P1.26 A METEOROLOGICAL SYSTEM FOR PLANNING AND EVALUATING GLIDER FLIGHTS IN PENNSYLVANIA USA

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1. BACKGROUND

The modern glider (sailplane) is the most efficient flying machine ever. For example, glide ratios (lift/drag) have reached 60/1; the machines can glide in still air 60 miles while loosing 1 mile of altitude (Fig. 1). Most gliders are equipped with GPS-flight recorders which store the position (x, y, z) as frequently as every 2-seconds. Further, the sinking speed of the glider as a function of forward speed is well-known (eg. American Soaring Handbook, 1971). Consequently, these machines can be atmospheric probes; they can identify and measure regions of rising, sinking and horizontally moving air, Bradbury (2000) describes the movement, in exceedingly fine-scale. Conversely, given predictions of the regions from a meso-scale numerical weather-prediction model, the glider can be 'flown' through the regions to predict the feasibility of a flight. Then, following the flight, the flight-recorder data can be compared with the predicted flight to help evaluate the weather predictions.

Accordingly, a meteorological system consisting of a meso-scale numerical weather-prediction model coupled with a glider flight algorithm was developed for Colorado USA and shown to be successful in predicting long-distance glider flights (Hindman, et al., 2007). This meteorological system was adapted in fall 2006 for the region surrounding Fairfield PA USA, the site of the Region 4 North (R4N) contest. Additionally, the system was expanded in the spring of 2007 to cover the Reedsville PA region, the site of the 15m Nationals (15m). These fall and spring east coast contests provided data with which to investigate the system in climatic conditions almost the opposite to those found in Colorado.

The meso-scale numerical weather-prediction model, the Regional Atmospheric Modeling System (RAMS), was developed at Colorado State University (Cotton, et al, 2003). The glider flight planning and evaluation algorithm, called TopTask Competition (TTC), was developed by Liechti and Lorenzen (2004).

It will be shown in this paper that the weather prediction and flight planning capabilities of the RAMS-TTC system, on average, were accurate for contest days with winds < 20 knots and for days with accurately predicted surface temperatures and dew-points. Additionally, this study is a first-step toward an on-line glider pilot self-briefing system for the USA.

2. PROBLEM

The RAMS-TTC system was used to predict weather conditions and the subsequent glider flights for the R4N and 15m Nationals contests. Then, the predictions were evaluated using weather data and glider flight-recorder data.

3. PROCEDURES AND RESULTS

Data were collected for a total of 18 contest days: five days occurred during 2006 R4N (8-10, 13 and 14 October 2006), eight days occurred during the 15m Nationals (15, 17-19 and 21-24 May 2007) and five days occurred during the 2007 R4N (7-10 and 13 October 2007 with a practice day on the 6th).

3.1 *Collect the flight recorder files*

To determine the characteristics of the glider flights, the GPS flight recorder files (*.igc) were obtained from the scorer at the end of each contest. The files for the 1st and 2nd place finishers in each class were selected for each contest day. These flights were chosen because they represented the best flights.

3.2 *Collect weather data*

To validate the RAMS forecasts, the atmospheric sounding data, satellite images and surface observations and measurements (METARS) were collected for each day of the contests. The sounding data came from www.arl.noaa.gov/ready/amet.html. The locations of Fairfield (FFD) and Reedsville (RED) were entered (respectively, 39.7N, 77.3W and 40.7N, 77.7W). The

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NAM soundings (12km) for 12, 15, 18, 21, 00 GMT (07, 10, 13, 16, 19 EST) were saved both as *.gif images and as *.txt files. The satellite images and METARS came from www.rap.ucar.edu/weather/satellite/. The images were downloaded using the following sequence: BWI, hourly, large-size, Visible 1145 through 2345 GMT and Infrared (B/W) 1143 through 2343 GMT. The hourly-METARS were downloaded from the BWI location.

3.3 *Construct the RAMS-TTC interface files*

The meteorological predictions (temperature (T), dew-point (T_d), horizontal winds, cloud and precipitation mixing ratios, etc) were made by the RAMS on horizontal grids with 12km resolution (Fig. 2). The grids were spaced at about 75m intervals from the surface to about 3km; above 3km, the vertical resolution was progressively coarser. The predictions were made every 30-minutes between 06 and 18EST (2006 R4N) and between 07 and 19EST (15m and 20007 R4N). The calculations took about 3 hours on a standard computer workstation. Therefore, the 00GMT (19EST) data were used to initialize the model to produce, by the early-morning of the next-day, the required predictions.

The grid-point meteorological predictions were averaged over forecast regions (Hindman, et al., 2007) to interface with the TTC. The regions were areas with relatively similar topography (e. g. ridges, valleys, etc). Figure 3 illustrates the regions and the RAMS grid-points surrounding FFD and RED. The predictions at all grid points in a region were averaged to produce one set of values for the entire region.

3.4 *Determine convective boundary layer (CBL) depth*

The actual and predicted depths of the CBL at FFD and RED were determined as follows. The *RAOB* program (www.raob.com) was used with the atmospheric sounding text files to determine the actual depth of the CBL at 07, 10, 13 and 16 EST for each contest day at FFD and at 07, 10, 13 and 16 and 19 EST for each contest day at RED. The corresponding predicted depth for Forecast Region 800 (the region containing FFD) was read from the TTC display (Fig. 4) and similarly for Forecast Region 857 (the region containing RED).

The actual and predicted CBL depths were tabulated (Table 1) as a function of time-of-day and plotted in scatter diagrams (Fig. 5) from which a linear regression analysis was performed (note, for this and the other regression analyses that follow, the intercepts of the trend lines were set to 0).

Another estimate of the CBL depth was the maximum achieved altitude during a contest flight determined from the *.igc files with the *SeeYou* program (www.seeyou.ws). The maximum height was read from the Flight Statistics section and tabulated (Table 2) along with the 16 EST CBL depths from the soundings and from the RAMS-TTC. The 16 EST depths were chosen because the maximum CBL depth occurred near that time.

The 2007 R4N CBL depths were not determined because of a timing problem with the predicted surface T and T_d values. The problem is addressed in the Discussion section. Because of this problem, the analyses performed below for the 2006 R4N and 2007 15m Nationals contests were not performed for the 2007 R4N contest.

3.5 *Determine glider climb rates*

The *SeeYou* program was used to determine the average climb rates from the *.igc files. The average climb rates were determined from the Flight Statistics section using the Circling Total values.

