THE INTEGRATED FLAPPING WING - TRYING OUT A NEW CONCEPT

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ABSTRACT

The integrated flapping wing principle is introduced in theory and practice. Different alternatives of the model SF8 are tested in order to find the best way to obtain both constant lift and propulsion during flight. It results that both is difficult to realize by using only one flapping wing. Hence, a new model SF9 is presented, whereby those problems could be solved with two flapping wings on top of each other.

1 THE IDEA

Since 1986 I've been working on the flapping wing concept as an alternative to ordinary propeller propulsion. My original inspiration were flights with human-powered airplanes, like the English channel crossing by Paul Mac Cready with the Gossamer Condor. I searched for a concept that achieves similar or better outputs without building even bigger or lighter planes. I developed an "integrated flapping wing" which to me appeared to be the only alternative.

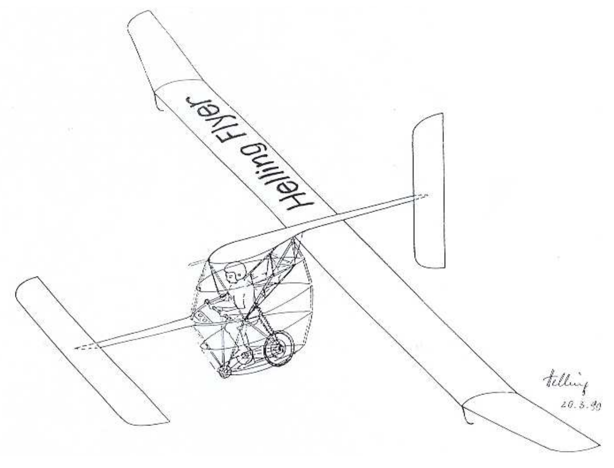

Figure 1: Human powered airplane with integrated flapping wing, german patent 1990 [1]

*Translation

I applied for a patent in 1990. Figure 1 shows my idea for a human powered airplane from 1990.
Since that time I worked on flying models powered by an integrated flapping wing: eight different projects were planned and partly also realised.

2 THE PRINCIPLE

2.1 Flapping Wing Principle

In the following pictures you can see the ordinary flapping wing principle. During the down stroke both lift and propulsion are produced due to a positive angle of attack, figure 2. The up stroke forces depend on a variable angle of attack: If this angle is positive, the air flow comes from under the wing, which leads to a lift and a drag ("negative propulsion"), figure 3. The other possibility is to choose the angle of attack to be negative, so that the air flow comes from above the wing. The result would be propulsion and a negative lift, figure 4.

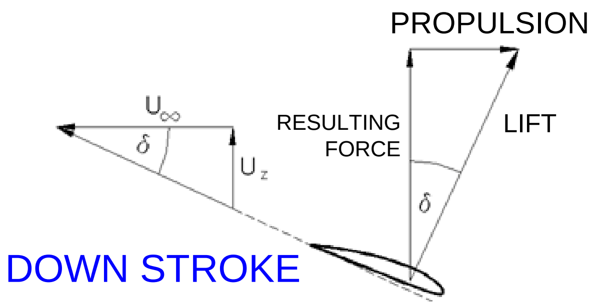

Figure 2: Forces during down stroke [2]

Since it is not possible to fly with negative lift, a positive angle of attack has to be choosen during both strokes. This leads to a continuous, but unbalanced lift during up and down stroke. This unbalanced lift leads to vertical motion of the fuselage, further called "fuselage dancing". On the other hand there's a problem with propulsion: since there's a drag during up stroke, the down stroke velocity has to be bigger than

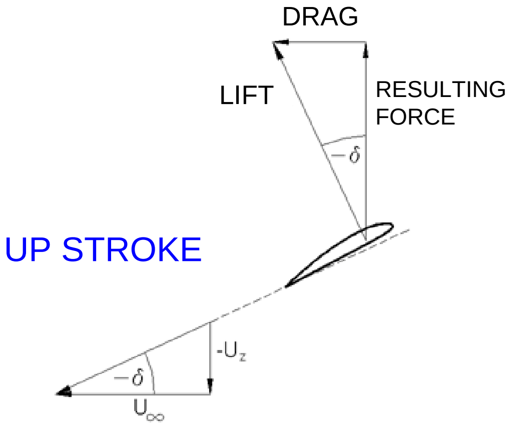

Figure 3: Forces during up stroke with positive angle of attack [2]

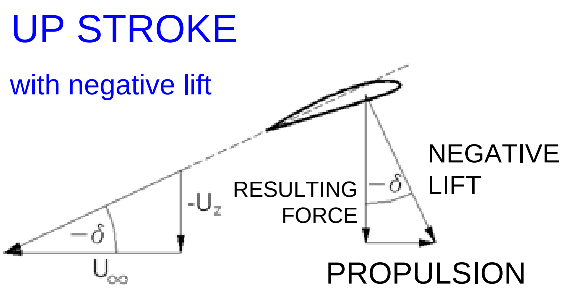

Figure 4: Forces during up stroke with negative angle of attack [2]

