INTEGRATED FLAPPING WING FOR AEROPLANES

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1 THE IMPULSE TO THIS WORK

In 1977 Paul Mac Cready and his team completed a one mile long figure-eight flight with the human powered aeroplane Gossamer Condor and crossed the English Channel in 1979 with the Gossamer albatross (fig. 1). I was amazed, although at that time I had no access to technical details. Besides the sporting performance of the pilot, the solution with high-strength new materials fascinated me. The aircraft has a wing span of 30 m and a weight of only 30 kg. The propeller has a diameter of just less than 4 m and the power output is between 200 and 300 Watt. However, flying in windy conditions is unthinkable. In 1988 Daedalus that was built in the Massachusetts Institute of Technology (MIT) flew 115 km over the Aegean Sea (fig. 2).

These performances made me think whether it is possible to achieve similar outputs without building an aircraft even greater or lighter.

Bigger, geared-down propellers increase the efficiency, because the air column with bigger cross section that is moved by the propeller does not need to be accelerated so strongly. However, the enlargement of propellers is limited by mass, gears, reaction moment and height of the undercarriage. In small propellers the friction of the accelerated air column in the surrounding air and at the fuselage and the angular momentum losses lead to an output loss up to 50% as frictional heat. Good propellers can reach an efficiency rate of about 80%.

2 THE ALTERNATIVE TO THE PROPELLER

2.1 Classical flapping wing

In the flapping wing of birds the cross section of the air column accelerated is considerably bigger, because the whole span is used (fig. 3). Therefore I considered a flapping wing as an alternative to the propeller.

How is thrust generated when a bird is flapping its wings? During down-stroke birds twist their wings around the shoulder joints lengthwise to the wing span. That happens in such a way that the lift force remains constant in the sum. Towards the wingtip a forward component results from inclination of the aerodynamic force in direction of travel. During the following, normally slower up-stroke the wings are twisted in the opposite direction. That results in low additional air resistance but the lift force remains constant. Thus thrust is only provided during down-stroke.

Initially my thoughts went in this direction in 1986. Different gears and torsion elastic wings were conceived (fig. 4 and 5).

However, the kinematics of the wing flapping of birds with their torsion elastic wings cannot be realized with regard to profile accuracy generally applied today. At this critical factor all previous trials of using flapping wings to generate thrust more efficiently than propellers have failed. Examples are tests that were carried out by von Lippisch in the nineteen-thirties and by Arno Vogel in the nineteen-forties. Von Lippisch used a combination of fixed and flapping wings where the elastic flapping wings created thrust but no lift (fig. 6 and 7) [5]. Arno Vogel conducted measurements with component scales in a free air flow (fig.8). The results were used to accomplish a human powered flight with a modified SG 38 with flapping outer wing sections (fig. 9) in 1942 near Hartenstein, Germany. Arno Vogel continued these attempts with a VOX-1 in 1953 in Hartenstein and 1954 in Ballenstein (fig. 10). His project VOX-2 with a modified Baby 2b was not realised anymore (fig. 11).

After the end of World War II the aircraft designer A. Schmid equipped French forces “Grunau babies” with small flapping wings mounted at the sides of the fuselage behind a larger fixed wing. The flapping wings were powered by a 3.6 HP Sachs engine with 60 to 100 strokes per minute (fig. 12). Another variation during flight is shown in fig. 13.

2.2 Integrated flapping wing

Inspired by the fluke of a whale, I had the idea to mount the wing not directly to the fuselage, but to attach it to a linear guide that moves up and down. This way it was possible to build an aeroplane with an end-to-end rigid wing without shoulder joints. I applied for a patent of the principle of the integrated flapping wing in 1990 [1] (fig. 14). Unfortunately a financial promotion by the Patent Centre of German Research was rejected. The aviation industry had no interest in this propulsion system, because a sensible application is only indicated in lower speed ranges. Only Mr. Köhler, at that time Technical Manager of HOFFMANN AIRCRAFT, found the principle fascinating and encouraged further development.

