FEASABILITY STUDY FOR THE PRODUCTION OF ENERGY FOR BOUNDARY LAYER SUCTION IN SOARING

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Summary

In order to achieve high cruising speeds with a high-performance sailplane the altitude gained in strong up currents must be applied by means of high gliding speeds.

The x'climbing or the energy growth rates in the upcurrents are often very different during one flight.

The sometimes less strong climbing ranges of 5 to 20% of the overall climbing time can be used for power absorption by dispensing with further climbing in order to draw energy from the flow by means of a folding turbine. The energy stored is then used later during gliding for boundary layer suction.

As a result of the boundary layer suction of the wing and tail surfaces the overall drag nearly is halved, resulting in nearly doubling the glide ratio. Decisive is the overall efficiency of the turbine, storage and suction.

The storage of energy in a fly-wheel accumulator best meets this requirement. If the energy is, on the other hand, stored electrically, this offers many advantages for suction and control.

The best solution is a combination of a generator and an electrical driven fly-wheel accumulator.

Introduction

The demands made on a high-performance sailplane are essentially at two extremes:

On the one hand the minimum speed has to be as low as possible with a low rate of vertical descent, in order to climb in an optimum way in the thermal.

On the other hand, good gliding angles up to the high-speed range are expected to make use of the altitude gained in an optimum manner. A good solution can only be the sum of many compromises.

On the one hand, low weight, high aspect ratio and high lift coefficients are desired, whereas on the other hand, high weight, low drag coefficients and a small wing area are advantageous.

All these are design measures in order to achieve the highest possible cruising- speed from the range of different types of upcurrent, upcurrent intensities and distributions of upcurrent.

The flight path climb time is meant at the same time to be as short as possible. Short flight path climb times are, however, only achieved with strong upcurrents. Here, the energy-growth-rate of a sailplane is highest. (Figure 1.)

1. Absorption of Energy

The strength of a thermal upcurrent changes frequently with altitude. Due to the temperature gradient and the age of a thermal bubble, relatively large differences can be obtained.

The thermal upcurrents are often particularly strong under the cloud base. In addition different upcurrents are often also different from one another.

Due to local terrain features or also air mass changes considerable differences are frequently shown. (Figure 1 b)

In the top example (Figure 1a) a sailplane with a weight of 4,320 N at 1,000 m gain in altitude gains a potential energy of 4,320,000 Nm. The total flight path climb time in this case is approx. 720 sec (12 min).

In accordance with the intensity of this thermal, the gain of energy is 4.320 Nm/sec at a climb rate of 1 m/sec and 12.960 Nm/sec at a climb rate of 3m/sec.

The high rates of energy increase, here between 1,300 and 1,500 m, have, however, in regards to time add only a small share to the total energy gain. In this example the additional energy gain is only 9%. Accordingly to this it would be

Notation and units

A	wingarea	P	power
C_p	surface pressure coefficient	Q	suction flow rate
C_{pa}	suction cefficient	sec	second
C_q	suction flow coefficient	t	time
D	drag	u	suction velocity
DLR	Deutsches Zentrum für Luft-u. Raumfahrt	v	airsped
E_t	glideratio with prop-thrust	w	velocity of sink
km/h	kilometer/hour	W	weight
m	meter	η	efficiency
min	minutes	λ	aspect ratio
N	Newton		
Nm	Newtonmeter		

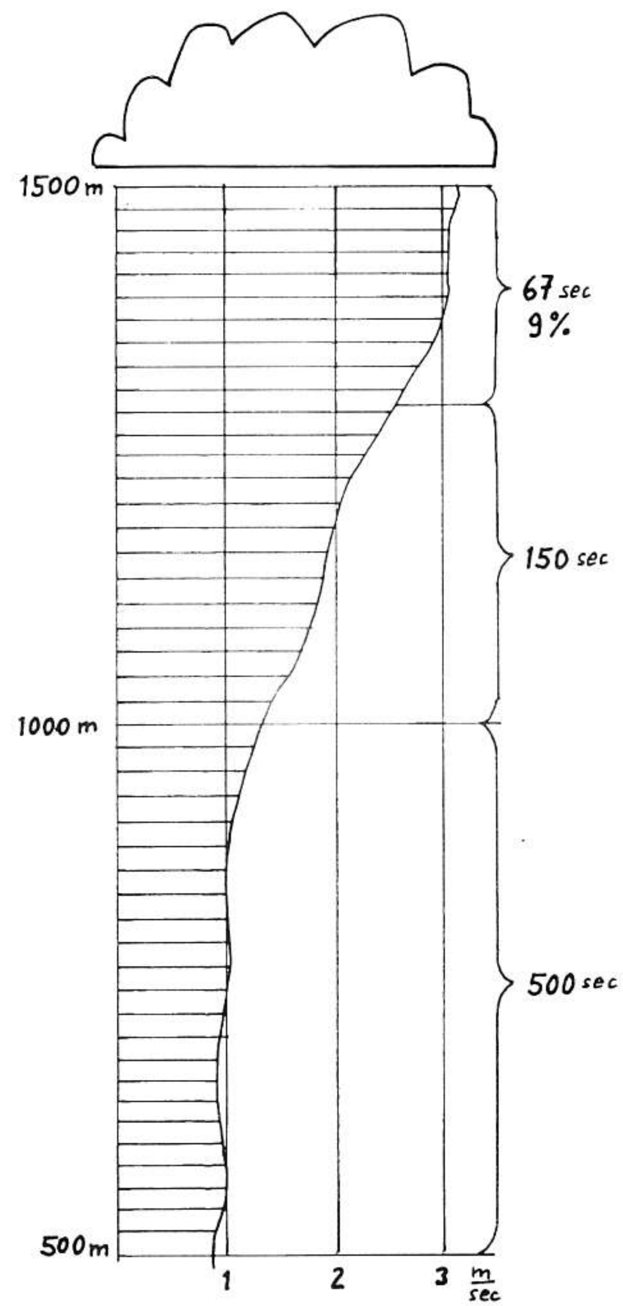

Figure 1a

desirable to remain for some time at a level of high-energy increase in order to store part of the energy there.

