their PU03 and PU04 pager motor propulsion sets. At that time both used a 10 ohm 6x15mm Namiki pager motor. Since then the Didel 4.5 ohm 6x12mm motor has revolutionized the small end of the micro RC plane spectrum with its higher power output. The higher power output also brings with it higher amp draw, but it is still well within what the E-Tec 90mAh LiPoly cell can supply (see the October 2003 RC Microflight ET-90 article). So, it's a good tradeoff. Falcon has responded by switching the higher geared 6.5:1 PU04 to the lighter and more powerful 4.5 ohm Didel motor. The lower geared 5.25:1 PU03 is now available with either the Namiki or the Didel motor. You can tell if you have the 4.5 ohm motor as the plastic back bell on the motor is green, while on the Namiki motors it is black. My focus here is on the versions with the Didel pager motor. Since beginning this article Falcon has improved the gearbox yet again. They have added a second prop shaft support at the back of the motor with its own brass bearing. The PU03 and PU04 are available direct from Falcon or their distributors, Bob Selman Designs in the US. The rest of this article is devoted to understanding these very nice propulsion sets and how to get the most out of them.

Gearbox Construction

Both gearboxes use custom molded 0.25 modulus gears. These are very high precision gears and they run very quietly. The sound in flight with either gearbox is just a whisper. For those wishing to construct their own gearboxes Falcon also sells gear sets separately. Both gearboxes use an 8 tooth pinion. The PU03 uses a 42 tooth spur gear to obtain a 5.25:1 gear ratio and the PU04 uses a 52 tooth spur gear to obtain a 6.5:1 gear ratio. The new style main gearbox housing consists of two pieces CNC machined from fiberglass

sheet. The motor is glued in the larger opening of each piece, and a brass bearing is glued in the other. This insures precise alignment and spacing of the gears. Although I haven't needed to replace the motor, it should be possible to dissolve the glue and remove the motor should replacement be necessary. A 1mm piano wire prop shaft passes through the spur gear and the brass bearing and is retained at the back by a washer and a flattened end of the shaft. The fiberglass housing has two holes on either side that allow mounting the gearbox either on two carbon fiber rods or into a bulkhead with screws. The old style PU03 weighs 1.73g and the PU04 weighs 1.85g. The new style with two bearing supports will weigh slightly more.



The new style two-support gearbox, which came out while this article was being written.

Gearbox Oiling

Initially I assumed the Falcon Gearboxes were pre-oiled and ready to go. It turns out the gearbox is not pre-oiled. Later gearboxes now have a note about oiling in with them. To get an idea of the importance of oiling, a PU04 with a GWS 5x3 prop will develop about 10g thrust if not oiled and about 14g thrust if oiled. To oil the gearboxes simply press on the spur gear with both thumbs with the prop shaft down on a table. With the gear moved partially down the shaft, apply some light oil like 3-in-one household oil to the shaft, slide the shaft back into the bearing, and press the gear back up the shaft with the back end of the shaft against a table surface. Try to avoid getting oil on the part of the shaft where the gear will be pressed back on. It may be possible to get enough oil in the bearing without moving the gear, but I have not tried this.

Props and Mounting

The higher geared PU04 comes with a special KP00 folding 96mm prop that presses on the 1mm prop shaft. The PU03 comes with a smaller non-folding 80mm U80 prop that also presses on the shaft. There are GWS props that might be good candidates to use with these propulsion sets. However, most of the smaller GWS props have a 4mm bore which makes using them with a 1mm shaft difficult. Bob Selman Designs has just introduced a set of six molded prop adapters (two of each size) that will convert the 4mm

bore GWS props to a press fit on three different small shaft sizes: 1mm, 1.5mm, and 0.046 inch. With these a wider variety of props can be used with the Falcon propulsion sets.

