THE EFFECT OF INSECT CONTAMINATION ON AVERAGE CROSS-COUNTRY SPEED

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SUMMARY

In this paper the performance degradation of a hypothetical Standard Class sailplane due to insect debris on wing surfaces is estimated. This has been based on wind tunnel measurements of a modern airfoil with and without artificial bug pattern. Speed polars have been calculated. The peculiar characteristics in straight and circling flight and the effect on the average cross-country speed have been considered. Attention has also been directed towards the influence of different types of thermals and the glider pilot's appropriate reaction.

NOTATION

c_l, c_d	:	lift coefficient, drag coefficient
D	:	distance
R	:	circle radius
V_{cc}	:	average cross country speed
V_{stf}	:	speed-to-fly
W/S	:	wing loading
$w(V)$	:	polar sink rate in straight flight
$w_{ci}(R)$	:	polar sink rate in circling flight
w_{air}	:	vertical speed of the air during cruise period
w_{av}	:	(expected) average climb rate in climb period
w^0_{av}	:	average climb rate of the clean glider
$w^0_{av,50kg/m^2}$	:	average climb rate of the clean glider with W/S = 50kg/m2 below which water ballast is not reasonable
Δw_{ic}	:	additional sink rate, caused by insect contamination
Δw_{wl}	:	additional blimb rate, caused by minor wing loading
ρ	:	density of air

1. INTRODUCTION

For more than 30 years great efforts have been made to achieve laminar flow over a major fraction of the wing surface of gliders. It is well known that insect contamination counteracts this endeavor and can lead to premature transition. Wind tunnel measurements of airfoils in a clean and articificially dirtied state make it possible to investigate the effect of insect contamination.

2. INPUT DATA

The airfoil being used is the WW97155, which was developed at the Laminar Wind Tunnel of the University of Stuttgart (Wuerz [1]). A bug polar was derived with a standard bug pattern with about 130 bumps per meter span. Four strips of mylar film were used, 0,06mm thick with bumps of half spherical shape, 0,5mm high and 30mm spaced. From strip to strip all bumps are shifted half of their distance in spanwise direction. Figure 1 shows the lift-to-drag polars of the clean and the roughened airfoil. Experience tells that for airfoils with artificial bugs drag is nearly reynolds number independent.

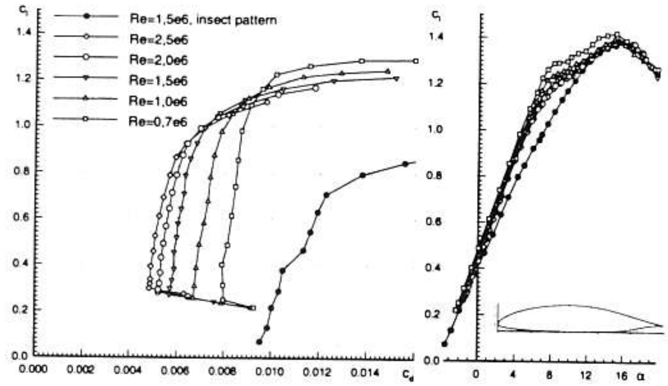

Figure 1: Lift to drag polar of the WW97155 for different Reynolds Numbers, with and without bug pattern.

The airfoil data was combined with the wing shape of an existing Standard Class glider. A computer program "Steuer" (Althaus[2]) basing on the Weisinger-Algorithm was used to calculate speed and circling polars in a clean and in a contaminated condition with different wing loadings.

3. STRAIGHT FLIGHT

The calculated speed polars for both configurations and two extreme wing loadings are show in Figure 2. As a matter of principle, vertical velocities facing downwards have a negative sign.