The predicted climb rates were determined using TTC. The flight track was displayed using TTC (Fig. 6) and the interval of time the pilot was in each forecast region was estimated as follows. By increasing the Departure value, the grey segment expanded along the track; the tip of the segment corresponded to the position of the glider. Concurrently, the grey segment expanded in the barogram trace and the tip of the segment indicated the time during the flight. The predicted climb rate for each time-interval was read from the TTC display and recorded. Then, the individual rates were averaged to obtain the value for the predicted climb rate.

The actual and predicted climb rates, for FFD, were tabulated (Table 3a) and plotted in a scatter diagram (Fig. 7a) from which a linear regression analysis was performed. The comparable results for RED are shown in Table 3b and Fig. 7b.

3.6 *Determine 1000m winds*

The atmospheric soundings were analyzed in the following manner to determine the 1000m winds. The wind speed and directions measured above and below 1000m for Forecast Regions 800 (FFD) and 857 (RED) were linearly interpolated to find the values at 1000m. The predicted winds were read from the TTC display (Fig. 4).

The actual and predicted winds were tabulated (Table 4a (FFD) and Table 4b (RED)) and plotted in corresponding scatter diagrams (Fig. 8) from which linear regression analyses were performed.

3.7 *Determine task speeds*

The TTC was used to determine the actual and predicted task speeds. The actual speed is the distance flown divided by the flight time. The procedure to determine the predicted speed is described by Liechti and Lorenzen (2004) and Liechti, et al. (2007). Briefly, the algorithm utilizes the RAMS weather prediction, the sailplane polar and speed-to-fly-theory to simulate a flight along the flight track recorded in a *.igc file. The Departure (time) was adjusted between 10 and 30 min to produce the fastest predicted speed. The corresponding actual speed was recorded.

The actual and predicted speeds were tabulated (Table 5a (FFD), Table 5b (RED)) and plotted as corresponding histograms (Figs. 9a, 9b). The mean and standard error for both populations were calculated and appear in Figs. 9a and 9b.

3.8 *Determine the onset of convective clouds*

The hourly satellite images for each contest day were inspected. The time that convective clouds first appeared in the vicinity of FFD and RED was recorded. Then, the TTC display of the weather for that region was inspected. The time the first convective cloud was predicted to appear was recorded. The actual and predicted onset-times were tabulated (Table 6).

4. DISCUSSION

The results are analyzed to establish the performance of the RAMS-TTC system for the regions surrounding Fairfield and Reedsville PA. From these analyses, the strengths and weaknesses of the RAMS-TTC system are identified. This study is the first application of the system on the East Coast USA. The first application of the system in the USA was in Colorado (Hindman, et al., 2007).

4.1 *Convective boundary layer depths*

The actual and predicted CBL depths as a function of time-of-day are listed in Tables 1a (FFD) and 1b (RED). The average actual and predicted CBL depths at FFD were 921+/-132 and 1026+/-215 m AGL, respectively, and at RED they were 1160+/-101 and 1559+/-156 m AGL The predictions systematically were too high by 105 m (FFD) and 399 m (RED).

Table 2 presents the actual and predicted CBL depths, T and T_d values at 16EST, typically the time of the deepest CBL. Additionally, the maximum achieved altitudes from the 1st and 2nd place finishers are tabulated (determined using the *SeeYou* program). It can be seen, the maximum achieved altitudes are greater than the CBL depths determined from the soundings indicating the soundings systematically underestimated the CBL depths. Further, the predicted T values are systematically warmer and T_d values are systematically drier than the sounding values. Since the top competition pilots do not climb to the top of the CBL (and TTC accounts for this fact) the predicted T and T_d values may have been reasonable. This was checked using the surface METAR values which averaged 23C and 4C, respectively. The corresponding predicted values (Table 2 for RED) were 24 and 4C**.** So, the RAMS T and T_d predictions were accurate and the surface T and T_d values from the soundings were, respectively, too cool and moist. This result explains the discrepancy between the actual and predicted CBL depths in Tables 1a and 1b.

The corresponding linear regression analyses (Fig. 6) show scatter among the values. Nevertheless, the R^2 values are above 0.60 producing a satisfactory linear correlation coefficient (R~0.8) meaning good prediction skill was demonstrated. Therefore, the RAMS-TTC system predicted accurate CBL depths at FFD and RED through the daily convective cycle.

4.2 *Climb rates*

The average actual and predicted glider climb rates (Tables 3a and 3b) were 1.3+/ 0.1 and 1.1+/-0.1 m/s, respectively, for FFD and 1.5+/-0.1 and 1.6+/-0.1 m/s for RED. So, the actual and predicted values were quite close. Additionally, when the standard-error values (+/) are added to the means, the means overlap indicating there is no significant difference between the mean values.

The corresponding linear regression analysis (upper Figs. 7a and 7b) show the large scatter between the individual values. As a result, the R^2 values are small (-0.82 and -3.5) meaning little predictive skill was demonstrated.

Closer inspection of the results (Table 2), however, reveals systematic differences. The predicted values on 13 and 14 October 2006 were almost a factor of two smaller than the actual values and similarly for 15 and 19 May 2007. This was due to the strong predicted winds (which verified). The wind-factor in the climb rate algorithm (Hindman, et al., 2007) reduces the climb rates for wind speeds greater than 20 knots.

Consequently, the climb rates were re-analyzed by removing the wind-factor. Now, the average actual climb rate is almost identical to the predicted rate: 1.3+/-0.1 and 1.2+/- 0.1 m/s for FFD and 1.5+/-0.1 and 1.7+/-0.1 m/s for RED. There is no significant difference between the means. Plus, the linear regression analysis (lower Figs. 7a and 7b) now shows R^2 values of 0.070 and -1.24, an improvement from the earlier values of -0.82 and -3.5. However, due to the large scatter, the correlation coefficients are poor.

Therefore, the RAMS-TTC system made accurate average climb rate predictions, but inconsistent individual rates for days with 1000 m AGL wind speeds less than 20 knots. For days with speeds > 20 knots, additional studies are required and are detailed later.

