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Editor: Tony Condon

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The 182 Prototype when it was new, from the Cessna Flyer Association Facebook page

KSA CALENDAR

July 5th - July 11th - Region 10 North - Sunflower

July 12th - KSA Meeting - Cookout at Sunflower

July 15th-24th - Sports Class Nationals - Midlothian, TX

July 19th - 52nd Kansas Kowbell Klassic - Sunflower

August 4th - 8th - Region 10 South - Waller, TX

August 9th - KSA Meeting - Cookout at Sunflower

September 13th - KSA Meeting - Cookout at Sunflower

September 25th - 28th - Great Plains Vintage Rally - Wichita Gliderport

Sunflower Seeds

June 7th: **Rafael Soldan** instructed **Sebastien Pepin** and **Jerry Martin**. **Jack Seltman** towed. **Matt Gontizke** and **Kevin Ganoung** ran the line. **Tony Condon** gave a ride in the Grob to Keith, a Chiropractor from Hutchinson, and then flew two instructional flights with **Don Jones**. The second flight featured a rope break at about 100'. The landout and resulting retrieve will be detailed elsewhere in this edition. **Dennis Brown** flew LY. **Steve Leonard** did some mowing and made some new ropes.

June 14th: Saturday, windy and nobody flew. Cleanup and maintenance at Sunflower was done by **Steve Leonard, Andrew Peters, Paul Sodamann, Jerry Boone** did some welding and maintenance on the east end of the t-hangars, and **Matt Boone** scraped walkways around the restrooms. **Bob Park** was observing. Dinner was served at around 6pm, **Don Jones** and **Paul** brought amazing deserts and **Andrew** served up burgers and dogs, good stuff! **Paul** brought his nice John Deere mower and weed sprayer, then pitched his tent for the night… but it rained so hard in the middle of night that he had to retreat to his truck.

June 15th: Sunday, calm winds and wet fields. **Paul Sodamann, Matt Boone, Mike Orindgreff** and **David Kennedy** helped out on line duty, **Jerry Boone** made eight tows. **Matt Boone** also did some more weed scraping. **Kevin Ganoung** got his 3 currency flights in the Grob, **John Wells** and **Andrew Peters** launched at around 3:30pm and stayed up for an hour reporting tops around 4500 as some CU started to move in from the Southeast. **David Kennedy** got 3 flights in the 2-33 and is now resuming solo time. Observers were **Dennis Brown**, **Steve Leonard**, and later arriving were **Bob Hinson** and **Lynn Juby**.

June 21st: No report but **Andrew Peters** flew his LS-3

June 28th: **Mark Schlegel** towed. **Tony Condon** instructed in the 2-33 flying with **Kevin Ganoung** and **Matt Gonitzke** (Flight Reviews) and **Luke Marquardt**. Also gave a ride to friend Steven LeBlanc. **Jimmy Prouty** put in a lot of hours working on the 182. Thanks!

June 29th: **Tony Condon** arrived early to work on the Cherokee. **Mark Schlegel** arrived for tow duty as well as **Dennis Brown** and **Luke Marquardt** for line duty. It quickly became obvious that there would be no customers on account of the wind.

June 30th: **Tony Condon** and **Dennis Brown** arrived early to work on their gliders. **Tony** mowed the grass around the tower and **Dennis** decided it was too windy to fly. **Mike Logback** arrived later in advance of doing the annual on his Phoebus. **Tony** rigged the Apis (F1) with help from Jacob Frye and took a tow around 4:15. 1 knot to 2500 AGL was all he found and landed shortly after that. **Jimmy Prouty** then arrived to do the annual on the Phoebus.

Rules for the Annual Kansas Kowbell Klassic

1. Any soaring pilot and sailplane may enter
2. Only one flight per pilot will be eligible for konsideration, and that flight must be made on the date selected for Kowbell Klassic
3. The winner each year will be the pilot who makes the longest flight, as measured on U.S. Koast and Geodetic sectional charts, from the release point to his first point of landing, as verified on a standard SSA landing form. In kase of any dispute on the measurement of distance, said dispute will be settled by Indian “rasslin”, (Texas rules).
4. The release altitude will be no higher than 2000 feet above the kontest site
5. The release point will be vertically above the kontest site.
6. The Annual Kowbell Klassic will be held each year on the first Saturday after the first full moon that falls on or after the summer solstice (i.e., the first point in the sign of Kancer)
7. Normal adverse soaring weather, i.e., rain, overcast sky, lack of thermals, etc., shall not knostitue a valid reason for postponement of the Kowbell Klassic. If the weather is unsafe for glider flight on the appointed day, then the next following Saturday during which unsafe flying weather is not present shall be the date of the Kowbell Klassic.
8. A suitable trophy has been fabricated (original by Mickey Jensen and Marshall Claybourn. Replacement by Steve Leonard) and the aforementioned trophy shall be placed in the possession of the Officers of the Kansas Soaring Association who will be charged with its annual presentation, in accordance with these rules
9. Any person who wins the Kowbell Klassic Trophy thrice in succession shall become the permanent owner of the trophy and a replacement trophy will be provided.