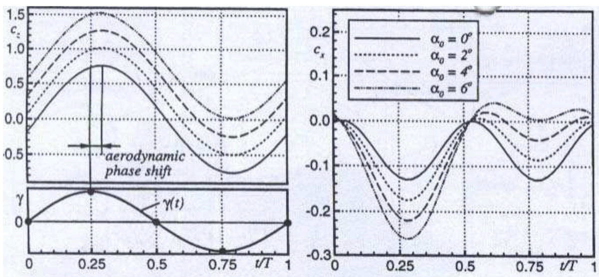

Figure 5: Lift (left) and drag (right) coefficient over a period of a whole plunging cycle [3]

the up stroke velocity in order to have a positive total propulsion for a whole plunging cycle. Otherwise propulsion during down stroke and drag during up stroke would cancel out each other. The unsteady propulsion leads to quite big variation of momentary velocity.

These relations between lift and drag coefficient over a period of a whole plunging cycle are shown in figure 5.

2.2 Integrated Flapping Wing

Integrated flapping wing means that the whole - normally fixed - wing is used as a flapping wing. The trajectory is controlled in a way that the result is a constant lift during up and down stroke and propulsion during down stroke. This is achieved by a combined plunging and pitching motion of the wing.

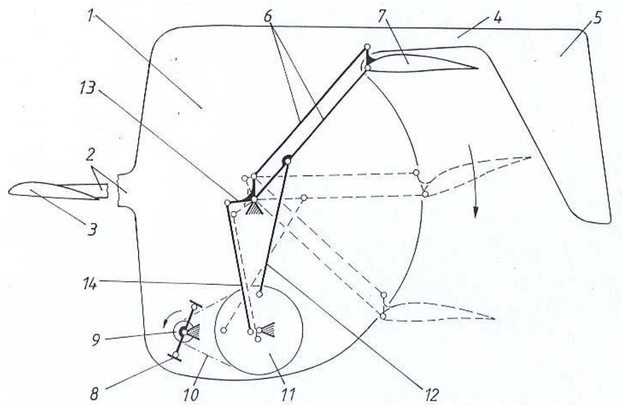

Figure 6: Principle and Trajectory of the integrated flapping wing [1]

3 ADVANTAGES AND DISADVANTAGES

3.1 Advantages

Many advantages are based on the use of the whole fixed wing as a flapping wing: The flow cross section is much bigger than for an ordinary propeller and a bird, figure 7. The result is a high efficiency up to 90 percent [3] - which is the highest of all known propulsion principles. Besides, the integrated flapping wing has always an elliptical lift distribution in contrast to bird flight. And in contrary to a variable pitch propeller it can adapt exactly to all flight regimes. Another advantage is the lower aircraft noise.

3.2 Disadvantages

As mentioned in section 2, only the down stroke leads to propulsion. Thus momentary velocity varies over time. Furthermore much greater masses have to be accelerated compared to an ordinary propeller.

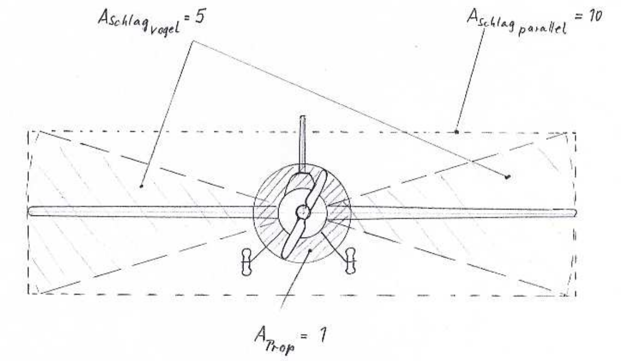

Figure 7: Comparing flow cross sections of propeller, bird flight and integrated flapping wing

4 DIFFERENT PROJECTS

4.1 Project SF1

The first model SF1 (figure 8) was built in 1988 and had its first successful flight in 1992 after I made some alterations. It had an spring operating storage (rubber strap) which compensated the fuselage weight at bottom dead center. Thus the down stroke force was higher as the up stroke force so that propulsion resulted.
Furthermore plunging frequency, pitching angle and phase difference between plunging and pitching motion signal were coincidental right, therefore fuselage "dancing" could not be noticed.

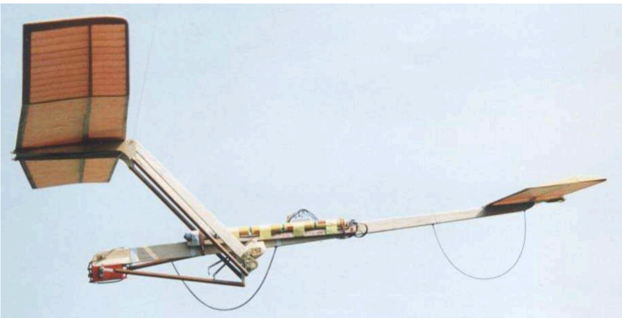

Figure 8: Model SF1 in flight

4.2 Project SF5

SF5 is a quite big model with a wing span of 3.20 m and a mass of 4 kg, figure 9. It is capable of flying, but inappropriate as a testing model. It will fly again when the connection between pitching and plunging in motion and amplitude is clearer.

