

ReWright- A Human Powered Aircraft in the making

Patrick Berry

IEI

Linköping University

`Patrick.berry@liu.se`

Abstract. Human powered flight is probably as close as you will ever come to real bird flight. To design, build and fly an aircraft based on human power only is a real challenge but the dream to do so still exists and Linköping University is no exemption.

At Linköping University it has become more or less of a habit to design and build model aircraft as demonstrators of potential full sized conceptual designs. The main idea with this approach is to identify potential problems at an early stage before entering full size development and to learn about flight behaviour in beforehand, in order to reduce project risk and nasty surprises. This paper digs a bit deeper into the procedure used for designing human powered aircraft at Linköping University. It also describes design evolutions, challenges met and lessons learned.

Keywords. Human powered, hang glider.

1 Introduction

Designing, building and flying model aircraft has been the motto for aircraft education at Linköping University for many years and has turned out to be a good approach to let students gain their very first experience of designing, producing and flying their own designs.

In 2014 the design assignment in the yearly aircraft project design course was to design a human powered aircraft. The aircraft, named “ReWright”, was inspired by hang glider design, i.e. pitch control by means of weight shift and a typical hang glider/flying wing, layout.

Why then this approach? Two reasons mainly:

Most human powered aircraft produced are of conventional design. Copying existing designs isn't that challenging but a flying wing concept using weight shift for control is challenging indeed.

The other reason for choosing a flying wing/hang glider concept is due to the hang glider's simple structural design, i.e. very essential when trying to design and construct something light.

We started the design procedure with conceptual design, i.e. basic calculations and sizing of the full sized aircraft and then continued designing and building three demonstrators in order to prove and test the viability of the chosen concept.

Much of the work with the first and second demonstrators was completed in 2014, but we didn't have time to finish work on the third demonstrator unfortunately.

We continued the project in 2015-16 where we concentrated on getting the third demonstrator ready for flight.

2 Conceptual design of the full scale aircraft

2.1 Sizing

Available power is as always a limiting factor in aircraft design and especially so when designing human powered aircraft. A good pilot/cyclist can peak around 300W and the pilot has to be well trained to stay aloft for longer times. Aircraft size depends on available power, airfoil selected and all up weight with the weight of the pilot/engine being the dominant factor. This means you have to find someone who is light and well trained.

For us this turned out to be no problem since one of our PhDs happens to be a well-trained cyclist at low weight (70 kg) and an experienced glider pilot as well. So eventually the aircraft was designed around him. The airfoil selected was the Lissaman 7769 a quite usual airfoil with generally good performance for human powered flight. Assuming an empty weight of 30 kg, we end up in 100 kg totally. The initial design was based on an aircraft designed to cruise at 30 km/h using 260W of shaft power delivered to the propeller assuming a prop efficiency of 0.85, which according to calculations, ends up in a needed wing area of 20,6 m² and a span of 25m. This gives you a very long and slender wing, which has to be swept 15 degrees to achieve basic stability and made stiff and light at the same time.

2.2 Designing for low weight

To achieve the low weight anticipated we would have to imitate the structural simplicity and efficiency of the hang glider, which combines simple load paths with external bracing.

Paul MacCready, the designer of the Gossamer Condor and Gossamer Albatross, successfully used this principle. His first Condor design (Gossamer Condor I, Figure 1) was a very much larger aircraft (wing area=98 m²), but still came out impressively low on weight (38 kg), so a 30 kg empty weight assumption on our aircraft does not seem to be too much out of the blue.

