Human Powered Aircraft at Altitude

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So far, virtually all human powered flight has been at low altitude in ground effect, in smooth weather conditions.

What is the minimum standard of airworthiness which would enable a human powered aircraft to operate safely at altitude? Having made a machine safe enough to fly at altitude, how much performance can be realised? What is the best way of storing human power to enable a climb to where lift can be exploited?

There is a whole range of human powered flight or human assisted flight possibilities at altitude, out of ground effect and using slope, thermal and dynamic lift which have not yet been explored or developed.. These possibilities are “self-supported” autonomous flights using nothing except the pilot’s energy and that which can be extracted from the environment. All birds exploit lift when it is available and there is every reason why human powered aircraft should do the same. For the purpose of this article, the rapidly expanding field of on-board solar power generation is not discussed.

Most large birds are incapable or unwilling to make long flights without exploiting lift. A common example in the UK is the Buzzard which will wait until a thermal lifts off, skilfully riding the lift from tree top level all the way to cloudbase and then gliding off at speed. It is probable the ancient Pterodacyls were primarily soaring creatures, nesting in cliffs where slope lift would prevail. Geese fly in a V formation which reduces induced drag for each bird. Sea birds exploit dynamic soaring in the wind gradient over the surface.

Over the last 45 years hang gliders and paragliders have been developed which allow the pilot to have a simple, affordable, airworthy, self contained, portable aircraft. When Sumpac, the first HPA, was flown 50 years ago, such aircraft did not exist. Hang gliding and now paragliding have blossomed into a sport enjoyed by thousands whereas HPA have yet to make the same transition.

Sailplanes have demonstrated astounding flights of over 1,500km, but these flights generally require a powered winch or aerotow launch and the energy of the pilot plays no part.

Today it has been demonstrated that a human, with no external assistance, can fly a portable aircraft on extended journeys over several days, at least through mountainous terrain. This ancient dream has been realised, but very few people are aware of it.

Based on this fact Brian Milton, the first person to circumnavigate the globe by microlight aircraft, has formulated a migration challenge for self-supported human flight as follows:

MIGRATION RULES

1. Length of Flight - Should follow migration pattern from Latitude 50N to 10N. The northern limit of 50 degrees in Europe is just south of Frankfurt. It is south of the Central European summer nesting place for most birds. In North America, 50N is north of Vancouver, about level with Winnipeg. The southern limit, 10N, is north of Addis Ababa, south of Kano in Nigeria, about level with the eastern Horn of Africa. In North America, 10N is just above the Panama Canal, about level with Caracus in Venezuela. A crude measure of the distance between the two latitudes is 2,600 miles. In Europe, that is the distance covered by a big migrating bird in the Autumn, on one of the two most-used routes, via Gibraltar and the Western Sahara, or via Turkey, Syria, Israel, Egypt and the Sudan.

2. Duration of Flight - Should not exceed 120 days, about 4 months, giving an average southerly distance of 22 miles/day.

3. Ethics - If you come down on a flat plain, you must launch from where you land or walk back over your previous route carrying your glider to find a launch point. All launches must be made by foot, and no use is allowed of a winch or any other kind of aid.

4. Glider - You may only use one glider, although it can be extensively repaired.

5. Sporting Spirit - Flyers are expected to take all sensible steps to certify their flight. They are also expected to conform to the sporting spirit of the challenge.

There is no reason why launches should be by foot only and a pilot-driven winch inside the aircraft should also be permissible. However, the basic idea of self supported human migrating flight is captivating as an adventure, a test of piloting skill and endurance as well as a technical challenge.

