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Comparison of the Standard Thermal Mix Model to an Alternate Approach of Sailplane Design and the Resulting Impact on Cross-Country Flight Performance

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ABSTRACT

High-performance racing sailplanes are able to exploit sources of lift in the atmosphere and have regularly flown distances of over 1,000 kilometers. Without an engine, sailplanes are always sinking relative to the airmass they are flying in, forcing them to rely on various weather phenomena to stay aloft. Typically, cross-country soaring involves several cycles of climbing in lift, usually by circling in thermals, then utilizing altitude gained in a straight glide to the next thermal. A sailplane must fly efficiently both while climbing at low speeds and high C_L's and while gliding at higher speeds and low C_L's in order to obtain the fastest average cross-country speed. The speed-to-fly while gliding is determined by the strength of the thermals present on a given day. Therefore, the weather model used during the design process will determine the sailplane's predicted performance and directly impacts the resulting design. An alternate weather model that considers a wide variety of thermal strengths and cross-country performance at different wing loadings was investigated in this study. This method produced a different wing area result than the thermal mix model originally used in designing the Ventus 3. The alternate method used in this thesis shows that additional cross-country performance gains may be available by increasing the wing area by 5 to 10 percent on the Ventus 3. It is unknown which method will result in better cross-country performance overall. Future work can look to quantify this performance gain and any differences in soaring strategy that may improve average cross-country speeds.

TABLE OF CONTENTS

LIST OF FIGURES

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Chapter 1

Introduction

Background

The design of a high-performance racing sailplane must find a balance between several design objectives in order to be successful in competition. Maximum lift-to-drag ratio is often regarded as a measure of overall sailplane performance; however, this measure fails to capture the nuance of optimizing performance over all speed ranges used by a racing pilot. Sailplanes must be able to operate efficiently while climbing in thermals at low speeds and while gliding between thermals at high speeds. Reducing induced drag is desirable for slow climbing flight, while reduction in profile drag is most important while operating at fast inter-thermal cruising speeds. Towards the end of the twentieth century, slightly swept planforms and non-planar wing geometries, including winglets, have been introduced on sailplanes to produce higher performance gains than planar wings [1]. The purpose of winglets is to aid in obtaining the largest reduction in induced drag possible without increasing the span in span-restricted classes or creating excessive profile drag while flying at high speeds. A properly designed winglet should help climbing flight without being detrimental to cruise performance. Optimum inter-thermal cruise speeds vary depending on the size and strength of thermals present on a given day, which presents challenges in determining an optimal design. Different designs will be optimal for different weather conditions.

Sailplanes are able to carry water ballast to adjust wing loading. This allows the pilot to maximize performance for the weather conditions at any given time or day. Higher wing loadings shift the polar so all lift-to-drag ratios occur at higher speeds. This is advantageous on strong thermal days when the reduction in climb performance due to the higher wing loading is more than compensated for by the higher cruising speeds between thermals. Water ballast can be dumped in weak conditions to improve climb performance.

The main wing for the Schempp-Hirth 18-meter Ventus 3, shown in Figure 1, was designed using a traditional thermal mix model with the goal of maximizing average cross-country speed. This thermal model was created based on in-flight logger data from several contests in a variety of conditions. Winglets were designed after main wing design, which was optimized using the aforementioned thermal mix model. An alternate method considering various wing loadings and thermal strengths was used in designing a well-rounded winglet design that is able to perform well in all types of weather.

Figure 1 Schempp-Hirth Ventus 3 [2]

Objectives

The purpose of this work is to compare two different methods of high-performance sailplane wing design. The primary difference lies in the thermal model being used and the wing loadings considered. The main wing of the Ventus 3 was designed using an updated version of a traditional thermal mix model. Wing planform and area are selected to maximize the average cross-country speed for an average distribution of thermal strengths and sizes.

An alternate method was used to design the winglets employed on the Ventus 3. The winglets were evaluated at a variety of wing loadings and thermal strengths in order to gain an idea of performance across a wider variety of weather conditions, not solely average conditions. The main wing of the Ventus 3 was resized utilizing this method in order to investigate the effect of main wing sizing on average cross-country speed. The sailplane's performance was analyzed while considering a range of thermal strengths and whether or not water ballast is carried.

The purpose of this thesis is to determine if there is a significant difference in the result of these two methods. If so, the issue then becomes as to which method produces the best design.

Nomenclature

bal	Ballasted
d	Distance flown
FOM	Figure of merit
lt	Unballasted
t_c	Time climbing
t_g	Time gliding
V_c	Climb rate
V_{CC}	Average cross-country speed
V_g	Glide speed
V_s	Sink rate in glide
V_{s_c}	Sink rate in climb
V_T	Thermal strength

Chapter 2

Sailplane Performance Modeling

Speed-to-Fly Theory

The ‘speed-to-fly’ is the optimum airspeed to fly in order to maximize the average cross-country speed. Speed-to-fly theory can be represented both mathematically and graphically and is detailed in Ref. [3]. A pilot may want to fly the farthest distance possible from a given altitude depending on winds, or to maximize overall average cross-country speed when flying between thermals. Average cross-country speed is determined by the distance flown in the time spend both climbing and gliding:

$$V_{CC} = \frac{d}{t_c + t_g} \tag{1}$$

Determining speed-to-fly between sources of lift is an essential element in predicting average cross-country speed resulting from both thermal models used in designing the Ventus 3. During the 1930s-1940s, several methods to determine speed-to-fly were developed [4]. Wolfgang Späte had originally developed tables documenting best cruise speeds between thermals in 1938. He along with other Polish pilots, Szwarc and Kasprzyk, had published articles documenting their results that have been lost. Karl Nickel had also developed his own theory in 1946 and published in 1949. Speed-to-fly theory is often referred to as MacCready theory, since Paul MacCready was the first to widely publish the method in the United States for use by sailplane racing pilots and designers.

A sailplane's speed polar is the foundation of speed-to-fly theory. This plot shows the aircraft's sink rate over a range of airspeeds at a given wing loading. Maximum lift-to-drag ratio for a sailplane can be demonstrated graphically by drawing a line from the origin to the tangent of the polar. As wing loading increases, the speed at which the maximum glide ratio occurs increases, along with the glide ratios at all higher speeds, allowing the sailplane to fly a given distance at a higher speed. This is why sailplanes carry water ballast in stronger weather conditions. The theoretical ballasted and unballasted speed polars for the Ventus 3 are shown in Figure 2 below. Generally, water ballast is carried in stronger weather conditions when the increased glide performance during cruise offsets the penalty in climb performance. If thermals become weak, water ballast can be dumped in order to achieve desirable climb performance. This will be discussed in more detail in Chapter 3.

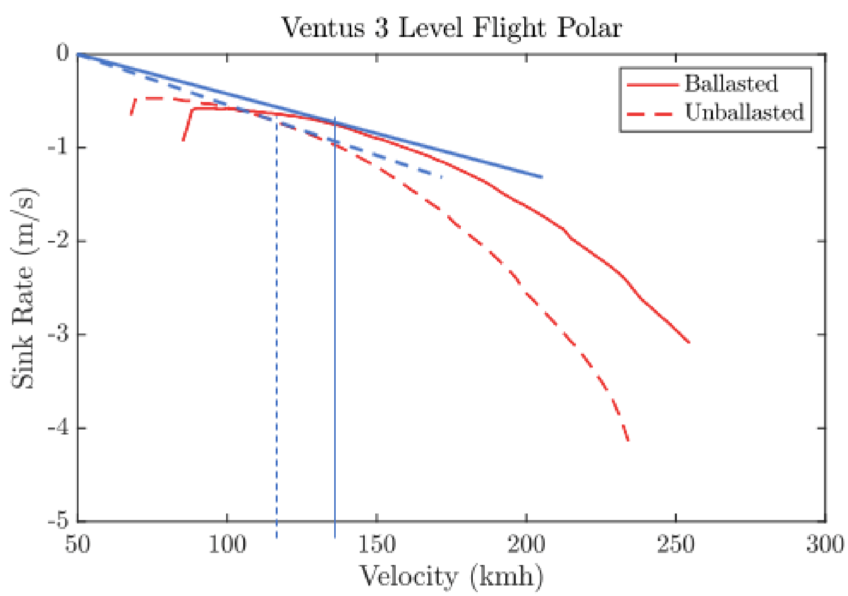

Figure 2 Ventus 3 Ballasted and Unballasted Speed Polars

Speed-to-fly between thermals is based on the anticipated climb rate in the next thermal and the sink rate at a given cruise speed. The sink rate increases as cruise speed increases. Pilots want to cruise as fast as possible without losing too much altitude. Too much altitude is lost when it cannot be made up quick enough in the next climb. Figure 3 shows an illustration of pilots flying at three different speeds. Pilot B flies the proper MacCready speed for the anticipated climb in the next thermal and completes their next climb first. Pilot A flies too slow in the glide and arrives later than pilot B; whereas pilot C flies too fast and loses too much altitude in the glide that cannot be made up in the climb and also arrives later than pilot B.