This happens in the most optimum way if the altitude with the highest flight path climb value is maintained and at the same time energy is tapped from the flow. That means the air must be retarded.

Practicably and optimally this can be effected with a propeller in turbine operation according to the aerodynamic rules of a propeller.

A favorable concept for this folding turbine is the aircraft tail where the turbine geometry is subject to almost no limits. The folding turbine sketched in Figure 2 is installed in the extended fuselage pipe.

After take-off, in combination with raising the landing gear, the turbine will extend and still fit well with the telescope shaft while producing no additional drag.

When it becomes suitable in a strong upcurrent to absorb energy the turbine blades can mechanically be folded backwards, and commence to rotate. The generated shaft-power will transport the power via the shaft into the fuselage for storage.

An efficient design automatically leads to a large turbine circle area where with a low speed of rotation, and small thrust coefficients, high efficiencies can be reached.

According to the momentum theory, the efficiency is high if a large volume of air is only minimally retarded. With a careful selection of airfoil and design, efficiencies of 85% - 90% can be reached.

If in the strongest part of the upcurrent the climb is given up for the purpose of energy absorption, the drag increases due to the rotating turbine in the following example by 540 N.

W=4,320N, v=24m/sec, (86km/h), w=3,0m/sec, E=8, $D_{turb.}$=540N

Efficiency for energy-absorption and storage η=0,8

$P = D \times v \times \eta$ = 540N x 24m/sec x 0,8 = 10,368Nm/sec(W)

After 2 minutes of power absorption the energy stored adds up to 1.244.000 Nm.

(10,368 Nm/sec x 120 sec)

2. Glide with propeller-thrust

In the following example a glide over a length of 30 km at an airspeed of 50 m/sec (1 80km/h) is assumed.

The energy stored is constantly distributed over this distance to be applied again in the form of propeller thrust.*

Example:

Sailplane: 18m FAI, v=50m/sec (180km/h), w=1,60m/sec, t=600sec (10min),

P= 2,074W, efficiency of energy-conversion into thrust η=0,8

Propeller thrust: T= $P \times \eta / v$= 2,074W x 0.8/50= 33,2N

glide-ratio E: 50m/sec/1,60m/sec=31,2 D=4,320N/31,2= 138,5N

glide-ratio incl. propeller-thrust Et: $D_{res.}$= D-T= 154N-41,7N = 105,3N, 4320/105,3=41

3. Energy-storage

In Figure 3 it is shown how the initial time loss resulting from absorption of energy affects the overall time and the loss of altitude.

In the case described above in the total balance for this flight-segment a time saving of 111 sec is calculated and a loss of altitude of only 732 m (Figure 3, case #2).