4.3 ***1000 m AGL winds***

The speed and direction analyses (Tables 4a and 4b) revealed the average actual and predicted speeds were almost identical at 12+/-2 and 13+/-3 m/s for FFD and 15 m/s each for RED and the corresponding directions were, respectively, 214 +/- 28 and 239 +/- 28 degrees at FFD and 227+/-18 and 254+/-16 degrees for RED. So, the wind directions differed by about 26 degrees at both locations. When the standard-error values (+/-) are added to the means, the means overlap indicating there is no significant difference between the mean values.

The linear regression analyses of the speeds (upper 8a) for FFD and (upper Fig. 8b) for RED shows scatter between the values. As a result, the correlation coefficients are modest (R = 0.84 and 0.81 for FFD and RED, respectively) meaning useful skill was demonstrated.

The linear regression analyses of the directions (lower Fig. 8a) for FFD and (lower Fig. 8b) for RED show some scatter between. Nevertheless, the correlation coefficients (R = 0.90) for FFD and (R = 0.99) for RED are high meaning useful skill was demonstrated. Therefore, the RAMS-TTC system made accurate wind speed and direction predictions.

4.4 ***Task speeds***

The average actual and predicted task speeds were, respectively, 84 and 68 kph for FFD (Table 5a) and 109 and 86 kph for RED (Table 5b). The significantly faster actual speed was due to the much faster actual speeds on 13 and 14 October 2006 at FFD and on 15 and 19 May 2007 at RED. On these days, the predicted wind speeds were between 25 and 35 knts (Table 4) which caused an under prediction of the climb rates and the reduced climb-rates caused TTC to "land out" the fleet. That is, TTC predicted the tasks could not be completed for all classes.

But, the pilots were able to fly in these windy conditions by using "aligned lift": cumulus cloud 'streets', wave and ridge lift. The TTC version used in this and the Colorado study does not account for these types of lift; the version is strictly for "thermal-only" lift. A version of TTC has been developed as of 20 November 2006 that accounts for these types of lift (Liechti, personal communication). But, it will take additional study to improve the RAMS-to-TTC interface programs to extract these types of lift from the RAMS forecasts.

If the 13-14 October and 15 and 19 May flights are removed (Fig. 9), the actual and predicted average speeds are not significantly different (74 vs 79 kph) for FFD and (99 vs 95 kph) for RED. Thus, the RAMS-TTC system, on average, made accurate task speed predictions for days with wind speeds < 20 knts ("thermal-only" flights).

4.5 ***Onset of convective clouds***

It can be seen in Table 6, that three of the five contest days were cumulus-free "blue days" at FFD and at RED. The RAMS-TTC system exhibited significant skill in identifying these days. Furthermore, of the seven days during which cumulus formed, the onset was predicted exactly on three and, on-average, one-hour later than the actual onset on four days. Consequently, the predictions of cumulus formation ranged from on-time to late by about 1-hour.

4.5 ***Comparison with the Colorado study***

Table 7 lists the CBL depths, climb rates, 1000 m AGL winds and task speeds resulting from this study and those from the Colorado study (Hindman, et al., 2007). The differences between the values from the two regions are much larger than the differences within the regions. This result illustrates the robustness of the RAMS-TTC system; the system has produced useful results for these two topographically extreme regions. Additionally, the PA and CO actual and predicted task speeds are displayed in Fig. 10. It can be seen that the average speeds are in excellent agreement. But, the system overestimated weather for weak days (slow actual speeds) and underestimated weather for strong days (fast actual speeds).

4.6 ***2007 R4N timing problem***

The average actual and predicted T and T_d values from all three contests are illustrated in Fig. 11. It can be seen reasonable agreement was obtained between the values except for the 2007 R4N results. There the minimum temperature was reached unrealistically late in the morning and the subsequent warming was too slow. Notice, however, the T_d values are in excellent agreement. Therefore, the predicted CBL developed too late in the day for TTC predictions to be useful. The reason for this result, which did not occur as badly in the 2006 R4N results, is under investigation. This result demonstrates the requirement for accurate predictions of surface T and T_d values.

5. CONCLUSIONS

For the October 2006 glider contest near Fairfield PA and the May 2007 contest near Reedsville PA, the RAMS-TTC meteorological system produced:

- accurate predictions of boundary layer depths through the daily convective cycle.
- accurate predictions of average climb rates, but inconsistent individual rates, for days with 1000 m AGL wind speeds less than 20 knots.
- accurate predictions of 1000 m AGL wind speeds and directions.
- accurate predictions of task speeds for days with wind speeds less than 20 knots. The system overestimated slower-than-average actual speeds and vice versa.
- accurate predictions of “blue days” and the onset of cumulus, on average, was predicted to be on-time to about 1-hour late.

The results achieved in this study are comparable to those achieved in the Colorado study (Hindman, et al., 2007) indicating the versatility of the RAMS-TTC system.

The system requires additional studies to produce reliable glider climb rate and task speed predictions for days with wind speeds > 20 knots. Also, the reason must be found for the inaccurate surface temperature and dew-point values for the October 2007 R4N contest.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

American Soaring Handbook, 1971: *Sailplane Aerodynamics* (Ch. 9). Soaring Society of America, Hobbs NM, 91 pp. (out-of-print).

Bradbury, T., 2000: *Meteorology and Flight*. A & C Black, London, 186 pp.

Cotton, W., et al., 2003: RAMS 2001: Current status and future directions, *Meteorology and Atmospheric Physics*, **82**, 5-29, rams.atmos.colostate.edu/realtime/

Hindman, E., et al., 2007: A meteorological system for planning and analyzing soaring flights in Colorado USA. *Technical Soaring*, **31**, 67-78.

Liechti, O. and E. Lorenzen, 1998: A New Approach for the Climatology of Convective Activity, *Technical Soaring*, **22**, 36-40.

Liechti, O. and E. Lorenzen, 2004: TopTask: Meteorological flight planning for soaring, *Technical Soaring*, **28**, 1-6.

Liechti, O., et al., 2007: Verification of thermal forecasts with glider flight data, *Technical Soaring*, **31**, 42-51.