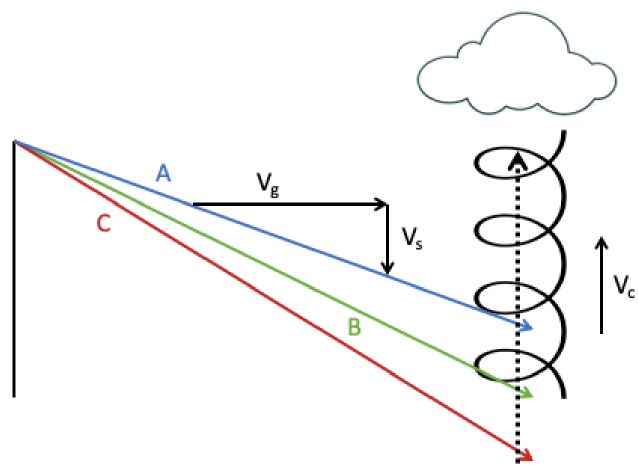

Figure 3 Speed-to-Fly Representation

Average cross-country speed is calculated using the climb rate and the cruise speed between thermals. Climb rate is determined by overlaying the thermal strength distribution with the sailplane’s turning performance as a function of turn radius:

$$V_{CC} = V_g * \left(\frac{V_c}{V_s + V_c}\right) \tag{2}$$

$$V_c(r) = V_T - V_{s_c} \tag{3}$$

Sink rate in a turn is dependent on bank angle and airspeed. The net climb rate, which is a function of turn radius, velocity, and bank angle, can be determined by overlaying a turning performance polar over a thermal strength profile. An example of a turning performance plot is shown in Figure 4. There exists an optimum circling radius corresponding to the greatest net climb rate; this is the climb rate used in the calculation of MacCready speed-to-fly while cruising to the next thermal.

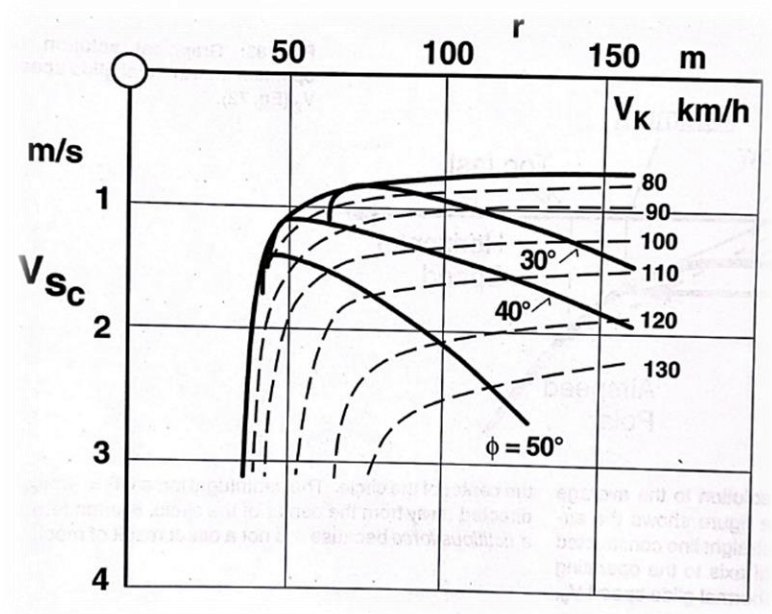

Figure 4 Turning performance for given airspeed, bank angle, and turn radius [5]

It is important to note that speed-to-fly theory for thermal flight is a special case of a more generalized theory. A sailplane has zero forward airspeed while climbing in a thermal. Dolphin flight is an example of a phase of flight that needs a different model to accurately represent and is discussed in Ref. [3].

Sailplane Performance Evaluation Tools

Two Penn State tools were utilized in order to evaluate designs and their cross-country performance: PGEN and ACCS [6]. PGEN is a program that evaluates the aerodynamic characteristics of the aircraft using the wing planform, geometry, airfoil, flap data, and weight. The program outputs straight and turning flight performance data including the corresponding sink rate for a given turning radius, bank angle, and airspeed. These data can then be input into ACCS, an average cross-country speed evaluator, along with a particular thermal radius. This program utilizes speed-to-fly theory in order to calculate glide speed between thermals, sink rate while gliding, net climb rate in the given thermal, circling radius, bank angle, and average cross-country speed for a given thermal strength. Sample output from PGEN can be found in Figure 19 and Figure 20 along with sample output from ACCS in Figure 21 in the Appendix.

Thermal Mix Modeling

One of the early thermal mix models created by Horstmann and Quast [5], shown in Figure 5, is based on pilot experience and inflight measurements attempts to capture the distribution of thermal strength and size encountered on an average day. This model categorizes thermals into four categories:

A1 – weak and narrow

A2 – strong and narrow

B1 – weak and wide

B2 – strong and wide

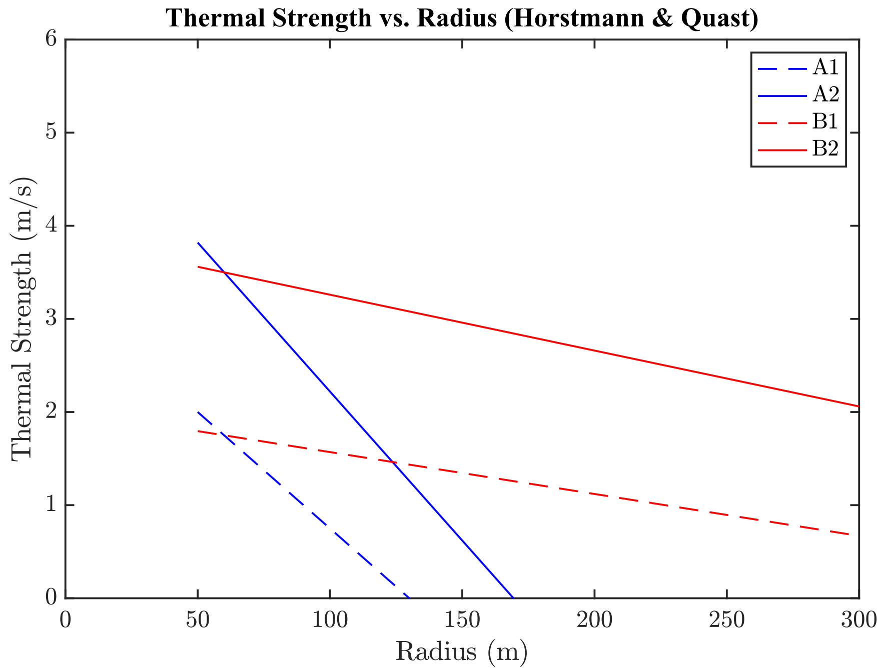

Figure 5 Horstmann and Quast Thermal Model

This thermal model was recently refined based on competition data collected from in-flight logger data generated by several high-performance sailplanes flying in a variety of weather conditions [7]. Logger data includes ground track, altitude, airspeed, and heading information which can be analyzed to determine bank angle, lift coefficient, and whether the sailplane is circling or in straight flight. These logger data revealed that 18-meter sailplanes spend less time circling in thermals compared to predictions from the Horstmann and Quast thermal model. The following additional phases of flight were added on to the Horstmann and Quast thermal model:

C1 – straight flight with no altitude gain

C2 – climbing straight flight

EA – final glide from a given distance and altitude away from finish circle

Chapter 3

Wing Design

Design Methodology

The Ventus 3 wing was designed in two parts, each using a different design method. The main wing was designed utilizing the updated traditional thermal mix model. The planform geometry was optimized using results from the thermal mix model to obtain the maximum average cross-country speed at the maximum gross takeoff weight of 600 kg. The winglets were designed using an alternate method that incorporates a variety of thermal strengths and considers various wing loadings, that is, whether ballast is carried or not. A three-view drawing of the Ventus 3 is shown in Figure 6.

