Verification of Thermal Forecasts with Glider Flight Data

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Abstract

The soaring flight planning and analysis algorithm TopTask was used for multi-class national and international gliding championships in Switzerland and Sweden. The routinely operated meteorological models LME-TOPTHERM and HIRLAM provided the regional thermal forecasts required by the TopTask algorithm: the depth of the convective boundary layer, the lift rate and the horizontal wind at flight altitude. TopTask predicted speeds for the set tasks were compared to the scored speeds of the first and second place finishers for all days and classes of these competitions. For Swiss Glide 2004 the predicted task speeds matched the scored speeds with no bias and a standard deviation of 10%. For Viking Glide 2005 the predicted task speeds (108+/-8 kph) matched the scored speeds (104+/-15 kph) with a bias of 4 kph. The standard deviation for Viking Glide 2005, however, was larger than for Swiss Glide 2004 with the appearance of three classes of accuracy: accurate predictions (speed within +/-10%), underestimated predictions (scored speed up to 22% higher than predicted), and overestimated predictions (scored speed up to 39% lower than predicted). TopTask also was used for a model intercomparison between the HIRLAM and the LME-TOPTHERM models. TopTask predicted flight speeds based on the regional forecasts from both meteorological models were compared to the scored speeds for Viking Glide 2005. The task speeds obtained from HIRLAM (118+/-5 kph) were higher than those from LME-TOPTHERM (108+/-8 kph) and indicated a bias in the predicted lift rates. The width of the HIRLAM speed forecasts of +/-5 kph was smaller than the +/-8 kph of the LME-TOPTHERM speed forecasts and the ranges of both speed predictions were smaller than the range of the scored speeds (104+/-15 kph). Thus, both meteorological models do not yet catch the full range of variation found in the scored speeds of the winning gliders. Nevertheless, routine numerical thermal forecasts have reached a quality that is useful for soaring practice. Pilot briefing systems make such forecasts available and provide the possibility of thermal flight planning to the gliding community. Glider flight data can be used to verify the performance of numerical weather prediction for thermals.

Introduction

The on-line pilot briefing system "pcmet" of the German Weather Service[1] contains regional thermal forecasts for a major part of central Europe. As a first step in the selection of a flight task adapted to the weather, glider pilots can view maps of the potential flight distance (PFD) for each region. Once a task has been defined by clicking a number of turnpoints, pilots can interact with the weather forecast through the meteorological flight planning algorithm TopTask[2]. Based on the performance of the glider and the thermal forecast the feasibility of the task is checked by having the task speed calculated as a function of the departure time. The task length may then be adjusted to match the weather and individual preferences.

The Regional Gliding Competition 2003 held at Birrfeld (LSZF), Switzerland, was the first contest for which TopTask was available in a "Competition" version for the daily task setting. In May 2004 it was used again for the Regional and also for the National Gliding Championship in the same location. In this paper both these contests will be referred to as "Swiss Glide 2004". PFD maps and TopTask "Competition" predictions were key steps in the daily task setting procedure. Nine contest days provided a first set of data to evaluate the performance of this meteorological flight planning system with the scored speeds of the competitors.

The performance of the system during Swiss Glide 2004 encouraged us to make it available for the World Gliding Championship (WGC) to be held in Eskilstuna, Sweden. Twenty-seven regions were created for southern Sweden including the contest area. Both the German and the Swedish Weather Services decided to produce thermal forecasts for these 27 regions with their operational numerical weather prediction (NWP) models LME-TOPTHERM and HIRLAM, respectively. The regional forecasts from both models became operational just in time for Viking Glide 2005 (pre-WGC). Two practice days and five contest days in June 2005 provided a second set of scored flights to evaluate the flight planning system, now fed by two different meteorological models.

In this paper, it will be investigated how routine numerical weather prediction can support the meteorological flight planning during gliding competitions. The Swiss Glide 2004 and the Viking Glide 2005 data sets will be analyzed.

Meteorological prediction models for thermals

LME-TOPTHERM

The German weather service uses the GME and LME models for global and continental scale weather prediction. Regional thermal forecasts are produced by the convection model REGTHERM[3], which was named TOPTHERM for distribution through "pcmet". For the 27 new Swedish regions REGTHERM was initialized with model profiles. In 2005 the profiles were taken from the global model GME. For 2006 this was changed to LME profiles with a finer vertical resolution.

REGTHERM is guided by the LME with data at the standard levels from nine grid points (7 km horizontal resolution) centered on each region. It recalculates the evolution of the convective boundary layer by using its own parameterizations for radiation and land/atmosphere interactions and a vertical resolution of 100 m. Vertical profiles of the lift rate are obtained from a parcel method. The area-elevation distribution of the region is taken into account because of the associated volume effect in complex topography[4]. REGTHERM assimilates early morning surface observations.

Regional forecasts of the convective cycle between 06 and 18 UTC are issued for each day with three different initialization times (-24,-12, and 00 UTC). The 00 UTC based forecast is available shortly after 04 UTC. A final update is provided at 06:40 UTC that uses the surface observations of 06 UTC instead of the MOS predictions for the surface temperature and dewpoint. An example is shown in Table 1. The essential variables for flight planning are the lift rate, the depth of the convective boundary layer (CBL), and the horizontal wind at 800 m GND (or in the part of the CBL above this threshold value). The lift rate is converted to the cross-country speed of a Standard Class sailplane and its potential flight distance throughout the convective cycle is included in the forecast of each region. Additional predicted parameters are the top of and the fractional cloudiness due to convective clouds, the lift rate profile in thermals, indications for turbulence, cloud streets and ridge lift. The LME-REGTHERM regional forecasts are transferred to the on-line pilot briefing system "pcmet" under the name TOPTHERM. "pcmet" visualizes the regional thermal forecasts on maps and barograms.