Figure 1 The modern glider (sailplane)

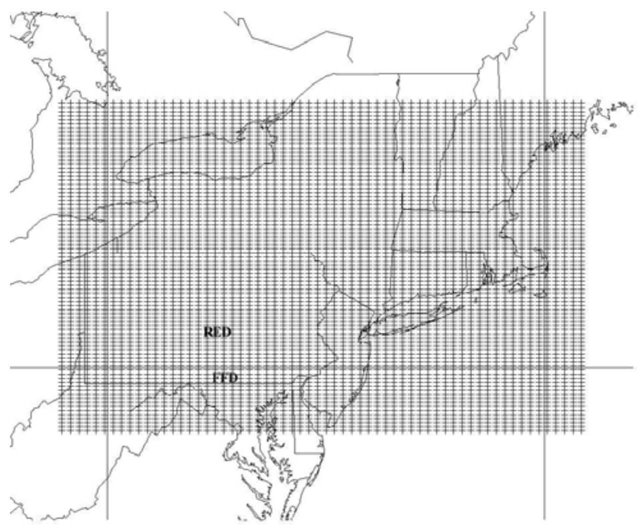

Figure 2 The RAMS Grid 2 (12km grid spacing). The location of Fairfield PA (FFD) and Reedsville PA (RED) are indicated.

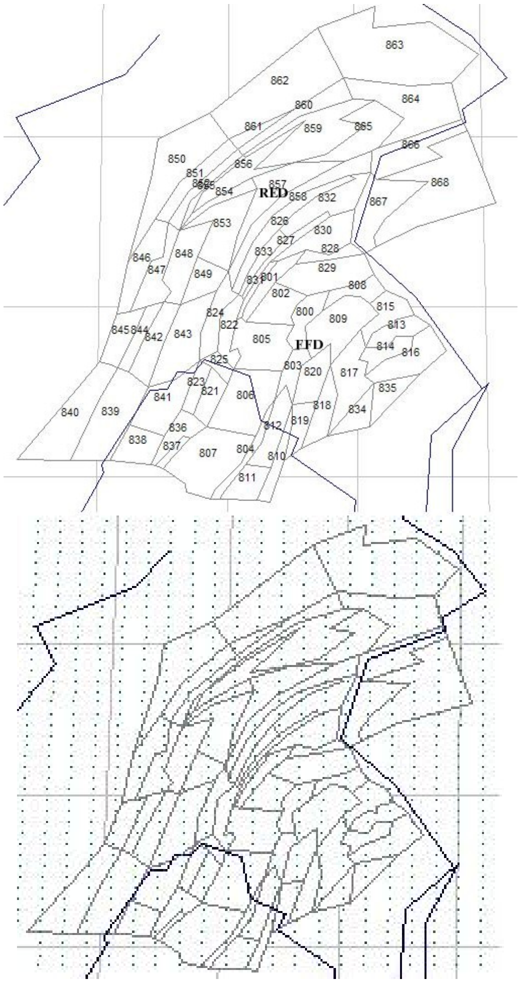

Figure 3 (upper) The forecast regions surrounding Fairfield (FFD) and Reedsville (RED). The Potomac River is the wiggly line in the bottom and the Susquehanna River is in the right flowing into the upper portion of the Chesapeake Bay. **(lower)** The forecast regions and the corresponding RAMS grid-points.

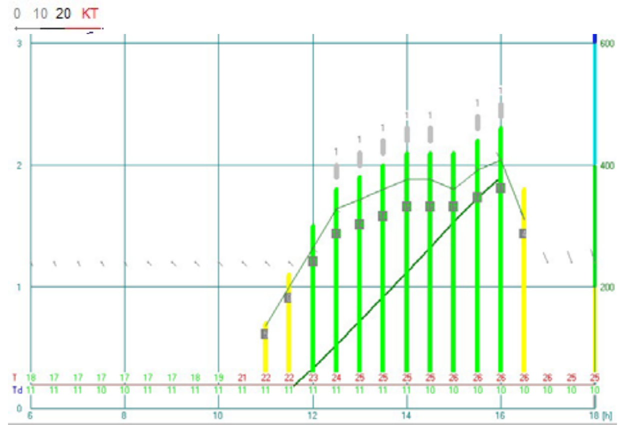

Figure 4 The TTC display of the RAMS predictions for Forecast Region 800 for 10 October 2006. The time (horizontal axis) is EST, the height (vertical axis) is km above MSL and the horizontal brown line is the average elevation of the region (180 m); the surface T and T_d values are displayed on, respectively, the top and bottom of the line. The vertical bars illustrate the depth of the CBL, the lift rates in m/sx10 are in the boxes and the grey squares atop the bars indicate the presence of cumulus clouds. The 1000 m AGL winds are the horizontal row of barbs (oriented in the direction the wind is blowing); the speed is given by the scale. The line connecting the top of the bars is the average altitude the glider is assumed to fly. The diagonal line is the Potential Flight Distance (PFD, km, right vertical scale) as a function of time. Liechti and Lorenzen (1998) define the PFD as the distance a Standard Class glider can fly from the first-to-last thermal of a day.

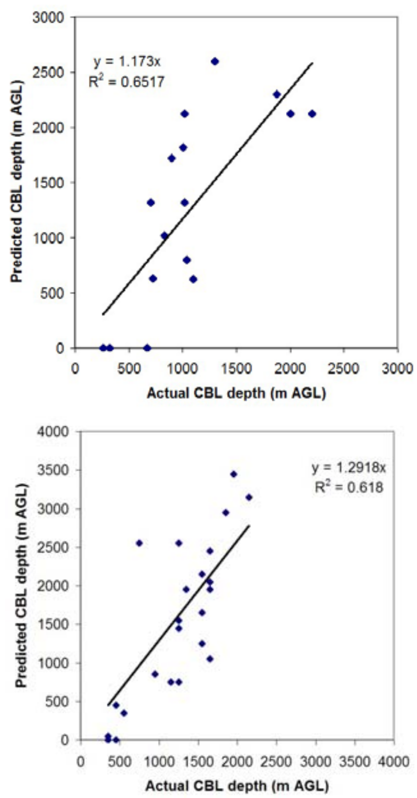

Figure 5 Actual versus predicted convective boundary layer (CBL) depths (**Upper**) from FFD, Table 1a, and (**Lower)** from RED, Table 1b.