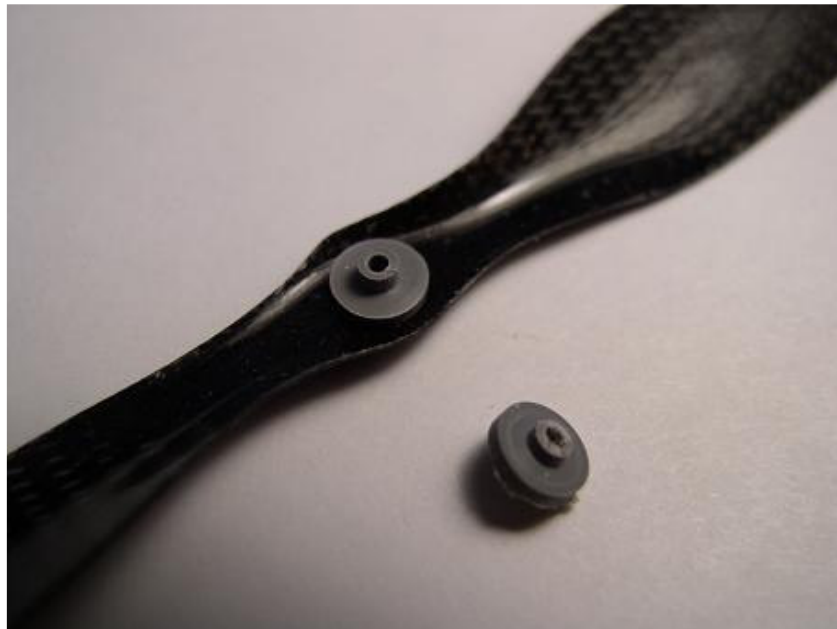


The new Bob Selman Designs prop adapters. Two of the six adapters allow the popular GWS 4mm bore props to be used with a 1mm shaft.

On pager-powered planes weight is everything. One area where weight can be saved is the prop. Some new carbon fiber props have recently become available that are well suited to the PU03/04 gearboxes. Stefan Gasparin and his associates in the Czech Republic have recently introduced a very nice family of carbon fiber props under the name MCF props. These come in 5x3 and 4x3 sizes. Each size is available in a “wide”, “narrow”, and “historical” blade. The MCF props are very light and range from 0.37 to 0.53 grams. I only test the wide and narrow blades here. The MCF props are available in the US from Bob Selman Designs. The props come with a hole in the center of the prop and are designed to be mounted on the Gasparin gearboxes which have an integrated thread-on prop retainer. For the Falcon gearboxes something else is required. For my tests I machined a small plastic prop adapter with a shoulder that inserted through the hole in the prop from the back side, and then was glued in place. Similar molded plastic prop adapters will soon be available from Bob Selman Designs.



The new lightweight MCF carbon fiber props come in 5x3 and 4x3 sizes. Each is available in “wide” and “narrow” blade versions. These props will be available from Bob Selman Designs in the US.



To mount the MCF props on the 1mm prop shaft I machined plastic hubs which were then glued on the back side of the props, allowing a press fit on the prop shaft. Bob Selman will be offering similar molded adapters for use with these props.

WES Technik in Germany has long been known for their beautifully crafted carbon fiber props. RC Microflight contributor John Stennard sent WES Technik a PU04 propulsion set and asked if they could develop a prop for it. I also sent WES Technik static tests for

the PU04 with various props. The result is the 4.8x3.1 prototype prop in the picture below. It has an integrated hub that press fits on the 1mm PU04 prop shaft and weighs a mere 0.51g compared to a GWS 5x3 prop with BSD adapter at 1.55g. Please note that the prototype prop shown here does not have the highly polished and perfect finish that production WES Technik props are noted for. Nevertheless John was able to test the prop on his Quick Junior stick plane with a PU04, with great success, and I have been able to perform static tests with it. The prop performs very well, which is as expected since it was optimized specifically for the PU04 propulsion set. The prop has a very nice shape with pointed Schuman tips similar to most of the larger WES Technik props. This prop will be available in the US from Dave Lewis of Homefly.com.



The WES Technik 4.8x3.1 carbon fiber prop has an integrated hub for press fitting on 1mm shafts and is optimized specifically for the PU04.

Static Tests

Some time ago my friend Joachim Bergmeyer derived a set of formulae (see the February 2003 Inside Story column on www.EzoneMag.com) that allow measuring and calculating motor constants. Roger Carignan extended Jochen's formulae slightly for no-load measurements to increase the precision. I used these formulae and techniques to derive the theoretical max power and max efficiency RPM levels for the 4.5 ohm Didel pager motor at 3.6 volts. Without going into a lot of detail, at a given voltage level knowing the RPM where the motor achieves its max efficiency and the RPM where it achieves its max output power, in Watts, helps us interpret static test results and choose the prop for our model for either of the two gear ratios. The top panel in the table gives the max efficiency and max power values for the Didel 4.5 ohm pager. Thus we can see that at 3.6 volts under load for the ET-90 cell the motor develops its max power output of 0.64 watts at 23,500 RPM. We can also see that at this RPM it is 43% efficient and has an amp draw of 0.41 amps.