1) Mountain flights by hang gliders and paragliders

In mountainous regions, some remarkable self supported “vol-bivouac” flights have been made. The first person to really travel in this way was Didier Favre, by hang glider. He conceived the CAP 444 challenge, to fly 444 kilometres unsupported, with less than 10% of the distance made on foot. From his mountain takeoff point, he soared during the day and landed at a point where he could spend the night close enough to the next day’s takeoff. In order to do this he perfected the so called “fly on the wall” landing, approaching at high airspeed towards a slope (often downwind) and flaring up it. Sometimes he would spend the night in an Alpine hut and light a fire, sometimes he would sleep inside his folded wing. After a few seasons he succeeded in the CAP 1111, eleven hundred kilometres, flying from Monte Carlo to Slovenia in three months during the summer of 1993. There is some good video footage of his adventures on the web (ref.1).

In 2006, two French paraglider pilots made a journey of 270 miles with 13 miles of walking over 10 days in the Karakoram, thermalling to 22,000 ft each day over uninhabited and hostile terrain. They used Ozone Addict special lightweight paragliders, weighing approximately 4.5kg. Paragliders are easier to land in mountainous terrain but are slower and more susceptible to turbulence, which may be critical at low level.

Other pilots have made long journeys including hitch-hiking, but this is not considered self-supported flight!

2) Self-supported flight from flat land.

Brian Milton’s point 3 above requires the pilot to get back into the air from a flat plain, by his own efforts. Hang glider pilots have had “low saves” from a hundred feet altitude or so, thermalling back to cloudbase. However, usable thermal sources this low are rare and it also takes the lift-spotting and thermal coring ability of a buzzard.

Getting airborne from a flat plain is possible in 4 ways

a) Climb a hill facing the wind and take off.
b) Using a human powered winch in the aircraft, employ a combination of the wind and human power to climb up a towline, then cut away from it.
c) Store human energy in the aircraft sufficient to take off and find a thermal.
d) Use human power in an aircraft efficient and light enough to climb out of ground effect

The nearest that HPA have come to realising the goal of ascending from flat land into regions where lift can be harnessed were developed for the Kremer speed prize competition. The objectives of this successful competition were:

From ref.2,

"THE KREMER WORLD SPEED COMPETITION

AIMS

In the early 1980s there was much discussion by the committee of the then called Man-Powered-Aircraft-Group of the RAeS about where we go from here, whether the time was ripe for another competition, and if so what form of competition. The figure eight had been flown. The English Channel had been crossed, and hence in some ways the hopes of 1957, and of centuries before, had been more than realised.

However,

1. Muscle-powered-flight was still impractical,
2. Flying was restricted to freak calm weather, and
3. The aircraft were of monstrous size.

Apart from the obvious need for improvement in these ways there were also the hopes of

4. Initiating a sport,
5. Maintaining the momentum of development,
6. Continuing to encourage the pursuit of excellence, which was seen to imply high-technology,
7. Tending towards enabling the man-in-the-street to be the man-in-the-air, which was seen to imply low-technology, &
8. Prizes being awarded on a wider basis than previously."

For the Kremer speed competition it was permissible for the pilot to store energy for up to 10 minutes before flight. This would enable the pilot to store approximately 3 kw minutes of energy. Energy storage was not mandatory for the prize but was used by Paul MacCready's Aerovironment team with the Bionic Bat. With the technology of 1983, the electrical energy storage/recovery system was only 20% efficient and the energy density, using Ni-Cad cells, was poor compared to today's Lithium based cells. There were technical problems with record claims until a recognised definition of zero battery charge state was accepted. Other craft such as Wayne Bliesner's used twisted rubber to store energy.

The advantage of using energy storage for this competition was by no means clear cut, as a directly powered HPA would have the advantage of lighter weight and the full anerobic power of a rested pilot at takeoff. The Kremer speed prizes were successively won by the MIT Monarch, the Bionic Bat and the directly powered Musculair 1 and 2.

The Bionic Bat was designed to a flight envelope permitting operation in a wider range of conditions than previously. It's design was influenced by the Solar Challenger which was flown at altitude for 5 hours, 163 miles from France to England on 6hp.