Tuning REGTHERM for Sweden

For the newly defined Swedish forecast regions the surface parameters for albedo and evaporation in REGTHERM were tuned with glider flight data prior to the operational runs. In April 2005 recorded flight tracks (*.igc files) were downloaded from the Swedish on-line contest[5] and analysed in the extended version of TopTask named TopTask Competition (TTC). The recorded flight tracks were visualized on barograms and on maps that showed the forecast regions (see Fig. 1). For days with well established high pressure conditions the diurnal cycle of the convective boundary layer was calculated by REGTHERM for all regions and saved as *.gra text files. The convection model was initialized with 00 UTC radiosonde data from Göteborg, Visby, Kopenhagen, and Sundsvall. None of these stations is located within a forecast region, but Göteborg is close to the forecast regions in the southwest of Sweden. No data from NWP models were used for this tuning step thereby assuming full sunshine and no advection in REGTHERM.

On the barogram, the REGTHERM calculated depth of convection that corresponded to the recorded position of the glider was displayed as a background for the flight trace as illustrated in the barogram of Fig. 1. Thus, the recorded climb altitude and the predicted depth of convection could be compared. It was recognized that the recorded flight altitudes were mostly higher than the calculated depth of convection which asked for an increase of the sensible heat flux in the model calculations. So the evaporation was reduced until the calculated cloud base met the recorded flight altitudes.

Once the flux of sensible heat had been tuned to the recorded flight altitudes, the lift rates were adjusted by comparing the simulated to the recorded task speeds for a number of flights. The recorded flight track was treated as a flight task for which TTC calculated the flight plan with the TopTask algorithm, more details follow in the section "Flight simulation". In the barogram of Fig. 1 this is illustrated by the sloped diagonal lines for the simulated and the real flight. In REGTHERM the lift rate was tuned through the dT term that controls the buoyancy of the rising air parcels. The tuned values for both evaporation and dT indicate that Sweden has more favourable land characteristics for the development of thermals than northern Germany. Apparently the reduced evaporation is more important than the numerous small lakes. In the PFD map an additional class was introduced for the range from 800 to 1000 km. The long midsummer daylight conditions in high latitudes also contribute to such PFD values.

The operational runs of LME-TOPTHERM started on 6 June 2005 and became available to pilots through "pcmet" on 13 June 2005 - just in time for Viking Glide 2005, the pre-WGC, that were held in Eskilstuna, Sweden.

HIRLAM

With HIRLAM the regional thermal forecast was produced for the same forecast regions by post-processing the direct model output of a single grid point profile according to Olofsson and Olsson[6]. An example of a HIRLAM thermal forecast (htf) is shown in Table 2. The essential variables for flight planning with TopTask are again the lift rate, the depth of the CBL, and the horizontal wind at 800 m GND (or in the part of the CBL that exceeds this threshold value). No tuning of the HIRLAM thermal forecast with flight data was performed in this case.

The operational runs of the HIRLAM thermal forecasts started on 6 June 2005. The predictions were produced as *.htf text files and archived for later analysis. The *.htf files were not available for flight planning in real-time. TopTask Competition was adapted to read the *.htf files for this investigation.

Meteorological flight planning

TopTask

Within "pcmet" pilots can use TopTask interactively to check the feasibility of flight tasks with the LME-TOPTHERM meteorological forecast. The "pcmet" version of TopTask reports the best predicted speed for the task and the corresponding departure time, if the task is feasible. If the task is too long, the report is limited to the partial distance that can be covered before thermals cease. The predicted flight is illustrated on a map and a barogram.

The TopTask[2] flight model is based on three different flight modes which depend on altitude: gliding when above the convective boundary layer, climbing when within, and soaring at the top of the CBL. The soaring mode is the combination of gliding down into the CBL and climbing back to its top in thermals. The gliding speed is a function of the lift rate according to the speed-to-fly theory which maximizes the cross-country speed for isolated thermals. The cruising speed of the glider is highest in the gliding mode, moderate in the soaring mode, and zero in the climbing mode. A fourth mode comes into play for the final glide. It corresponds to the gliding mode with a goal altitude that can be as low as the ground elevation. The gliding speed is always deduced from the predicted lift rate according to speed-to-fly theory, no matter whether the glide is towards another thermal or towards a goal altitude. Initially, the "gentle" version of TopTask switched to final glide mode as soon as the goal could be reached with a ring setting of 0.8 m/s.

While gliding and cruising the horizontal wind adds to the glider speed. The TopTask flight model needs to know the depth of the convective boundary layer, the lift rate in thermals, and the horizontal wind in the upper part of the convective boundary layer. A meteorological model that provides forecasts of these parameters is suited for thermal flight planning with gliders.

The temporal and spatial resolution required for thermal flight planning are connected through the average cross-country speed of the sailplane. A temporal resolution of 30 minutes asks for a spatial resolution of 50 km if the cruising speed of the glider is 100 kph. Forecast regions should therefore cover a surface area of 50x50 km^2. The European forecast regions cover 5,000 km^2 on average with larger regions (10,000 km^2) over the plains and smaller regions (2,000 km^2) in the complex terrain of the Alps. Topographical and land surface features were considered for the determination of the forecast regions in order to match the conceptual demand for homogeneous conditions in each region.

TopTask Competition

TopTask Competition (TTC) is an extended and stand-alone version of the TopTask tool in "pcmet". TTC reads regional forecasts from REGTHERM (*.gra files), LME-TOPTHERM (*.ttm files), and HIRLAM (*.htf files). The PFD is contained in the *.gra and the *.ttm files. For the *.htf files it is computed in TTC from the lift rates given at 30 min intervals. TTC presents maps of the PFD and the wind at selected scales. Fig. 2 shows the overview of the operational LME-TOPTHERM forecasts as of 30 May 2006. In the TTC barogram the diurnal cycle of the convective boundary layer is visualized for each region, Fig. 3 illustrates a PFD map for Sweden and the predicted diurnal cycle of the CBL for a particular region. Horizontal winds are shown as flags on both the map and the barogram (grey 0-10 kts, black 11-20 kts, red above 20 kts).

Task selection and optimization

TTC reads flight tasks created either in "pcmet" with TopTask (TaskTemp.dat), in SeeYou (*.cup), or in StrePla (*.stt). After reading a task file all tasks are listed in TTC and submitted to the TopTask flight planning algorithm. An example of a predicted flight plan is shown in Fig. 4 for a proposed 500 km task out of Eskilstuna, Sweden. The altitude of departure is set manually to 1800 m MSL. The selected flight polar is characteristic for an Open class sailplane with a best L/D of 56 at a speed of 103 kph. On 15 June 2005 the best task speed is expected to be 129 kph for such a glider according to the LME-TOPTHERM forecast and TTC.