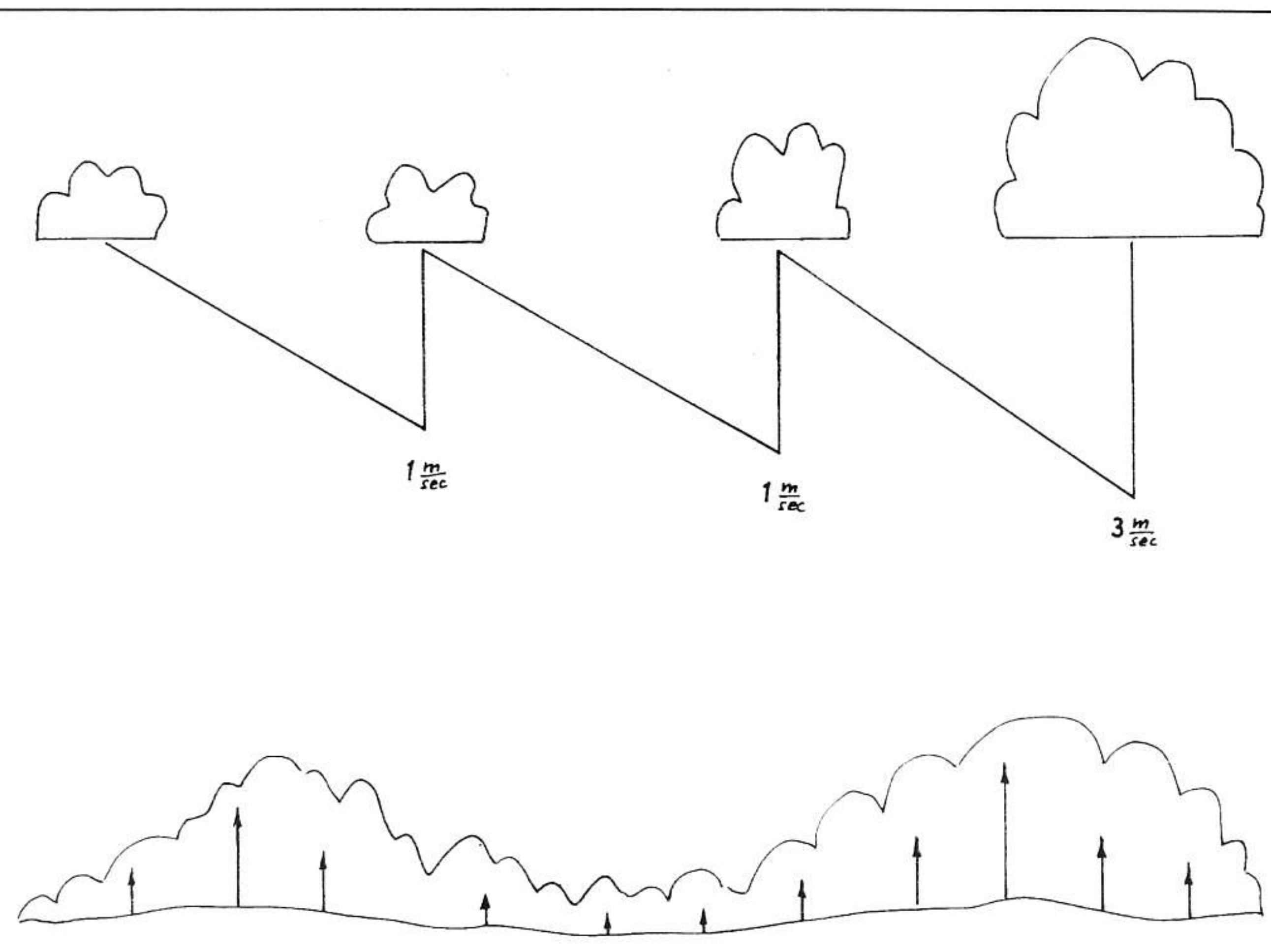

Figure 1b

**The turbine cannot be transformed into a propeller simply by blade adjustment and reversal of the sense of rotation. The geometric pitch of a turbine blade runs exactly in reverse as compared with a propeller.*

A compromise here would be a propeller blade without geometric pitch and a symmetrical airfoil but markedly reduced efficiency.

The cruising-speed increases from 84,5 km/h to 92,5 km/h. In case #3 even up to 102 km/h, if the energy absorption time is 4 - 6min. A higher energy absorption of 6 min in this example no longer yields any improvement.

Figure 4 shows the influence of the energy storage to the cruise speed Vc. Basic for the calculation is the distribution of Fig.1 with a climb rate of 3m/sec on the top of the thermal upcurrent.

An energy storage in a homogeneous climb rated distribution results in a lower cruising-speed. In this example with 1,4-m/sec average climb rate 80km/h instead of 84,5 km/h without energy storage.

Without major differences in the intensity of the thermals, no time advantages are obtained because the losses predominate.

A further advantage can be that long gliding distances over areas showing weak thermal upcurrents or no thermal upcurrents can only in this way become possible at all.

Due to the energy losses from the production and storage ($\eta = 0.8$) and the conversion into propeller thrust ($\eta = 0.8$) a maximum of 64% of the original total energy of 622.000 Nm/min is utilized.

Besides the application of energy via a propeller for an improvement of the gliding angle there exists, however, one other possibility.

4. Energy stored utilized for laminar flow control

The energy stored is utilized for laminar flow control of the wing and the tail surfaces.

Initially the boundary layer up to 50-60% of the airfoil chord is laminar and thus shows low skin friction. The streamlines move towards one another on parallel paths. As the individual layers move with different velocities, viscous forces arise which lead to a loss of kinetic energy in the flow.

The braked flow can therefore not penetrate downstream too far into the area of higher pressure. It then yields laterally to the area of higher pressure, detaches itself from the body and drifts into the interior of the flow.

Due to this instability of the flow the laminar boundary layer changes into a turbulent boundary layer resulting in