Fig 1, the Bionic Bat

FLIGHT ENVELOPE

The wings were designed to carry 3g or minus 1g. Minus 1g represents inverted flight. The Bionic Bat never actually flew upside down, but it was strong enough to have been able to. For safety, a flight envelope is drawn so that any actual anticipated manoeuvres are well inside it. The fuselage was designed to withstand a 4g vertical landing load or a 6g head-on load. The wheel was designed to withstand 1g aft from braking with a 0.7g simultaneous side-load. The nose wheel was designed for 1.5g vertically with a 0.7g side load. The maximum airspeed catered for by the structure was 50 mph (22.4 m/s). The design manoeuvring speed was 40 mph (17.9 m/s). This is the maximum speed for which the structure permits full control deflection. Stall at 1g, i.e normal flight was anticipated as 25 mph (11 m/s)

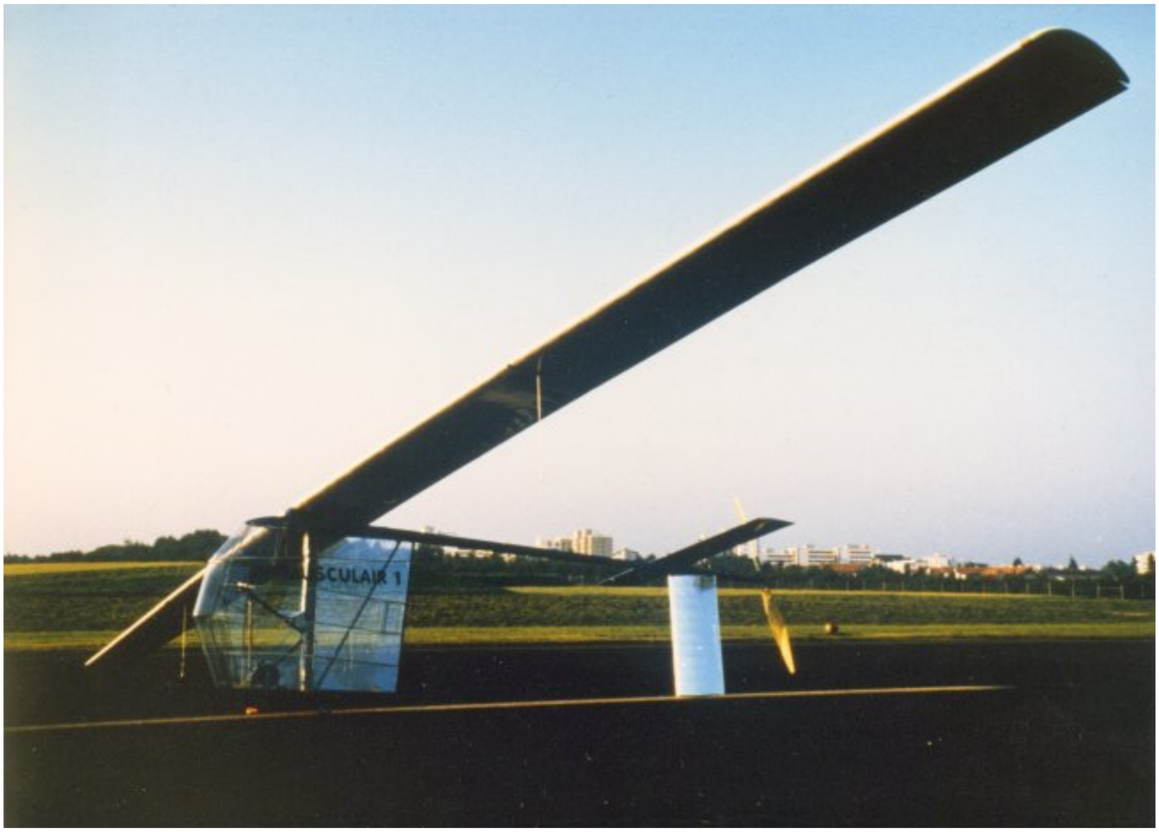


Fig 2, Musculair 1

Musculair 1 is probably the best all-round performing HPA yet built. The Pilot, Holger Rochelt, was even able to take his sister (28kg) for a flight and was still able to launch from a flat surface. The machine was strong enough to cope with gentle winds and was demonstrated at some air shows.