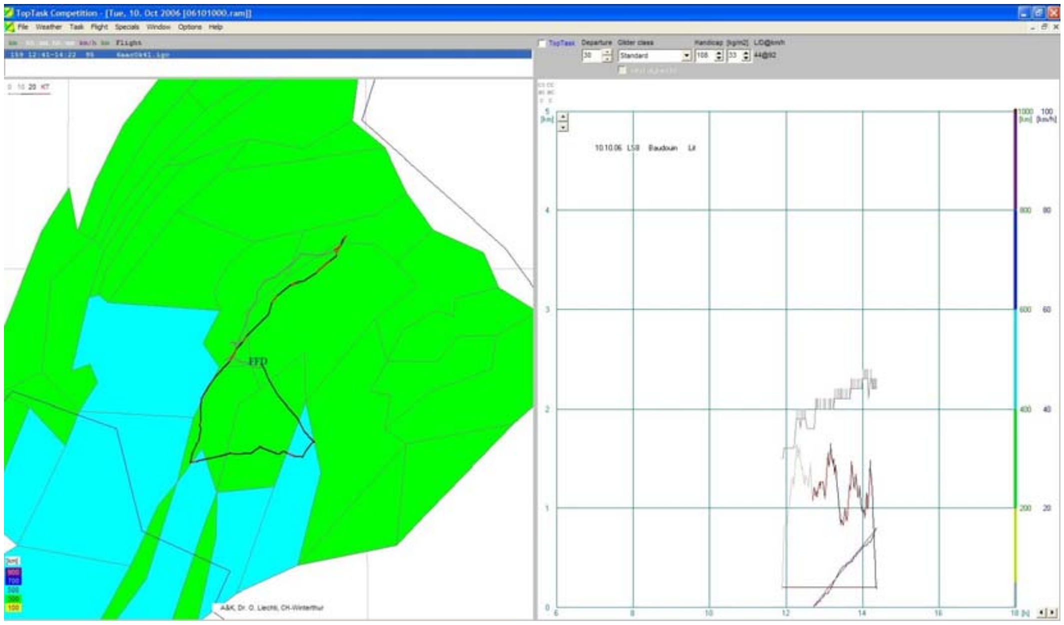

Figure 6 The TTC display of pilot Baud Litt's flight on 10 October 2006. The plan view (left) shows the flight track superimposed on the forecast regions; the grey portion of the track indicates distance completed (the origin of the flight is at the center of the diagram). The barogram trace of the flight is shown at the right with the grey portion of the trace indicating the completed portion of the flight (1155 to 1240EST). The predicted depth of the CBL is the grey line above the barogam trace. The vertical lines originating from the CBL depth indicate a prediction of cumulus clouds.

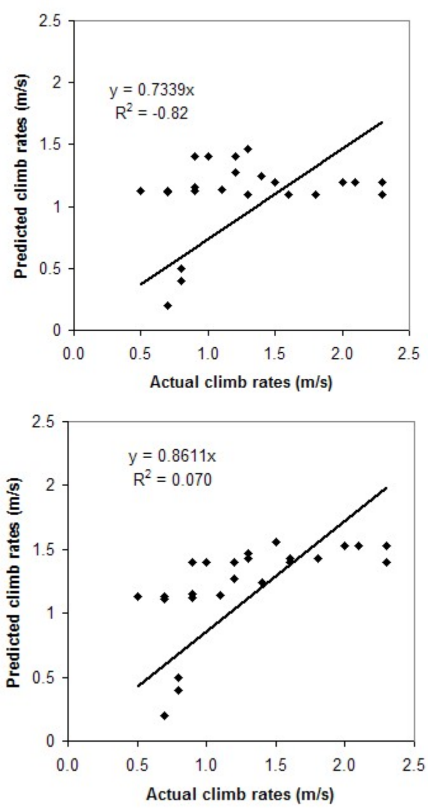

Figure 7a (**Upper**) Actual versus predicted climb rates from Table 3a, all values, (**Lower)** all values with no wind-factor.

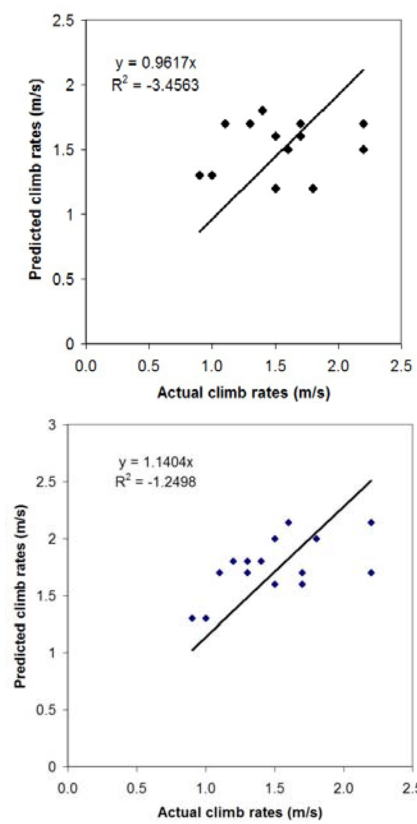

Figure 7b (**Upper**) Actual versus predicted climb rates from Table 3b, all values, (**Lower)** all values with no wind-factor.

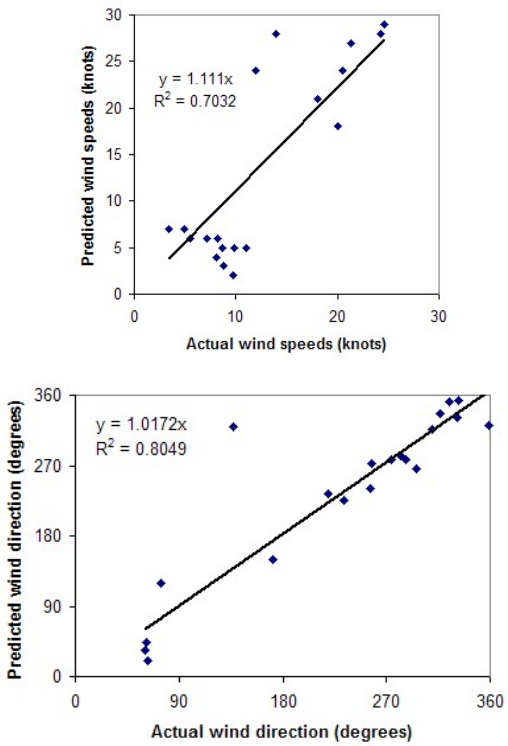

Figure 8a Actual and predicted 1000 m AGL winds from Table 4a (FFD).