Before going over the static test results it is worth noting that in general lower pitch props tend to show up better in static tests. If we are selecting a prop for a higher speed or possibly aerobatic plane we might find that a lower pitch prop looks great in static tests but performs poorly in flight. However, most pager powered models are probably not going to be highly aerobatic or fly at very high speeds. Thus the static test results will be reasonably relevant. But, if you are building a plane that is not a typical slow flying indoor plane you may need to experiment with different prop pitches on the plane to

determine what works best in flight. The Selman prop adapters should make this easier to do.

The lower panel in the table below has the results of static tests for the PU03 and PU04 with the props that come with them as well as a variety of other props, where the GWS props use the Bob Selman prop adapters. Both prop and motor RPM are given. In general for single engine planes, unless we are concerned primarily with duration, at 3.6 volts we will want to prop the motor so it operates reasonably close to its max power RPM of 23,519. Additionally we should never operate the motor at less than its max power RPM (for a given voltage), otherwise thrust will decrease and power consumption will increase. At max power efficiency for this motor is 43% compared to the max efficiency of 52%. With LiPoly cells like the E-Tec 90mAh duration isn't a problem and we can prop for something close to the max power instead of max efficiency. In contrast, if we are building a plane with more than one motor/prop we may want to prop the motor closer to the max efficiency RPM if thrust is not a problem, but amp draw from the battery is.

Falcon PU03/04 with Didel 4.5 Ohm Pager at 3.6 Volts							
			Predicted Motor Measures				
			Amps	Efficiency (%)	Power (W)	Motor Rpm	
MAX EFFICIENCY			0.23	52.4	0.50	32,818	
MAX POWER			0.41	43.4	0.64	23,519	
Prop & Gearing			Static Measurements				
Prop	P/D	Prop Wt	Amps	Watts	Thrust (g)	Prop Rpm	Motor Rpm
PU04, 6.5:1 Gearing							
GWS 4x4	1.00	1.07	0.37	1.33	9.8	4,200	27,300
KP00 96mm, 3.7x2.8	0.76	1.00	0.35	1.26	9.9	4,320	28,080
Gasparin 4x3 wide	0.75	0.40	0.26	0.94	10.2	5,130	33,345
GWS 4.5x4	0.89	1.35	0.39	1.40	11.4	3,750	24,375
Gasparin MCF 5x3 wide	0.60	0.53	0.40	1.44	12.5	3,510	22,815
Gasparin MCF 5x3 narrow	0.60	0.49	0.37	1.33	13.2	3,930	25,545
GWS 5x3	0.60	1.44	0.36	1.30	14.0	3,960	25,740
GWS 5x4.3	0.86	1.56	0.41	1.48	14.1	3,420	22,230
Westtechnik 4.8x3.1	0.66	0.51	0.40	1.44	14.0	3,720	24,180
PU03, 5.25:1 Gearing							
U80 3.2x2.0	0.63	0.68	0.27	0.97	7.8	6,870	36,068
Gasparin MCF 4x3 narrow	0.75	0.37	0.36	1.30	9.8	5,490	28,823
Gasparin MCF 4x3 wide	0.75	0.40	0.37	1.33	10.5	5,220	27,405

* MCF prop weights include my plastic prop hubs.

Looking first at the PU04 with the supplied KP00 folding prop we see that it delivers 9.9g static thrust. The motor RPM is reasonably close to the max power RPM. And, the amp draw of 0.35 amps is well within the max amp draw of 0.5 amps for the E-Tec 90mAh cell. So, this prop is a good choice for this gearing. However, if more thrust is

desired, and the model can handle a larger diameter prop, the GWS 5x3 prop, which has a lower pitch/diameter (P/D) ratio, results in a lower motor RPM but a much higher static thrust of 14g. Amp draw is marginally higher at 0.36, but this is not a problem. In my experience, curved undercamber carbon fiber props pull slightly higher amps than equivalent molded GWS props, deliver slightly less thrust, but are substantially lighter. The new Gasparin MCF 5x3 CF prop, has lower thrust, and marginally higher amp draw. It is a good substitute for the GWS prop. But its weight is just 0.6g compared to 1.55g for the GWS prop with BSD adapter. Since weight is everything with micro pager-powered planes, the weight savings can be a substantial portion of a plane's all-up-weight. On a 15g plane, going from the GWS 5x3 to either the Gasparin MCF or WES Technik CF prop results in a 6% reduction in weight. But, the coolness factor is "priceless." Of the two 5x3 Gasparin props the "narrow" blade prop pulls less amps and has a higher RPM, and thus higher thrust of 13.2g than the "wide" blade's 12.5g. So, the narrow blade prop is the better overall choice in terms of static tests.