Fig 3, Musculair 2

Musculair 2 won the Kremer speed prize at 30mph for 2 minutes, a remarkable achievement. The design was optimised purely for speed and required relatively high power for flight, sacrificing some of the practicality of Musculair 1 for pure speed performance.

span 19.5m
wing area 11.7 m2
Aspect ratio 32.5
Empty weight 30.0 kg
Minimum power flight speed, 36 km/h (19KEAS)

Flight envelope

The minimum *limit* G load for manoeuvres on certificated small aircraft (e.g. CSA-VLA requirements) is +3.8, -1.5 g. The aircraft also has to resist a defined vertical gust of 3m/sec. For fast aircraft with light wing loading, the gust loading dominates and may exceed the manoeuvre load case. For certification a further ultimate factor of 1.5 is required. For composites there is a further factor of safety for variability in manufacture and environmental strength degradation, making the total safety factor 2.25 unless a more rational factor can be agreed with the Authority. This results in an aircraft designed to

+9g! The imposed superfactor makes it impossible to exploit the structural advantages of composites to the full compared to a metal or wood structure. Under this regime a carbon airframe can still be 10 – 15% lighter, but a glass fibre one carries a weight penalty. For composites there are issues of compression strength after barely visible impact damage and tensile failure at stress concentrations such as ply drop offs or notches.

For a human powered aircraft, it is not too hard to conduct a proof load test on each example – or at least, each spar, so that the ultimate factor may be reduced.

The +3.8 g case (or general +4g case for BCAR-S) has proven sufficient to prevent catastrophic failure in all expected weather conditions providing the flight envelope speed and g limits are not exceeded.

In normal flight a +2g manoeuvre is a coordinated 60 degree bank. In most normal flying operations it is rare to exceed +3g even in strong turbulence. Looking at aircraft in the Japan birdman competition, wing torsional stiffness sufficient to prevent divergence at speed seems to be a limiting factor. The Macready aircraft were built with the Lissaman 7761 aerofoil which had a near neutral pitching moment, compared to the Wortmann series which have strong negative moments.

Recent developments with ornithopters have given rise to the possibility of an aeroelastic wing structure which deforms and dumps excess lift instead of carrying it. The very light (22kg) Clubman hang glider was found in BHPA airworthiness testing to be incapable of producing +4g lift at any angle of attack up to VNe 55mph, due to aeroelastic washout. It may also be possible to do this electronically by using an accelerometer to actuate spoilers in the event of over-loading. It is said that a gull's wing can only resist about 2g, it relieves larger loads by deforming.

Second chance – the total recovery parachute.

Hang glider and paraglider pilots generally carry reserve parachutes, capable of recovering the aircraft and pilot together. These are useful in the event of an upset or failure in extreme turbulence, failed unwise aerobatic manoeuvres, medical emergency or mid air collisions. These reserve systems are not infallible but have saved many lives, even from 100ft altitude or so. The weight penalty can be as little as 2kg. The lightest systems require the pilot to throw out a deployment bag, though other systems deployed pyrotechnically or by compressed air are common on microlight aircraft.

3) Human assisted gliding

For a sustained period, a fit human of 75kg can produce 250 watts power by pedalling (ref. Wilkie).

The effect of applying 250 watts power to a rigid wing hang glider (ATOS), a competition flexwing hang glider (Wills Wing Talon) and a paraglider (DHV 2 rating) is shown. A propulsive efficiency of 85% is assumed and a weight of 120kg for the hang gliders and 90kg for the paraglider.