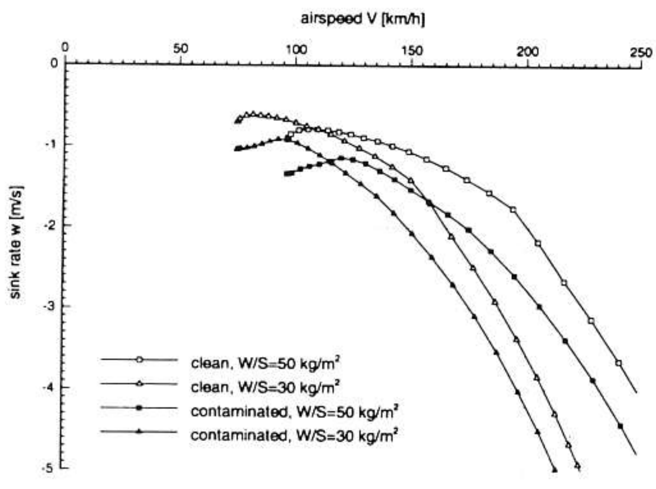

Figure 2: Speed polars of a hypothetical standard class sailplane with and without contamination.

With contamination there is not only overall greater sink rate but also the large loss at low airspeeds are remarkable. The smallest sink rate is now obtained with airspeeds some 15 km/h higher. From this point, the additional sink rate through contamination increases both to lower and to higher speeds.

4. CIRCLING FLIGHT

Circling polars for the analyzed configurations are diagrammed in Figure 3. Subsequently they will be used to estimate the degradation of the climb rate in thermals.

The airspeed necessary to attain the smallest sink rate is shown in Figure 4. Surprisingly, the ideal airsped has a local minimum at a certain radius (e.g. for wing loading 30 kg/m^2: V = 80km/h at R = 125 m). For the contaminated configurations the alteration is more intense and at larger radii. Likewise lift coefficient, load factor and angle of bank vary strongly at that point (Figure 5). An explanation might be gained from the term describing the sink rate in circling flight (Eq. 1).

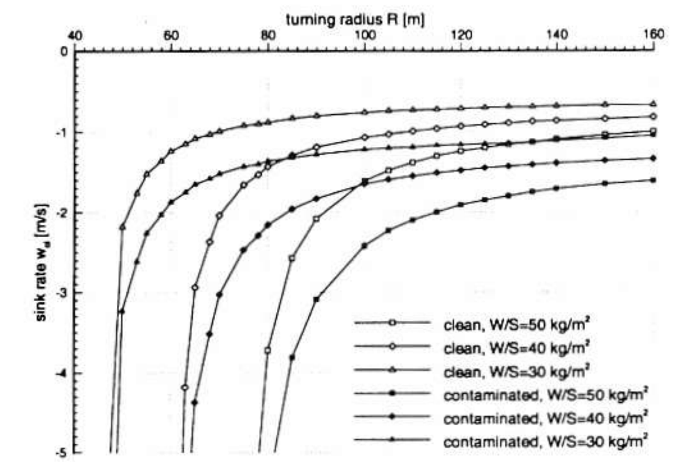

Figure 3: Sink rate in circling flight as a function of turning radius.

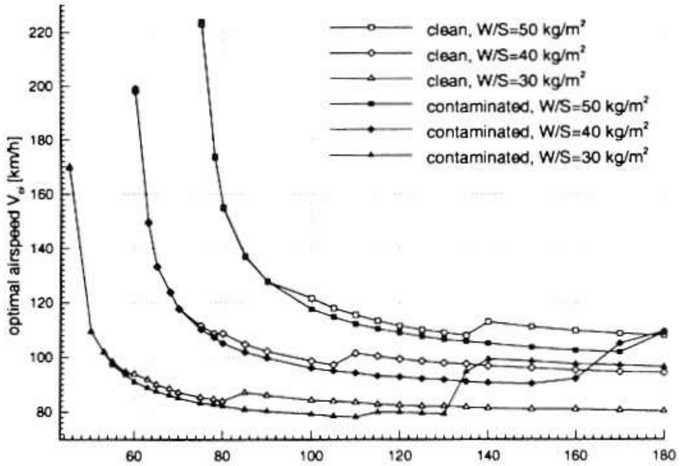

Figure 4: Optimal airspeed to achieve the smallest sink rate in a circle of given radius.

