# Technical Note

## ENERGY GAIN IN PITCHING MANEUVERS

Dipl. Phys. Wolfram Gorisch

*Akademische Fliegergruppe München e.V.*

In *Technical Soaring*, Vol. V, No. 4, June 1980, pages 39-45, Frank Irving has analyzed the energy loss of sailplanes in pitching maneuvers. A pull-up flight maneuver temporarily increases the load factor and hence increases the drag. As far as drag is concerned, the influence of load factor deviations from unity has satisfactorily been treated in the above-mentioned paper. But load variation also significantly affects energy transfer when the glider traverses moving air masses. In this author's opinion this effect is most important and deserves full consideration. In the following I shall focus on the energy extraction from the movements of the atmosphere and on the influence of the load factor on it, rather than on drag effects.

The assumption that the total energy exchange of a glider solely depends on the atmosphere's vertical motion is a widespread misconception which ignores the fact that the load factor dominates the interaction force,and thus the rate of energy transfer between sailplane and atmosphere. For example: zero load (parabolic) flight leads to zero energy exchange rate, irrespective of any atmospheric climb or sink rate; or, the rate of total energy gain is twice when the load is twice that of the acceleration due to gravity during horizontal flight through a thermal as compared to the situation where load factor (n) equals unity. It appears that an appropriate load variation flight style which implies high load in climb areas and low load in sink regions, greatly influences extraction of energy from the atmosphere and finally determines success in soaring.

The role of the load factor for energy extraction from the atmosphere was first derived and published at the 1976 Rayskala OSTIV Congress.[1] An elementary mechanical analysis of the non-stationary flight of a sailplane through moving air masses can be

derived in a straight-forward manner without the need for introduction of simplifying assumptions. This will be shown towards the end of this note. The result will be that the rate of energy transfer depends on the product of two vectors: the air velocity vector and the load vector.

Modern sailplanes with large wing spans and high aspect ratios allow fast cruising due to good quality aerodynamic design and high wing loading. High speed in straight flight allows an average load factor beyond unity to be maintained throughout the traverse of a confined thermal,thus increasing the total energy gain. Since a large wing span directly diminishes the induced drag, energy loss due to the pull-up flight maneuvers becomes less important.

All the consequences of this recent advance in the theory of soaring have not yet been fully disclosed. It appears, however, that an appropriate "load-variation" flight style governs dolphin-style soaring, rather than speed adjustment based on the MacCready ring.[1,2,3,4] Dynamic soaring theory has been advanced using this strict theoretical approach[1,5] and traditional thermalling can be better understood as well.[6,7] I would like to refer to a recent work published by Pierson and Chen who have calculated optimal trajectories of a glider through sinusoidal vertical lift distributions[8,9] which show good agreement with our own findings.[3,4]

To better define the concept,I will first define the mechanics of a sailplane flying through moving air masses:

The equation of motion of a sailplane in a fixed coordinate system is

$$M\ddot{\vec{r}} = \vec{L} + \vec{D} + M\vec{g} \tag{1}$$

with mass M, second derivative of vector of position $\vec{r}$, lift and drag vectors $\vec{L}$ and $\vec{D}$ and acceleration due to gravity $\vec{g}$.

The velocity of the glider is

$$\dot{\vec{r}} = \vec{v} + \vec{w} \tag{2}$$

with its speed relative to the surrounding air $\vec{v}$ and the air motion $\vec{w}$.

Let the derivative of the total energy

$$E = M\vec{\dot{r}}\vec{\dot{r}} - M\vec{g}\vec{r} \qquad (3)$$

Introduction of (1) and (2) into (3) gives

$$\dot{E} = (\vec{L}+\vec{D})\cdot(\vec{v}+\vec{w}) = \vec{L}\vec{v} + \vec{D}\vec{v} + (\vec{L}+\vec{D})\vec{w} \qquad (4)$$

The product $\vec{L}\vec{v}$ vanishes since both vectors are perpendicular with respect to each other. Replacing the drag term

$$\vec{D}\vec{v} = -Mgv_s$$

($v_s$ = total energy compensated polar sink rate) and introducing $\vec{n}$ as

$$\vec{L} + \vec{D} = Mg\vec{n}$$

we obtain

$$\dot{E} = dE/dt = Mg(\vec{n}\vec{w} - v_s) \qquad (5)$$

The result (5) clearly establishes the important role of the aerodynamic load factor $\vec{n}$ when considering energy transfer.

There may be two reasons why the load dependence of the energy transfer has so long escaped the attention of the physicists who have dealt with the theory of soaring. Firstly, the concept that the airplane's altitude and hence its potential energy varies in accordance with the climb or sink rate of the surrounding air is so appealing that a strict analysis of the interactive flight mechanics did not seem necessary. Secondly, older slower gliders require more time to cross a thermal during cruising so that the integral of the load factor within that time when the thermal strength can be assumed to be constant, is close to unity even in pitching maneuvers, and thus, the simple theory may be sufficiently valid. This has changed with the development of modern high performance gliders.

## REFERENCES

[1]Gorisch, W., "Energy Exchange between a Sailplane and Moving Air Masses under Instationary Flight Conditions with Respect to Dolphin Flight and Dynamic Soaring", *Aero Revue*, November 1976, pp. 691-692, December 1976, pp. 751-752, March 1977, p. 182.

[2]Gorisch, W., "Delphinstil: Lastvariation statt Fahrtvariation? Eine kritische Betrachtung zur herrschenden Sollfahrt-theorie", *Aerokurier*, May 1978, pp. 856-858.

[3]Collins, L. and Gorisch, W., "Dolphin-Style Soaring - A Computer Simulation with Respect to the Glider's Energy Balance," *Technical Soaring*, Vol. 5, No. 2, pp. 16-21.

[4]Gorisch, W., "Delphin-Flugstil und Reisegeschwindigkeit," *Aerokurier*, May 1979, pp. 590-593.

[5]Gorisch, W., "Zum Problem des dynamischen Segelflugs in der horizontalen Grenzschicht zwischen ruhender und bewegter Luftmasse," *Aerokurier*, September 1977, pp. 856-858.

[6]Woodward, B., "A Theory of Thermal Soaring," *Aero Revue*, June 1958, OSTIV Section.

[7]Gorisch, W., "Energiebilanz des Segel-flugzeugs beim Kreisflug in der Thermik," *Aerokurier*, April 1980, pp. 450-452.

[8]Pierson, B.L., and Chen, I., "Altitude-Loss Soaring in a Specified Vertical Wind Distribution," presented at Third Int. Symp. on the Science and Technology of Low-Speed and Motorless Flight, NASA Langley Research Center, Hampton, Virginia, March 29-30, 1979.

[9]Pierson, B.L., and Chen, I., "Minimum-Time Soaring Through a Specified Vertical Wind Distribution,"9th IFIP Conf. on Optimization Techniques, Warsaw, Poland, September 4-8, 1979.