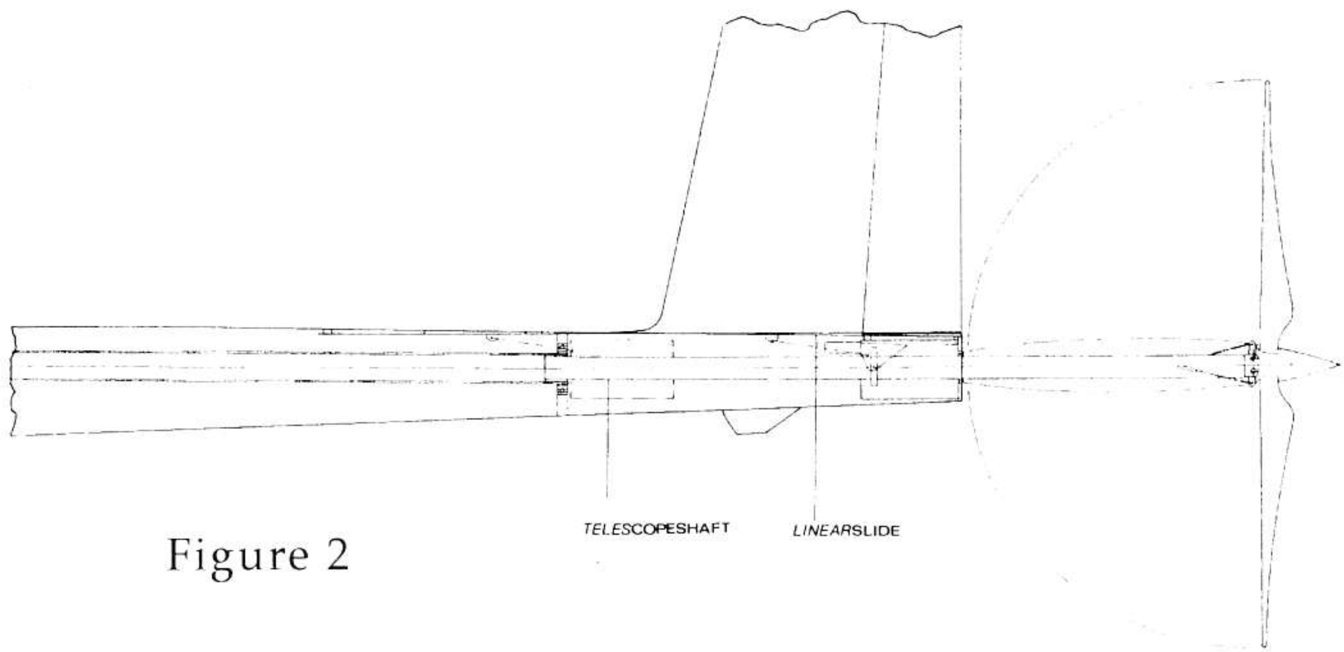

Figure 2

a high increase of the airfoil drag. This, however, can be avoided if this inner part of the flow is sucked off.

The thickness of the boundary layer is reduced and the thin boundary layer has fewer tendencies to change into the turbulent form of flow.

5. Suction-airfoil

In addition, by means of the suction, a laminar boundary layer profile is produced. The airfoil drag saving in the airfoil diagram to be seen in Figure 5 is very illustrative.

The DLR suction airfoil can be seen here with and also corrected by the suction co-efficient Cpa.

By an increase in the suction flow rate, the boundary layer thickness can be reduced as required.

An excessively great suction flow rate is, however, uneconomical as then a considerable part of the power saving achieved by the drag saving is used up again for suction.

This is achieved with what is referred to as the minimum suction flow rate, which at the same time yields the greatest drag saving.

In addition it can be said: every greater suction flow rate produces a thinner boundary layer and thus a greater skin friction drag.

6. The suction flow rate

Q (m^3/sec) can be calculated from Q = Cq $\times$A$\times$u and is proportional to the airspeed v.

The Cq for the minimum suction flow rate is in the order of magnitude of 0.001.

Example:

Wing area A = 12 m^2

v = 108 km/h (30m/sec)best glide Q = 0,001 $\times$ 30m/sec x 1 2m2 = 0,36m^3/sec

v = 180 km/h (50m/sec) Q = 0,001 x50m/secx12m^2 = 0,60m^3/sec

7. Suction velocity

The DLR suction airfoil shown in Fig. 6 has, on the upper surface 6 and on the lower surface 2 ducts which take up to 26% of the airfoil surface exposed to the flow of air.

With a wing area of 12 m^2 which has a total area of 24.9 m^2, that corresponds to 6 m^2 area which has to be sucked off.

suction velocity u: a. v=30m/sec u=Q/As= 0,360m^3/ 6m^2= 0,06m/sec

b. v=50m/sec u=Q/As= 0,600m3/6m^2= 0,1 Om/sec

8. Suction pressures

The necessary suction pressures are obtained from the pressure coefficients cp. In the following example an order of magnitude is shown:

v=30m/sec, p=1,112kg/m3 (1000m), cp= -1,0

Δp=cp $\times$ p/2 $\times$ v^2 = -1 /2 $\times$ 1,1 1 2kg/m^3 $\times$ 502m^2/sec^2= 500N/m^2

with v=50m/sec Δp=1,280N/m^2

9. Suction capacity

From the suction flow rate and the suction pressure the suction capacity P = p x Q can be calculated.

Example: wing area 12m^2,

u=30m/sec P= 500N/m^2 xO,36m^3= 500Nm/sec

u=50m/sec P=1280N/m^2 xO,6m^3 = 730Nm/sec

The balance power of a sailplane of this size has an amount of 2,540W at 30m/sec and 4,075W at 50m/sec. As a matter of principle the suction capacity to be applied is

