HUMAN POWERED FLIGHT WITH VELAIR

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INTRODUCTION

The human powered flight is one of the oldest dreams of humanity, and as a glider pilot and former bicycle racer, the author had to fulfill his own dream and started the project Velair as soon as he finished his studies and earned enough money.

Theoretical design and optimization (wing, airfoils, prop and structure) have taken place since 1986 and the construction was started in the summer of 1987 with the help of two friends. Velair has flown since the summer of 1988 and it is a great pleasure for all.

The goal of the project is (besides fun) to build up experience in the optimization of very light structures, wing — airfoil — and propeller — aerodynamics, aeroelasticity and composite-technology for the evaluation of low-power/long-range aircraft.

In spite of a low budget and chronic lack of time (it is only a leisure time project) it was possible to develop a practical aircraft with acceptable performance (Figures 1 and 2).

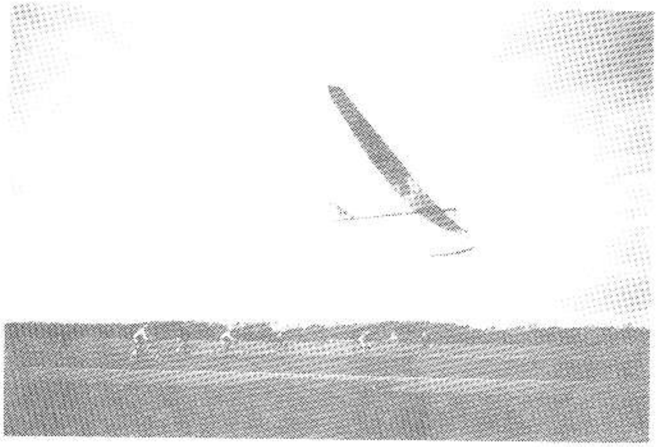


Figure 1. Flight Testing Velair

DESIGN

The "cruising power" of a pilot is about 3.35 watt/kg (compared to an aeromodeller engine: 6000 Watt/Kg). This gives a 60 kg pilot power of about 200 watts, just enough to illuminate 2 lightbulbs, but with this low power level the 60 kg payload must be carried in the air.

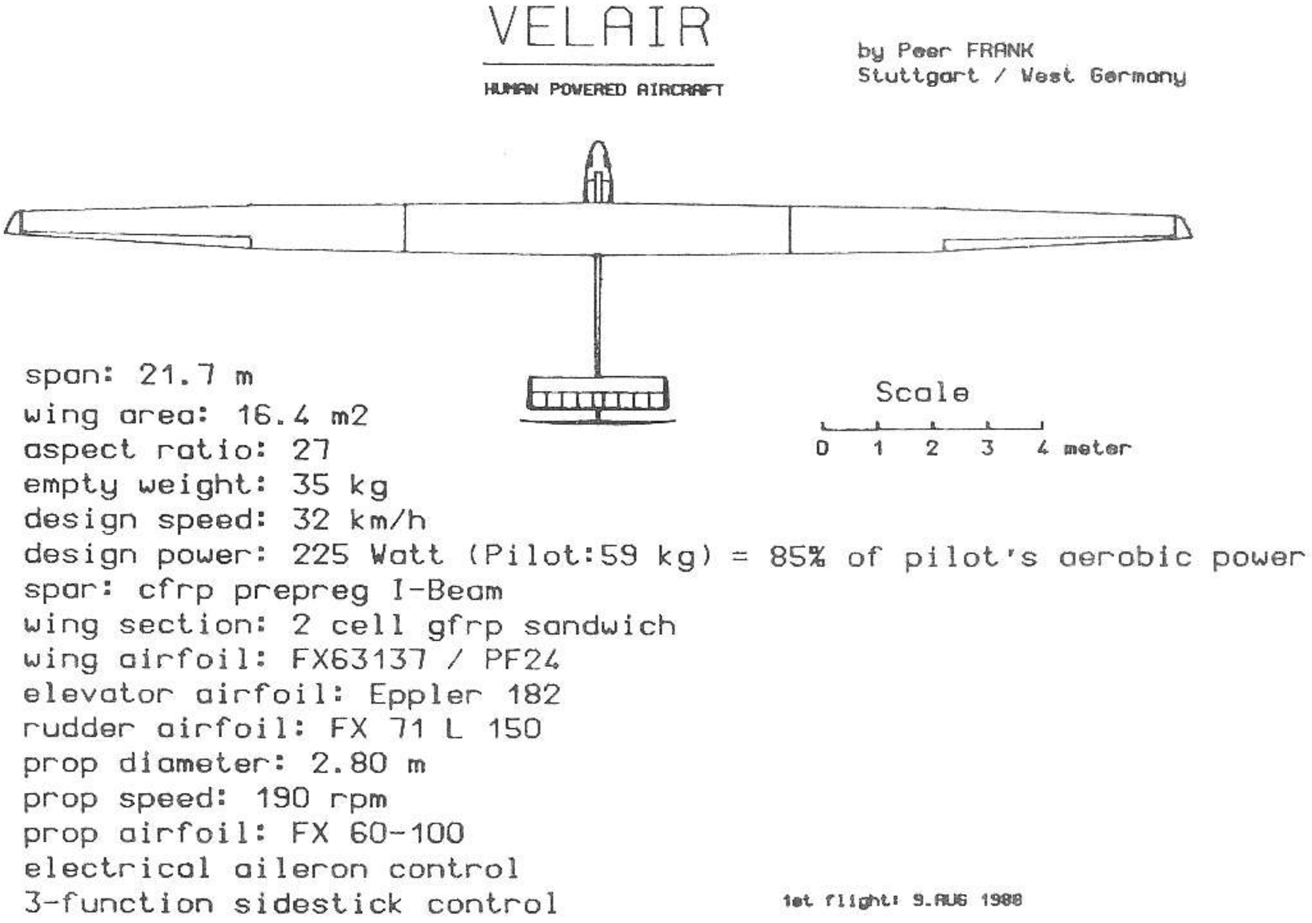
This can be done with three strategies: low speed, low weight and low drag. But, these goals cannot be reached independently because they influence each other in a complex manner and other constraints are important, such as workshop dimensions, transport facilities, costs and available manpower for the development. Low weight requires small span and low aspect ratio; low speed requires big wing area and high lift coefficient. This leads to high induced drag that can be reduced with high aspect ratio and so on.