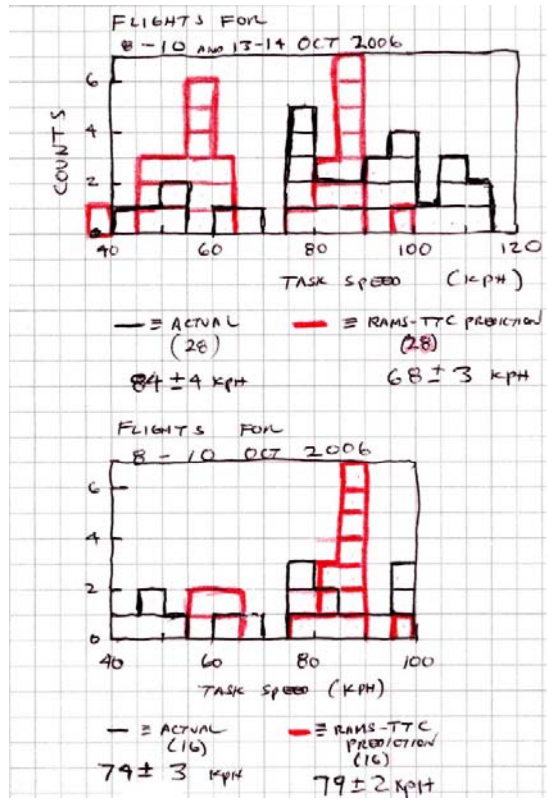

Figure 9a The actual and predicted task speeds from Table 5a.

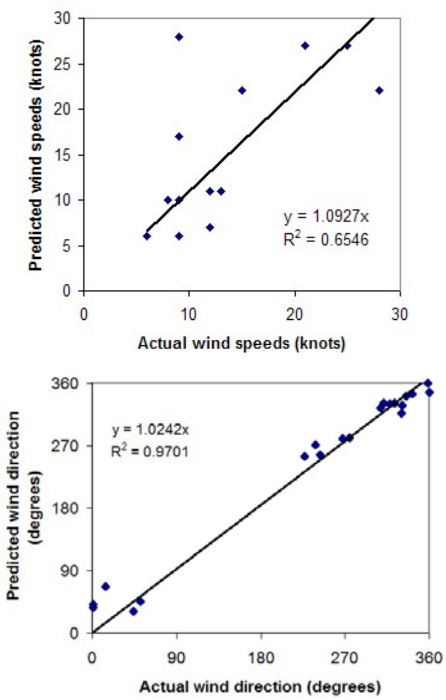

Figure 8b Actual and predicted 1000 m AGL winds from Table 4b (RED).

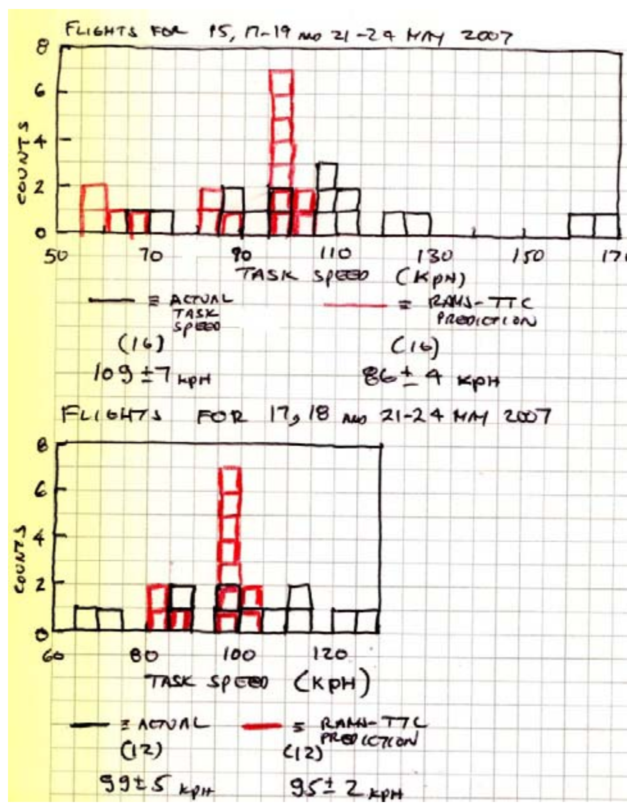

Figure 9b The actual and predicted task speeds from Table 5b.

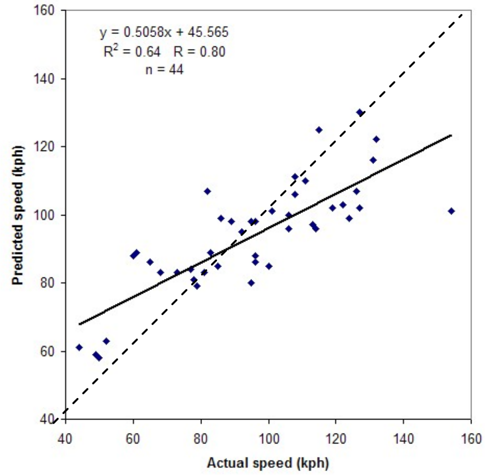

Figure 10 Actual and predicted task speeds for the PA (October 2006, May 2007) and CO (May 2006) studies. The average actual speed was 95+/-4 kph and the average predicted speed was 94+/-2 kph. The dashed line is the 1:1 line.

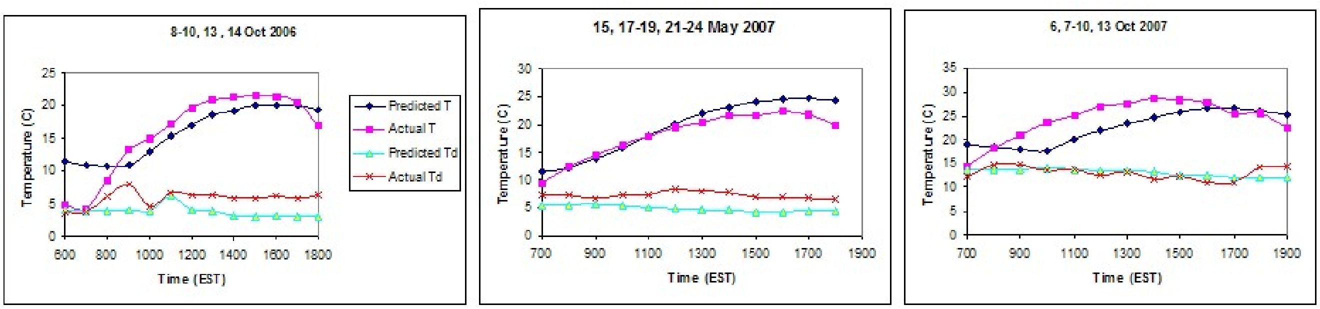

Figure 11 A comparison of actual and predicted surface T and T_d values for FFD (left and right) and for RED (center).

