Modeling thermals

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Abstract

Thermal models are used by sailplane designers in order to decide on major configuration data for their design. Based on their own gliding experience and in communication with pilots models of thermals have been developed and modified over the years.

Introduction

Every thermal is an individual and our colleagues of the OSTIV Scientific Section are eagerly exploring the secrets of this meteorologic phenomenon. For glider pilots however thermals are the energy supply for their flights and every new thermal increases the pilots' experience and adds to their knowledge.

Sailplane designers are mostly experienced glider pilots themselves, having flown thousands of hours in the convection layer of the lower troposphere. They try to use their experience for the design of more efficient sailplanes and are driven and encouraged by the best competition- and record pilots.

Early history of modeling thermals

In the May/June 1954 issue of *Soaring*, Bruce H. Carmichael published three standard thermal profiles, see Fig. 1, reproduced from his famous article "What price performance" [1]. The author of this paper measured the performance of the D34d-sailplane in level and turning flight [3] at DVL-FFM and a K8 was evaluated in the same way. Both measurements showed that the measured polar curves in turning flight are marginally — if at all — inferior to the calculated ones. The calculations were done using formulas published by Zacher, Eppler and Haubenhofer, see Ref. 4 and Fig. 2. Additionally, Wolf Lemke flew the small and relatively heavy D34d in the 1962 German Nationals in the Open Class, as it had a retractable landing gear. He found quickly that he had to turn with more bank than the other pilots, frequently with as much as 40-45° of bank when working tight thermals at low altitude.

With that knowledge in mind, W. Lemke and G. Waibel, both members of the Akaflieg Darmstadt, had an student internship at the English Steel Corporation at Sheffield, England and dreamt about the D36 design. Both set the "Ka6-condition," that the new sailplane should not be inferior in sink to the Ka6 in 40° bank turns. They found that this condition is the optimum bank for a "thermal gradient" of -0,02 sec^{-1}, equivalent to 2 cm/sec more climb for 1m tighter radius of turn. The D36 turned out to be an excellent design for the time.

Measuring real thermals

In an important paper D. A. Konovalov [5] summarized the available information *on the structure of thermals* given by A. S. Dubov (1959), Betsy Woodward (1959 and 1962), N. I, Wulfson (1961), P. McCready (1962) and Yu. V. Chernov and R. S. Scorer (1965). Konovalov's paper

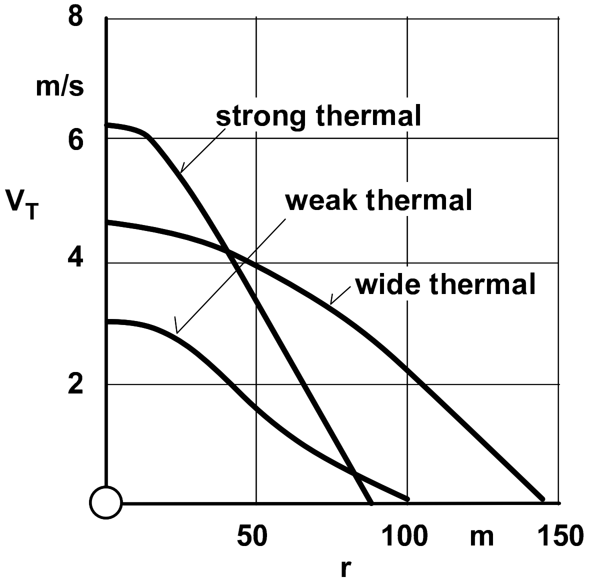

Fig. 1: Standard thermal models in Carmichael model [1, 2]
V_T thermal strength
r distance from center of thermal.

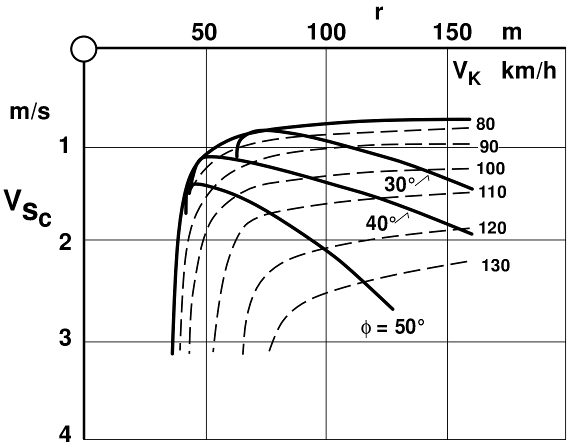

Fig. 2: "Turn polar" for ASW-19 [2]