The excessive light-weight construction leads to flexible structures where the variation of aerodynamic loads, due to the deformation of the structure, has to be considered. Of course, the exact airfoil shape must be preserved.

For an optimum design it is necessary to know and be able to evaluate all these effects to decide where stiffness has to be increased or weight can be saved. Nearly every gram has to be saved and it is important to have an accurate calculation-model that simulates aerodynamic and elastic behavior, weight distribution and loads of the aircraft.

WING DESIGN

Velair has a double-tapered cantilever 21.7 m wing divided into three panels and a trailer which has a length of 7.3 m. The



span: 21.7 m
wing area: 16.4 m2
aspect ratio: 27
empty weight: 35 kg
design speed: 32 km/h
design power: 225 Watt (Pilot:59 kg) = 85% of pilot's aerobic power
spar: cfrp prepreg I-Beam
wing section: 2 cell gfrp sandwich
wing airfoil: FX63137 / PF24
elevator airfoil: Eppler 182
rudder airfoil: FX 71 L 150
prop diameter: 2.80 m
prop speed: 190 rpm
prop airfoil: FX 60-100
electrical aileron control
3-function sidestick control

Figure 2. Velair-Human Powered Aircraft

I-spar is made of high-tensile carbon fiber prepregs (Fiberite 1048) with T300 fiber) and glass/Rohacell sandwich web and a glass-sandwich cell. With a lifting wire the spar weight could have been reduced by nearly 2 kg and the fuselage connection could have been simplified, but the relatively small wing requires a speed that is already to high and the wire drag would require more power than would be saved by the weight. So we enjoy quick assembly and there is no danger of hanging ourselves in the nearly invisible wire. In spite of stiffness requirements, the 120 degree C prepreg with the high tensile fiber has been chosen because of the very small layup radius in the connection parts where the use of high modulus fibers is impossible.

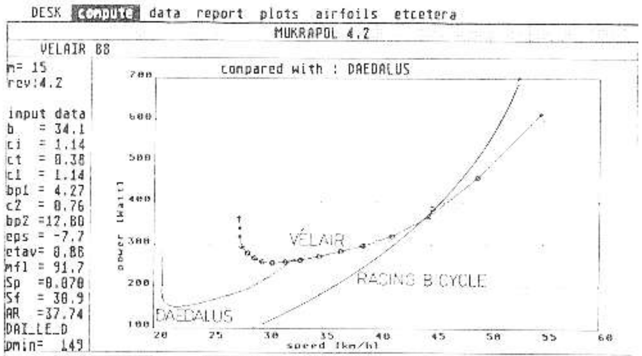
For the best design the optimum between the light but flexible and heavier but stiff wing must be found. Torsion divergance has to be avoided. An iteration algorithm that puts bending and torsion stiffness in equilibrium to the aerodynamic loads has been implemented. The calculations showed that convergance was hardly reached. It can be shown that a carbon tube spar gives much more torsional stiffness than the light glass-sandwich double-cell shell, in spite of the great enclosed area. The disadvantage of course, is the worse specific bending stiffness that has to be compensated with a lifting wire and/or high modulus fibre-prepregs that are 3 times as expensive as those with high tensile fibers. But on the other hand, the maximum design bending moments can be kept much lower than on cantilever wings (Daedalus/34.1 m span about 1000, Velair/21.7 m about 3500 Nm) so that the buckling problems of the thin-walled structure elements can be solved more easily.