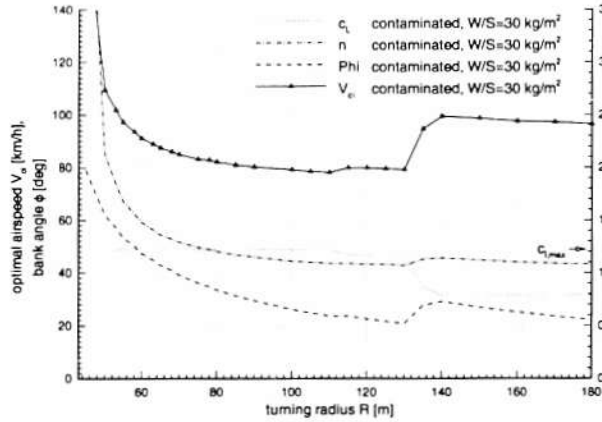

Figure 5: Optimal airspeed, bank angle, lift coefficient, and load factor for a contaminated glider with wing loading W/S = 30kg/m^2 while circling.

$$w_{ci} = -\underbrace{c_D c_L^{-3/2}}_{1^{\text{st}}\text{ factor}} \sqrt{\frac{2}{\rho}\frac{W}{S}} \underbrace{\left(1-\left(\frac{2}{\rho}\frac{W}{S}\frac{1}{Rgc_L}\right)^2\right)^{-3/4}}_{3^{\text{rd}}\text{ factor}} \quad (1)$$

If the fraction $2g/(pSRgc_L)$ approaches the value one, the third factor in (Eq. 1) reaches infinity. Consequently with small turning radii the sink rate is influenced most strongly by the lift coefficient C_L in the third factor. To achieve a small sink rate one should fly with maximum lift coefficient and low speed. With very large turning radii the influence of the first factor, the climb and ceiling factor, $c_D c_L^{-3/2}$ is larger. This recommends to fly with the lift coefficient of the smallest sink rate of straight flight.

Along the polar the following takes place: The closest curves are flown with CL_{max}. Radius and lift coefficient determine load factor; bank angle and airspeed decline with increasing radius. There must be a radius where the maximum lift coefficient is still optimal. This is when the favorable airspeed is minimal. Towards larger radii the optimal lift coefficient decreases rapidly, thus airspeed grows again. Approaching C_L of minimum $c_D c_L^{-3/2}$ airspeed will start to vane again.

For the clean glider the smallest sink rate in straight flight is obtained for a speed and a lift coefficient close to those of slow flight. Thus this phenomena hardly becomes apparent, and the optimal airspeed decreases almost monotonously. With contamination, the speed of the smallest sink rate rises by 10-20 km/h, accordingly the appropriate lift coefficient attenuates. Therefore the favorable airspeed varies more strongly with the radius. To loosen the turning radius by ten meters can connote to fly 20 km/h faster for good reason.

No glider pilot is able to keep the best speed for his turning radius all the time. Hence the consequence of differing from the optimal speed is worth investigating. The additional sink rate against the minimal possible may

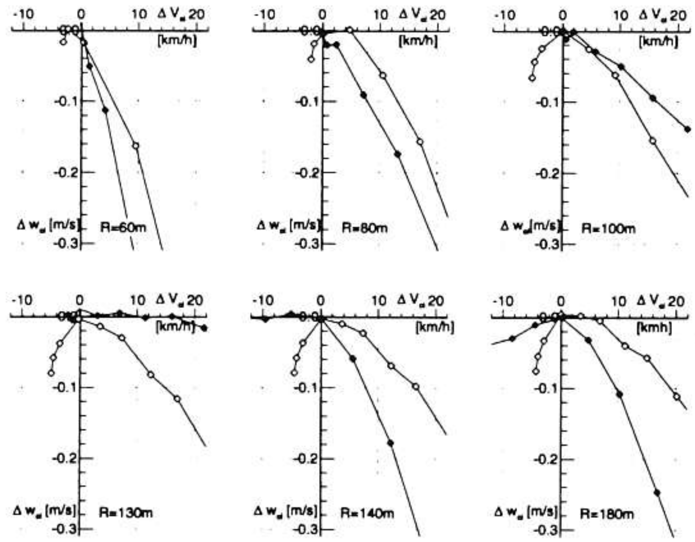

Figure 6: Additional sink rate of the clean (empty symbols) and contaminated (full symbols) glider if deviating from the optimum airspeed. Different diagrams for different turning radii (wing loading 30 kg/m²).