TTC displays the predicted task speed as a function of the time of departure, if the task is feasible. TTC indicates that this proposed task can be finished when departing between 0900 LT and 1615 LT. Departure times after 1615 LT result in outlandings along the task when thermals end. The flight plan shown is for the departure time resulting in the best task speed. The task length could actually be increased substantially with such an excellent thermal forecast. This is illustrated by the extended horizontal line at 500 km (task length) between the earliest and the latest predicted departure time for finishing the task. The speed and distance curves in the barogram allow for a proper choice of the task length.

Assigned area tasks (AAT) are also supported in TTC. The radii of the turnpoint areas and the minimum task time are specified when the task is designed in SeeYou or StrePla. An AAT flight task can interactively be modified in TTC by clicking into the turnpoint areas to see the effect on the task speed.

Verification

Swiss Glide 2004 and Viking Glide 2005

The immediate calculation of an entire list of tasks in the "Competition" version of TopTask is useful for the pre-briefing task selection and optimization. This was heavily used during Swiss Glide 2004, where it supported repeatedly and successfully the proposition of tasks that had never been called before in competitions at Birrfeld. In nine competition days in May 2004, 27 tasks for three classes (standard, 18m, open) were predicted with TopTask using the LME-TOPTHERM forecast.

During Viking Glide 2005 the called tasks were published in real-time[7]. These tasks were reproduced in the flight planning software SeeYou[8] and saved as *.cup files. TTC predicted the meteorological flight plans with the regional thermal forecasts from LME-TOPTHERM (*.ttm files) obtained through "pcmet". In this 2005 championship the TTC calculations were not available to the competition director. The predicted task speeds were listed for two practice days and five competition days for all classes (Standard, 15m, 18m, Open). On some days certain classes were cancelled, so there were 23 predicted task speeds left after seven flying days.

Scored speed

A pragmatic verification was to compare the predicted task speeds to the scored speeds of the first and second finishing pilots. Such a verification does not take into account that pilots do deviate from the shortest track in order to find lift, especially in difficult weather. The real flight distance is always longer than the scored task distance. Thus, the scored speeds are always less than the real speeds. For Swiss Glide 2004 the deviations were generally higher than for Viking Glide 2005 due to the complex topography of Switzerland. In extreme cases the real distance can exceed the scored distance by 20% in the Alps. When comparing predicted and scored task speeds, the departure times also are usually different. The characteristics of the speed polars used in the TopTask predictions for the various classes of gliders are listed in Table 3.

For Swiss Glide 2004 Fig. 5 shows 54 scored speeds and 27 task speeds predicted by LME-TOPTHERM-TopTask. The majority of the points differ by less than 10% in the scored and predicted speeds. In a very few cases the scored speeds were up to 30% higher than predicted. In these cases the tasks were aligned with the topographical ridges. This can lead to aligned lift and allows pilots to reduce their fraction of time spent spiraling in thermals. Of course, pilots may occasionally find and use thermals that are better than the average. This is another possibility for higher scored than predicted speeds. The few opposite cases with scored speeds up to 30% less than predicted were related to either inaccurate forecasts or significant deviations from the shortest track.

For Viking Glide 2005 Fig. 6 shows 46 scored speeds and 23 task speeds predicted by LME-TOPTHERM-TopTask. The task lengths averaged 341+/-106 km. The speed predictions averaged 108+/-8 kph, the scores averaged 104+/-15 kph. The bias between the average speeds was 4 kph. To some extent this can be attributed to deviations from the shortest track. Twenty-two predicted speeds (out of 46) differed only between -10 and +4% from the scored speeds and can be classed as accurate. Fourteen predicted speeds (out of 46) were 14 to 37% faster than scored. These cases were mostly due to inaccurate forecasts with fronts moving faster into the task area than expected. Ten predicted speeds (out of 46) were 11-18% slower than scored. This can be attributed to aligned lift on 20 June when only the 15m Class competed. The winning Italians were able to find aligned lift on their 220 km team flight according to the SeeYou flight statistics. On 14 June with all classes flying, the regional thermal forecast for a single region was inaccurate.

Model intercomparison

Figure 7 presents a comparison of the TopTask speeds predicted with LME-TOPTHERM and HIRLAM. The scored speeds are shown for reference. The task speeds obtained from HIRLAM (118+/-5 kph) were clearly higher than those from LME-TOPTHERM (108+/-8 kph) and indicate a bias in the HIRLAM predicted lift rates for thermals.

The width of the HIRLAM speed forecasts of +/-5 kph was smaller than the +/-8 kph of the LME-TOPTHERM speed forecasts. The ranges of the speed predictions were smaller for both models than the range of the scored speeds (104+/-15