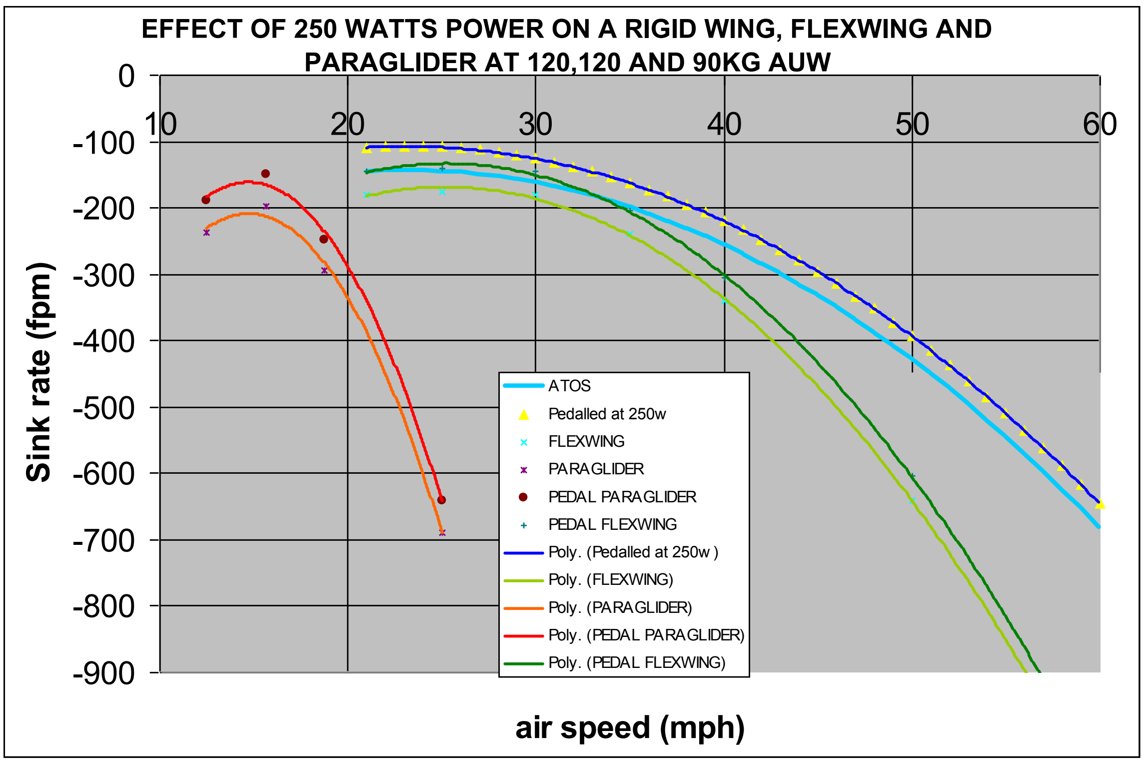
Fig 4. The ATOS VR-10

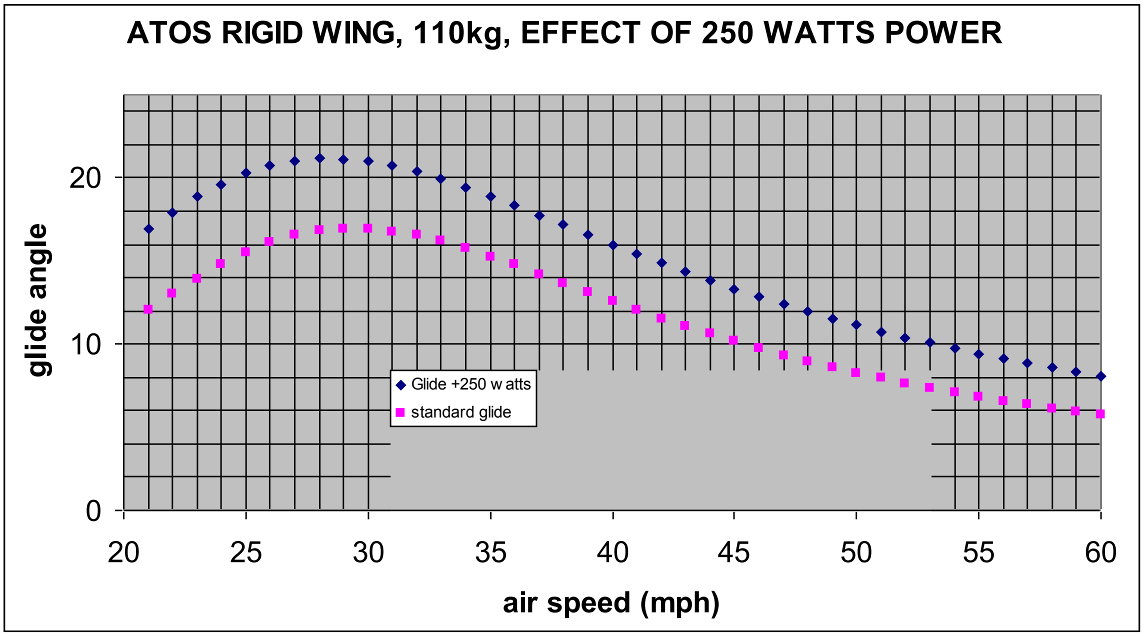
Span: 13,8 m
Area: 14,3 m^2
Aspect ratio: 13,4
Min. sink: 0,63 m/s = 123 ft/min
Weight: 41 kg
Payload 90 – 183 kg (can take 2 pilots)
Packed size : 5,15x0,48x0,2 m
Rigging time: ca. 18 Minutes