Compared to wings of a bird the cross section of the air column accelerated by an integrated flapping wing is twice as large (fig. 15). Another big advantage is that the elliptical lift distribution and thus, a least possible lift-induced drag are preserved in all stroke stages. The lift distribution of bird's wings shows a waveform with a trough in the middle that causes a higher lift-induced drag. In contrast to a variable pitch propeller where only in the middle section of the propeller blades the pitch generates optimal output the integrated flapping wing has optimum airfoils along the whole wing span and is exactly adapted to the flight regime. Because the transient airflow allows higher lift coefficients, a large aspect ratio is sensible.

3 TEST IN THE MODEL

3.1 First successful flight

With my first model SF1 of 1988 (fig. 16) that is today exhibited in the Lilienthalmuseum in Anklam, Germany, I have tried to apply my knowledge acquired into practice.

The construction difficulty to change the angle of attack during flapping I have solved with a parallelogram steer. Another problem was the use of a “work store” for up-stroke. Until today there is the incompletely resolved question how the motion sequences of flapping amplitude and rotary amplitude should be optimized to generate constant lift. The work store prevents a negative drive torque during up-stroke and provides a faster down-stroke than up-stroke. To generate large thrust during the down-stroke and to minimize additional aerodynamic resistance with a single flapping wing the down-stroke has to be faster than the up-stroke. This problem I have solved with an over dimensioned spring-operating work storage for model SF1.

After several modifications and changes of the model the first successful flight could be videotaped in 1992.

I have submitted an application of the concept of the Integrated Flapping Wing for the "Berblinger-Preis 1992", an award of the Culture Office of the city of Ulm. Figures 17-20 show drafts for this competition. Nevertheless, the participation was unsuccessful, because the award had been suspended in favour of the first self-launch solar aeroplane in 1996.

3.2 Other models

After the SF1 I have designed model SF2 in 1993 and assembled the body shell together with Karl-Heinz Wagler and Hans Langenhagen. SF2 (fig. 21) is a canard model with a pair of flapping wings mounted to a common steer. The concept of two flapping wings does not require a work store mechanism, however, has the disadvantage that the rear flapping wing is in the wake of the front one. For the same reason concepts with two pairs of flapping wings that work 90 degrees phase-shifted also appear problematic. The advantage of such a design would be a nearly constant thrust. The model was not finished because the technical design seemed to be too complex to begin with.

SF3 and SF4 are drafts of manned ultra light aircrafts in a conventional configuration. They are just put down on paper.

SF6 and SF7 are demonstration models that were designed and built for a school project on the subject: "Why birds fly". Because of the simplified propulsion kinematics the models seem only suitable for being a flying toy (fig. 22).

3.3 Constant elevator control

Model SF8 as a light and slow testing model with low risk of breakage I have built in collaboration with Claus Thiele (fig. 24 and 25). SF8 is a tail-first model, a canard, whose flapping wing is also used for elevator control. Constant elevator control is realised by a gyro that measures the rotation of the fuselage around its lateral axis and controls the elevator servo.

The forerunner model SF5, with 3.2 m wing span and a mass of approx. 4 kg, (fig. 26-28) should only fly again when the motion interrelationship between flapping amplitude and rotating amplitude is determined. At first I want to reduce the surface load from 50 to 30 g/dm² by using a lighter wing and lithium polymer cells. The model has already overcome three crash-landings. Causes were, however, not the flapping wing propulsion, but at first a missing aileron, inexperience with the canard design and a not recognised change of the angle of attack setting after the 2nd crash.

3.4 New Project

According to fundamental research of HERTEL [2] and CLAUSS [3] the flapping wing motion is compound harmonic motion vertically to direction of travel (plunging) and a phase-shifted harmonic rotary motion (pitching). For that purpose NEEF and HUMMEL have conducted model calculations [4]. Accordingly the expected propulsive efficiency of a symmetrical airfoil is approx. 90% (fig.29). NEEF and HUMMEL concluded that in flapping wings the impact of the lift-induced drag is dominant (higher lift coefficient as a result of transient airflow possible). However, starting and stopping vortices induced by a flapping wing are weak and similar to those in travel flight of big birds.