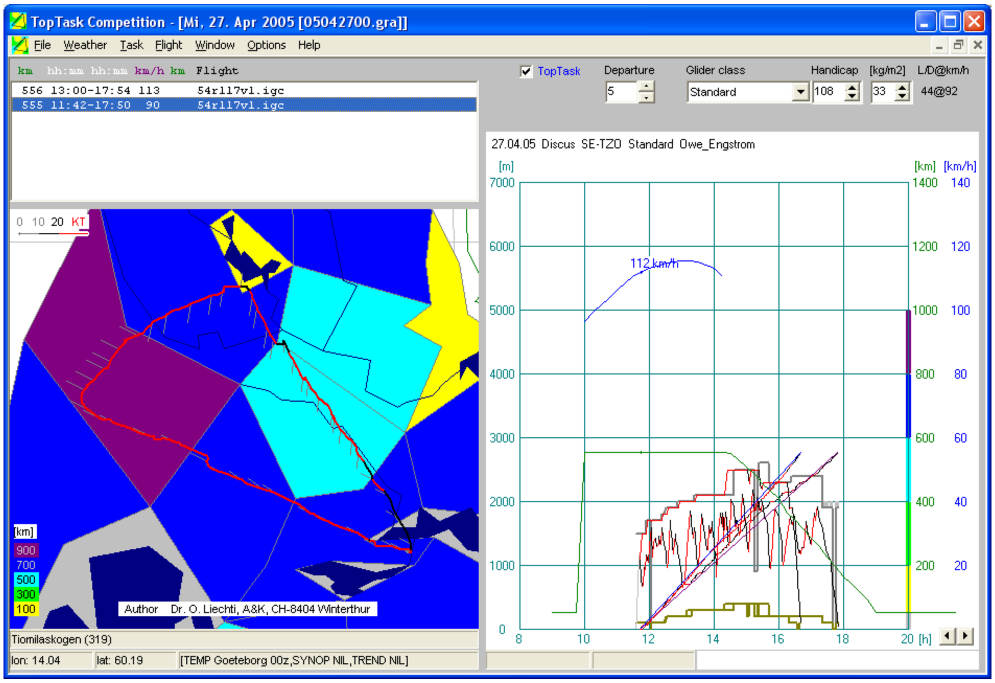


Figure 1 Left: map with a flight track and regional forecasts of the potential flight distance (km) based on (remote) radiosoundings. Right: barogram with recorded flight altitude and calculated depth of convection (m); recorded and TopTask calculated flight distance as sloping diagonal lines (km).

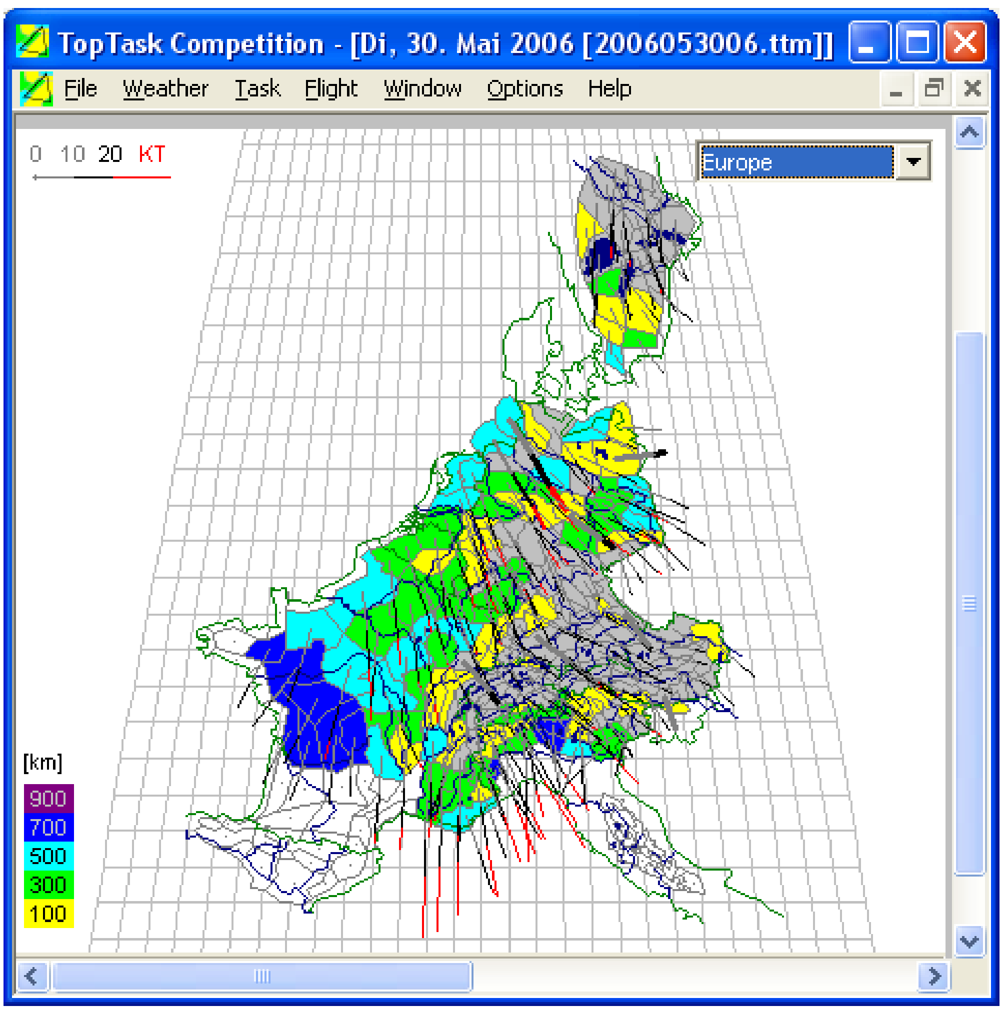


Figure 2 European thermal forecast regions as of 30 May 2006. The coastlines and the major lakes and rivers are indicated. The color represents the potential flight distance (km) for a standard class sailplane. Horizontal winds at 800 m AGL are shown as flags (grey 0-10 kts, black 11-20 kts, red above 20 kts).