The paraglider has a slightly worse sink rate than the hang glider but this is compensated by the reduced weight. In practice the slow flying speed and good manoeuvrability make them very good at climbing in thermals, especially when they are small and broken near the ground. Pedalling a paraglider has it’s own challenges, with the possibility of fouling the lines.

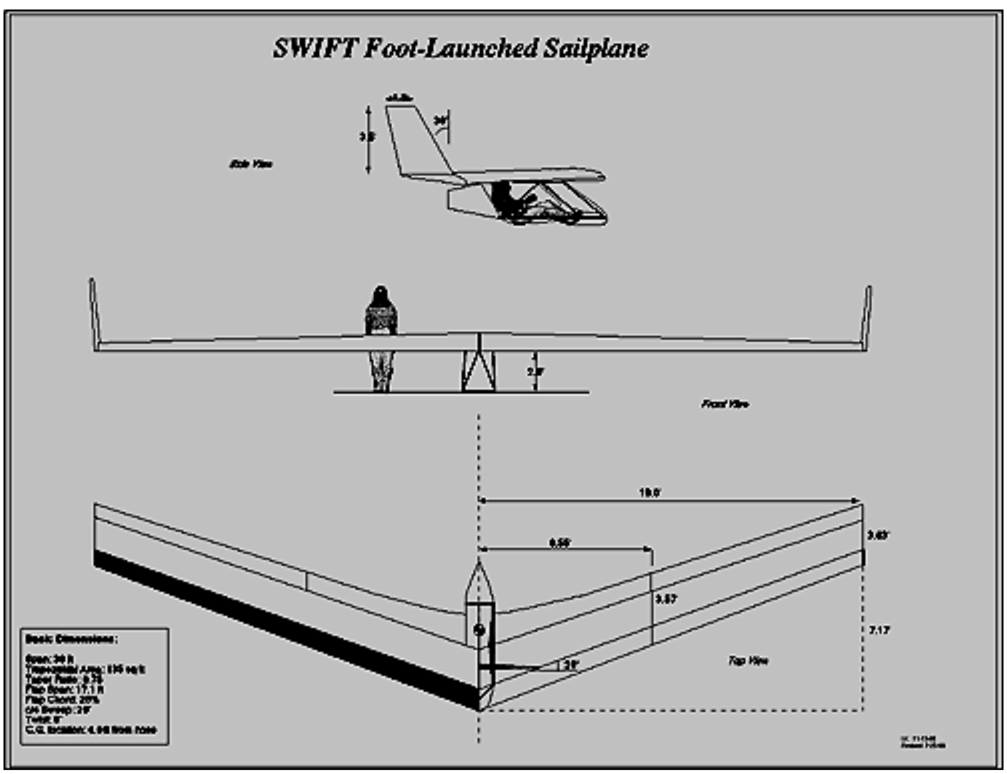
Any claims that it is possible to maintain level flight out of lift in with a hang glider by pedalling are clearly false. However, there is a definite performance improvement to be gained.