Considering these findings I have conceived a new model SF9. In contrast to the earlier concepts with two or four flapping wings that were mounted in a row SF9 is designed with two flapping wings fixed one above the other. The wings operate in opposite directions in an undisturbed airflow. Fundamentals of the design are derived from results of NEEF and HUMMEL [4]; their calculation results are shown in graphs of lift and thrust coefficients (fig. 31). The motion sequences are shown in the fig. 32 and 33.

If lift coefficients of both wings are added up for an angle of attack of 6 degrees, constant lift is generated. The mean thrust coefficient doubles. This solution allows a perfect mass balance of all moving components and does not need a work store mechanism for up-stroke. Furthermore doubling the propulsive frequency results in more homogeneous momentary velocities.

SF9 will have a folding propeller that can be activated in the middle position of the flapping wings and allows problem-free takeoff and landing.

4 SUMMERY

This study focuses on the development of a propulsion system that works with higher efficiency than propellers. Originally planned for human-powered aeroplanes the principle of the integrated flapping wing could also be used for development of micro air vehicles (MAV), ultra-light planes and solar aeroplanes.

With respect to the theory of flapping wings HERTEL [2] and CLAUSS [3] have gained fundamental insights in 1967/ 68. NEEF and HUMMEL [4] conducted calculations and determined efficiencies for the travel flight regime of approx. 90%.

The central idea of the integrated flapping wing, generated by the author in 1990, is the use of a rigid, undivided lift generating wing as a flapping wing. The wing is mounted to a guide that is moving vertically to the fuselage. Motion sequence and angle of attack are controlled in a way that a constant lift and thrust is generated in all stroke stages. Fluctuations of momentary velocities are disadvantageous. A reduction of inhomogeneous velocities is possible by the use of two inversely flapping wings.

Advantages of flapping wing propulsion are:

- highest efficiency in comparison to other known propulsion systems,

- optimum adaptation to all flight regimes: in contrast to propeller this applies all airfoils of the flapping wing,

- high environmental compatibility by low aircraft noise.

5 REFERENCES

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Figure captions:

Fig. 1: The Gossamer albatross crosses the English Channel in 1979
Fig. 2: Man-powered Daedalus88, built at MIT, flies 115 km across the Aegean Sea in 1988
Fig. 3: The gull as a classic model for the flapping wing
Fig. 4: Draft of a torsion elastic wing
Fig. 5: Drive system for torsion elastic wings
Fig. 6: Model of von Lippisch with thrust generating flapping wings
Fig. 7: Flapping wing drive system with petrol engine
Fig. 8: Flapping wings with 3m span on big component scales
Fig. 9: Man-powered airplane with outer flapping wing sections in 1942 in Hartenstein, Germany: a modified SG38
Fig. 10: Test aeroplane Vox-1 before takeoff in Ballenstedt, Germany
Fig. 11: Vox-2
Fig. 12: Adelbert Schmid in front of his successful aeroplane
Fig. 13: Baby with thrust generating flapping wings during flight
Fig. 14: Principle of the integrated flapping wing [1]
Fig. 15: The airflow cross sections of propeller, bird's wing and integrated flapping wing
Fig. 16: SF1 during flight
Fig. 17: Man-powered aeroplane with spring-operating storage
Fig. 18: Electric motor glider
Fig. 19: Commuter aircraft

Fig. 20: Hybrid airship
Fig. 21: Canard short-range aircraft
Fig. 22: Flying toy SF7
Fig. 23: SF7 during flight
Fig. 24: Author with SF8
Fig. 25: SF8
Fig. 26: Takeoff preparation for SF5
Fig. 27: SF5 during flight
Fig. 28: SF5 gears
Fig. 29: Mean lift (c_L), mean thrust (c_T) and efficiency (η) for a combined plunging/ pitching motion at different mean angles of attack [4]
Fig. 30: SF9 in takeoff and landing configuration with an activated folding propeller
Fig. 31: Time-dependent force coefficients for different mean angles of attack [4]
Fig. 32: Time history of plunging/ pitching motion for phase shift Φ=90 deg and mean angel of attack α_o= o deg. [4]
Fig. 33: Schematic of a two-dimensional airfoil in plunging/ pitching motion around the c/4 axis. Angle of attack γ through plunging is indicated for the down-stroke [4]