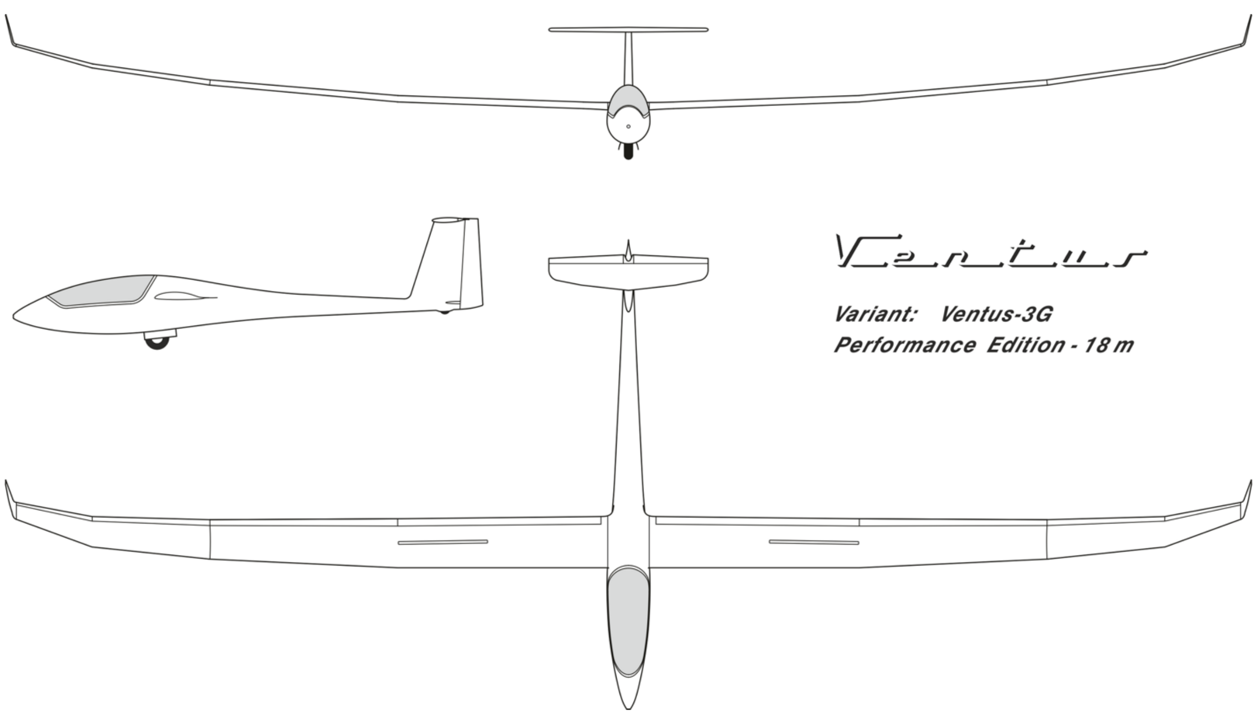

Figure 6 Ventus 3 Three-View Drawing [2]

Selecting an appropriate wing area is one of the main design elements that will determine a sailplane's ability to climb and glide efficiently. Larger wing area is necessary to allow slower flight and tighter turn radii to achieve higher climb rates in a thermal; however, this comes with the price of more profile drag when cruising, harming high speed performance. Lower wing area reduces sink rates at higher speeds but is detrimental to climb performance at low speeds. In weak weather, sailplanes with less wing area will be unable to climb when necessary and may be forced to land.

This method looks to capture the overall cross-country performance as it depends on thermal strengths and ballast carried. To determine if a result different from that obtained using the thermal mix model, the method used for the main wing in this work is similar to methods used in the design of the Ventus 3 winglets. The main wing of the Ventus 3 was altered in order to determine if there is a better optimum wing area that may further improve its cross-country performance. Wing planform shape was not significantly altered as this is outside the scope of this thesis. Winglets were removed in order to isolate the impacts of varying wing area on cross-country performance. A few views of the basic planform geometry without winglets used in this analysis is shown in Figure 7, Figure 8, and Figure 9.