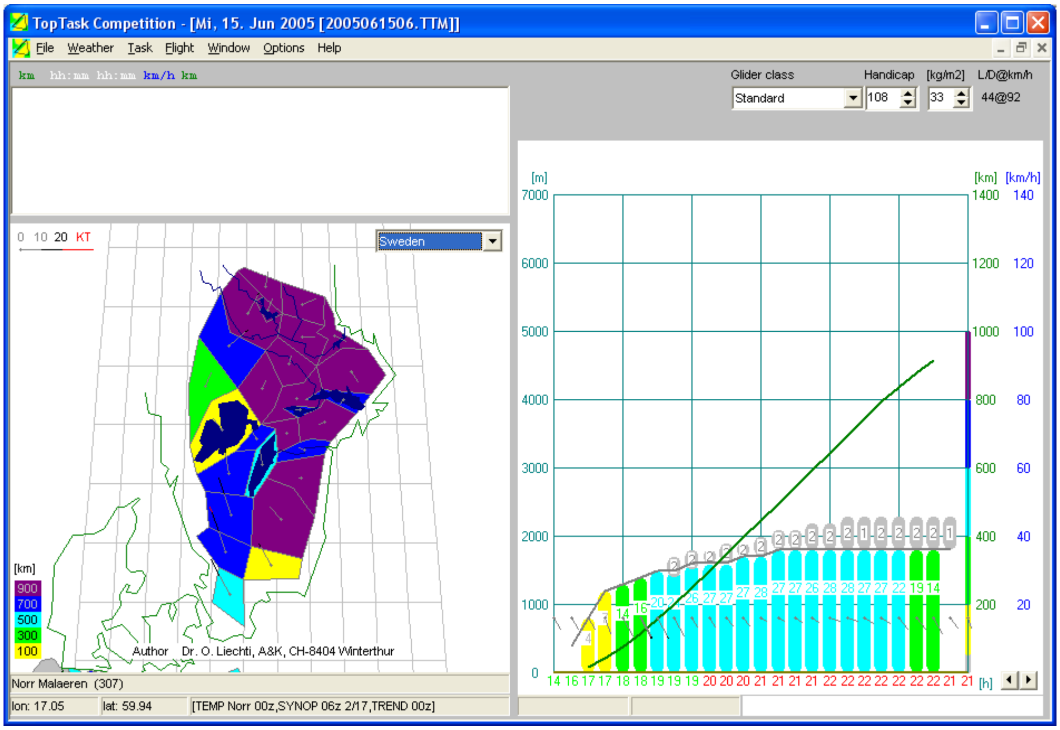


Figure 3 Left: the thermal forecast regions for southern Sweden. Right: diurnal cycle of the convective boundary layer for region Norr Malaeren as predicted by LME-TOPTHERM for a day during Viking Glide 2005. The columns show the lift rate (m/s*10), the sloped diagonal line represents the cumulative potential flight distance. Temperatures (°C) are indicated along the ground. Convective cloud is gray and cloudiness (octals) is denoted. Left and right: horizontal winds at 800 m AGL are shown as flags (grey 0-10 kts, black 11-20 kts, red above 20 kts).

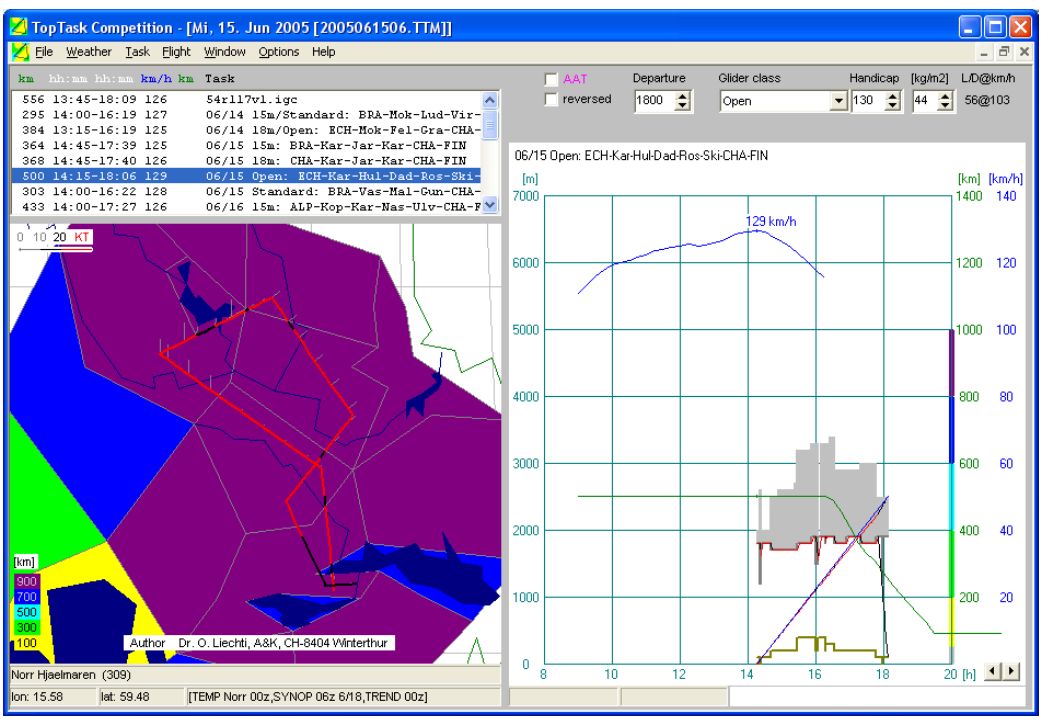
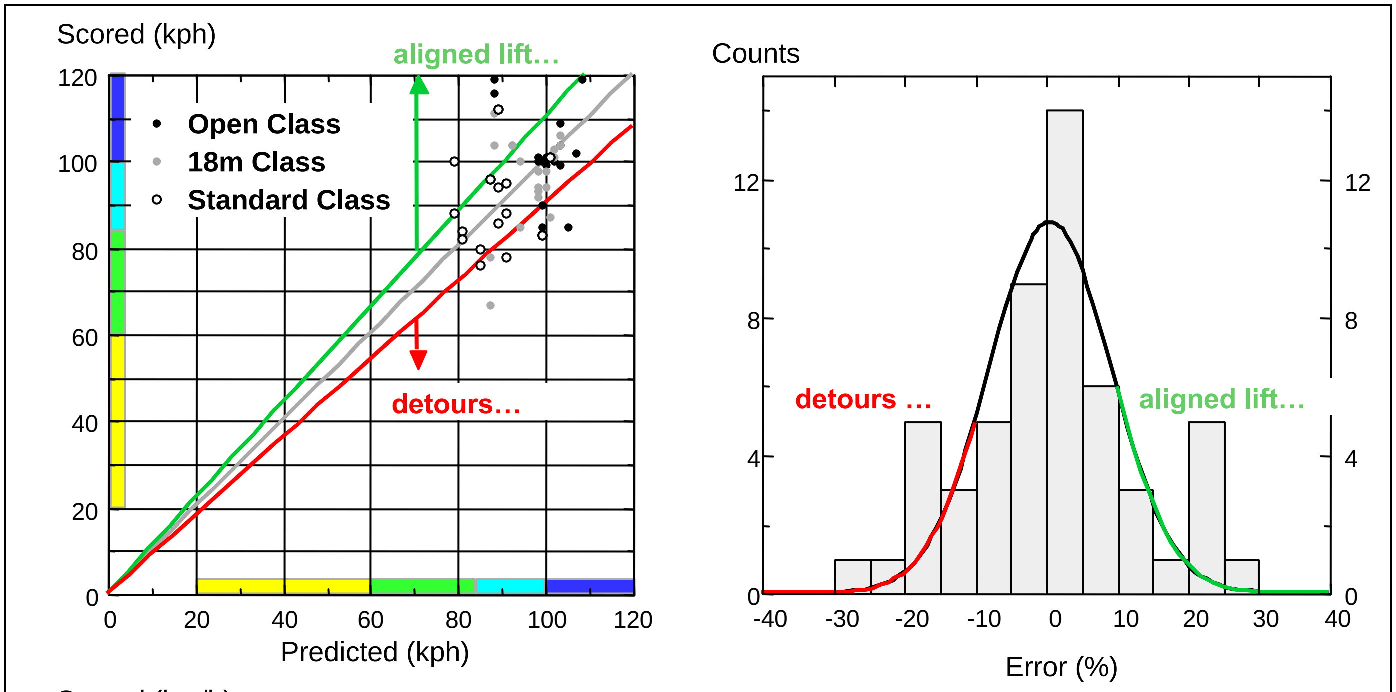


