Understanding Scale Speed
By
Bob Boucher

The Technique of building beautifully detailed aircraft scale models has advanced greatly in the past decades. Unfortunately we have all witnessed the flight of under powered models that best can be described as an accident waiting to happen. Armed with the proper knowledge we can avoid making these expensive mistakes. This paper will derive the basic scaling laws which if followed will insure good flying behavior. With proper scaling a model can be built that replicates the flying characteristics of the original full size prototype. It will execute all maneuvers in scale dimensions. If you want to build your next model so that it will take off in scale runway length, will perform a scale size loop and fly at scale speed then read on!

Keith Shaw's with his famous Gee Bee Racer
Powered by an Astro 25 geared motor

Scale Weight

If a construction drawing of a full size airplane were reduced in scale and used to build a scale miniature from the very same materials as the full size airplane, then all the surfaces would be reduced in area by the SQUARE of the scale factor and the thickness of all the materials would be reduced by the scale factor. The net result would be that the VOLUME of materials used and therefore the weight of the materials would be reduced by the CUBE of the scale factor. This scaling law is expressed in Rule 1.

RULE 1. The weight of the scale model should be equal to the weight of the full size airplane times the cube of the scale factor. For example, a Piper J-3 Cub weighs 1000 pounds and has a 36 foot wing span. A six foot model of the Cub would be 1/6 scale and therefore should weigh 1000 / (6 x 6 x 6) = 4.6 pounds at scale weight. A quarter scale model of the same Cub should weigh 1000 / (4 x 4 x 4) = 15, 6 pounds. The model airplane may very well be built from very different materials than the real airplane; nevertheless the weight of the finished model should be conformity with RULE 1.

Scale Wing Loading

Since the wing area of the model is reduced by the square of the scale factor while the weight of the model is reduced by the cube of the scale factor it follows that the wing loading is directly proportional to the scale factor. For example the wing loading of a quarter scale model will be ¼ that of the real airplane.

Rule-2. The wing loading of a model built to scale weight will be reduced from that of the real airplane by the ratio of the scale factor. A quarter scale J-3 Cub will have a wing loading of 20 oz per square foot instead of the 80 ounce wing loading of the real airplane.

Keith Shaw's Horten ducted fan flying wing powered by twin Astro 05 motors and custom built 60 mm fans.

Scale Thrust

The Thrust to weight ratio of an airplane determines how long it takes to accelerate to flying speed during take off, how steeply it can climb and how fast it can fly. I we want to make our model fly like the real airplane we need to make sure that the model has the same thrust to weigh ratio as the real airplane. The thrust of the model needs to be reduced by the same ratio as the weight of the model. By applying rule 1 we get rule 3.

Rule 3. The thrust of the model airplane propeller or fan should be equal to the thrust of the real airplane times the scale factor cubed. For example the thrust of the quarter scale Cub needs to be 1/64 that of the full size Cub.

Scale Rpm

Assuming that our model is constructed to exact scale and therefore is fitted with an exact scale size propeller, what RPM is required to produce scale thrust? The thrust of any propeller varies as the RPM squared and Diameter raised to the fourth power. This means that as diameter is reduced rpm must be increased. This fact leads us to Rule 4.

Rule 4. Scale thrust requires that the RPM of the propeller on the scale model be increased by the square root of the scale factor. For example the prop on a full size Cub spins at 2,000 rpm so the prop on the quarter scale Cub needs to spin at 4,000 rpm to produce scale thrust.

Bob Boucher's 1/8 scale Velie Monocoupe
Powered by an Astro 020 motor

Scale Time

Another way of thinking about the upward shift in RPM is to say that TIME has been made to run faster in our model than in real life. The model's clock is ticking at a faster rate than ours. This is an exact truth, I a model clock were make at exact quarter scale it would tick exactly twice as fast as the original clock. This same scaling law explains why the humming bird's wings beat so much faster than the wings of an eagle. This brings us to rule 5.

Rule 5. Scale time for the model is faster than real time by an amount equal to the square root of the scale factor. This relationship between scale time and real time is used every day by the cameramen in Hollywood who create realistic footage of train wrecks, explosions and other disasters. They run their cameras at high speed while filming model train wrecks and then play the film back at normal speed. This is known as Slow Motion and the effect is very realistic.

Randy Smithhisler with winning quarter scale Piper J-4 Cub Coupe. Randy Qualified at the Scale master's Contest in Mesa Arizona. The model weighs 19 lbs and is powered by Astro 90 Geared Cobalt Motor, and a 24 cell Nicad battery pack.

Scale Speed

Suppose our full size cub flies at 60 miles per hour or one mile per minute. We want our quarter scale Cub to fly one quarter scale mile in one quarter scale minute. Since in quarter scale distance is divided by four and time is divided by two our model will fly at one half the speed of the full size Cub or 30 miles per hour. Like scale time scale speed varies as the square root of the scale factor. This brings us to rule 6.