The author’s experience in pedalling a hang glider was that in smooth conditions it was possible to cross gaps in ridge lift by pedalling, which would ground other pilots, but combining the concentration required for accurate thermal soaring with power production was difficult. However, once at cloud base it was easy to pedal whilst gliding between thermals which had the added benefit of keeping the pilot warm.



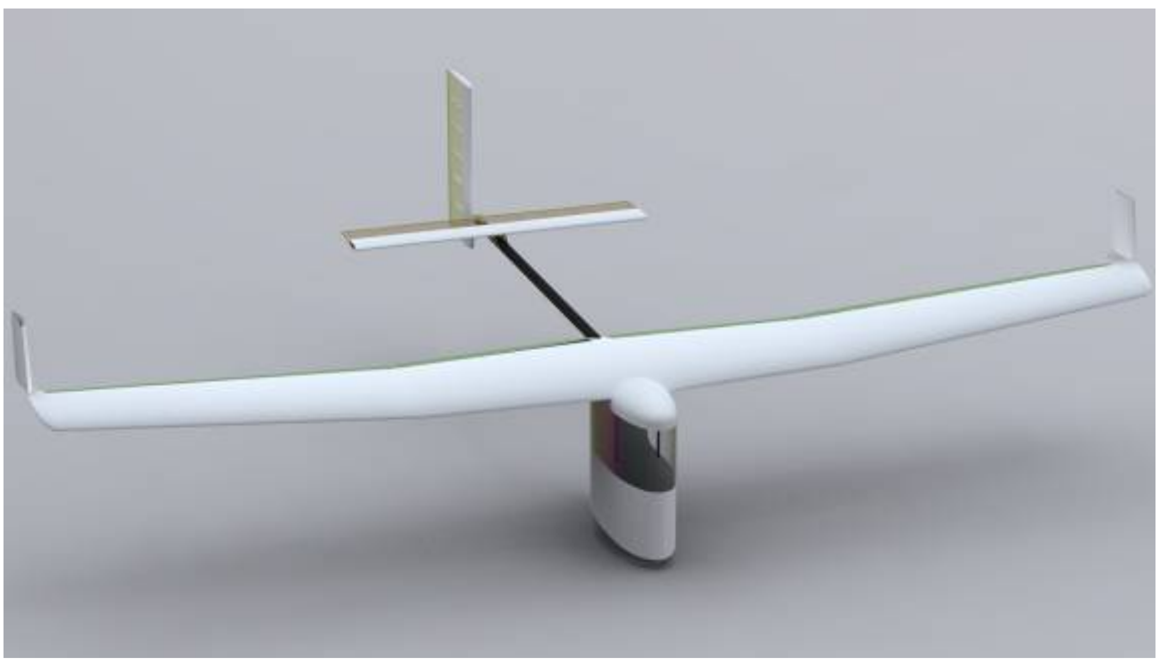


An optimized soaring HPA could have a supine pilot position inside a streamlined pod, using weight shift pitch and aerodynamic roll control like the ATOS, or be a 3 axis controlled layout.



The SWIFT foot launched sailplane

Span – 12.8m
Weight – 48kg
Sink rate – 0.6m/sec = 120fpm
Glide – 27:1



Sean Frawley's 2010 Worthing glider is like a cut-down HPA. Span 10m, weight 12kg.

Didier Favre CAP444 video

http://www.wikidelta.com/deltaplane/records-et-exploits/video-didier-favre-01-cap-444-lq.html

Article on the soaring strategies of a falcon vs. hang gliders and paragliders.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2393768/

Design and development of the SWIFT

http://aero.stanford.edu/Reports/SWIFTArticle1991.html