Figure 4 LME-TOPTHERM-TTC prediction of a proposed 500km task from Eskilstuna, Sweden, on 15 June 2005 for an Open class sailplane. The departure to produce the fastest task speed (129 kph) is at 1415 LT from 1800 m MSL. The task is feasible when departing between 0900 LT and 1615 LT. A later departure leads to an outlanding because thermals cease en route. The horizontal green line illustrates the distance that can be flown along the task as a function of the departure time. Early and late departure times lead to slower task speeds because the predicted lift rates are highest during the afternoon hours. The sloped diagonal lines represent the time it takes to cover the indicated distance (km).



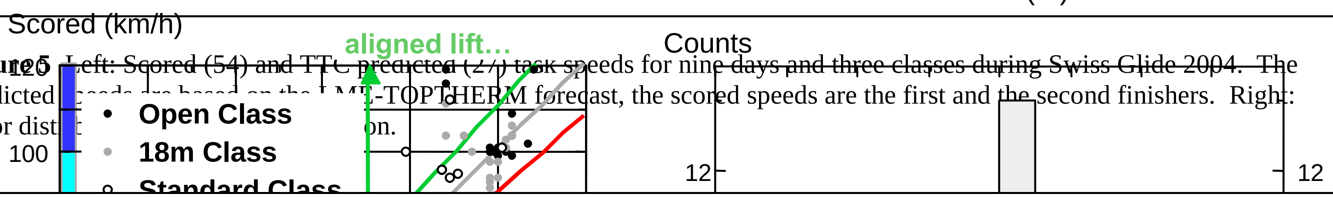


Figure 5 Left: Scored (54) and TTC predicted (27) task speeds for nine days and three classes during Swiss Glide 2004. The predicted speeds are based on the LME-TOPTHERM forecast, the scored speeds are the first and the second finishers. Right: Error distribution in the speed prediction.

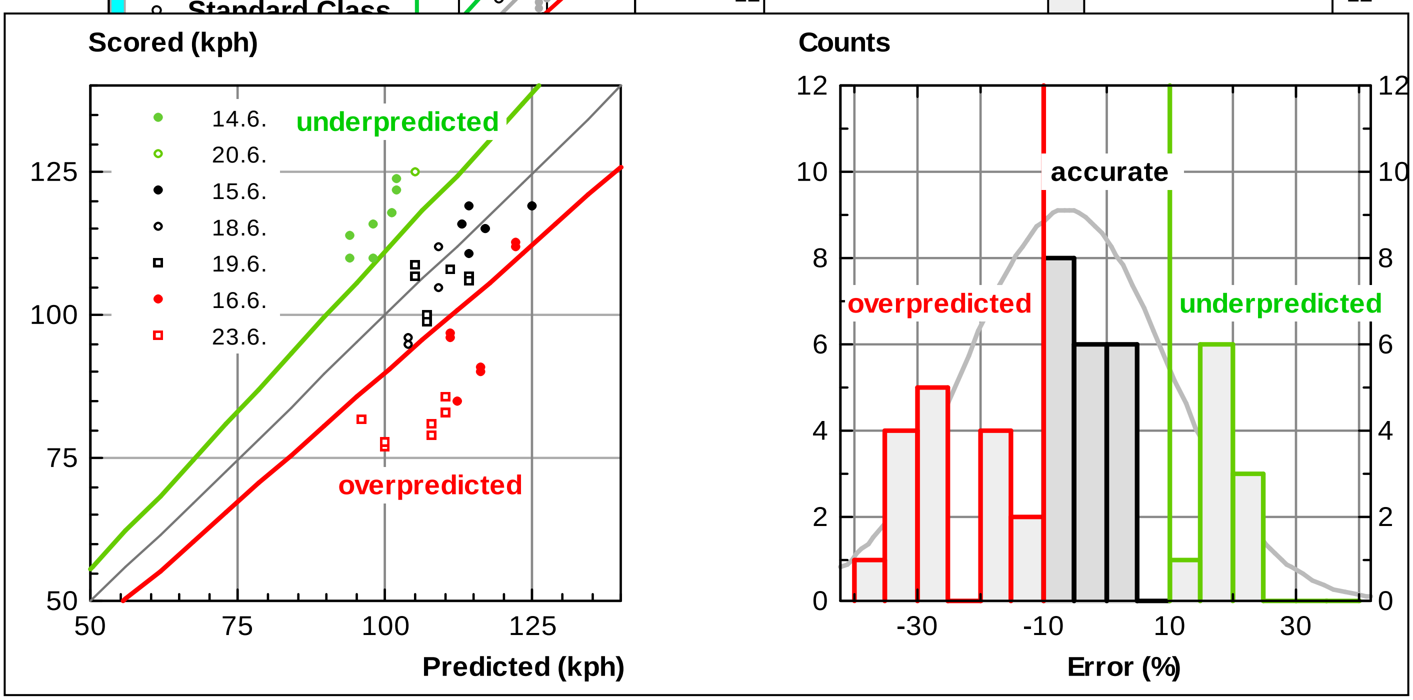


Figure 6 Left: Scored (46) and TTC predicted (23) task speeds for seven days and four classes during Viking Glide 2005. The predicted speeds are based on the LME-TOPTHERM forecast, the scored speeds are the first and the second finishers. Right: Error distribution in the speed prediction.