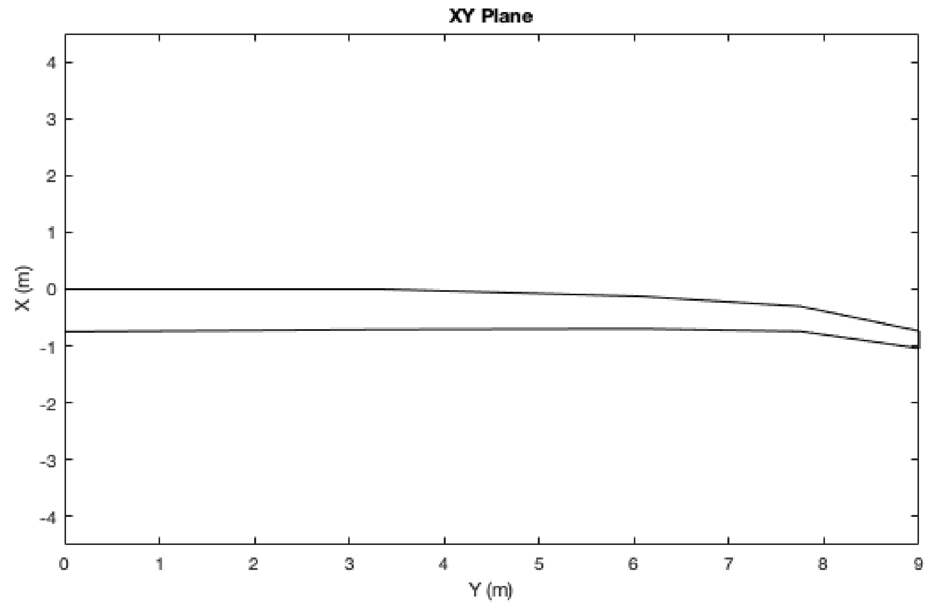

Figure 7 XY Plane 18m Ventus 3 without Winglets

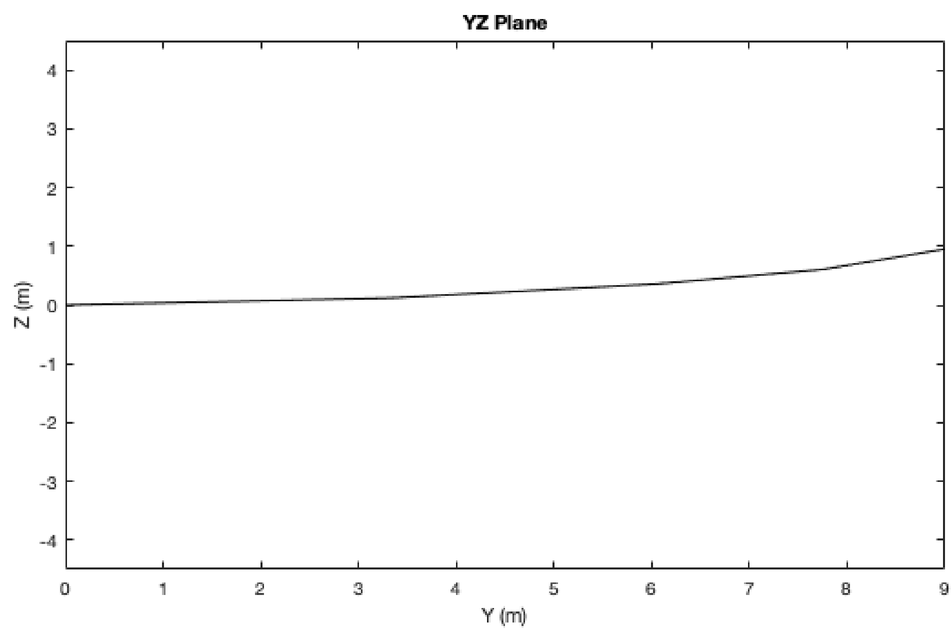

Figure 8 YZ Plane 18m Ventus 3 without Winglets

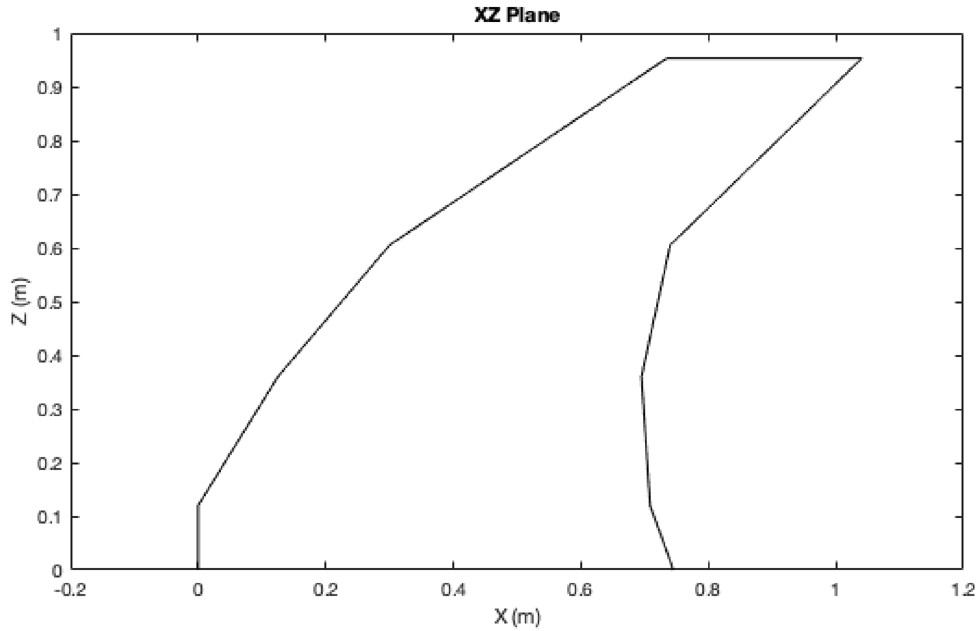

Figure 9 XZ Plane 18m Ventus 3 without Winglets

Parameters like taper, twist, sweep, dihedral, and airfoil selection remained constant. Since the Ventus 3 competes in the 18-meter class, only chord length was scaled across the span to see how varying wing area may impact performance. The chord length of each wing panel was scaled from 0.9c to 1.2c in 0.05c increments. Performance was evaluated for each of these cases as described in the next section.

Cross Country Performance Evaluation

A script was used in order to create the input planform and aircraft geometry files for PGEN. Ballasted and unballasted polars were generated for each wing area considered. Straight flight and turning polars for each wing planform are output from PGEN. These files are fed into ACCS to calculate the overall average cross-country speed based on the basic performance data.

Each output from ACCS gives the cross-country performance corresponding to a thermal radius of 150 meters and core strengths ranging from 0 m/s to 10 m/s. Average cross-country speed was plotted with varying thermal strengths for a given area as shown in Figure 10. Ballasted and unballasted performance are plotted with solid and dashed lines, respectively.

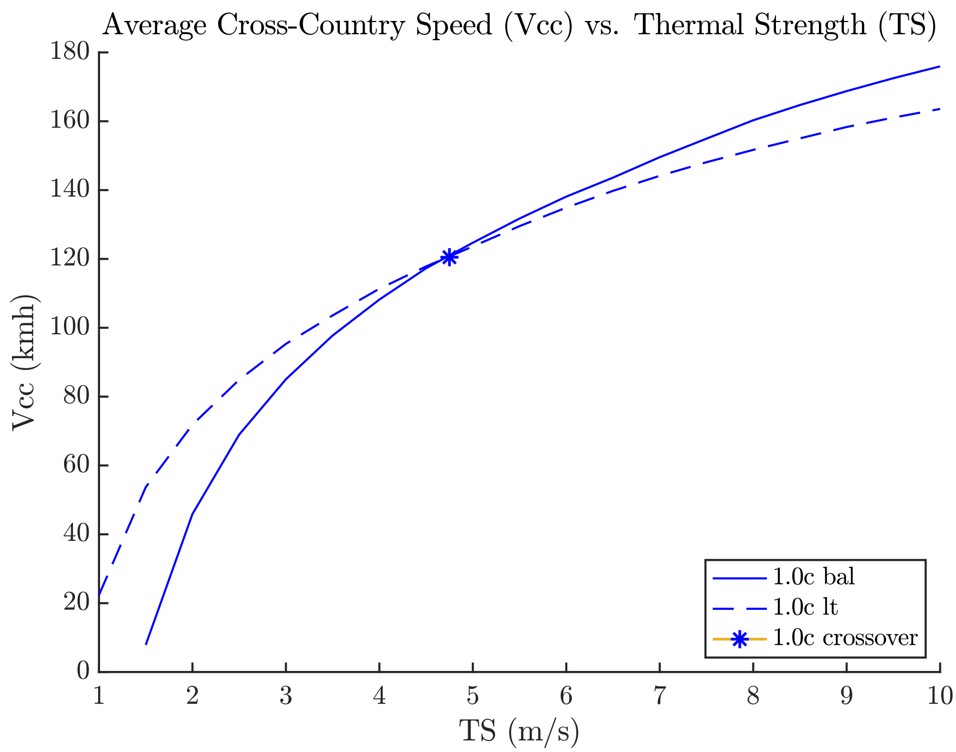

Figure 10 Cross-country speed versus thermal strength - Ventus 3 without winglets

Crossover points are plotted for a given area. If thermals are expected to be stronger than this point, it will be beneficial to performance to carry water ballast. In weaker weather, ballast hurts climb performance such that it is detrimental to overall cross-country performance – this is where it is best to dump ballast. A successful sailplane design must be able to perform well in both weak and strong conditions in order to be competitive in racing contests all around the world. The next chapter focuses on attempting to quantify the Ventus 3's performance as the wing area is changed.

Chapter 4

Results and Discussion

This section explores results from using the alternate design method in order to determine if this method gives a different wing area than in the original method. Wing area is chosen in order to maximize overall performance given by the average cross-country speed. Average cross-country speeds will change depending on whether or not ballast is carried and the strength of thermals present when racing. The crossover point determines the minimum thermal strength where pilots can expect to increase their average cross-country speed by carrying water ballast. The location of this point will shift depending on the wing area of the sailplane. The dependence of average cross-country speed on thermal strength for different wing areas is plotted in Figure 11.