be named Δw_{ci} and diagrammed as a function of the difference to the optimal airspeed ΔV_{ci} (Figure 6).

The computation was performed with Eq. 1 and with the relation of lift and drag from the straight flight polar (Figure 2). Reynolds number-effects arising with high load factors have not been taken into account. This leads to small errors, e.g. in some cases $\Delta w_{ci}(\Delta V_{ci} = 0)$ is not equal to zero.

In flying the clean glider faster than recommended, the sink rate grows slower than it does when flying too slow. As the contaminated glider sinks least with minimum speed up to a radius R ≈ 130m, there is no flying too slow in this range — except for safety. In larger circles the losses of too high airspeed are higher than those of too low. Accordingly, from a theoretic point of view, the clean glider should rather be circled too fast than too slow; the contaminated one, vice versa. Although the contaminated glider seems a bit more tolerant in some situations, one must not forget that it still sinks about half a meter per second faster. Generally not optimal airspeed has less effect with increasing radius.

5. CROSS COUNTRY FLIGHT

As a simple model of a cross country flight the well-known speed-to-fly theory will be used (MacCready [3]). It treats a cross country flight as a series of cruise-climb-cycles. The average cross country speed can be calculated with Eq. 2.

$$V_{cc} = V_{stf} \frac{w_{av}}{w_{av} - w(V_{stf}) - w_{air}} \qquad (2)$$

6. CRUISE PERIOD

Speed to fly tables can easily be calculated. Speed-to-fly values for the glider models examined are diagrammed in Figure 7.

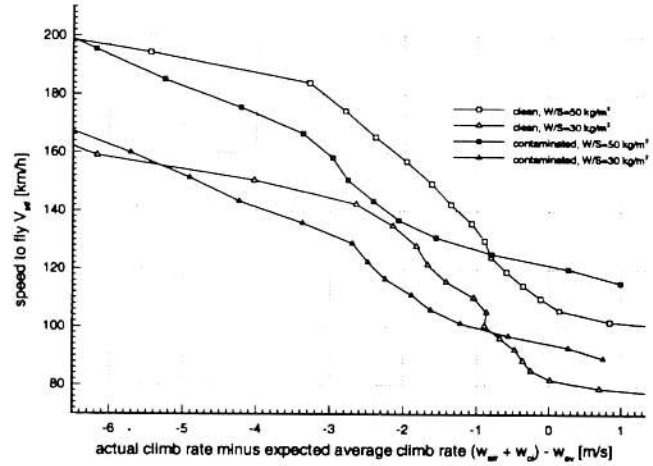

Figure 7: Speed-to-fly diagrams for the examined glider models.

It is noticeable that the pilot of a contaminated glider is recommended to fly up to 15 km/h faster, when variometer readings $w(V) + w_{air}$ are slightly below the value of the expected, average climb rate w_{av} (max 0.8 m/s below). The reason is that the speed of minimum sink rate is about 15 km/h higher with contamination for all wing loadings. In case of higher sink rates, the contaminated glider should be flown slower, as its polar falls off more strongly with higher airspeeds.

7. CLIMB PERIOD

Figure 8 shows the additional sink rate caused by the surface roughness during circling as a function of the radius. Leading to a smaller average climb rate, it grows with increasing wing loading and decreasing radius. Thus especially narrow thermals will handicap the contaminated glider.