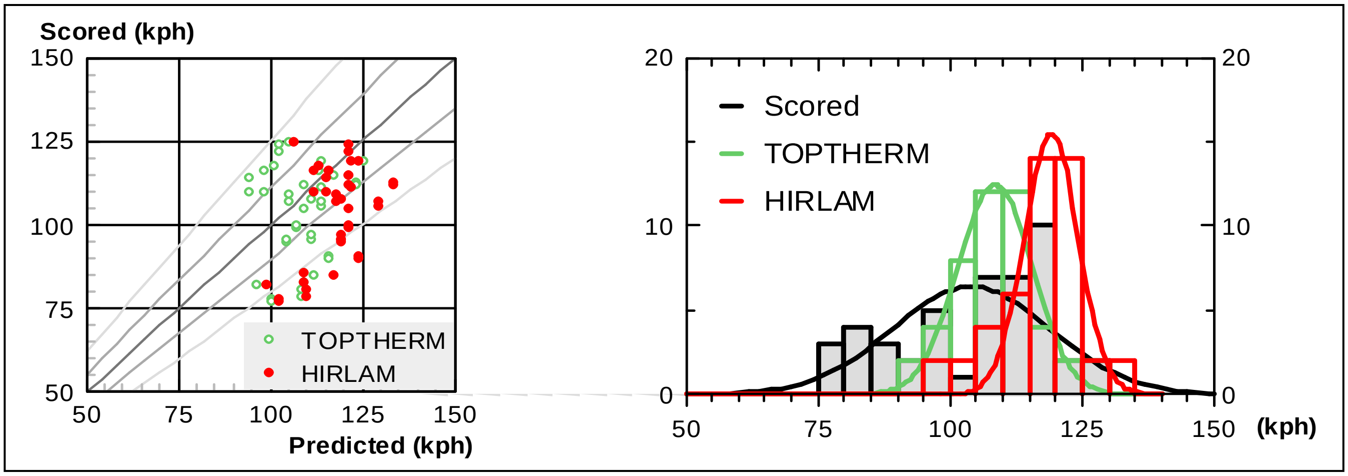


Figure 7 Left: scored versus TTC predicted (LMA-TOPTHERM, HIRLAM) task speeds for seven days and four classes during Viking Glide 2005. Right: histograms of scored and predicted task speeds.

Table 1
Predicted values of the meteorological variables for the Norr Malaeren forecast region in Sweden extracted from 06050506.gra (5 May 2006, LME-REGTHERM):
Surface temperature and dew-point (T, Td), lift rate profile (0.5m/s) average lift rate (m/s), cloudiness (1/8-8/8), convective boundary depth (m MSL, a cloud with no base means a cloud-free boundary layer), cloudiness (low-, mid-, and high level), 800 m AGL wind direction (blowing from) and speed, turbulence and precipitation index, potential flight distance (km).

GG307 Norr Malaeren, Fr 05.05.2006 [TEMP NORR 06z,SYNOP NIL,TREND 00z]

UTC hh:mm	T [C]	Td [C]	Aufwind [0.5m/s] 0km 1km 2km 3km 4	Steig [m/s]	Cumuli [octas]	Basis-Top [m] - [m]	CL [octas]	CM	CH	Wind [deg/kt]		T	NS	PFD [km]	kum [km]
06:00	11	6	:----:----:----:----:				0	0	0	90	1				
06:30	12	6	:1---:----:----:----:				0	0	0	90	1				
07:00	13	5	:1---:----:----:----:				0	0	0	135	1				
07:30	14	5	:1.--:----:----:----:				0	0	0	135	1				
08:00	14	7	:11--:----:----:----:	0.6		400	0	0	0	125	3				
08:30	15	6	:221-:----:----:----:	0.8		600	0	0	0	125	3				
09:00	16	6	:222.:----:----:----:	1.1		700	0	0	0	115	3				
09:30	17	5	:2222.----:----:----:	1.3		900	0	0	0	90	3			35	35
10:00	17	5	:23332.---:----:----:	1.3		1100	0	0	0	90	3			37	72
10:30	18	5	:233321.--:----:----:	1.3		1300	0	0	0	90	3			37	108
11:00	18	4	:24444321-:----:----:	1.8		1600	0	0	0	90	4			42	150
11:30	19	5	:34554432-:----:----:	2.0		1700	0	0	0	90	4			44	194
12:00	19	5	:345555431:----:----:	2.3		1800	0	0	0	70	4			46	240
12:30	19	5	:345555542.----:----:	2.4		1900	0	0	0	70	5			47	287
13:00	20	5	:3456655431----:----:	2.5		2000	0	0	0	90	5			48	335
13:30	20	5	:34566554**----:----:	2.7	*	1800-2100	1	0	0	90	4			49	385
14:00	20	5	:345665554*----:----:	2.7	*	1900-2100	1	0	0	90	3			50	434
14:30	20	5	:34566655***---:----:	2.8	*	1800-2200	1	0	0	90	3			50	484
15:00	20	6	:24555554***---:----:	2.6	*	1800-2200	1	0	0	90	3			49	533
15:30	20	6	:23445544***---:----:	2.2	**	1800-2200	1	0	0	90	3			46	579
16:00	20	5	:.2233333***---:----:	1.5	**	1800-2200	1	0	0	90	3			39	618
16:30	20	5	:.1223332.**---:----:	1.3	*	1900-2200	1	0	0	90	3			36	654
17:00	19	3	:----:----**---:----:		*	1900-2200	1	0	0	135	7				
17:30	19	3	:----:----:----:----:				1	0	0	135	7				
18:00	19	3	:----:----:----:----:				0	0	0	125	7	L			

kph). Both models failed to foresee the reduced speeds on the difficult days with scored speeds below 90 kph.

