The Physics of Low Energy Flight
By
Bob Boucher

Years ago in 1970 ago when my brother Roland and I were struggling to invent the worlds first successful electric powered radio control airplane, we were constantly offered the free advice that our crazy idea would never work. Luckily we paid no attention to all that free advice. We figured that is the advice were any good they would be charging for it. In 1971 our dream of electric powered flight became a reality. The biggest problem in those days was the weight of the battery, and even today with the new lithium batteries flight time is still limited compared to gasoline. In model airplanes the battery usually accounts for up to 25 percent of the total gross weight of the model. In contrast the fuel weight in the typical glow powered model accounts for only 1 or 2 percent of the total model weight and is so small that its weight is usually ignored.

Are all Batteries too heavy?

I have been building model airplanes ever since my first ride in a real airplane in 1937. My father took my brother and me to a small grass field airport in Bristol Connecticut where we had our first airplane ride in a Gull Wing Stinson Reliant. Our first models were stick and tissue kits powered by a rubber band and they flew just fine. Later on after the war we built gas jobs and they also flew just fine. Now do any of you readers know just how much energy is stored in a fully stretched rubber band? The answer is that there is enough mechanical energy it the stretched rubber band that if converted into altitude the rubber band could pick itself up about 3,000 feet. The same calculation for the 1200 mahr sub c Nicad cell of 1970 vintage yields and altitude of 30,000 feet or ten times higher than the rubber band. Before you get all excited and jump up and down with glee, remember that the same calculation for gasoline yields 3 million feet!!! Gasoline has 100 times more energy than most batteries and that is why we love it so. Still my brother and I were not ready to give up. We knew that a well designed Competition rubber powered Wakefield model with a motor mass fraction of 25% would reach an altitude of about 300 ft on the energy stored in its rubber motor. The Wakefield model could reach an altitude of about 10% of the potential energy in the rubber motor. We figured that if we could attain the same energy efficiency with our electric powered model it should be able to climb to altitude of about 3,000 ft. While 3,000 feet is small compared to the 19,000 ft altitude record that Maynard Hill had recently set for gas powered models, 3,000 feet was still plenty high enough to put an electric powered sailplane into thermal country.

How much power is required to fly?

Now that we know that we have enough energy, the second question is do we have enough power? This question can be broken down into two parts: 1st how much power is required to sustain level flight? And 2nd how much excess power is required to enable the model to climb to a safe altitude? We will see that the power required for level flight in still air is primarily a function of weight and wing span. The shape and plan form of the airplane changes the answer a little bit but shape and plan form are not critical factors.
An aircraft's sink rate can be estimated from equation 1 below.

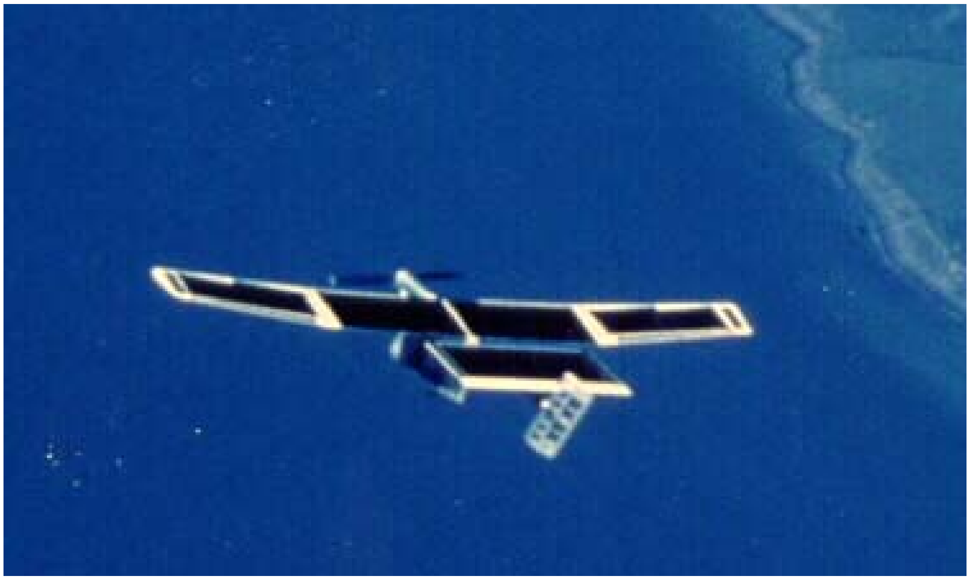
EQ 1 Minimum Sink Rate = SF x SQRT (Weight)/ Wing Span
Weight is in pounds.
Wing Span is in feet.
Shape Factor SF is number between 2 and 10
Minimum Sink Rate is in feet per second.

A really clean sailplane like the ASW 21 has a shape factor of about 2, a Piper J-3 Cub about 6, a Stearman Biplane about 7 and a hang glider about 10. This simple equation is a remarkably accurate predictor of minimum sink rate and you do not need to be an aerodynamic genius to figure it out. The late Willie Messerchmitt used to say "If it looks good it will fly good". Many years ago I calculated the shape factor for 100 different real airplanes and model airplanes based on published flight test data for these planes. At that time the best full size sailplane was the ASW-17 and it had a calculated shape factor of two and one half. Competition Radio Controlled Sailplanes have shape factors between four and five. This is a very powerful formula. It totally ignores all the sacred aerodynamic parameters like Aspect Ratio, Airfoil Profile, and the latest fad in wing tip shape, but still predicts the correct value every time. The power needed in level flight needs only to overcome the sink rate. The power equals weight x sink rate. Using equation 1 we obtain equation 2.