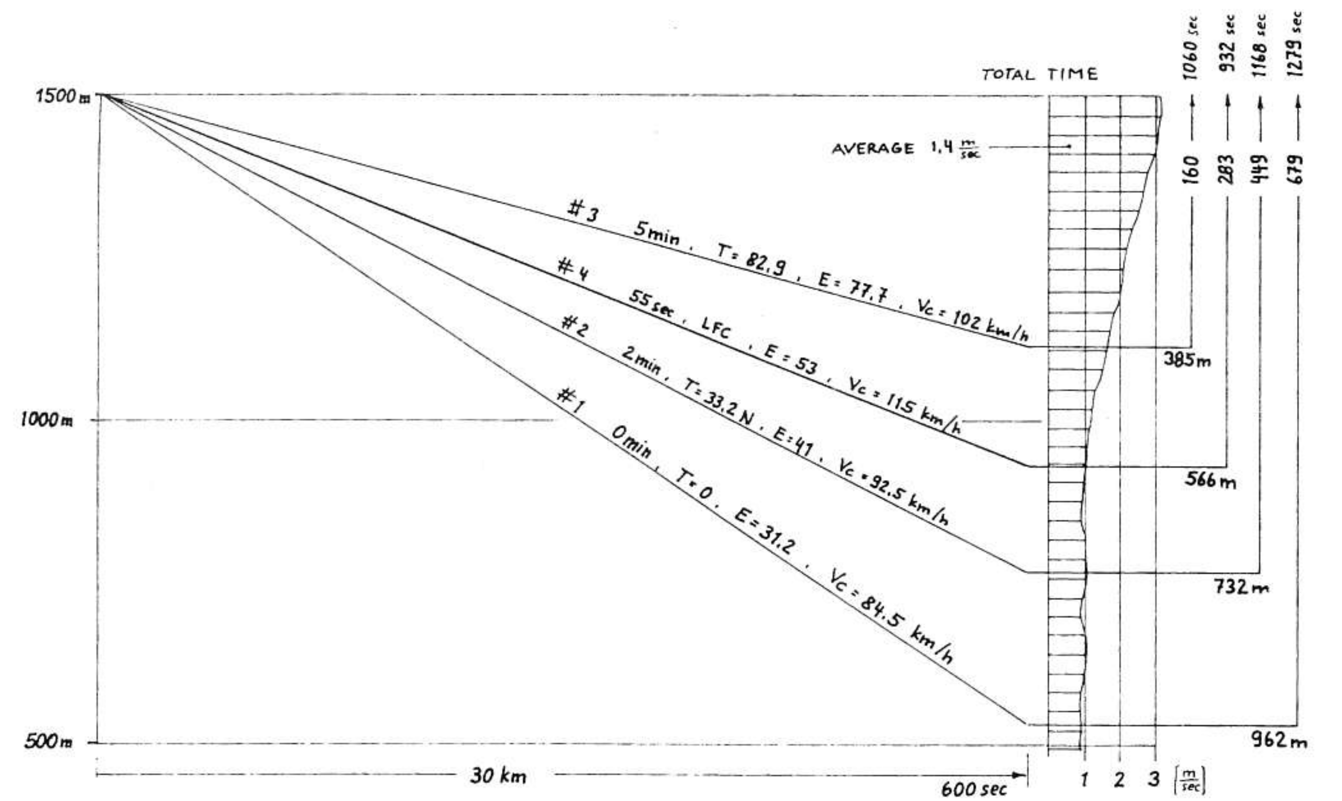

Figure 3

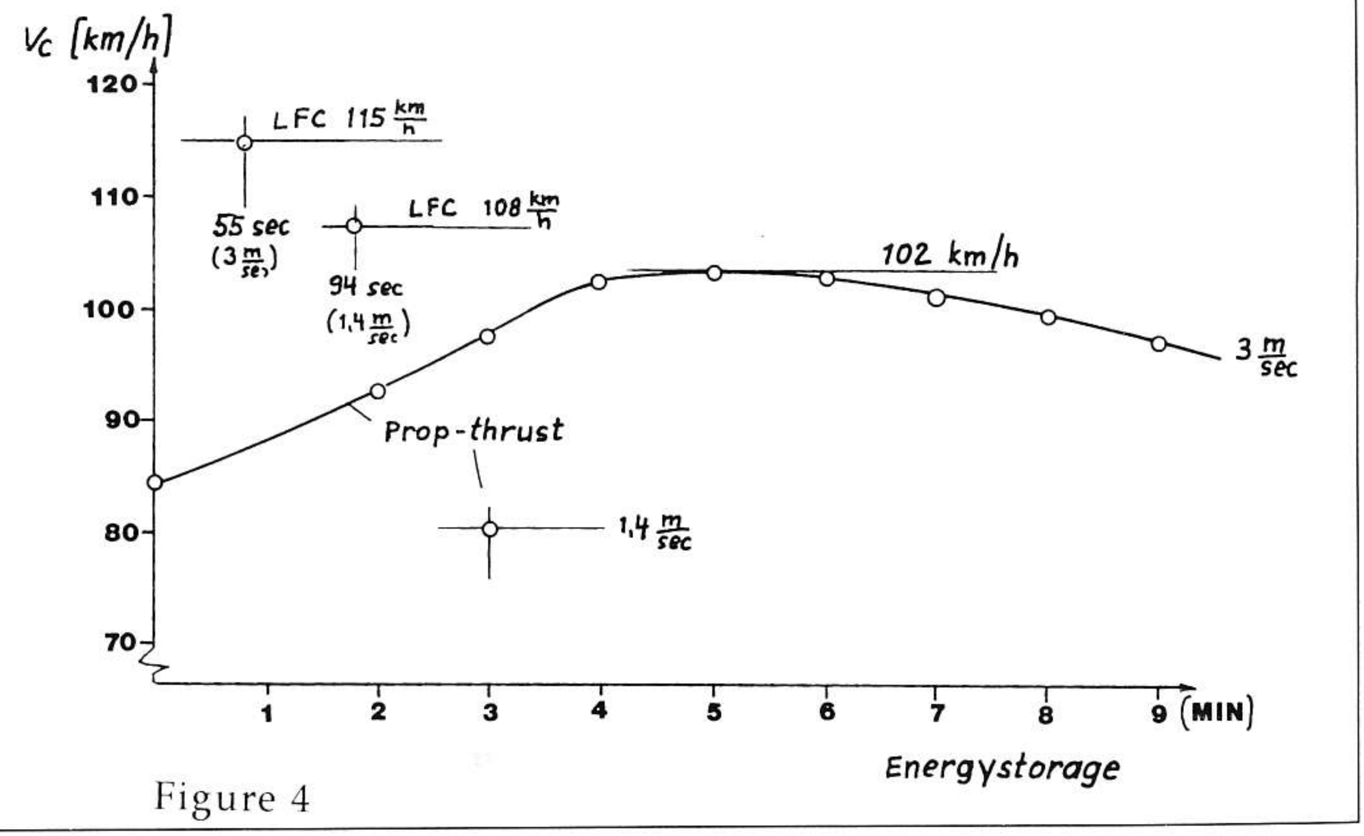

Figure 4

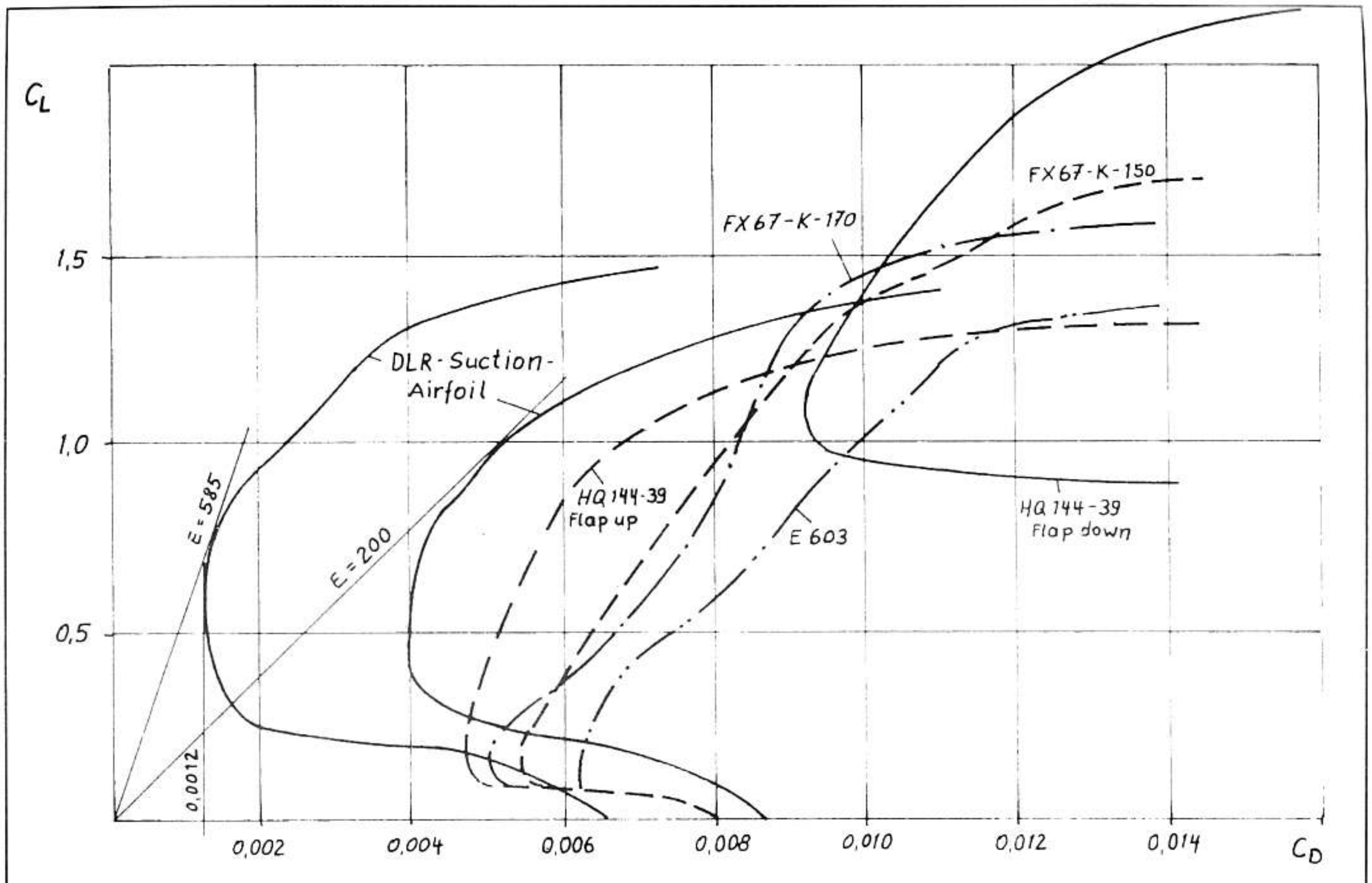

Figure 5

in the order of magnitude of 8 to 10% of the balance power.

As a result of the losses of efficiency of the vacuum blowers and their drives the necessary capacities are, markedly higher. In the case of a blower efficiencies of 0.8 due to the low differential pressures are realistic.

10. Drag speed analysis

Figure 7 shows a drag analysis for a 15-m FAI sailplane. Striking is the relatively large share of the airfoil drag particularly at high speeds. The airfoil drags of wing and tail surfaces have, at 100 km/h, a 46% share of the total drag, at 150 km/h 59% and at 200 km/h 62%. In the case of a sailplane with a large wing span, this share increases accordingly, the induced drag markedly decreasing particularly in the lower speed range.

