The phase diagram of soaring: flight mode transitions in combinations of isolated and aligned lift patterns

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Outline

• Introduction

• PFD with **thermals**

• PFD with **wind** and **thermals**
Soaring in **wind** and **thermals**

- Wave
- Ridge lift
- Thermals
- Combination of W and T
Wave: 13 h, 2'400 km, 192 kph
Ridge: 8.5 h, 1'180 km, 138 kph
Thermals: 7.75 h, 1‘186 km, 153 kph

173 kph

80 kph
Combination: 13.5 h, 1'400 km, 103 kph
Combination: 10.5 h, 1'430 km, 142 kph
Combination: 14.5 h, 1‘900 km, 132 kph
Flight distance in cross-country soaring
Soaring speed

- climb rate
- spatial lift distribution: isolated, aligned
- flight polar
- pilot skill and experience

Weather controls the duration, the strength and the spatial distribution of updrafts.

Predictions of these weather elements provide the potential flight distance (PFD).
Outline

• Introduction

• PFD with thermals

• PFD with wind and thermals
Regional thermal forecast

Stratiform Clouds
Cumulus Clouds

cross-country conditions

Source: pc-met@DWD
Climb rate --> cross-country speed

• flight polar

• speed-to-fly theory for *isolated* lift

• cross-country speed

• potential flight distance (PFD)
Flight polar

V_z [m/s]

[m/s]

0 10 20 30 40 50

[km/h]

0 10 20 30 40 50 60 70

-1 -2 -3 -4

0 10 20 30 40 50 60 70 80 90 100

-1 -2 -3 -4

124 (1:53, 100 km/h)
114 (1:47, 96 km/h)
100 (1:39, 90 km/h)
84 (1:30, 80 km/h)
77 (1:27, 55 km/h)
51 (1:12, 48 km/h)
39 (1:5, 30 km/h)

Archaeopteryx
Hangglider
Paraglider
Sailplanes

Handicap
(BGR@speed)

ARCHAEOPTERYX
SEGFLUGZEUGE
SAILPLANES
HANGLIDERS
PARAGLIDERS

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Optimum cross-country speed

- **Handicap (BGR):**
  - 124 (1:53) 25 m
  - 114 (1:47) 18 m
  - 100 (1:39) 15 m
  - 84 (1:30) 15 m old
  - 77 (1:27) Archaeopteryx
  - 50 (1:12) Hanglider
  - 38 (1:5) Paraglider

- **V_{XC} [kph]**
  - 120
  - 110
  - 100
  - 90
  - 80
  - 70
  - 60
  - 50
  - 40
  - 30
  - 20
  - 10
  - 0

- **climb rate [m/s] thermals**
  - 3
  - 2
  - 1
  - 0
Speed-to-fly theory

flight path vectors

speed vectors
result: $V_{\text{Glide}}(w_{\text{Thermal}})$, $V_{\text{Track}}(w_{\text{Thermal}})$
Potential flight distance (PFD)
PFD map
Outline

• Introduction

• PFD with thermals

• PFD with wind and thermals
Approach

- Wind induces airmass vertical motion in aligned patterns

- Speed-to-fly theory with airmass vertical motion during the glide
Speed-to-fly in **sinking** airmass

**Path vectors**
- track
- glide
- climb
- downdraft

**Speed vectors**
- $w$ [m/s]
- $v$ [kph]

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**Graphical representation**
- Speed vectors for different wind conditions
- Path vectors showing track, climb, glide, and downdraft.
**Speed-to-fly in rising airmass**

**Path vectors**

- **Track**
- **Glide**
- **Climb**
- **Airmass updraft**

**Speed vectors**

With sufficient **airmass updraft** the minimum sink of the glider is compensated ....
$V_{\text{Track}}$ in rising airmass (standard class)

![Graph showing $V_{\text{Track}}$ and track speed against climb rate.]

- **Aligned lift**
  - 2.4 m/s
  - 1.8 m/s
  - 1.5 m/s
  - 1.2 m/s
  - 1.0 m/s
  - 0.8 m/s
  - 0.6 m/s
  - 0.5 m/s
  - 0.3 m/s
  - 0.0 m/s

- **Circle & glide mode**
  - Pure glide mode in strong aligned lift
  - Pure glide mode in weak aligned lift

- **Standard class: 44 @ 92 km/h (33 kg/m²)**
$V_{\text{track}}$ in rising airmass (Open class)

**XC speed [kph]**

- **aligned lift**
  - 54 @ 101 km/h (42 kg/m2)
  - 1.2 m/s
  - 1.0 m/s
  - 0.8 m/s
  - 0.6 m/s
- **pure glide mode**
  - 1.8 m/s
  - 1.6 m/s
  - 1.4 m/s
- **circle & glide mode**
  - 1.2 m/s
  - 1.0 m/s
  - 0.8 m/s
  - 0.6 m/s

**Climb rate [m/s] when circling**

- **pure glide mode in strong aligned lift**
- **circle & glide mode in weak aligned lift**
Phase diagram of soaring

Climb rate in isolated lift

V_{track} = 100 kph

Open class: 54 @ 101 km/h (42 kg/m²)
Summary

• Speed-to-fly theory for isolated lift can be extended to aligned lift

• The time fraction spent climbing is the order parameter controlling the phase transition from „climb & glide mode“ to „pure glide mode“

• Predicted aligned lift can be used for flight planning ... How about such predictions?