Table 1a
Actual and predicted convective boundary layer depths
at Fairfield PA

Date	Time (EST)	Actual depth from RAOB (m AGL)	Predicted depth (m AGL)
8-Oct-06	7	261	0
	10	724	627
	13	831	1021
	16	700	1321
9-Oct-06	7	261	0
	10	669	0
	13	1017	1321
	16	900	1721
10-Oct-06	7	261	0
	10	671	0
	13	1007	1821
	16	1018	2121
13-Oct-06	7	321	0
	10	1036	800
	13	1878	2300
	16	1300	2600
14-Oct-06	7	261	0
	10	1097	621
	13	2203	2121
	16	2000	2121
	Average	921	1026
	StdDev	574	938
	StdError	132	215

Table 1b
Actual and predicted convective boundary layer depths
at Reedsville PA

Date	Time (EST)	Actual depth from RAOB (m AGL)	Predicted depth (m AGL)
15-May-07	7	350	0
	10	950	850
	13	1250	1550
	16	1250	2550
	19	750	2550
17-May-07	7	350	50
	10	1550	1250
	13	1650	1950
	16	1650	2050
	19	1550	1650
18-May-07	7	550	350
	10	1250	750
	13	1350	1950
	16	1650	2450
	19	1550	2150
19-May-07	7	450	0
	10	1650	1050
	13	2150	3150
	16	1950	3450
	19	1850	2950
21-May-07	7	450	450
	10	1150	750
	13	1250	1450
	16	1350	1950
	19	1550	2050
22-May-07	7	350	500
	10	950	750
	13	1350	1550
	16	1350	2450
	19	1350	2550
23-May-07	7	450	0
	10	850	500
	13	1250	2050
	16	1350	2550
	19	1250	2250
24-May-07	7	350	350
	10	650	550
	13	1250	2350
	16	1250	2450
	19	950	2150
	Average	1160	1559
	StdDev	483	976
	StdError	101	156

Table 2

Maximum achieved altitudes, CBL depth and T and T_d values at 16 EST from the soundings and RAMS-TTC

Fairfield PA

Date	Time	Depth from RAOB	Depth from RAMS-TTC	Maximum achieved altitude
	(EST)	(m AGL)	(m AGL)	(m AGL)
8-Oct-06	16	800	1300	800
9-Oct-06	16	1000	1700	1300
10-Oct-06	16	1000	2100	1400
13-Oct-06	16	1200	2600	1800
14-Oct-06	16	2000	2100	2300
	Average	1200	1960	1520
	StdDev	469	488	563
	StdError	235	244	282

Date	Time	From RAOB surface		From RAMS surface	
	(EST)	T(Centigrade)	Td (Centigrade)	T(Centigrade)	Td (Centigrade)
8-Oct-06	16	20	11	22	8
9-Oct-06	16	23	13	26	11
10-Oct-06	16	24	16	22	14
13-Oct-06	16	11	-1	13	-6
14-Oct-06	16	12	-4	13	-7
	Average	18	7	19	4
	StdDev	6	9	6	10
	StdError	3	4	3	5

Reedsville PA

Date	Time	Depth from RAOB	Depth from RAMS-TTC	Maximum achieved altitude
	(EST)	(m AGL)	(m AGL)	(m AGL)
15-May-07	16	1250	2550	1900
17-May-07	16	1650	2050	1800
18-May-07	16	1650	2450	1900
19-May-07	16	1950	3450	2200
21-May-07	16	1350	1950	1400
22-May-07	16	1350	2450	1600
23-May-07	16	1350	2550	1600
24-May-07	16	1250	2450	1800
	Average	1475	2488	1775
	StdDev	249	450	243
	StdError	94	170	92

Date	Time	From RAOB surface		From RAMS surface	
	(EST)	T(Centigrade)	Td (Centigrade)	T(Centigrade)	Td (Centigrade)
15-May-07	16	26	16	32	8
17-May-07	16	16	6	16	1
18-May-07	16	16	7	18	1
19-May-07	16	19	5	23	-2
21-May-07	16	18	7	21	-2
22-May-07	16	21	11	26	1
23-May-07	16	23	15	29	10
24-May-07	16	25	16	30	12
	Average	21	10	24	4
	StdDev	4	5	6	6
	StdError	1	2	2	2

Table 3a

Actual and predicted climb rates for the 1st and 2nd place finishers in the R4N contest

Date	Class (Place)	Actual climb rate	Predicted climb rate
		(m/s)	(m/s)
8-Oct-06	Standard (1)	0.8	0.5
	Standard (2)	0.7	0.2
	Sport (1)	0.8	0.4
	Sport (2)	0.8	0.4
9-Oct-06	Standard(1)	0.9	1.1
	15m(1)	1.1	1.1
	Sports(1)	0.7	1.1
	Standard(2)	0.7	1.1
	15m(2)	0.9	1.2
	Sports(2)	0.5	1.1
10-Oct-06	Standard(1)	1.2	1.3
	15m(1)	1.4	1.2
	Sports(1)	1.3	1.5
	Standard(2)	0.9	1.4
	15m(2)	1.2	1.4
	Sports(2)	1.0	1.4
13-Oct-06	Standard(1)	1.8	1.1
	15m(1)	1.8	1.1
	Sports(1)	1.6	1.1
	Standard(2)	1.6	1.1
	15m(2)	1.5	1.2
	Sports(2)	1.3	1.1
14-Oct-06	Std (1)	2.1	1.2
	Std (2)	2.1	1.2
	15m (1)	2.3	1.2
	15m (2)	2.3	1.1
	Sports (1)	1.6	1.1
	Sports (2)	2	1.2
	Average	1.3	1.1
	StdDev	0.5	0.3
	StdError	0.1	0.1

Table 3b

Actual and predicted climb rates for the 1st and 2nd place finishers in the 15m Nationals