The aerodynamic coefficients of the wing are calculated by a modified Multhopp method, that takes into account the whole airfoil characteristics over the required Reynolds number range and the post-stall behavior. Together with the weights, aerodynamic and mechanical effectivities the required power can be calculated and compared easily and quickly with other configurations (Figure 3).

AIRFOIL DESIGN

In spite of the narrow speed range the Reynolds numbers varies from 180000 to 700000 because of the strongly tapered wing. This range comes to lie exactly between the Reynolds numbers of aeromodeller and glider airfoils so very few airfoils are appropriate. For reasons of costs and time further developments can only be done with the computer. Airfoil drag accounts for 40% of total aircraft drag meaning airfoils with high L/D at relatively high lift coefficient must be developed. The airfoil can be designed for a narrow Cl range from 0.9 to 1.5 and drag must be reduced with pressure distributions that allow maximum length of laminar flow. Great attention must be focused on the laminar separation bubbles that increase airfoil drag considerably. It seems not to be a good solution to avoid bubbles with an earlier forced transition because the transition position moves too much with the angle of attack. Figure 5 shows the pressure distribution for the airfoil (Figure 4) designed with the very quick code of Prof. R. Eppler (Stuttgart) and recalculated with the code of Mark Drela (MIT) that allows drag calculation over the bubble and easy interactive design of the pression distribution. the bubble on the suction side can be seen distinctively.

The characteristics of the airfoils have to be achieved with low moment-coefficients, because they determine the weight of the torsion-structure and the volume of the stabilizer.



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VELAIR 88
m= 15
rev:4.2

input data
b    = 34.1
ci   = 1.14
ct   = 0.38
c1   = 1.14
bp1  = 4.27
c2   = 0.76
bp2  =12.80
eps  = -7.7
etav= 0.86
mfl  = 91.7
Sp   =0.870
Sf   = 30.9
AR   =37.74
DAI_LE_D
pmin=  149
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Figure 3. Calculated power required for 60 kg pilot, 0.792 propulsion efficiency and without any ground-effect.

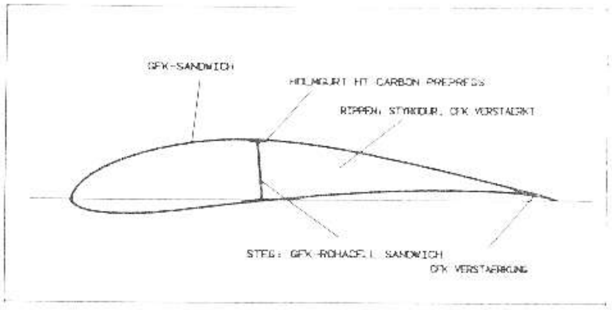


Figure 4. Wing section Velair

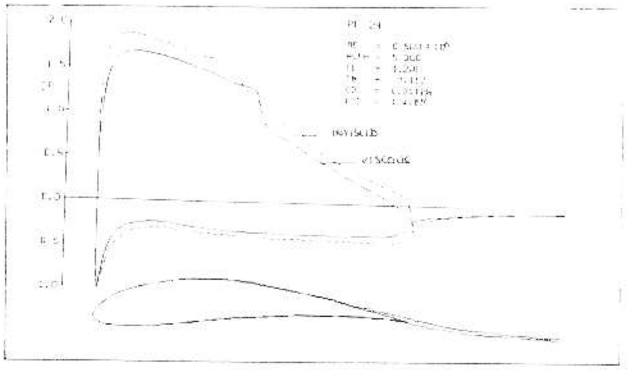


Figure 5. Calculated pressure distribution at wing airfoil.