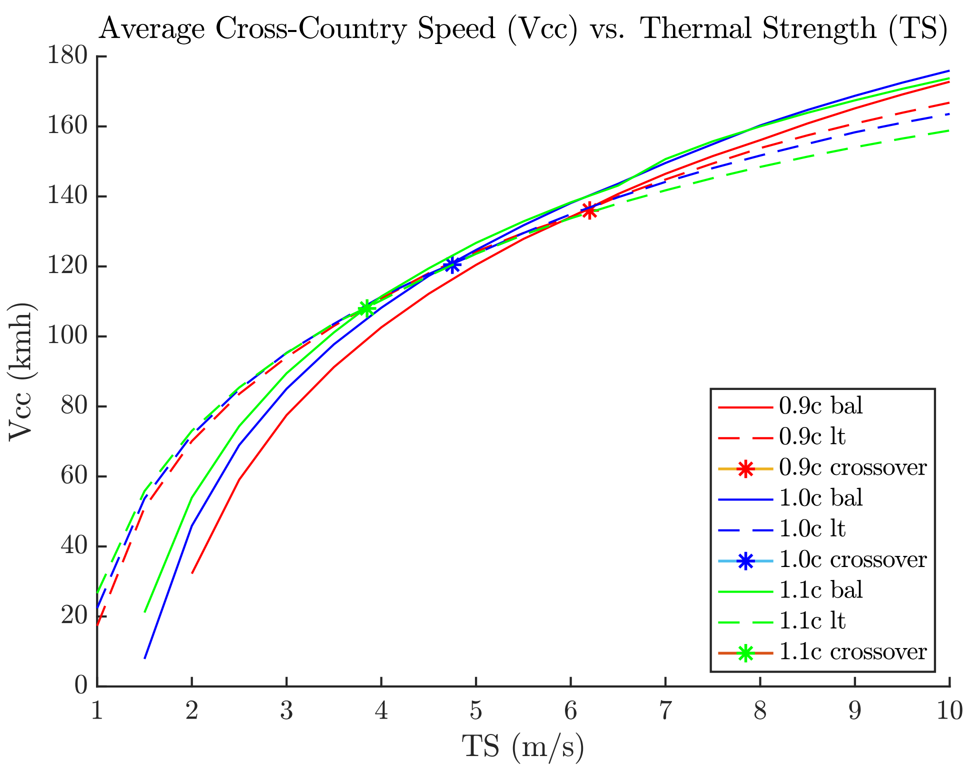

Figure 11 Cross-country speed versus thermal strength with different wing areas

The approximate crossover thermal strength is plotted for each wing area. In stronger thermals, it is desirable to carry water ballast, but ballast will hinder performance in weaker conditions. As wing area increases, the crossover point moves left. As the strength of thermals decreases, the lower climb rate makes it necessary to spend more time climbing. More wing area is better able to support climbs in weaker thermals while carrying ballast. Decreasing area moves this point to the right. With less area, the wing cannot support climbing with ballast as well as it can with more area. The effects of increasing and decreasing wing area on the speed polar are shown in Figure 12. The penalty for more wing area is shown clearly in the higher sink rates as airspeed increases.

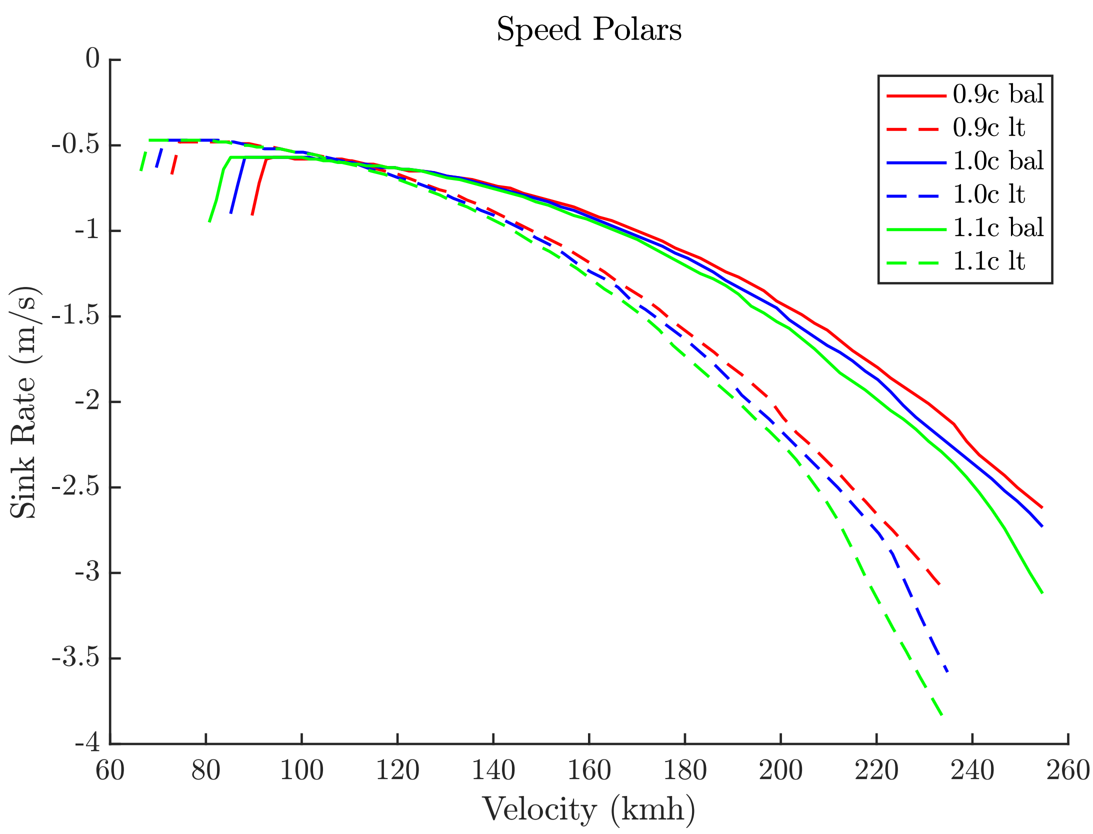

Figure 12 Wing area impact on speed polar

If it was only necessary to design for one specific thermal strength, it would be relatively straight forward to see which wing area and wing loading will result in the maximum cross-country speed. When considering a 2 m/s thermal when carrying ballast for example, more wing area will achieve better performance. Dumping water ballast will significantly improve cross-country speed. Without ballast, cross-country speed is not as heavily impacted by the wing area for weaker thermal strengths. This trend does not apply for strong thermals.

Selecting an appropriate wing area becomes challenging when analyzing the wide range of cross-country speeds as they depend on thermal strengths and wing loading. A figure of merit was developed in order to attempt to quantify overall cross-country performance in various types of weather. This FOM assumes that water ballast will be carried when thermal strengths are expected to exceed the crossover point and will be dumped if conditions weaken below this point. Climb and glide performance are considered when using PGEN and ACCS to calculate average cross-country speed as an overall performance measure.

This figure of merit uses the area under the cross-country speed versus thermal strength curve, assuming water ballast is carried when thermals are stronger than the crossover point. Towards the left of this point, the area is taken under the unballasted curve to represent where ballast would be dumped to achieve better overall performance. The FOM was calculated using the following equation:

$$FOM = \left\{ \int_{n}^{x} V_{cc_{lt}} d\left(V_{T\,core}\right) + \int_{x}^{m} V_{cc_{bal}} d\left(V_{T\,core}\right) \right\} * \left(\frac{1}{FOM_{1.0c}}\right) \qquad (4)$$

FOM was calculated using a trapezoidal sum and was normalized by the FOM for the baseline area. The lower and upper bounds of integration, *n* and *m*, were chosen as 2 m/s and 8 m/s since this represents a realistic and typical distribution of thermal core strengths. A visual representation of this calculation is shown in Figure 13.