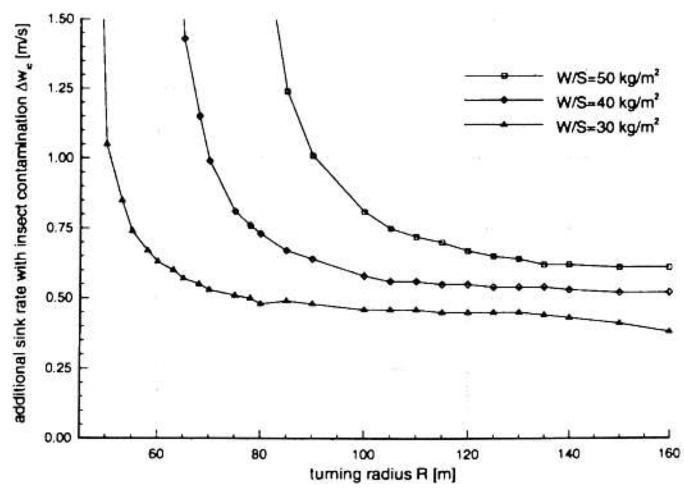

Figure 8: Additional sink rate in turning flight caused by contamination.

To calculate the decrease of average cross country speed, it is necessary to estimate how much the climb rate of the contaminated glider lags behind the one of the clean ship. To do so, some information about circling radius or at least the appearance of the thermals is needed. In Tab. 1 the parameters of four model thermals, introduced by Horstmann [4] are put together.

		A1	A2	B1	B2
updraft gradient	$[\frac{cm/s}{m}]$	2,53	3,91	0,42	0,58
updraft at $R = 30\,m$	[m/s]	2,50	4,44	1,88	3,70

Table 1: Parameters of Horstmann's model thermals, valid for 25m≤ R≤ 150m.

Adding a circle flight polar w_{ci}(R) and an updraft distribution w_u(R) results in a climb rate distribution w_{cl}(R). The difference between the maximum climb rates of the clean and contamined glider in one updraft gives a hint, how much the expected average climb rate has to be reduced due to insect debris on the wing surface. These diferences are tabulated in Tab. 2 for the four model thermals and different wing loadings.

W/S [kg/m²]		30	40	50
Δw_{ci} [m/s]	A1	0,57	0,67	0,75
	A2	0,57	0,69	0,78
	B1	0,47	0,54	0,61
	B2	0,48	0,56	0,62

Table 2: Difference between the climb rates of the clean and contaminated glider in Horstmann's four model thermals.

Accordingly, the upper and lower limits in Tab. 3 should deliver a good estimation of the loss of climb rate in thermals by insect conamination Δw_{ic} .

W/S [kg/m²]	30	40	50
Δw_{icmax} [m/s]	0,6	0,7	0,8
Δw_{icmin} [m/s]	0,45	0,55	0,6

Table 3: Estimated loss of climb rate in thermals by insect contamination.

8. AVERAGE CROSS COUNTRY SPEED

In this section the average climb rate of the clean glider w^0_{av} is used as a characterization of the weather situation. Thus, this value can also appear in context with the *contaminated* glider. Nevertheless care has to be taken whenever different wing loadings are to be compared, because the same updraft produces different w^0_{av} values for different wing loadings.

Resting air will be assumed during the cruise between the thermals. This is no drastic restriction to the model. A pilot always finding air with a certain climb rate w_{air} during cruise may read his or her average cross country speed from the diagrams using a modified average climb rate $w'_{av} = w_{av} + w_{air}$ and finally multiplying the read out with w_{av}/w'_{av}. Thus, all phenomenons will arise at different average climb rates, but the conclusions basically stay the same.

The cross country speed of the clean glider can be computed directly with Eq. 1. For the contaminated glider the average climb rate has to be reduced by the values from Tab. 3 and the worse straight flight polar has to be used.

In Fig. 9, the average cross country speed V_{cc} is diagrammed as a function of w^0_{av}. The upper limit of Δw_{ic} was used. By the way, the employed value of Δw_{ic} can be taken at the intersection point between curve and abscissa.