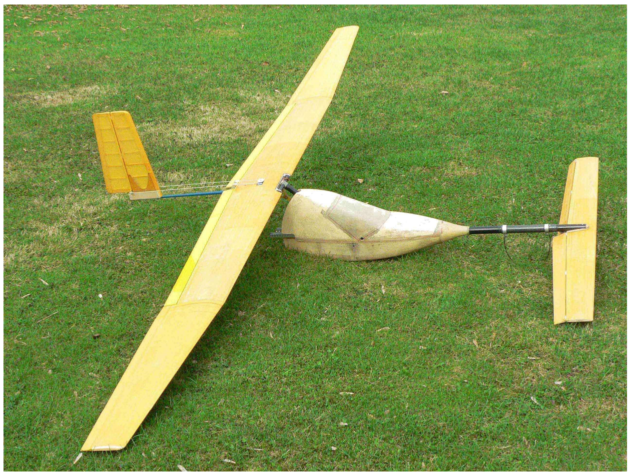

Figure 9: Model SF5

4.3 Project SF8

Since the trajectory to achieve propulsion and a constant lift cannot be calculated with simple methods, I built the light and slow testing model SF8. With this model different alternatives were tried in order to achieve a steady flight.

Figure 10: Model SF8

5 TESTING AND RESULTS

I tried to reduce the fuselage dancing by generating a constant lift. Automatical controlling by acceleration measurement and altering the angle of attack should achieve this. Unfortunately the servo was to slow, thus the whole controlling mechanism caused instability. Furthermore an extra damping plane in front of the fin was used to reduce the "dancing" amplitude. This worked during testing period, but does not seem like a final solution to the "dancing" problem.
Two main results showed the testing for a plane with one integrated wing: In order to get propulsion, the down stroke velocity has to be higher than the up stroke velocity. Secondly, the fuselage "dancing" can

be reduced only by a complicated controlling mechanism, whereby the pitching has to be altered in amplitude and phase depending on the plunging frequency. But I cannot realize this controlling mechanism.

6 NEW PROJECT SF9

For me a simpler solution to the main problems propulsion and constant lift will be realized in my new project SF9, which is in construction phase at the moment. It has two integrated flapping wings on top of each other and a folding propeller, as can be seen in figure 11. During take off the wings are fixed and the propeller is used for propulsion. During cruise flight the propeller is folded and propulsion is obtained by both wings.

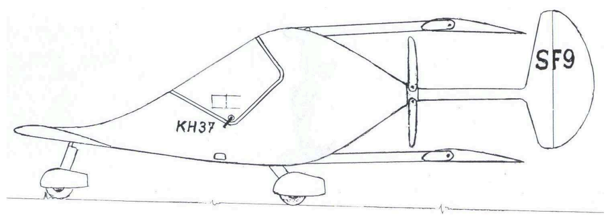

Figure 11: Sketch of the new project SF9

The plunging motion of both wings has a phase difference of 180 degree, which leads to a constant lift on one hand (if the angle of attack is constant and positive during whole plunging cycle). On the other hand this means also that the drag during up stroke is compensated - hence, up and down stroke velocities can be equal without loosing propulsion. This has a number of advantages: Since up and down stroke forces are compensated, a power storage isn't necessary anymore. The propulsion value and frequency is twice as high, thus altering in momentary velocity is minimized.
Moreover, adjustment to different flight regimes can be achieved by altering the pitching in amplitude and phase depending on plunging frequency. This adjustment is not as difficult as the controlling mechanism mentioned in section 5.

7 CONCLUSION

The integrated flapping wing has advantages over an ordinary propeller, and could be a real alternative for slow flying planes like human powered airplanes, microlights or unmanned micro air vehicles.
However, it is difficult to solve the two main problems: obtaining constant lift and propulsion. If one flapping wing is used, propulsion is achieved by making the down stroke velocity higher than up stroke velocity. But this still leads to an unsteady propulsion. A constant lift could be attained by a controlling mechanism, which alters the pitching in amplitude and phase depending on the plunging frequency and is not easy to realize (by me).
A better way to apply the integrated flapping wing concept would be to use two flapping wings on top of each other, like in the new project SF9. Thereby, a harmonic plunging motion causes a constant lift and a more evenly propulsion. It is still an open question wether the SF9 concept is as good in practice as in theory.

References

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[2] H. Räbiger: *Das Flugprinzip der Ornithopter*, http://www.ornithopter.de/prinzip.htm, checked 9.2007

[3] M. Neef and D. Hummel: *Euler Solutions for a Finite-Span Flapping Wing*, Technical University of Braunschweig, 2001