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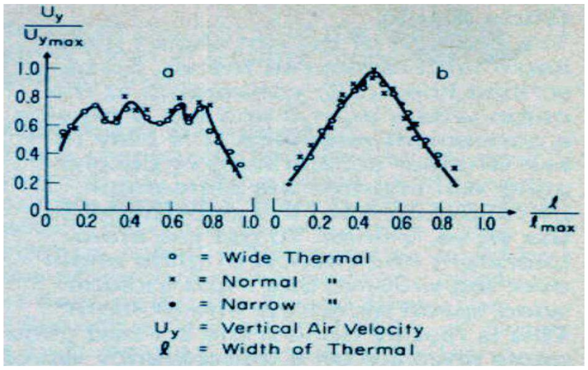

Fig. 3: Konovalov's measured thermals, types "a" and "b"

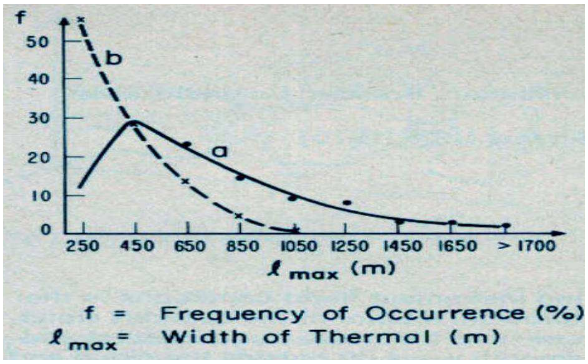

Fig. 4: Relative frequency of maximum updrafts in thermals of type "a" and type "b"

shows what the author's flight experience had indicated already. Bruce H. Carmichael's thermals were not wrong, however generally a bit too tight.

When Konovalov's paper was presented at Alpine, pilots at the World Gliding Championships experienced strong and wide thermals, which suggested the use of water ballast, even in the Standard Class. See Figures 3, 4 and 5.

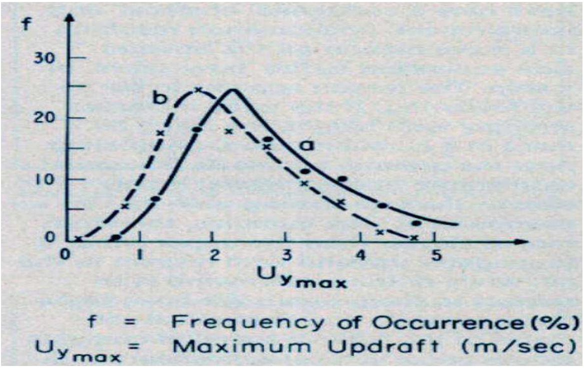

Fig. 5: Relative frequency of maximum thermal diameters as defined by vertical air velocity $U_y = 0$

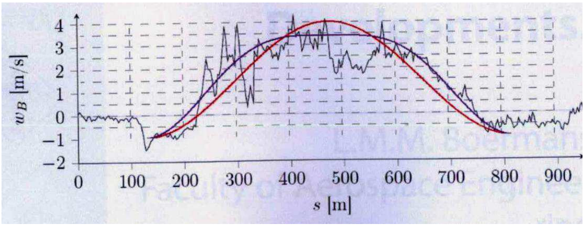

Fig. 6: Measured and modeled thermals by J. Frey

Thermals re-modeled

Previous discussion on thermals was summarized by Ann and Lorne Welch together with F. G. Irving in 1977 in "New Soaring Pilot" [6]. However, K. H. Horstmann read a paper at Räyskälä 1976, *Neue Modellaufwindverteilungen und ihr Einfluss auf die Auslegung von Segelflugzeugen* [7], which regards Konovalov's measured thermals as well as those measured by W. Martin from Akaflieg Stuttgart.

Wider thermals favor heavier wing loadings and lower bank angles in turns which was also in agreement with the experience of the top-ranked contest pilots. The parametric study of Horstmann's paper however favored wing aspect ratios of about 20 which leads to a 1000 kg MTOW sailplane for as little as 20 m span. While this was perhaps acceptable for record flying, it was not very practical and disregarded the needs of the competition pilots.

The author has himself discovered that competitions are decided on marginal soaring days and that the ability to vary the wing loading is important so that one can still perform in weak conditions. This may be more important than the advantage of slightly higher cruising speed gained with a high water ballast load.