Figure 9: Average cross country speed as a function of the average climb rate of the clean glider with the same wing loading.

Assuming Δw_{ic} is immediately zero, then every degradation is a result of worse performance in straight flight. In this case all curves originate from the center of the coordinate system. At a Δw_{ic} = 1 m/s the average speed decreases from 64 km/h to 52 km/h (W/S = 30 kg/m²) or from 72 km/h to 60 km/h (W/S = 50 kg/m² respectively. with improving weather situation (W/S = 30 kg/m2: 2.5m/s; W/S = 50 kg/m2: 3,5m/s) the curves approach each other again. Then the lower edge of the laminar bucket of the clean airfoil is reached in cruise flight.

Also, the influence of the worse climb rate can be studied on its own. To do so, the curve of the clean glider must be shifted to the right by the value of Δw_{ic}. It is obvious that the strongest degradiation has to be suffered with small climb rates w^0_{av} as with poor thermal conditions the additional sink rate Δw_{ic} constituts a greater part. In the extreme case no altitude can be regained any more. Therefore, weak (and found as before) close thermal upcurrent is especially disadvantageous for the dirtied glider.

Figure 10 contains the direct comparison between the clean and contaminated glider regarding the average cross country speed under the same thermal conditions. By means of the deviation from the median of the first quadrant, the performance loss can be read off directly. It can easily be seen that the loses by insect contamination become relatively small when high average speeds are possible. However, the calculation was performed up to an average climb rate of 7 m/s. The shape of thermal updrafts has little influence: The curves for different values of Δw_{ic} lay close together.

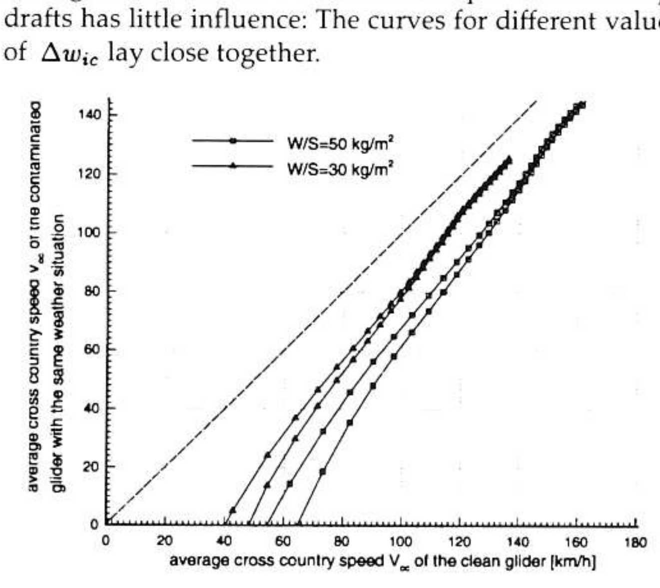

Figure 10: Clean and contaminated glider compared by average cross crountry speed - two curves for different values of Δw_{ic} (Tab.3).9.

WATER BALLAST

It is striking that with a given cross country speed V_{cc} a glider with lower wing loading loses less speed through insects. This raises the question, whether insect contamination influences the time of dropping one's water ballast. However, in that comparison the weather situation has to stay constant for all wing loadings. This is not possible with Fig. 10.

An answer can be found with Fig. 9. For this purpose, variation of wing loading from W/S = 50 kg/m² to 30 kg/m² is being considered as an example. Provided that thermals do not change their strength, decreasing wing loading will increase the overall climb rate of w^0_{av}. The size of this increase depends on the shape of the thermals again. It will be assumed that the climb rate of the lightweight glider is larger by a constant value Δw_{wl}.

To derive the cross country speed of the lightweight glider as a function of the climb rate $w^0_{av,50\text{kg/m}^2}$ with high wing loading, its curve in Fig. 9 has to be shifted to the left by the constant Δw_{wl}. Then the specific climb rate $w^0_{av,50\text{kg/m}^2}$ is sought after at which the cross country speed will be equal for both wing loadings.