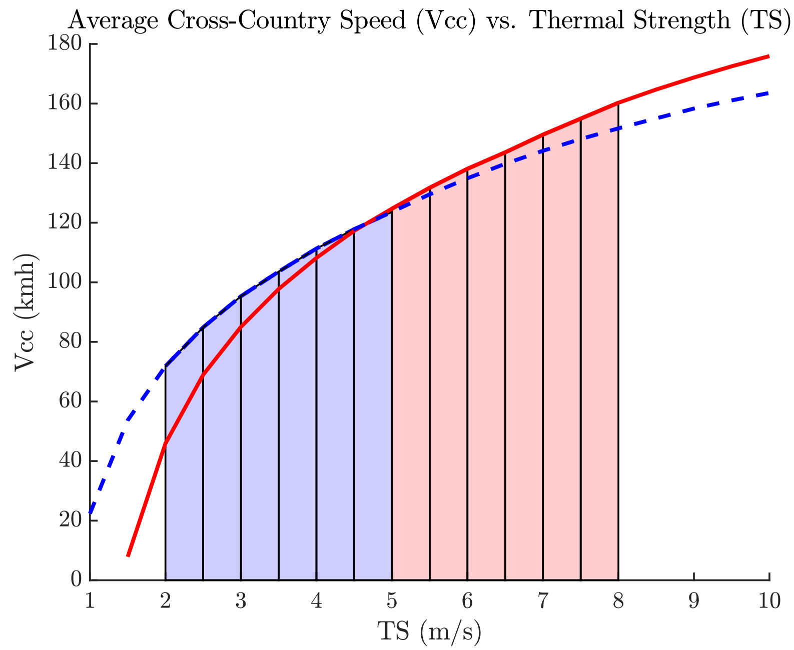

Figure 13 Graphical representation of FOM for baseline wing area (1.0c)

The figure of merit was calculated for each area, and they are compared in Figure 14.

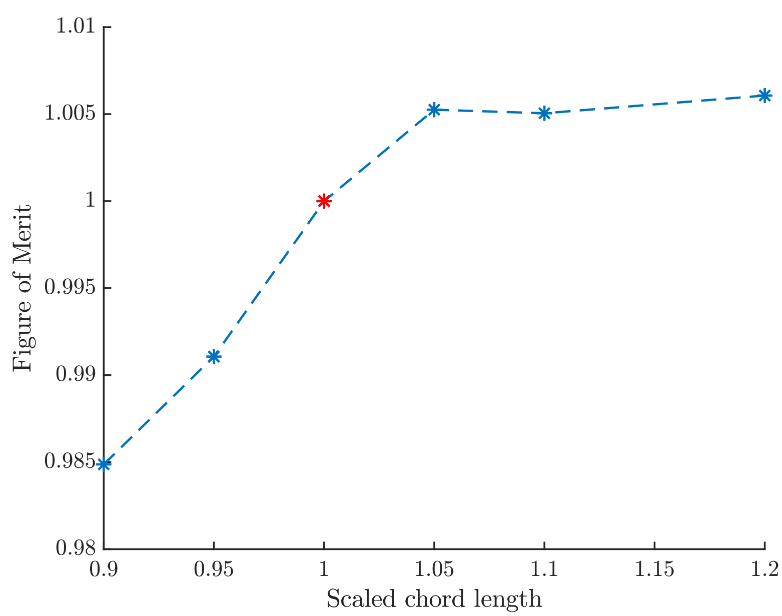

Figure 14 FOM versus scaled chord length for average conditions: 2 m/s to 8 m/s

The method using PGEN and ACCS seems to produce a different result than the thermal mix method originally used in designing the Ventus 3, assuming the FOM used is appropriate. The plot above suggests that anywhere from 5 to 10 percent more wing area may be beneficial to overall cross-country performance. This assumes that the racing pilot chooses the proper speed-to-fly between thermals. With additional wing area, the pilot would need to be disciplined and resist the common urge to chase other racing sailplanes. If a pilot flies faster than the MacCready speed-to-fly between thermals, the extra wing area will produce extra profile drag at cruise and reduce cross-country speed.

It is important to note the impact that the weather model or distribution of thermal strengths has on the figure of merit. Extending the range of thermal strengths to 3 to 10 m/s and favoring high speed performance, as shown in Figure 15, will alter the FOM trend as shown in Figure 16. More area becomes less favorable as higher inter-thermal cruise speeds are required to maximize cross-country speed as climb rates increase.

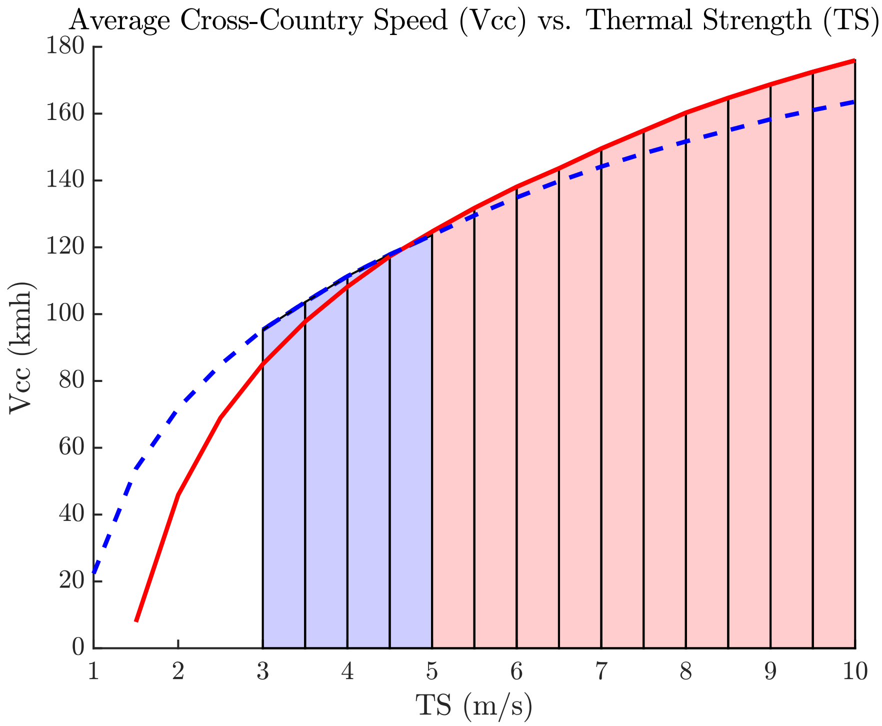

Figure 15 Graphical representation of FOM – stronger weather conditions

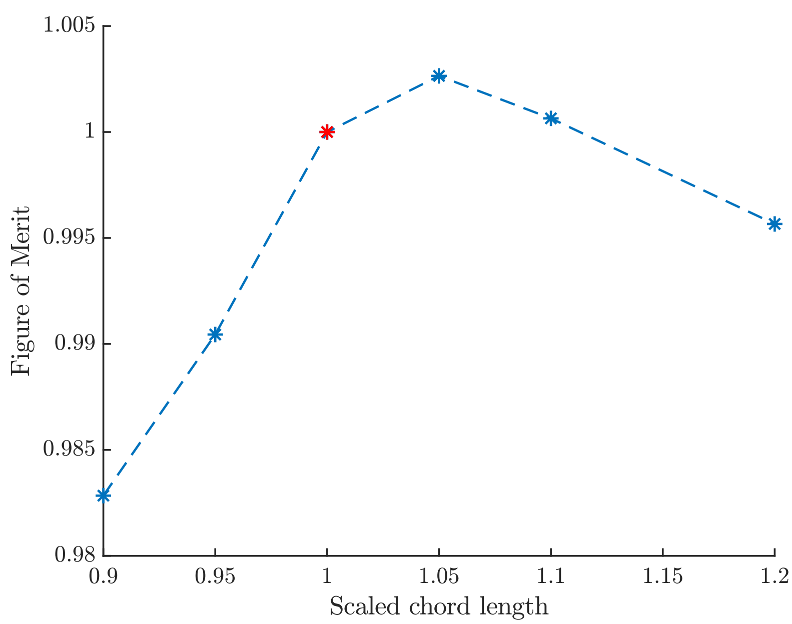

Figure 16 FOM versus scaled chord length – thermal strength: 3 m/s to 10 m/s

The trend more strongly favors an increase in wing area when a range of weaker thermals is used as demonstrated in Figure 17 and Figure 18.