In the following table three sailplanes with their dimensions and performance data are compared. In order to be able to compare the flying performances, the loads per unit area are shown uniformly as 35 dN/m^2. For comparison here, again, the airspeeds of 108 km/h (best glide) and 180 km/h are chosen.

The drag savings with airfoil drag around 75% and the raising of the aspect ratio have in the case of sailplane No. 3 with laminar flow control as a result a halving of the overall drag is shown.

The glider ratio rises to a value of round about 100 at 108 km/h and at 180 km/h is still above 50.

11. Example for a glide with laminar flow control

Back to the example given above:

The energy gain after a climb to 1,500 m by 2 min of power absorption by the turbine amounted to 1.244.000 Nm. After commencing the glide at 180 km/h and starting with suction, a power of 730 W is required. At an efficiency of 77% of blower and drive, the necessary power amounts to 950 W. After covering a 30 km distance and a flight time of 600sec (10min) 570.000 Nm of energy is consumed. At the same time the glide ratio is at a similar level of 53 and, after 30 km, results in a loss of altitude of 566 m.

However, the power consumption is only 26% of the

	15mFAI		18mFAI		20m suction-airfoil	
W	3140N		4050N		4320N	
A	9 m^2		11,68m^2		12 m^2	
W/A	35,5dN/m^2		35,4dN/m^2		35,2dN/m^2	
λ	25		27,7		33,3	
V(m/sec)	30	50	30	50	30	50
$D_{fuselage}$ +tailsurfaces	10N	42N	10N	42N	9 N	40N
$D_{induced}$	28N	9,3N	32,5N	10,7N	26N	10N
$D_{airfoil}$	28N	62N	36,5N	80,5N	8,5N	32N
D_{total}	66N	113,3	79N	133,2N	43,5N	82N
E	48	28,5	51	28,5	100	53