Flight simulation

A more sophisticated verification of a thermal forecast is to use the recorded flight track of a glider as a "task" for the flight planning algorithm. So TTC reads *.igc files and filters the recorded flight data: the transition points between circling and gliding (and vice versa) are determined and extracted as the "task" for the simulation. Thus, the length of the flight track and the "task" will be practically identical. The simulation can start at any of these identified transition points which refer to the entry and exit points of the used thermals. The flight plan for this "task" is calculated and superimposed on the flight as illustrated in Figure 1. Here, the simulation and the real flight start at the same time and altitude.

When the average speeds of both the flight and the "task" are identical, then the weather - above all the lift rates – is predicted accurately and the assumption of isolated thermals is correct. In addition to the flight speed, this more sophisticated method also allows for the comparison of the predicted depth of convection and observed flight altitudes. Hindman, et al.[9] used the sophisticated verification procedure in a meteorological system for planning soaring flights in Colorado USA.

Discussion

Inaccurate regional forecasts are easily identified in TTC when recorded glider flights are simulated. Systematic inaccuracies in the lift rates and in the depth of the CBL are recognized and support the tuning of the meteorological prediction models.

Speed-to-fly theory is a crucial element for flight plans because it converts the predicted meteorological lift rate into a cruising or gliding speed. It is applied for isolated thermals in TopTask. In the real atmosphere lift may be aligned due to wind and topography. This should be considered when TopTask predicted and recorded speeds are compared.

Large sized forecast regions limit the quality of the flight plans in weather situations with inhomogeneous conditions such as frontal passages. Flight plans for Sweden, where the forecast regions are quite large, can be affected by this.

Pragmatic verifications with scored speeds are useful to assess the accuracy of state of the art meteorological flight planning for the task setting in gliding competitions. Pre-briefing optimization of flight tasks can be recommended to increase the pleasure of participating in gliding championships by avoiding tasks with few or no finishers at all and by calling unusual tasks.

Sophisticated verifications with simulations of recorded flights can help to improve both the TopTask flight model and the meteorological prediction models.

In 2006 the described flight planning and analysis tool TopTask Competition was integrated in the on-line pilot briefing system "pcmet" to encourage routine flight planning. As scored speeds of the fastest pilots in national and international championships are quite accurately predicted by LME-TOPTHERM-TopTask, the predicted task speeds represent a serious challenge for most pilots. They are also encouraged to analyze recorded flights and the operational thermal forecasts with this tool. A convenient assessment of both the forecast and the pilot's performance is possible.

Conclusions

Glider flight data is highly useful to verify meteorological predictions for lift rates in thermals and for the depth of the convective boundary layer. The tuning of numerical models for the convective boundary layer is possible with such data. The intercomparison between LME-TOPTHERM and HIRLAM indicates that meteorological flight planning could be based entirely on post-processed direct model output, at least for flat topography. Thus, a regional convection model is not needed anymore for accurate lift rates in thermals. It is important, however, to tune the lift rate prediction in either approach. Operational numerical weather predictions for the convective boundary layer have reached a quality that permits accurate meteorological flight planning of soaring flights in thermals. On-line briefing systems are useful for making the predictions to pilots and competition directors. Pre-flight optimization of flight tasks is then a routine procedure. Tasks can be set that are adapted to the weather and to the skill of the pilot. This serves both safety and pleasure. Post-flight simulations of flights with the predicted weather provides immediate feedback to pilots about the accuracy of operational thermal forecasts. Speed-to-fly theory, finally, is not limited to in-flight decision making with variometer readings. It is a key element of meteorological flight planning in combination with the concept of forecast regions. Large sized forecast regions are a limiting factor for the flight planning of short tasks. In the long run the meteorological flight planning might be based entirely on direct model output from NWP models at their full resolution without going through forecast regions any longer.

Acknowledgements

Recorded flight data were downloaded as *.igc files from the websites of Swiss Glide 2004, Viking Glide 2005, the Swedish on-line contest RST, and the international on-line contest OLC[10].

References

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Table 2

Predicted values of the meteorological variables for the Norr Malaeren
forecast region in Sweden extracted from 05061506.htf (15 June 2005, HIRLAM):

Surface temperature and dew-point (T, Td), convective boundary depth (m MSL, a cloud with no base means a cloud-free boundary layer), 800 m AGL wind direction (blowing from) and speed.

```
GG307Norr Malaeren, Mi 15.06.2005

UTC      T  Td Steig   Basis-Top     Wind
hh:mm [C] [C] [m/s]   [m] - [m] [deg/kt]
 06:00  14   8                    297 02
 06:30  15   8                    312 03
 07:00  17   8                    323 03
 07:30  18   8                    328 03
 08:00  19   8  0.8    1600-1600  332 04
 08:30  20   6  1.1         1800  338 04
 09:00  21   5  1.5         2000  343 04
 09:30  21   5  1.7         2100  336 03
 10:00  22   4  1.9         2100  322 02
 10:30  22   4  2.1         2200  302 02
 11:00  22   4  2.3         2200  283 02
 11:30  23   4  2.4         2300  277 02
 12:00  23   4  2.6         2300  268 01
 12:30  23   4  2.6         2300  261 01
 13:00  23   4  2.6         2300  254 01
 13:30  23   4  2.4         2400  246 01
 14:00  23   4  2.2         2400  240 02
 14:30  23   4  1.9         2400  238 02
 15:00  23   4  1.6         2400  237 02
 15:30  23   4  1.3         2300  242 02
 16:00  23   4  0.9         2300  247 03
 16:30  23   4                    250 03
 17:00  22   5                    253 02
 17:30  22   5                    267 03
 18:00  22   6                    277 03
```

Table 3

Flight polars of gliders

Class	**best L/D**	**speed (kph)**	**wing loading (kg/m^2)**
Open	56	103	44
18m	49	102	42
15m	46	101	40
Standard	44	101	40