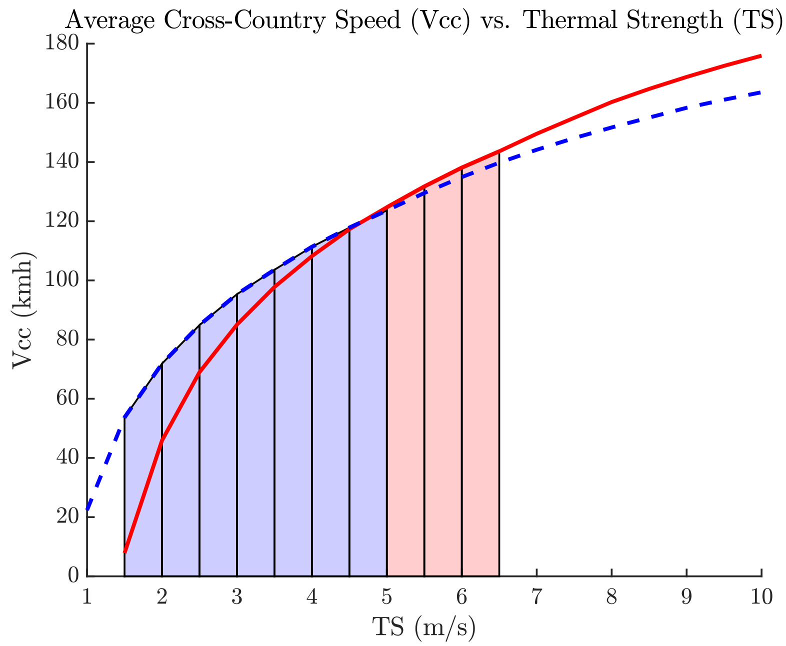

Figure 17 Graphical representation of FOM - weaker weather conditions

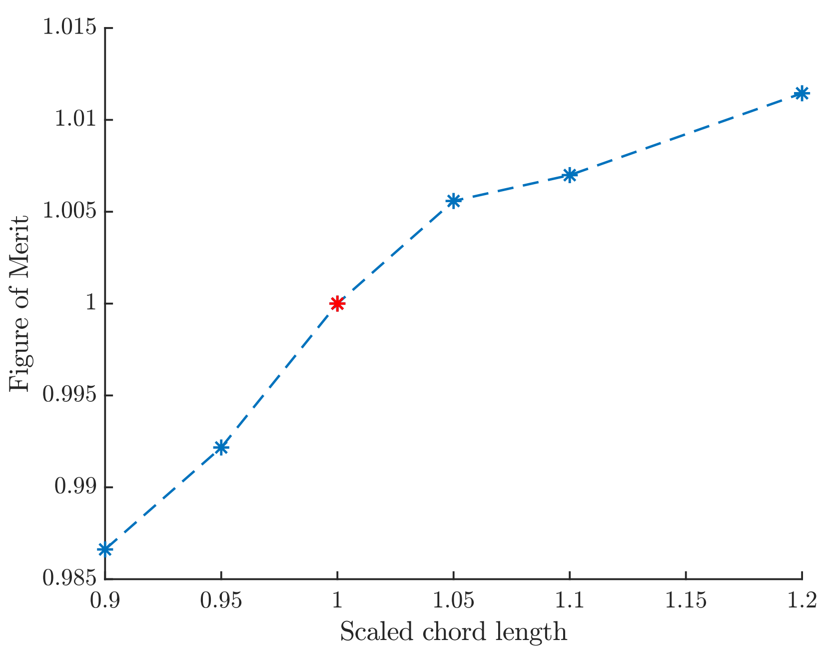

Figure 18 FOM versus scaled chord length – thermal strength: 1.5 m/s to 6.5 m/s

Less wing area will win on strong days where inter-thermal cruise speeds are high. Lower profile drag allows less altitude to be lost in the same distance at a given cruise speed with less wing area. More wing area wins on weaker days. Cruise speeds are lower which reduces the impact that the extra area has on sink rate when flying faster. Climb rates will be higher with more area which will allow this sailplane to climb in weak thermals that another with less area may not be able to. If a sailplane cannot find a thermal to climb in, it will be forced to land out, which will end the race day for that pilot.

Chapter 5

Conclusion

There seems to be a difference in the sailplane wing designs resulting from the thermal mix model originally used to design the Ventus 3 wing and the alternate method used in this work. When considering a wider variety of thermal strengths and whether or not ballast is carried, it appears that the Ventus 3 could benefit from an additional 5 to 10 percent more wing area, which is a surprisingly significant difference. Anywhere from a 0.5 percent to 1.5 percent increase in the figure of merit could be seen by increasing wing area for three typical thermal strength distributions, one favoring weak conditions, average conditions, and stronger conditions.

In this study, the area of the Ventus 3 wing was altered by scaling the chord length of each panel in 5 percent increments, from 90 percent to 120 percent or the original chord. Altered wing geometry was run through speed polar and cross-country performance evaluators to determine the average cross-country speed for a variety of thermal strengths. Cross-country performance was evaluated for each wing area for an unballasted and ballasted sailplane. Results show that increasing the wing area of the Ventus 3 by 5 to 10 percent may further improve average cross-country performance. The exact amount of area increase depends on the strength of conditions being flown in. Stronger conditions favor a smaller increment in wing area on the order of 5 percent, where weaker conditions favor a larger increment in wing area, up to a 10 or even a 20 percent increase. These projections are assuming that the FOM defined in this study is an appropriate way of quantifying average cross-country performance. It is likely that this FOM needs refinement and further investigation to gather more reliable results.

The precise significance in the trends of the FOM are unknown, yet there seems to be a clear trend favoring some level of increase in wing area, even in stronger weather conditions. It is also challenging to say what level of performance gains could be expected from a given change in wing area.

The weather model used in modeling cross-country performance is the main factor that will dictate sailplane wing sizing. If a glider is designed to heavily favor stronger weather, it may not have enough wing area to be competitive in weaker weather. Favoring weaker weather can result in excessive profile drag at high cruise speeds, harming performance when thermals are strong. Understanding how pilots are flying sailplanes is important since this may not exactly align with the theoretical best speed-to-fly, as explored in this work. If a sailplane is designed with more wing area, but pilots are flying faster than the speed-to-fly between thermals for that sailplane, the gain in climb performance with more area can easily be negated by the urge to keep up with other racing pilots while cruising between thermals. To aid in selecting a weather model, more studies like those done in Ref. [7] examining flight logger data could be used to gain more insight into how sailplanes are actually being flown in competitions.

Future work may want to consider using both methods in conjunction with one another to combine flight logger data along with a method that considers a wider variety of thermal strengths and wing loadings to further refine design studies. There is a possibility that several optimum designs exist, each having a different wing area. Say pilot A is flying a sailplane with more wing area than pilot B and each have similar wing loadings. Pilot A cruises slower, loses less altitude, then climbs at a higher rate in thermals than pilot B. Pilot B will cruise faster, losing more altitude in the glide, but take longer to climb in the next thermal. They may have the same average cross-country speed. Game theory or similar mathematical studies investigating soaring strategy as it relates to wing design and weather modeling are worth exploring. Ultimately, different designs will be optimal for different types of weather, and different soaring strategies are required for different conditions in order to maximize average cross-country speed. The designer faces the challenge of selecting design criteria that will result in the optimal high-performance sailplane design.

