Climb Rate – Altitude Correlation from Analysis of IGC Files

Christof Maul
Technische Universität Braunschweig
Johann Wolfgang Goethe-Universität Frankfurt (Akaflieg Frankfurt)
Source data: Competition flights

Advantages: Open access
Well-defined pilot strategy
Well-defined terrain and weather conditions

B1400235136607N01245193EA016980181000208173008
B1400475136514N01246159EA016790178000207169010

Convert data string to 5-dimensional flight vector $V(t, y, x, h, w=dh/dt)$

14.0064, 51.6101, 12.7532, 1698, -2.67
14.0131, 51.6086, 12.7693, 1679, -0.79
Competition data pre-treatment
removal of pre-start and post-finish data
Competition data pre-treatment

removal of pre-start and post-finish data
Analyzed competitions (2007):

1) Lilienthal Glide, Lüsse, Germany, July 14 to 27
   97 competitors
   July 16, 23, 26
   254 flights
   127,000 data points

2) European Gliding Championships, Issoudun, France, Aug 6 to 19
   91 competitors
   August 9, 12, 13, 16, 18
   386 flights
   177,000 data points

3) Junior World Gliding Championships, Rieti, Italy, July 28 to Aug 11
   53 competitors
   July 29, 30, August 4, 6, 7
   221 flights
   95,000 data points
Basic results – tracks – y(x):

well defined geographical area with homogenous sampling

Lilienthal Glide
From variograms $w(t)$ to vertical speed distributions $f(w)$:

projection of variogram onto $w$ axis
Climb and sink vertical speed distributions are general features

Rieti

Issoudun

vertical speed, m/s
From barograms $h(t)$ to altitude distributions $f(h)$:

projection of barogram onto $h$ axis
Circling vs. straight climb

\[ \text{total } f(h) \]

- climb \( f_c(h) \)
  \[ w = \frac{dh}{dt} > 0 \]
  \[ (dx/dh)^2 + (dy/dh)^2 \lesssim 0 \]
- sink \( f_s(h) \)
  \[ w = \frac{dh}{dt} < 0 \]
- thermal/circling \( f_c^t(h) \)
  \[ w = \frac{dh}{dt} > 0 \]
  \[ (dx/dh)^2 + (dy/dh)^2 \lesssim 0 \]
- aligned lift \( f_c^a(h) \)
  \[ w = \frac{dh}{dt} > 0 \]
  \[ (dx/dh)^2 + (dy/dh)^2 \lesssim 0 \]
Altitude distributions of thermal $f_c^c(h)$ (•) vs. aligned $f_c^s(h)$ (□) lift. Significant variations, aligned lift accounts for as much as 50% of total lift!
Description of circling climb altitude distributions $f_{c}^{c}(h,w>0)$.

If $w$-$h$ correlations are absent, $f_{c}^{c}(h,w>0)$ can be obtained by integrating over thermal entering and thermal exiting altitude distributions $f_{\text{in}}(h)$ and $f_{\text{out}}(h)$:

$$f_{c}^{c}(h) = \int_{0}^{h} \left( f_{\text{in}}(h') - f_{\text{out}}(h') \right) dh'$$

Consequently, $f_{\text{in}}(h)$ and $f_{\text{out}}(h)$ can be obtained by differentiating $f(h)$:

$$\frac{df_{c}^{c}(h)}{dh} = f_{\text{in}}(h) - f_{\text{out}}(h)$$

(2)

Alternatively, $f_{\text{in}}(h)$ and $f_{\text{out}}(h)$ can be directly obtained from identifying thermals from flight recorder data.

Both methods should give identical results!
Excellent agreement between altitude distributions $f_c^c(h)$ obtained from flight recorder data (⊗) and from integration of eq.1 (∇).

2907  Rieti  0908  Issoudun

3007  1208

0408  1308

0608  1608

0708  1808
Result corroborated by absence of w-h correlation.

Mean vertical speeds (black) are essentially independent of altitude. In contrast, maximum and minimum vertical speed values (blue) occur at medium altitudes.
Result is in contradiction to accepted theory, see e.g. "Meteorology and Flight" by T. Bradbury:

"Average rates of climb may be only half these values."
A second look to altitude distributions

Excellent agreement between altitude distributions $f_c^c(h)$ obtained from flight recorder data (●) and from integration of eq. 1 (∁).

Rieti

- 2907
- 3007
- 0408
- 0608
- 0708

Issoudun

- 0908
- 1208
- 1308
- 1608
- 1808

- systematically too large
- systematically too small
A second look to altitude distributions

Excellent agreement between altitude distributions $f_c^c(h)$ obtained from flight recorder data (⊗) and from integration of eq.1 (∇).

Good
A second look to w-h correlations

- **Strategy**
  - fit 3rd order polynomial to maximum climb rate data (black)
  - fix intercept at -0.5 m/s and compare to Bradbury
  - divide result by 2 (average rates of climb may be only half these values) and compare to mean climb rate data (red)

- **Graphs**
  - **0908**
    - **Climb Rate vs. Altitude**
      - Plot of vertical speed vs. altitude with maximum and mean climb rate indicated.
    - **Altitude vs. Vertical Speed**
      - Scatter plot showing altitude vs. vertical speed with trend lines.
  - **0908**
    - **Altitude vs. Vertical Speed**
      - Additional scatter plot with trend lines.
3rd order polynomial fit to maximum climb rate data
intercept -0.5 m/s

No fit! Result from above divided by 2, compared to mean climb rate data
"Bradbury correlation" applied to mean thermaling climb rates of Luesse and Issoudun competitions.
final comparison of statistical analysis to Bradbury’s model

another excellent agreement!
Another add-on to previous work concerning vertical speed distributions

Gaussian or non-Gaussian?

Issoudun, 9.8.07

- straight and circling Gaussian
- straight flight only Gaussian
- same data but look non-Gaussian
Issoudun, 16.8.07

Altitude distribution:
- Straight and circling

Vertical speed distribution:
- Straight and circling

More than 50% straight climb.
Circling climb rate distribution is Gaussian.
Summary of new results

1) vertical speed – altitude correlation

A close look reveals very good agreement of evaluated data with correlation reported by Bradbury.

2) vertical speed distribution

No deviation from Gaussian normal distributions is observed. Holds also for circling only climb data.