Rule 6. To fly at scale speed our models need to fly slower than the real airplane by an amount equal to the square root of the scale factor.

Scale Power

Before we can select the proper electric motor and gear box for our scale model we have to know how much torque will be require to spin our scale prop at scale RPM so that it will produce the needed scale thrust. The propeller is a transmission device that converts shaft torque to thrust. Propeller thrust is proportional to shaft torque and inversely proportional to propeller diameter. Since the required thrust is proportional to aircraft weight and therefore to scale factor cubed, the required motor torque is proportional to scale factor raised to the fourth power. Motor power is the product of motor torque x motor RPM. Since RPM increased as the square root of scale factor Power is reduced by scale factor raised to the 7/2 power. For example our 65 HP Cub in ¼ scale would require only ½ HP. This brings us to rule 7.

Rule 7. The power required of the scaled motor is reduced from that of the full size motor by the scale factor raised to the 7/2 power.

Steve Johnson's Northrop Gamma

Scale Performance

In the first paragraph of this paper I promised that if a model were built to these scale rules then it would have scale performance. What did I mean by scale performance? Scale performance means that the model will execute all maneuvers in scale dimensions. To prove this assertion let us examine a few basic maneuvers.

Scale take off distance

In order to take off from the runway the airplane must accelerate to flying speed from a standing start. Since the thrust to weight ratio for the model is identical to the thrust to weight ratio of the real airplane, both aircraft will have identical acceleration. Scale flying speed will be reached in scale time and therefore the model will travel scale distance down the scale runway.

Scale climb angle

Since the thrust to weight ratio is identical to that of the real airplane the climb angle will also be identical.

Scale size Loops

Both the thrust to weight ratio and the lift to weight ratio are identical in both model and real airplane, so all aerobatic maneuvers will be in scale dimension. The quarter scale model will perform a loop in ¼ the dimension as the full size airplane. Since the scale clock in the quarter scale mode ticks at twice the rate as our full size clocks, the quarter scale model will perform its loop in ½ the time required by the real airplane.

Adie and Tony Nacarrato with their fabulous B-36 powered by six Astro 05 motors.

Various scale factors

Scale Factor	1	1/4	1/5	1/6	1/10
Wing Span	100%	1/4	1/5	1/6	1/10
Weight	100%	1/64	1/125	1/216	1/1000
Wing Loading	100%	1/4	1/5	1/6	1/10
Air Speed	100%	50%	45%	41%	31.6%
Time	100%	50%	45%	41%	31.6%
Rpm	100%	200%	222%	243%	316%
Thrust	100%	1/64	1/125	1/216	1/1000
Power	100%	1/128	1/279	1/529	1/3160

Example North American P-51 Mustang

Scale Factor	1	¼	1/5	1/6	1/10
Wing Span	37 ft	9.25 ft	7.4 ft	74 inches	44 inches
Weight	7125 lb.	111 lb.	57 lb.	33 lb.	7.1 lb.
Wing Loading	31 lb.	123 oz	99 oz	82 oz	49 oz
Air Speed	437 mph	218 mph	196 mph	179 mph	135 mph
Rpm	2,700	5,400	5,994	6,561	8,532
Thrust	3,500 lb	55 lb	29 lb	16 lb	3.5 lb
Power	1695 hp	13.2 hp	6.1 hp	3.2 hp	0.61 hp

Example Piper J-3 Cub

Scale Factor	1	¼	1/5	1/6	1/10
Wing Span	35 ft	105 in	84 in	70 in	42 in
Weight	900 lb	14 lb	7.2 lb	4.2 lb	14 oz
Wing Loading	5 lb	20 oz	16 oz	13 oz	8 oz
Air Speed	82 mph	41 mph	37 mph	34 mph	25 mph
Rpm	2,350	4,700	5,217	5,710	7,426
Thrust	390 lb	6.1 lb	3.1 lb	1.8 lb	6.2 oz
Power	65 hp	0.51 hp	0.23 hp	0.12 hp	0.02 hp

Example Douglas DC-3

Scale Factor	1	¼	1/5	1/6	1/10
Wing Span	95 ft	190 in	142 in	114 in	95 in
Weight	16,289 lb	75 lb	31.8 lb	16.3 lb	9,4 lb
Wing Loading	16.5 lb	44 oz	32 oz	26 oz	22oz
Air Speed	192 mph	79 mph	68 mph	61 mph	55 mph
Rpm	2,100	5,100	5,940	6,640	7,275
Thrust	1,700	7.8 lb	3.3 lb	1.7 lb	15 oz
Power	850 hp	1.6 hp	0.59 hp	0.26 hp	0.14 hp