EQ 2: Power = Weight x SF x SQRT (Weight)/ Wing Span

Sunrise II on a dry lake in Mercury Nevada in 1975 being readied to launch for a high altitude flight to over 20,000 ft. Stan Hall and Dan Lott holding the wings and Bob Imersek on the tail, Bob Boucher running back to control station.

Sunrise II passes by the moon at about 10,000 ft altitude at 10AM, about one hour after launch from a dry lake in Mercury Nevada.



Solar Challenger shown crossing the English Channel on July 8, 1981 on its historic flight from Pontoise France to Manston RAF Base England. The Solar Challenger was powered by a 5 KW motor and solar array built by Bob Boucher at Astro Flight.

The Power required to overcome Sink Rate
For various Aircraft calculated using equation 2.

Airplane	Shape Factor	Weight	Wing Span	Sink Rate	Power
Piper Cub	**6**	**900 pounds**	**36 feet**	**5.1 fps**	**6.3 KW**
¼ scale Cub	**6**	**15 pounds**	**9 feet**	**2.6 fps**	**53 watts**
1/6 scale Cub	**6**	**5 pounds**	**6 feet**	**2.2 fps**	**15 watts**
Sunrise II	**5**	**22 pounds**	**32 feet**	**0.7 fps**	**21 watts**
Solar Challenger	**5**	**400 pounds**	**46 feet**	**2.2 fps**	**1.2 KW**

These are very low power levels. They represent the power imparted to the air stream by the thrust of the propeller. We can count on a propeller efficiency of at least 75% and a motor efficiency of at least 75% to be conservative lets double the above values. We made these calculations in 1970 and got all excited. We built a few electric powered models and they all promptly crashed! What was wrong? First, the model cannot fly in a straight line at a five foot altitude very long without hitting something. Second, the airplane needs to climb to a safe altitude. And the air is almost never standing still. The air is either moving up or moving down. If the model is at low altitude and encounters a down draft it will crash to earth unless it has enough power to climb at a rate greater than the down draft velocity. Our experience tells us and is confirmed by FAA specifications on Real Airplanes that a climb rate of 200 feet per minute is marginally acceptable and that a climb rate of 400 feet per minute is very desirable if one intends to fly in the real world. In order to climb at 200 feet per minute in still air with a zero drag airplane, one would need an electrical power to weight ratio of nine watts per pound of aircraft. For the much safer 400 feet per minute one would need 18 watts per pound of excess power. Going back to our previous table:

Electrical Power needed for adequate climb performance

Airplane Name	Flying Weight	Level Power	Climb Power	Total Power
Piper Cub	**900 pounds**	**12.6 KW**	**18 KW**	**30.6 KW**
Quarter scale Cub	**15 lbs**	**106 Watts**	**270 Watts**	**376 Watts**
Sunrise II	**22 pounds**	**44 Watts**	**396 Watts**	**440 Watts**
Solar Challenger	**400 pounds**	**2.4 KW**	**7.200 KW**	**9.6KW**

The Solar challenger had almost 90% efficient prop and 85% efficient motor so it flew fine on 5KW. But this climb rate is typical of trainer type aircraft like the Piper Cub. If you want P-51 type aerobatic performance and 2,000 feet per minute climb rates you will need more like 900 Watts per pound. Clearly the climb rate requirement dominates the power equation. Experience teaches us that trying to fly with power levels only two or three times the minimum power required for level flight will not be successful.

What about High Altitude Flight?

The electric powered airplane does not suffer a power loss with altitude as does a gas powered aircraft. The electric motor does not breath, it needs no oxygen. The electrical power is available undiminished but the thin air at altitude requires the flight speed to increase and the power for level flight to also increase. Air density drops in half for every 15,000 feet in altitude. Let's look at the Mini Challenger R/C Sailplane as an example. The Mini Challenger weighs 2 lbs and has a 60 inch wing span and is powered by an Astro 020 motor with over 150 watts of power.

Astro Mini Challenger Performance at High Altitude

Flight Altitude	Minimum Power	Excess Power	Climb Rate	Flight Speed	Prop Size
Sea Level	6 watts	144 watts	1,600 fpm	20 mph	12 x 12
15,000 ft	8.5 watts	141 watts	1,566 fpm	28 mph	12 x 12
30,000 ft	12 watts	138 watts	1,533 fpm	40 mph	12 x 12
45,000 ft	17 watts	133 watts	1,460 fpm	56 mph	12 x 12
60,000 ft	24 watts	126 watts	1,400 fpm	80 mph	12 x 12
75,000 ft	35 watts	115 watts	1,230 fpm	112 mph	12 x 12
90,000 ft	48 watts	96 watts	1,067 fpm	160 mph	15 x 21*
105,000 ft	70 watts	80 watts	850 fpm	224 mph	20 x 30 *
120.000 ft	96 watts	54 watts	600 fpm	320 mph	24 x 48*
135,000 ft	150 watts	zero	zero	452 mph	28 x 80*

Above 70,000 ft altitude the propeller tip speed is Mach limited.

The Mini Challenger would have no problem flying from the highest mountain in the world, Mount Everest. The problem is getting there. With only four minutes of battery power from is 1700 NIMH mahr battery pack the Mini challenger could only climb to 6,400 feet above sea level before running out of juice. Substituting a Lithium Polymer battery pack would double the altitude to about 12,000 feet. Substituting 20% efficient silicon solar cell for the battery would limit the power to about 40 watts. With 40 watts of power and keeping its back to the sun the Mini Challenger should be able to reach an altitude of about 75,000 feet during 8 hours of sunlight. Using the latest multi junction Gallium Arsenide solar cells with 40% efficiency one could increase the altitude to over 100,000 feet. The world's first solar powered aircraft the Astro Sunrise demonstrated this concept during its historic high altitude flight in September of 1975. Two decades later the AeroVironment Solar Airplane reached 100,000 feet.