Date	Class (Place)	Actual climb	Predicted climb
		rate (m/s)	rate (m/s)
15-May-07	15m (1)	1.5	1.2
	15m (2)	1.8	1.2
17-May-07	15m (1)	1.5	1.6
	15m (2)	1.7	1.6
18-May-07	15m (1)	1.7	1.7
	15m (2)	2.2	1.7
19-May-07	15m (1)	2.2	1.5
	15m (2)	1.6	1.5
21-May-07	15m (1)	0.9	1.3
	15m (2)	1	1.3
22-May-07	15m (1)	1.1	1.7
	15m (2)	1.1	1.7
23-May-07	15m (1)	1.4	1.8
	15m (2)	1.3	1.7
24-May-07	15m (1)	1.3	1.8
	15m (2)	1.2	1.8
	Average	1.5	1.6
	StdDev	0.4	0.2
	StdError	0.1	0.1

Table 4a
Actual and predicted 1000m AGL winds for Fairfield PA

Date	Time	Actual wind	Predicted wind	Actual wind	Predicted wind
	(EST)	speed (knts)	speed (knts)	direction (deg)	direction (deg)
8-Oct-06	7	9.9	5	61.5	43
	10	8.7	5	60	34
	13	11	5	62.6	20
	16	5.5	6	74.5	119
9-Oct-06	7	3.4	7.0	324.5	352.0
	10	5.0	7.0	332.3	354.0
	13	7.2	6.0	331.1	332.0
	16	8.2	6.0	359.0	322.0
10-Oct-06	7	8.8	3.0	316.32	336.0
	10	8.1	4.0	309.50	316.0
	13	9.7	2.0	137.00	320.0
	16	7.1	6.0	171.16	150.0
13-Oct-06	7	18	21	296	266
	10	20	18	256	240
	13	12	24	233	226
	16	14	28	219	233
14-Oct-06	7	24	28	282	282
	10	25	29	257	273
	13	21	27	274	278
	16	21	24	287	278
	Average	12	13	232	239
	StdDev	7	10	101	108
	StdError	2	3	26	28

Table 4b
Actual and predicted 1000m AGL winds for Reedsville PA

Date	Time	Actual wind	Predicted wind	Actual wind	Predicted wind
	(EST)	speed (knts)	speed (knts)	direction (deg)	direction (deg)
15-May-07	7	46	41	267	280
	10	40	39	275	281
	13	20	34	238	271
	16	24	33	243	257
	19	28	33	227	255
17-May-07	7	15	22	330	317
	10	9	17	331	328
	13	8	10	323	331
	16	6	6	360	347
	19	9	6	14	67
18-May-07	7	12	7	51	46
	10	13	11	44	31
	13	9	10	1	41
	16	12	11	1	37
	19	9	28	358	360
19-May-07	7	28	22	342	345
	10	25	27	335	341
	13	21	27	318	330
	16	27	31	308	325
	19	26	33	311	331
21-May-07	7	16	17	22	338
	10	15	16	355	343
	13	8	13	351	345
	16	10	7	347	343
	19	4	4	352	342
22-May-07	7	12	10	194	247
	10	10	9	226	285
	13	9	4	163	246
	16	5	3	160	201
	19	15	5	170	172
23-May-07	7	15	5	185	270
	10	12	3	212	244
	13	12	5	185	205
	16	13	8	177	188
	19	18	16	180	201
24-May-07	7	5	8	215	293
	10	4	3	230	300
	13	4	4	200	246
	16	6	10	210	203
	19	12	14	270	224
	Average	15	15	227	254
	StdDev	10	11	108	96
	StdError	2	2	18	16

Table 5a
The actual and predicted task speeds for the 1st and 2nd place finishers at the R4N contest

Date	Class	Actual	Predicted
		(kph)	(kph)
8-Oct-06	Std (1)	52	63
	Std (2)	44	61
	15m (1)	50	58
	15m (2)	49	59
	No Sports Class		
9-Oct-06	Std (1)	79	79
	Std (2)	78	81
	15m (1)	85	85
	15m (2)	81	83
	Spts (1)	65	86
	Spts (2)	60	88
10-Oct-06	Std (1)	96	86
	Std (2)	77	84
	15m (1)	96	86
	15m (2)	96	88
	Spts (1)	83	89
	Spts (2)	92	95
13-Oct-06	Std (1)	99	57
	Std (2)	90	56
	15m (1)	107	56
	15m (2)	100	58
	Spts (1)	85	54
	Spts (2)	79	62
14-Oct-06	Std (1)	113	47
	Std (2)	106	50
	15m (1)	111	50
	15m (2)	107	39
	Spts (1)	94	49
	Spts (2)	76	49
	Average	84	68
	StDev	20	17
	StdError	4	3

Table 5b
The actual and predicted task speeds for the 1st and 2nd place finishers at the 15m Nationals contest

Date	Place	Actual speed	Predicted speed (dry ships)
		(kph)	(kph)
15-May-07	1	108	57
	2	108	59
17-May-07	1	113	97
	2	114	96
18-May-07	1	124	99
	2	127	102
19-May-07	1	167	65
	2	164	62
21-May-07	1	68	83
	2	73	83
22-May-07	1	100	85
	2	86	99
23-May-07	1	96	98
	2	106	100
24-May-07	1	95	98
	2	89	98
	Average	109	86
	StdDev	27	16
	StdError	7	4

Table 6
The actual and predicted onset of cumulus clouds

Fairfield PA

Date	Actual onset (EST)	Predicted onset (EST)	Difference (min)
8-Oct-06	no cumulus	no cumulus	
9-Oct-06	no cumulus	no cumulus	
10-Oct-06	1132	1230	58
13-Oct-06	1145	1300	75
14-Oct-06	no cumulus	no cumulus	

Reedsville PA

Date	Actual onset (EST)	Predicted onset (EST)	Difference (min)
15-May-07	no cu	no cu	
17-May-07	845	845	0
18-May-07	1145	1100	0
19-May-07	1045	1100	0
21-May-07	no cu	no cu	
22-May-07	no cu	no cu	
23-May-07	1145	1300	90
24-May-07	1145	1230	75

Table 7
Comparison of the results achieved in this study (PA) with those from in the Colorado (CO) study[1]

Parameter	Actual-PA	Predicted-PA	Actual-CO	Predicted-CO
CBL depth (m AGL)	1080*	1381	3700**	3500
Climb rate (m/s)	1.2	1.1	2	2
1000 m AGL wind speed (knts)	13	12	10	15
1000 m AGL wind dir. diff. (deg)	26		22	
(actual dir. - predicted dir.)				
Task speeds (kph)	85	86	112	107
** average elevation 1600m				
* average elevation 180m				