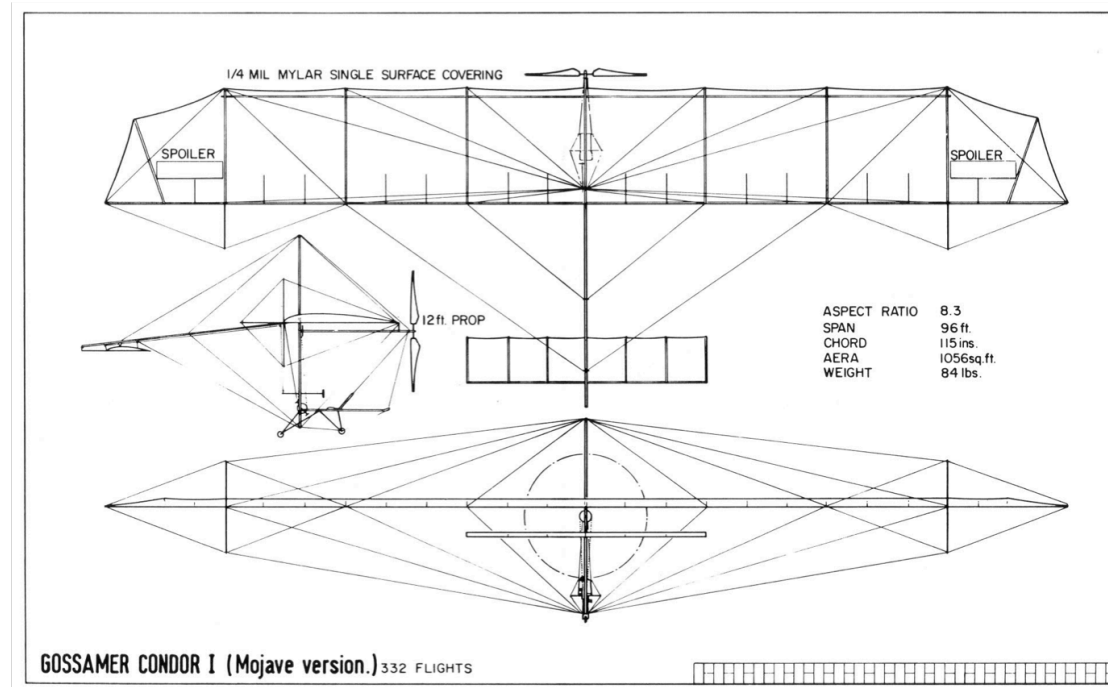


Figure 1: Gossamer Condor I

The real interesting part with the Gossamer Condor I [1] is its simple structural design and that the basic structure was based on the use of aluminum tubing as primary structure. The main spar was placed in the leading edge of the single surfaced wing. It consisted of a number of tubes of the same length, pinned together to form a very long spar from wingtip to wingtip. The main spar works together with the external wire bracing to form a giant framework in the vertical plane, causing tension in the lifting wires and compression in the main spar during flight. Since each tube section is pinned to one another and loaded in compression, Euler buckling will size each tube section as caused by local wire loading. The larger the angles between wires and tube in the vertical plane, the lower the compression load will be and lighter tube dimensions can be used. The distance between the central kingpost's lower end and the plane of the wing essentially controls the angles of the lifting wires and thus also decides the weight of the wing. This results in a quite extensive use of external bracing as you can see from Figure 1, since the end of every tube section has to be fixed in position by landing as well as lifting wires.

Everything has a prize though and the main drawback with this approach is that external wiring is not beneficial from a drag point of view and thereby suggests that for this kind of design lower cruise speeds should be considered only. In our case, if the cruise speed needs to be reduced below the anticipated 30 km/h, then the size of the ReWright wing will have to be sized up considerably.

The big advantage though with this approach besides the weight is ease of repairability.

The choice of material for the primary structure of a human powered aircraft is very much dependent on cost and availability. Aluminum tubes of the sizes and lengths needed can be bought from the shelf and at quite reasonable cost, but not so with carbon fiber tubes. There are no fitting sizes and lengths available on the shelf. This means you probably have to produce them yourself or let someone else do it, which can become costly. So all in all what to choose in the end depends on your budget.

3 Findings with the demonstrators

3.1 First demonstrator

The first demonstrator was unpowered, had a 3m span and was primarily designed to demonstrate weight shift as a control measure in pitch and secondly to evaluate different methods to make the aircraft turn. Weight shift seemed to work all right as pitch control, but the way to implement it needed further work in order to make it viable. The demonstrator showed that it might work all right in flight, but would be too vulnerable during take-off and landing.

It also showed that take-off and landing with a hang glider is quite easy, but the same principle wouldn't work with a human powered version.

Turning was also a problem as discovered earlier by MacCready and his teammates. They used wing warping as a means of turning, but wing warping has to be the other way around to work, i.e. producing wash in on the inward wing instead of wash out. Due to the sweep of the wing the wing tips on a flying wing act as horizontal stabilizers. So when applying wing warping you also get a pitch up

tendency, which too easily can end up in a stalled condition.