Appendix

v3_100bal

Vkmh	CLW	CL	CD	VS m/s	L/D	
85.1586	1.5443	1.5672	0.0595	0.90	26.36	8
86.6483	1.4928	1.5138	0.0457	0.73	33.12	8
88.1379	1.4438	1.4630	0.0342	0.57	42.78	8
89.6276	1.3973	1.4148	0.0323	0.57	43.76	8
91.1172	1.3530	1.3689	0.0307	0.57	44.60	8
92.6069	1.3109	1.3252	0.0292	0.57	45.31	8
94.0965	1.2707	1.2836	0.0279	0.57	45.99	8
95.5862	1.2324	1.2439	0.0267	0.57	46.63	8
97.0759	1.1958	1.2060	0.0255	0.57	47.21	8
98.5655	1.1536	1.1699	0.0244	0.57	47.89	7
100.0552	1.1203	1.1353	0.0234	0.57	48.52	7
101.5448	1.0824	1.1022	0.0225	0.57	49.06	6
103.0345	1.0519	1.0706	0.0216	0.58	49.55	6
104.5241	1.0227	1.0403	0.0208	0.58	49.98	6
106.0138	0.9948	1.0113	0.0201	0.59	50.30	6
107.5034	0.9680	0.9834	0.0194	0.59	50.58	6
108.9931	0.9423	0.9567	0.0188	0.60	50.82	6
110.4828	0.9176	0.9311	0.0182	0.60	51.02	6
111.9724	0.8939	0.9065	0.0177	0.61	51.22	6
113.4621	0.8712	0.8828	0.0172	0.61	51.36	6
114.9517	0.8493	0.8601	0.0167	0.62	51.45	6
116.4414	0.8282	0.8382	0.0162	0.63	51.58	6
117.9310	0.7959	0.8172	0.0157	0.63	51.98	5
119.4207	0.7764	0.7969	0.0152	0.63	52.35	5
120.9103	0.7576	0.7774	0.0148	0.64	52.65	5
122.4000	0.7395	0.7586	0.0143	0.64	52.89	5
125.0449	0.7090	0.7269	0.0137	0.65	53.20	5
127.6898	0.6803	0.6971	0.0131	0.66	53.39	5
130.3347	0.6533	0.6691	0.0125	0.68	53.44	5
132.9796	0.6280	0.6427	0.0120	0.69	53.37	5
135.6245	0.6041	0.6179	0.0116	0.71	53.11	5
138.2694	0.5815	0.5945	0.0113	0.73	52.72	5
140.9143	0.5603	0.5724	0.0109	0.75	52.36	5
143.5592	0.5401	0.5515	0.0106	0.77	51.89	5
146.2041	0.5211	0.5317	0.0103	0.79	51.47	5
148.8490	0.5031	0.5130	0.0101	0.81	50.97	5
151.4939	0.4860	0.4952	0.0098	0.83	50.49	5
154.1388	0.4698	0.4784	0.0096	0.86	49.88	5

Figure 19 Sample PGEN straight and level flight output

TURNING POLAR DATA:

R	Vel.	Phi	Vsink	Flap	CLw	CLAC
65.0	125.03	62.11	2.84	8	1.574	1.556
70.0	120.29	58.38	2.10	8	1.515	1.499
75.0	120.26	56.58	1.42	8	1.443	1.428
80.0	112.51	51.19	1.15	8	1.444	1.433
85.0	107.83	47.07	1.01	8	1.443	1.436
90.0	104.72	43.76	0.92	8	1.440	1.436
95.0	102.49	40.99	0.86	8	1.436	1.434
100.0	100.59	38.55	0.81	8	1.436	1.435
105.0	99.06	36.30	0.78	8	1.436	1.437
110.0	97.77	34.33	0.75	8	1.437	1.440
115.0	97.14	32.81	0.73	8	1.429	1.433
120.0	96.14	31.22	0.71	8	1.432	1.438
125.0	95.54	29.86	0.70	8	1.429	1.436
130.0	94.84	28.57	0.68	8	1.431	1.439
135.0	94.34	27.41	0.67	8	1.430	1.439
140.0	93.83	26.33	0.66	8	1.431	1.440
145.0	93.38	25.33	0.66	8	1.432	1.442
150.0	93.04	24.42	0.65	8	1.431	1.442

Figure 20 Sample PGEN turning performance output

Aircraft:v3_100bal
Thermal Radius: 150.0000
Min. Thermal Str.: 1.477455

TStr m/s	Vcr kmh	Vs m/s	Vcl m/s	CRad m	Phi deg	Vcc kmh
1.500	132.870	0.689	0.043	92.250	42.447	7.865
2.000	150.387	0.821	0.360	89.274	44.207	45.897
2.500	157.182	0.884	0.691	86.850	45.751	68.967
3.000	174.486	1.080	1.027	85.147	46.961	85.046
3.500	181.126	1.167	1.369	83.510	48.213	97.753
4.000	185.138	1.228	1.726	82.260	49.170	108.192
4.500	198.380	1.436	2.077	81.607	49.727	117.291
5.000	198.796	1.443	2.430	80.965	50.296	124.709
5.500	215.218	1.766	2.786	80.332	50.877	131.743
6.000	220.280	1.870	3.144	79.709	51.469	138.107
6.500	220.847	1.883	3.503	79.096	52.070	143.623
7.000	250.224	2.601	3.866	78.492	52.681	149.557
7.500	251.263	2.630	4.230	77.898	53.302	154.940
8.000	252.396	2.662	4.631	77.435	54.403	160.281
8.500	253.315	2.689	4.998	77.234	54.615	164.711
9.000	253.320	2.689	5.366	77.035	54.820	168.757
9.500	254.617	2.729	5.734	76.836	55.018	172.510
10.000	254.596	2.729	6.103	76.639	55.209	175.940

Figure 21 Sample ACCS output

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ACADEMIC VITA

EDUCATION

The Pennsylvania State University, University Park, PA | ***Schreyer Honors College*** *Graduating May 2022*

- **Bachelor of Science in Aerospace Engineering**
- Spanish Minor, International Engineering Certificate

Universitat Politécnica de Valéncia, Valencia, Spain *Sep. – Dec. 2019*

- Volunteered with local schools to assist in teaching English to 11-13-year-old students
- Adapted to living with a host family and communicating in a second language with locals every day

National Engineering University, Lima, Perú *May – Jun. 2019*

- Collaborated with Peruvian students to design a mudslide warning system using Arduino Microcontrollers

Private Pilot – Glider: Over 35 hours and 90 flights in sailplanes

ENGINEERING EXPERIENCE

AIAA Design Build Fly Competition: The Sailplane Lab, Penn State | *DBF 2022 Lead* *Jun. 2020 – present*

- Design remote control airplane to meet design constraints while maximizing mission performance
- Analyze aircraft aerodynamics, performance characteristics, stability and control, structures, and more
- Manufacture and test aircraft design with hands-on shop experience working with composites
- Coordinate team and organize deadlines throughout the year to be ready for competition flyoff

Undergraduate Thesis: Penn State *Sep. 2021 - present*

- Investigate the standard thermal mix model and an alternate approach to the design of sailplane winglets
- Compare the effect of varying winglet design on predicted cross-country sailplane performance

Lockheed Martin Corporation: Littleton, CO | *ATLO Systems Integration and Test Intern* *May – Aug. 2021*

- Coordinated effort to build 3D printed satellite model to reduce risk by trialing manufacturing procedures on non-flight hardware
- Drafted test requirements and procedures for mechanical and electrical testing of satellites
- Participated in program Critical Design Review

Lockheed Martin Corporation: King of Prussia, PA (remote) | *Systems Engineering Intern* *Jun. – Aug. 2020*

- Expanded test automation script coverage for verifying web platform functionality, database storage, and file parsing utilizing Python's Robot Framework
- Collaborated with intern team to design, develop, and test a new feature to be delivered to the customer

LEADERSHIP & INVOLVEMENT

The Penn State Soaring Club: Penn State | *President* *Aug. 2021 – Present*

- Foster a welcoming and fun environment for pilots and students interested in aviation to fly gliders with their peers

Global Engineering Fellows: Penn State *Jun. 2020 – Present*

- Mentor and guide students interested in studying abroad as peer advisor
- Recruit engineering students to study abroad through engagement events

Engineering Ambassadors: Penn State *Mar. 2020 – Present*

- Inspire young students to become involved in STEM through community outreach
- Lead tours for prospective engineering students and their families

SKILLS: MATLAB, XFOIL, AVL, Python, C++, SolidWorks, Spanish (Limited Working Proficiency)

HONORS: Sigma Gamma Tau Member (2021-Present), Evan Pugh Scholar Senior Award (2021), 4th place AIAA Design Build Fly (2020), Steva Award Aerospace Engineering - $2,800 (2020), Aero Pioneers Scholarship - $1,500 (2019), Best Engineered Design - College of Engineering Design Showcase (2019), The President's Freshman Award - 4.00 GPA (2019), Gaeckle Alumni Memorial Scholarship - $5,000 (2018), University Park 4 Year Provost Award - $4,000 (2018)