FUSELAGE

The pilot is sitting in a semi-recumbent position in a carbon-kevlar mould. The sandwich tubes are made of carbon fabric hand-layup. The carbon main undercarriage has a 200 mm tire without suspension. The front wheel has a small solid tire that can be easily lifted at a speed greater than 10 km/h. the fairing is made of glass sandwich and has been designed as small as possible and totally clear of the wing to reduce friction and interference drag. An intake provides enough fresh air for the pilot who produces four times as much heat as mechanical power. Figure 6 shows the panel-model that has been used to calculate some pressure distributions and boundary layer developments to evaluate and optimize the fuselage shape.

PROPELLER

It is difficult to say if the propeller has to be in front or at the tail. Both configurations have positive and negative aspects. In fact, the rear prop configuration is only about 100 grams heavier than the front because the shaft to the tail weighs only 95 g/m. In front, the big fuselage main tube would need to be long enough to allow the greatest prop diameter before the fairing. On the other hand, a maximum diameter (for high effectivity) is possible here. At the tail it would need to be reduced to allow rotating for take off and landing. Aerodynamically, the front prop has undisturbed flow conditions, but disturbs wing and fuselage flow. At the tail it gets some turbulence from wing downwash, fuselage and stabilizers but increases slightly the dynamic pressure at the stabilizers so that their effectivity can be increased.

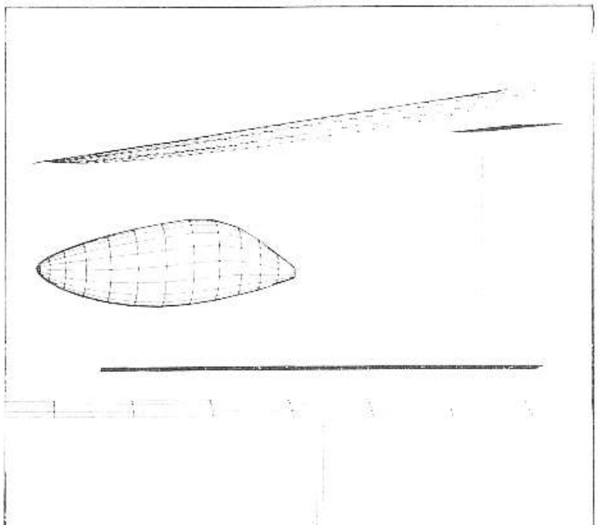
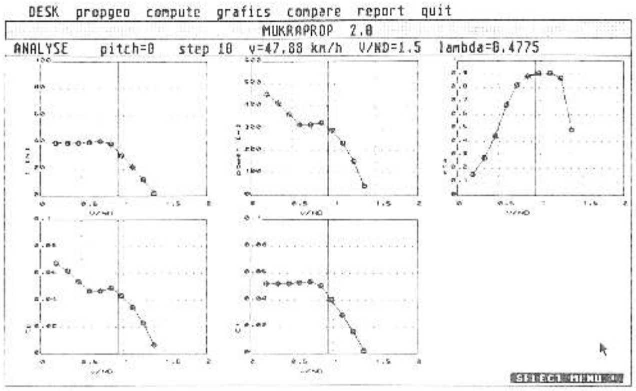


Figure 6. Panel model for fuselage drag analysis and optimisation.

For the prop design a minimum induced loss program has been implemented that also takes the whole airfoil characteristics into account. For the available diameter of 2.80 m the optimum shaft speed is 190 rpm. To illustrate the circumstances: at 8.33 m/s with 300 watt the design thrust is 32 Newton, the weight of the prop including free wheeling hub is 713 grams. The prop-blades are built in moulds with carbon fabric and epoxy. Some recalculation results are presented in Figure 7.

Every part of the drive line has to be designed for maxium effectivity. A light 4 mm chain transmits the torque from the pedals to the shaft without any diversion. The carbon shaft has low bending and high tension stiffness to fit deformations of the fuselage tube. Total weight from the pedals to the prop is 1812 grams.



ANALYSE pitch=0 step 10 v=47.88 km/h V/ND=1.5 lambda=0.4775

Figure 7. Calculated prop-coefficients.

STABILIZERS

Here too, the drag and weight minimum has to be found with maximum safety. The limits of control are outside of the speed range, and in comparison with gliders a smaller stabilizer volume can be chosen with similar static stability because no scatter in pilot weight and no winched takeoff has to be considered. Rudder and horizontal stabilizer are all moving surfaces. the horizontal stabilizer has spring trim, the rudder a strong spar and a soft kevlar tip to prevent the prop from touching the ground.