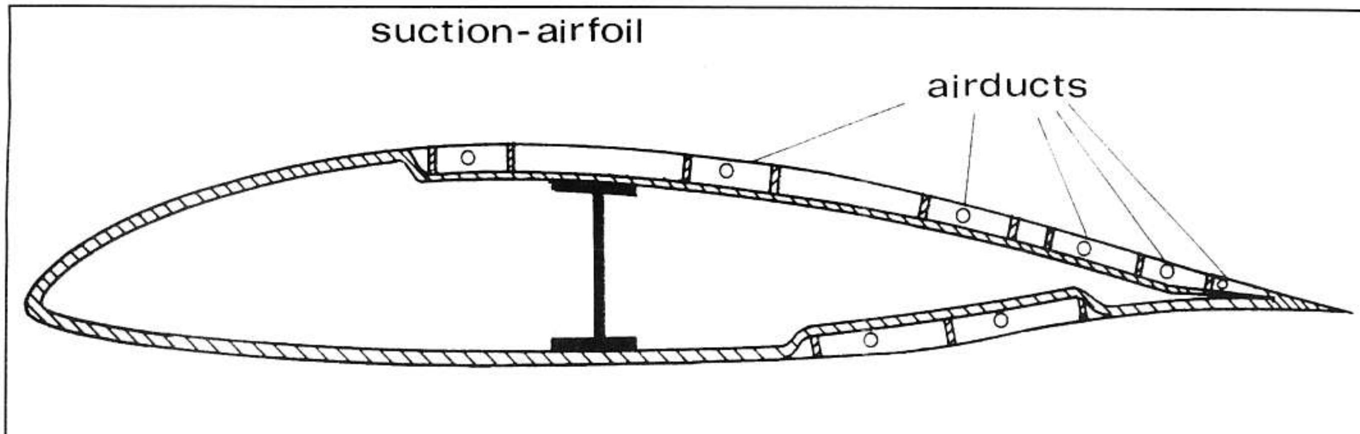

Figure 6

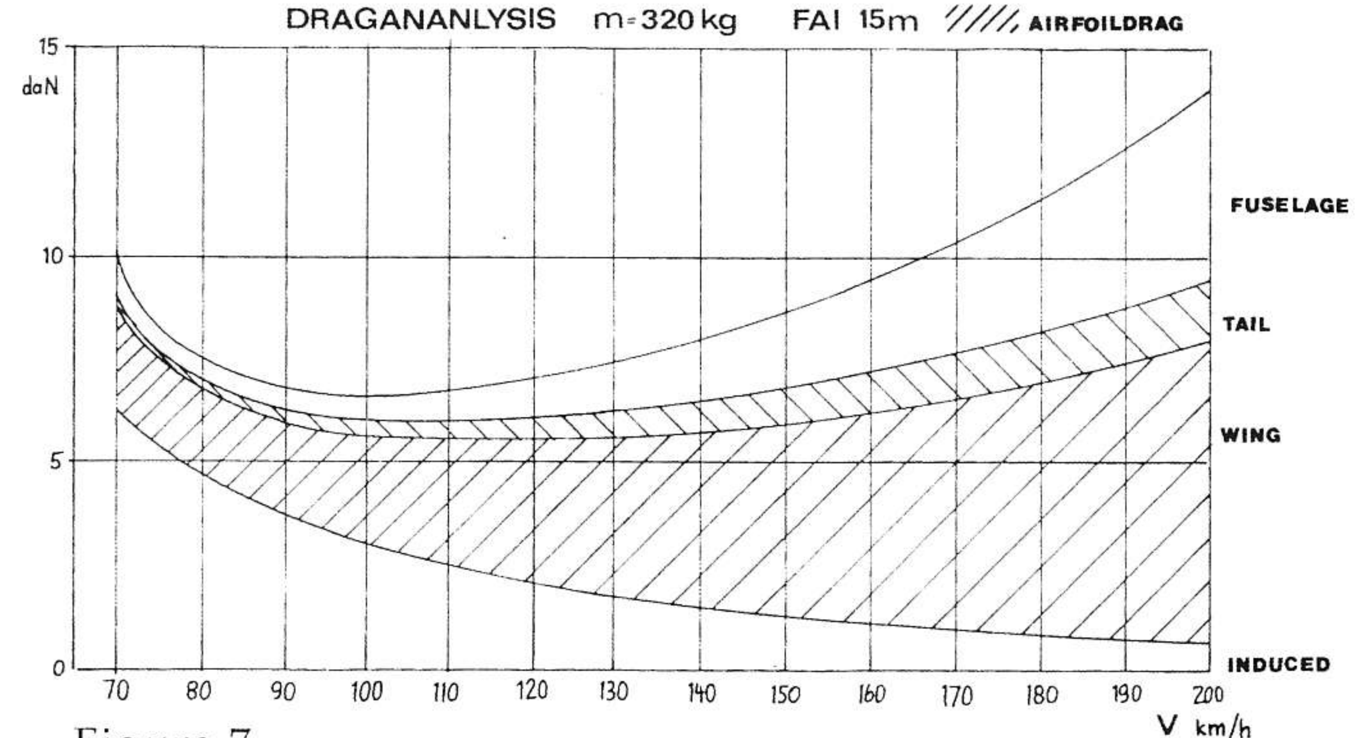

Figure 7

example mentioned above using propeller thrust. 1.000.000 Nm of stored energy is sufficient for 17 min fast flying at 180 km/h or with a power output of 350 W at best glide for 48min.

For the 30-km distance at 180 km/h, 55 sec of energy absorption is sufficient. The loss of altitude in this case is 566 m (Figure 3, case #4).

To reach the same gliding ratio of 53 with propeller thrust, a time of 3min 30sec for the absorption of energy is necessary.

On the basis of the low loss of time involved in energy absorption and the relatively good gliding ratio of 53 in the comparison, the highest cruising speed of 115 km/h is obtained.

Even with a homogeneous distribution of thermal currents with 1.4 m/sec, the cruising speed is 108 km/h.

12. Energy storage

High efficiency energy storage is important for the storage and output of energy. High efficiencies can be achieved by direct storage, i.e. the form of energy is retained and must not be converted.

One example of direct storage is a mechanical gyro. Here, the shaft output of the turbine can be stored with relatively low gear friction losses such as gyroscope energy. A storage energy of 4,000,000 Nm is required, which corresponds to 1.1 kWh.

In order to give an idea of the size of such a gyroscope we most consider to the following data:

A hollow steel cylinder of 35-cm dia. and a length of 10 cm has a mass of 16.2 kg and a speed of rotation ranging from 14,0001/min to 25,0001/min.

From the maximum energy of 6,000,000 Nm and the residual energy of

1,900,000 Nm a useful energy of 4,100,000 Nm (1.13 kWh) can be obtained.

A gyro of this mass and energy has an enormous moment of inertia and therefore must be designed as a free gyro in a cardanic suspension with a degree of freedom up to 80deg in all directions.

The disadvantage of this energy storage is that the whole control of the suction must be carried out mechanically.

All changes of air flow rate and pressure must be controlled by adjusting the speed of rotation via a complicated geared control system.

In addition, due to the position of the suction pump in the center of the fuselage, long air ducts are necessary.

If suction is effected via electrically powered pumps, these problems become considerably easier to solve.

In addition, motorized pump units could be placed in the wings, the air sucked off here being able to escape again via a trailing edge gap.

Individual suction ducts can be separately controlled as a function of the airspeed and the load factor.

First of all, the energy from the turbine must be fed via a generator after passing an additional energy conversion stage into a battery.

The electro-chemical storage in a battery, however, can be avoided by the use of an electrical driven flywheel accumulator as already presented from United Technologies. The stored energy could reach up to 7 kWh.

Conclusion

According to the rules of the FAI, it is not allowed to launch a sailplane with any kind of energy for propulsion. In pure competition soaring, the energy must be gained during the flight. An optimized solution for this requirement is a folding turbine behind the tail.

The first part of this study shows, that in spite of energy losses for storage and the later output of the energy in form of propeller thrust, the cruising speed significantly increases. Staying a while in a strong upcurrent for energy storage enables thereafter, due to the energy trading, much better gliding angles. The probability of again reaching a strong upcurrent increases considerably.

Utilizing the energy obtained for laminar flow control of the wings and the tail sufaces, the energy consumption decreases to 25%. An additional and important advantage is that the necessary storage capacity is considerably lower. Critical for energy storage is high efficiency for storage and output of the energy.

A flywheel accumulator best meets this requirement while on the other hand electrical storage of the energy is favorable due to the complex control of suction pressure and air capacities.

The necessary energy can be stored in batteries to avoid an additional energy conversion stage into electro-chemical energy. It is favorable to store the energy as mechanical energy into an electrical driven flywheel accumulator with further increased efficiency.

With a relative low time-share of 4 – 8% for the energy storage compared with the total flight time, the gliding angle and thus the cruising speed will increase considerably.

Energy derived from strong upcurrents leads to a new dimension in high performance soaring.