In 1978 L.M.M. Boermans presented a paper about his *"Development of computer program for parametric sailplane performance optimization"* [8], varying axial symmetric thermals of the Konovalov "b" type with strong gradients in strength. The weight of an ASTIR CS-Standard Class glider should be variable in MTOW from 280 kg to 520 kg to cover the range of 4 m/s to 8 m/s vertical speed of the thermals in the center. In 1987. Boermans improved his program with newer models of measured thermals, see J.R. Milford [9] and T. Küpper from DFVLR, which was very helpful for the author in designing the ASW 24 Standard Class sailplane. Both presented their work at the XX OSTIV Congress held at Benalla in 1987 and a paper discussing this was also presented [10]. A thermal model constructed of a combination of 15% narrow and 85% wide thermals was chosen to establish the aspect ratio for the sailplane. The model shows a flat optimum for aspect ratio and wing loading. For practical reasons a slightly lower aspect ratio was chosen compared the calculated optimum. This or similar design strategies have proven so far to be successful. The author recently saw a new parametric study [11] considering whether split flaps, slotted flaps and wing chord extending flaps were promising. A new model of thermals was used based on recent flight measurements. The measurements fit well in older ones, as can be observed in Fig. 6. The mathematical model seems very attractive.

A designer's experience

Studying turbulence in the boundary layer of aero- and hydrodynamic bodies, as well as that in the atmosphere that causes gust loads on airplanes, the author has found that one-dimensional turbulence is extremely stable, as, for example, the two vortices behind a high flying jet or a tornado which have a long life. Two-dimensional turbulence

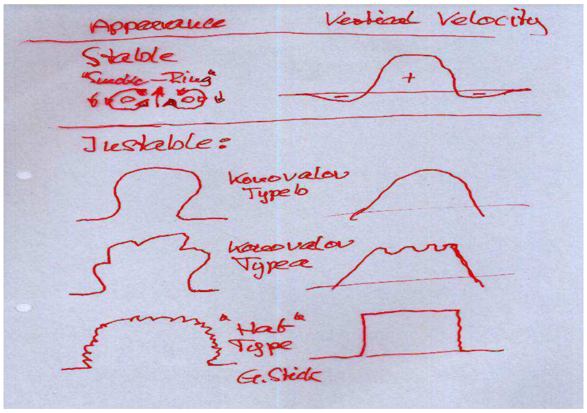

Fig. 7: Early ideas of G. Waibel about the structure of thermals.

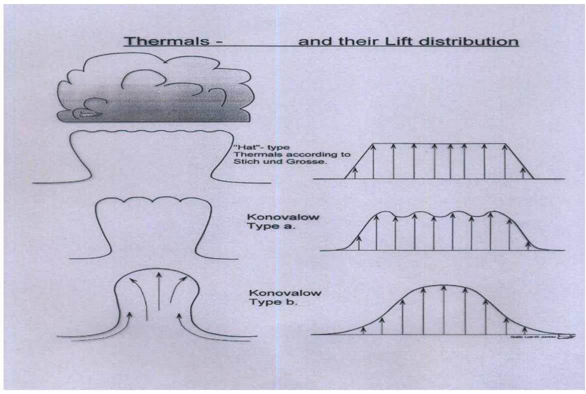

Fig. 8: A summary of thermal models including a new one without maximum updraft in the center.

like smoke rings or torus-type thermals is very stable too, but three-dimensional turbulence is quite unstable, as is the case with our beloved cumulus clouds, and follow Kolmogorov's law. This law says,that the energy of the turbulence stays constant when the big "eddies" split up in smaller ones in a cascade-process.

Only when the eddies get in the millimeter diameter range the energy dissipates into heat. This knowledge coincides much with the author's experience as a pilot.

- Thermals are most turbulent and narrow near the ground.
- Thermals get wider and smoother with altitude and the optimum bank angle gets flatter.
- When no wind shear disturbs thermals they get very smooth at altitude and have no strong core. Birds which out-climbed us low are soaring with us at altitude.

In an early overhead foil the author characterized the different thermals types, as shown in Fig. 7 and presented a paper at Bayreuth (not published in the Proceedings). Every thermal is an individual and what a glider designer extracts from thousands of flights and ten times more thermals presented in only one figure is only a very rough and simplified statistical average, truly not helpful in meteorologic research. It should be noted that the new "hat-type" thermal shown in Figs. 7 and 8 were actually described many years ago by H. W. Grosse and G. Stich in training workshops of the German National Soaring Team.

Concluding remarks

The author proposes to modify the models of thermal such that they include the "hat-type" thermal and that they vary in width and size of turbulence eddies with altitude. In this way, the models should be more accurate and provide a better representation of what the gliders experience.

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