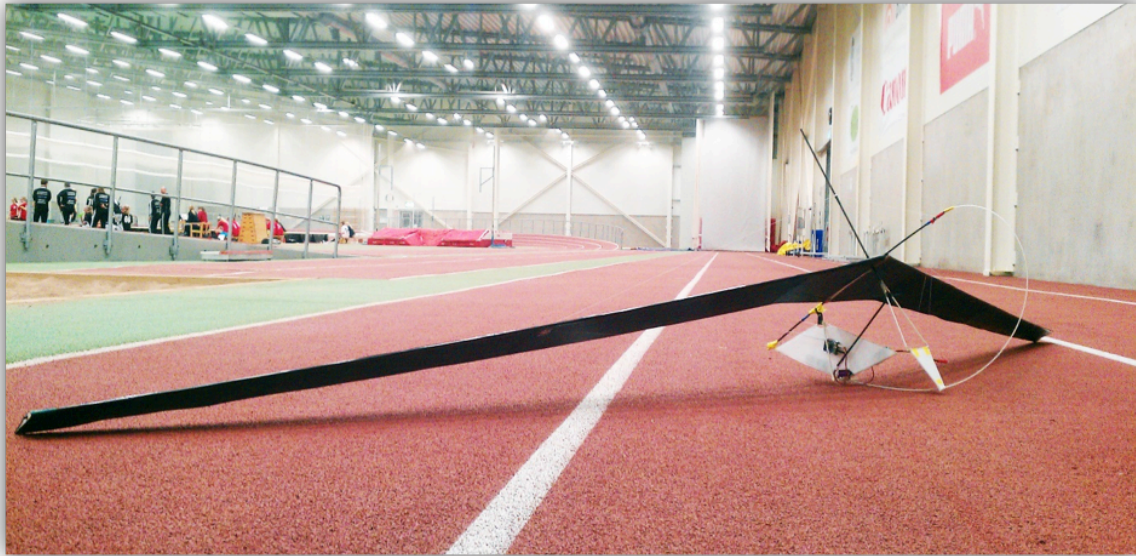


Figure 2: First demonstrator

3.2 Second demonstrator

The second demonstrator was designed as a ground based test rig, a three-wheeled bike driven forward by a pushing propeller. The purpose was to make sure that we would be able to accelerate the aircraft from standstill to take-off speed using propeller thrust only, as well as to test off the robustness of the transmission system between pedals and propeller. The propeller was designed and built by the students and had a diameter of 2.5 m. Each propeller half was constructed as a model plane wing, using a carbon fibre spar on which ribs were positioned and twisted along the span of it. The whole thing was then covered up with plastic film. The pilot pedalled at 90 rpm while the propeller was rotating at 120, i.e. requiring some gearing in between.

The tests revealed excessive deflections in the transmission system, due to poor design of the gearing and its attachments and stress problems in the propeller hub. The propeller itself worked fine though, but we had no clue how effective it really was.



Figure 3: Second demonstrator on a test run

3.3 Third demonstrator

The third demonstrator was designed to be as close in handling behaviour to the full sized vehicle as possible, i.e. in essence dynamically scaled. It was a double sized version of the first demonstrator, i.e. having a span of 6m, but in this case equipped with an electrically powered pushing propeller. The aircraft was positioned in a purpose built trolley for take-off. This aircraft took some time to build and being so large in span was very sensible for deflections of the wing, so it had to be stiffened up to make it work properly. This really gave us some sense in what kind of problems we might encounter in the full-scaled aircraft. Providing stiffness in bending as well as torsion would surely be a real challenge. The first rolling tests for take-off gave us some more things to think about, extensive wing flutter occurred. So the wing has to be stiffened up considerably, meaning more external wire bracing was needed or we had to lower the frequency of the wing somehow. We tested out different options using more external bracing and it worked quite well as long as the wires were well tensioned, but it was still too sensible and not robust enough to qualify as the final solution.



Figure 4: Third demonstrator ready for ground roll

4 Full scale aircraft

The full size aircraft has not been built yet and won't be built until we know how to solve the problems which has surfaced so far. The looks of the aircraft in full scale as it turned out in 2014, is shown below, but this will probably be far from the final layout.

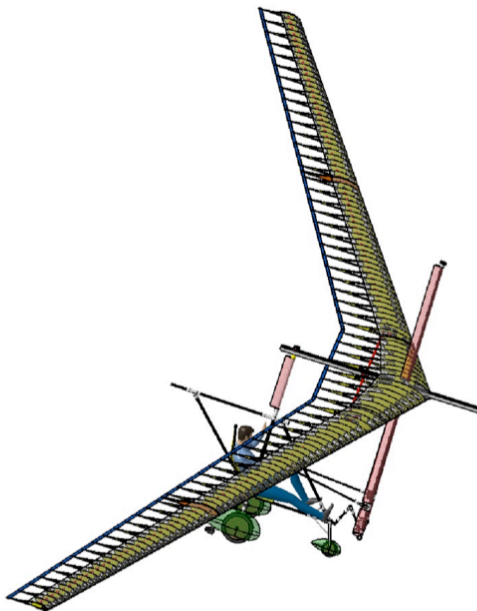


Figure 5: ReWright in full scale rendering 2014

5 Conclusion

Designing human powered aircraft is not easy, especially when you are trying to do something different like a flying wing. The result of this exercise might well be that we will have to change our initial assumptions and maybe go for a simpler configuration in the end, time will see, but we haven't given up as yet though. Maybe we will have to reduce our cruise speed to be able to cope with the extra drag produced by the excessive external wiring needed, but that would mean a much larger aircraft in size and the weight might become an issue again. It's a delicate balance procedure for sure but all parties involved have gained valuable experience which will gain the project in the future .

References

[1] J.D. Burke: The Gossamer Condor and Albatross: A Case Study in Design, AIAA professional study series