As the curve can actually not be shifted, a strip of graph paper is cut, its width corresponding to the value of Δw_{wl} in the measure of the abscissa. Placed parallel to the ordinate, the strip is moved along the w^0_{av} -axis until the "clean" curve for W/S = 30 kg/m² on the right side and the "clean curve for W/S = 50 kg/m² on the left side of the strip have the same value. The intersection point between the left edge of the strip and the w^0_{av} -axis determines the expected climb rate under which the pilot has better dropped his or her water ballast.

In the same way the same strip can be used for the contaminated gliders. As these curves already intersect the abscissa at different points, the different degradation through insects is automatically considered. Still the value to be read out at the point of intersection between paper strip and w^0_{av} -axis is the climb rate of the corresponding clean glider. Thus assuming that thermals attenuate monotonously in the evening, the derived values can be used to compare, whether water ballast should be jettisoned earlier with insect contamination. To obtain the climb rate of the contaminated glider, the $w^0_{av,50\text{kg/m}^2}$ values has to be subtracted by Δw_{ic} of the W/S = 50 kg/m² wing loading.

For this method it is necessary to know the improvement in climb rate Δw_{wl}. It could be estimated similarly to Δw_{ic}. However no further assumptions shall be made, but a wide range of values be tested, namely 0-3 m/s. Using the larger values from Tab. 3 for Δw_{ic}, Tab. 4 was obtained.

A m/s	B_1 m/s	B_2 m/s	C m/s
3,0	3,2	≫4,4	≫3,6
2,5	2,8	>5,0	>4,2
2,3	2,7	5,3	4,5
2,0	2,6	5,1	4,3
1,8	2,4	4,7	3,9
1,5	2,3	4,2	3,4
1,3	2,2	4,0	3,2
1,0	2,0	3,4	2,6
0,8	1,7	3,1	2,3
0,5	1,4	2,6	1,8
0,3	1,0	2,3	1,5
0,0	0,0	1,6	0,8

Table 4. Climb rates, below which wing loading should be reduced from W/S = 50kg/m² to 30kg/m²

A. Assumed difference Δw_{wl} between the average climb rate of the clean gliders with W/S = 30 kg/m2 and 50 kg/m²

B. Weather situation with that the lightweight and heavy ones resemble fast gliders, characterized by the average climb rate $w^0_{av,50\text{kg/m}^2}$ of the clean glider with wing loading W/S = 50 kg/m².

B_1 for clean gliders

B_2 for contaminated gliders

C. Value of B_2 converted to the average climb rate of the contaminated glider with W/S = 50 kg/m². Tab. 4 was obtained.

Comparison of row B_1 and B_2 recommends to drop water ballast earlier in the day with insect contamination. Rows B_2 and C show that despite the higher polar sink rate, the average climb rate of the contaminated glider is still higher at the time of dropping. Thus the pilot has to use a higher threshold when he intends to drop his ballast under a certain value of variometer readings.

10 CONCLUSIONS AND RECOMMENDATIONS

Besides generally higher sink rates insect contamination of a glider effects a different shape for the speed polar. Hence the airspeed of the lowest sink rate increases by 10-20 km/h. As a consequence circles should rather be flown too slow than too fast — as long as this can safely be done. The average cross country speed is most affected with poor thermal conditions and close updrafts. Water ballast should be dropped earlier in the day.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Wurz W., Entwurf und Vermessung von 2 Profilen fur Segelflugzeuge der Standardklasse, 21. Segelflugsympolsium, Stuttgart, 1997.

(2) Althaus D., Dokumentation zu den Programmen Steuer und Quer, Stuttgart, July 1996.

(3) MacCready P., Optimum Airspeed Selector, Soaring, 1954.

(4) Horstmann K H., Neue Modellauwindverteilungen und ihr Einfluss auf die Auslegung von Segelflugzeugen, Idaflieg Report I, 1975.

(5) Geiner M., Untersuchungen zur Insektenkontamination von Segelflugzeugn, Stuttgart, May 1999.