The WES Technik prop has a very different blade shape than the Gasparin MCF props, a slightly smaller diameter, but a bit higher P/D ratio. The result of all this is a prop that puts out the same thrust as the GWS 5x3, but at a slightly higher amp draw. The motor RPM of 24,130 is an almost exact match with the max power RPM of 23,519. This comes as no surprise as this prop was specifically developed for the PU04.

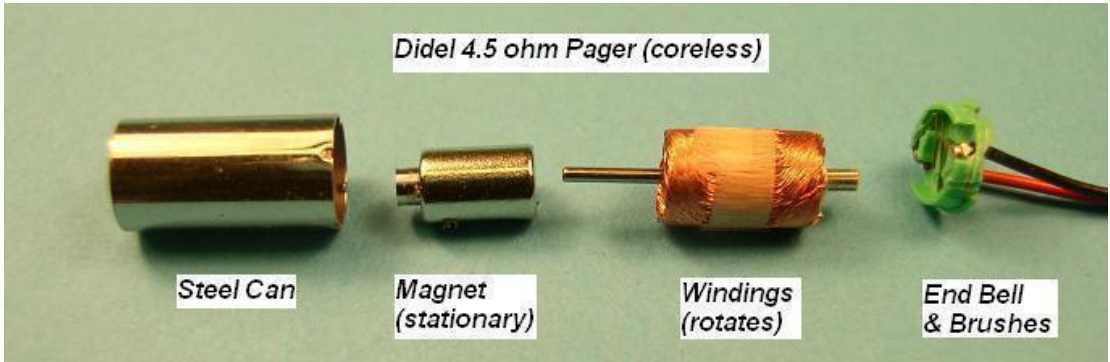
In summary, any of the GWS 5x3, Gasparin 5x3 narrow, or WES Technik 4.8x3.1 props are a good choice for the PU04 if a bit more thrust is desired. The CF props will save weight, but are more expensive. In the US the Gasparin MCF props are likely to cost about \$12 without adapter and the WES Technik prop is likely to cost about \$25.

Next let's look at the PU03. With its lower 5.25:1 gearing it won't be able to turn as large a prop as the PU04. The supplied U80 prop generates 7.8g of thrust. However the motor RPM of 36,068 is considerably above the max power RPM. If the model being built will fly on this thrust this is a perfectly acceptable combination. If, however, more thrust is needed a larger prop is needed. The problem is there are fewer appropriate props to choose from in this smaller size. I tested the GWS 4.5x4 and 4x4 props. The motor RPM for either was considerably below the max power RPM and the motor ran hot. So, those props are not good choices for the PU03's gearing and I have not included those results in the table. The two Gasparin 4x3 props move the motor RPM down much closer to the max power RPM. Here the "wide" version of the prop gets the nod with a 10.5g thrust and motor RPM of 27,405 that is much closer to the max power RPM. Thus, the U80 prop is a good cost-effective prop for the PU04. The Gasparin 4x3 prop has a more reasonable P/D and weighs just 0.4g, even less than the U80's 0.68g. So, if more thrust is needed the Gasparin 4x3 carbon fiber prop is a good light-weight choice.

Pager Motor Overview and Longevity

The Didel 4.5 ohm 6mm pager motor is a coreless motor. Pager motors are a class of inexpensive motors originally used to power a vibrating alert in pagers and cell phones. The picture below shows the Didel pager motor after it has been taken apart. There is a steel can that has the stationary magnet permanently attached to the inside of the front

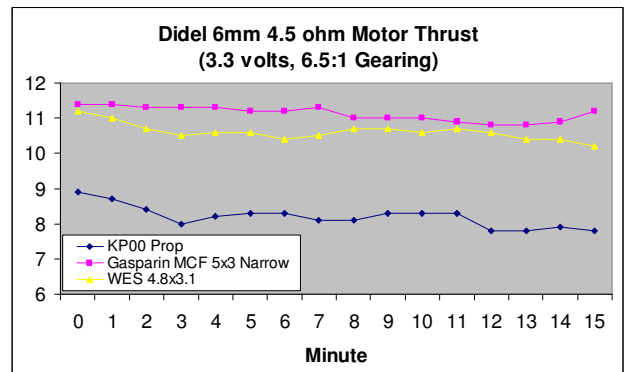
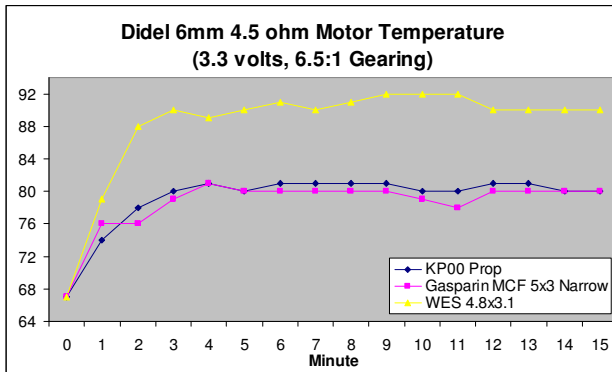
bell. A set of coreless windings fit over this magnet and a small plastic plate attaches the windings to the commutator. A shaft passes through the commutator, through bushes within the stationary magnet, and out the front bell. Essentially the windings are a drum that rotates around the magnet.