CONTROL

In human powered aircraft, the feet are naturally not available for control. With good conditions, there is no problem flying without ailerons (like Daedalus, Pelargos), but for European conditions with narrow runways and sidewind, take off and landing can be made much simpler and safer with the use of ailerons. The Velair wing has 20% chord ailerons moved by aeromodeller servos. On the right side of the seat the pilot has a little "cardan-joystick" that allows him to control all three functions — rudder, stabilizer and ailerons.

INSTRUMENTATION

Presently, there is only an airspeed indicator as used by for para-gliders with a little windmill mounted on the canopy that sends a frequency to a small solar powered receiver with a digital speed LCD-display. (It is not true that the aircraft is powered by this instrument.) Some strain gages are fixed at several positions on the wing and the prop-shaft, and when the flight data acquisition system is ready, some interesting measurements can be done.

ERGOMETER TESTS

To determine the pilot's power some ergometer tests have been run at the Sport Medicine Institute of the University of Tubingen (Figure 8). The power has been augmented by 50 watts every 3 minutes until the pilot faced exhaustion, while heart rate, electrocardiogram, breath rate, oxygen and uptake and blood lactose level were continuously monitored to determine the anaerobic limit. The test was run with a good trim state (12000 km bicycle training/year).

COMPARISON OF WEIGHTS WITH THE MIT DAEDALUS

It would be interesting to compare the measured required power and range of Velair with those of Daedalus. These results have already been demonstrated impressively by the Daedalus team and the theoretical predictions could be proved. For Velair, range and measurement — flights are scheduled for summer 1989.

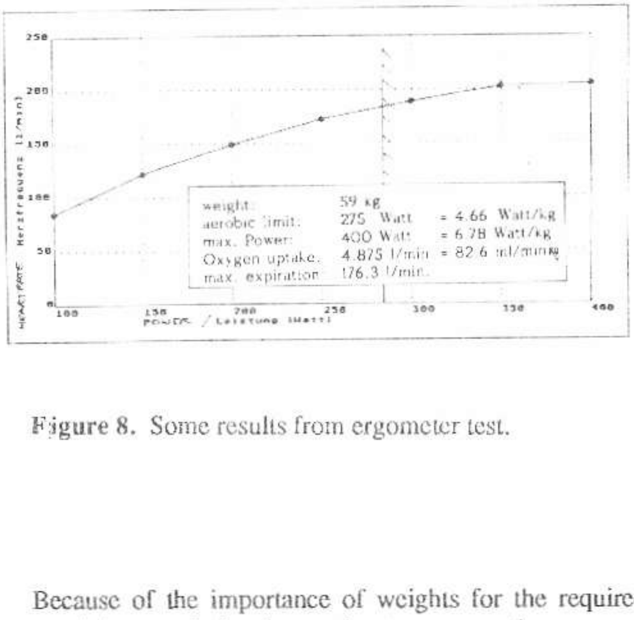


Figure 8. Some results from ergometer test.

Because of the importance of weights for the required power it is nevertheless interesting to compare these:

Component	Velair	(Design-as is)	Daedalus
Wing	18900	21790	18985
Fuselage	12000	11620	10130
Stabilizers	1400	1616	1162
Propeller	1000	713	800
Totals	33300	35739	31077 Grams

The difference between design and actual weight of the Velair wing is due to a load-test where the structure has buckled. Due to financial considerations and time restraints, the wing was only repaired and the resulting additional weight had to be accepted.

Considering the aircraft dimensions together with the weights as compared in Figure 9, we see the great advantage for the Daedalus. But it must be kept in mind that a professional project is compared with the result of a hobby. Anyway, it is the great experience and knowledge of the whole team that lead to the wonderful success of Daedalus.

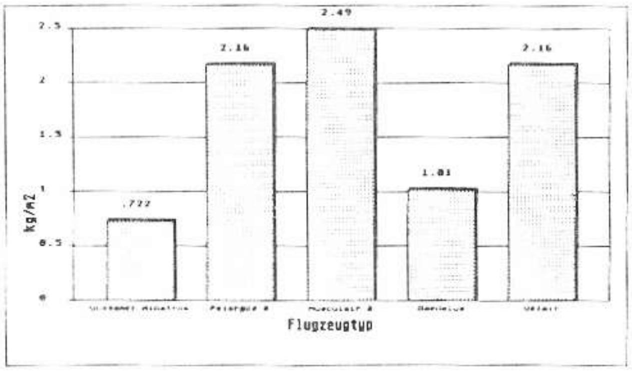


Figure 9. Specific weights.

ACKNOWLEDGEMENTS

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