In a coreless pager motor the windings rotate around a stationary magnet. In a

Coreless pager motors are very inexpensive and don't have the precision or materials that, say, a \$40 DC5-2.4 coreless motor has. They are mass produced in extremely large quantities at very low prices. A pager motor cannot be abused the way a M20 motor like that used in the KP00 propulsion set can be. Running a pager motor at excessive RPM can result in centrifugal force causing the rotating windings to hit the motor casing. Once this happens the motor is likely to be fatally damaged. Never run the PU03/04 without a prop, and avoid under propping propping such that motor RPM are too high. Coreless motors are also not as good at dissipating heat as conventional motors. If a pager motor is run for extended periods at a high amp draw it may heat up too much and burn out.

To evaluate the heat issue for this motor I ran tests over time at 3.3 volts for the PU04's 6.5:1 gearing for the KP00 folding prop it comes with, as well as the MCF 5x3 narrow and the WES Technik 4.8x3.1. The 3.3 volts is a higher voltage level than the ET-90 cell can sustain at full throttle past the second or third minute. Thus, these tests represent a "stress" test at higher volts than would be possible under normal flying conditions with an ET-90 cell.



The KP00 prop at 6.5:1 gearing and 3.3 volts pulls 0.33 amps, the Gasparin MCF 5x3 narrow pulls 0.35 amps, and the WES 4.8x3.1 pulls 0.37 amps. The left graph above shows that temperature quickly levels off at 80 degrees Fahrenheit for the KP00 and the Gasparin 5x3 narrow. But, for the WES prop it levels off at around 90 degrees. With just a 0.02 higher amp draw the temperature rises by 10 degrees. However, 90 degrees is far from what we might describe as a motor running "hot". The graph to the right shows static thrust for all three props over time. In all cases the thrust drifts down as the motor heats up. But, even for the higher amp draw WES prop the drift is reasonable. This is additional evidence that heat induced fade is not a huge problem.

These stress tests indicate that the Didel 4.5 ohm motor can stand up to gearing and props with up to about a 0.37 amp draw at 3.3 volts. This doesn't mean the motor will take this abuse forever. Remember, we are using this motor at voltage levels and loads that far exceed the manufacturer's specs. But, since replacement motors typically cost less than \$4 we can afford to replace them periodically.

Suitable Planes

The PU04 with its need for larger props may be better suited to stick type planes that don't require a scale size prop, or for larger but very light scale planes. For an example of a stick plane suitable for the PU04 see my Quick Junior in the October 2003 RC Microflight article on E-Tec 90mAh cells. Plans and construction article for this plane can be downloaded from the December 2003 Inside Story column on www.ezonemag.com. Or, by the time you read this the Quick Junior with the PU04 propulsion set will be available in kit form from Bob Selman Designs.

To test the lower geared PU03 in a scale plane with its requirement of a smaller diameter prop I built a 13-inch all Depron semi-profile Citabria. Weight is just 16.8g. The graphics, which were done by my friend Chris O'Reily, are printed on tissue and then applied to the plane. The other equipment is a JMP Combo receiver, a pair of Bob Selman MinAct's, and an E-Tec 90mAh LiPoly. The prop is a 3.5x2.7 carbon fiber prop I molded for this plane, but the Gasparin MCF 4x3 wide prop would work well. Wing area is 37 square inches. The Citabria flies quite well, has plenty of power, and with its low wing loading of just 2.3 oz/sq.ft, it can fly quite slowly and take advantage of a single basketball court gym. A wide variety of scale planes could be built with similar dimensions and equipment. Why not try one for your next micro model?



The PU03 propulsion set is put to good use in my 13-inch span, 16.8g, all Depron semi-profile Citabria.