Rules for the Kansas Kowbell Klassic Konsolation

The rules for the Kansas Kowbell Klassic Konsolation are the same as for the Kansas Kowbell Klassic, except as amended below.

1) Any soaring pilot and sailplane may enter, except for the winner of the previous days Kowbell Klassic.

2) The winner each year will be the pilot who completes the longest pre-declared task, as measured on US Koast and Geodetic sectional charts, from the release point, through any pre-declared turnpoints, to his point of landing, as verified on a Standard SSA Landing Form.

6) The Annual Kowbell Klassic Konsolation will be held each year on the Sunday following the Annual Kowbell Klassic, unless the second place competitor in the Kowbell Klassic flew farther than 200 miles. In this kase, the Kowbell Klassic Konsolation will be held on the Saturday following the Kowbell Klassic.

Member Accomplishments

Bob Holliday placed 6th at Region 9 in Moriarty, winning two days, flying the PIK-20E

Ron Leonard placed 4th at Region 9 in Moriarty, flying the HP-18

Tony Condon scored the most points at the 1-26 Championship, but unfortunately the contest did not get enough days in to be official.

Matt Gonitzke earned a VSA Restoration Award for the excellent restoration on his SH-1, as well as the VSA Journalism award for his articles in the *Bungee Cord* detailing the restoration.

KSA Director Election

Congratulations to **Rafael Soldan** for winning the election for the open KSA Director spot. A big Thank You to **Harry Clayton** for being willing to serve!

Hutchinson Seeds

June 7th: **Jerry Boone** departed Sunflower in the morning in the Grob behind **Tony Condon** in the 175. Shortly after, they were cleared to land by Hutchinson tower and participated in Hutchinson's Fly-In. 4 rides were given to happy customers and they returned to Sunflower.

June 8th: **Jerry Boone** and team once again gave rides at Hutch, about 4 in all after waiting all morning for the weather to clear. **Don Jones** and **David Kennedy** helped with ground ops. **Rafael Soldan** towed in the morning and **Mark Schlegel** towed in the afternoon. **Lyn Boone** was primarily staffing the booth and showing off the Zuni both days. Thanks **Lyn**!

Grob and 175 holding short at Hutchinson during the fly-in

<u>Tinkerbell's first trip to Oklahoma</u>

By **Keith Smith**

I have been chomping at the bit to get another chance at a Gold Distance. With that task I could get my Gold Badge. It has now been a few years since my flight to Nebraska when I was about six miles short of the Gold Distance. I had been bugging multiple members about better weather planning for long cross countries. I have been looking for ways to maximize my chances of a good XC day considering the drive down, plus lining up a chase crew issues. We all know the weather can change from home to the gliderport but it is often significantly different up here west of Salina than it is at Sunflower. So, I had been spending lots of time comparing various weather sources on the computer. My main sources are Dr. Jack's, and XC Skies (which often do not agree closely), and the NOAA site by latitude/longitutde which has hourly forecasts that are pretty accurate. I keep the NOAA site set on Yoder for surface winds, temp/dewpoint, sky coverge of clouds and the possibility of rain. When the lift looked about good to better for W-SW of Sunflower for a couple of days, I decided to seriously accept **Bob Holliday'**s offer of a mid-week tow.

That morning I had emailed **Tony** before I left that the forecast had changed my plans. Originally I had wanted to head straight west toward Limon, Colorado. I was slow getting loaded, so, right before I left I called him and he was already at the gliderport! I asked what he thought about the XC chances and explained the Limon task didn't seem good because the forecast winds had changed, so maybe I should head for Amarillo? There was some discussion in the background of his phone. I had made it clear that I wanted to fly to a goal so he laughed and suggested Guymon – so Guymon was set in my mind. When I got to Sunflower we checked the logger and the paperwork was signed.

I was number five for takeoff because **Mike Ordingreff** had graciously allowed me to go in front of him since his 55-1 has new wingtip wheels. That way he would run my wing and then do a no wing-runner takeoff without saprks flying like on the PW skids. **Mike** was the final tow as number six. **Bob** landed and put away the towplane, and then he grabbed everybody's wingwheels, weak links and taildollies, etc and put them in the hangar. He took off in the PIK which came into play on my flight, later.

On tow we crossed an area of lift on the northeast end of the runway and **Bob** circled back into it. I felt something in the glutimus maiximus vario, released, and I remember him asking why I got off so early. He was right! It was a scratchy 1kt up on the mechanical vario that seemed to persist forever until I could get enough altitude to push the start button and declare a good start on the radio. On SeeYou it was about 28 minutes from release until I started the task and I had made it to 4856 ft MSL, so I guess it wasn't so bad after all. It just seems that when you declare a task, getting to the start point is always that first major hurdle.

At this point in my story, I begin retyping, since I lost about a page of text due to fumblefingers and not paying attention to regular save data.

So, we headed off to Castleton and Pretty Prairie, taking a last look over the shoulder at the security of Sunflower. That is how I have a two-step commitment procedure for going XC. Some call it the wimp method, but even though I was firmly committed on the XC and the destination, I still had to reassure myself that there was no going back just because the thermals weren't 8-10kts up at that point.

On to Kingman with a brief bit of nostalgia for a very hot landout a couple of summers ago. The FBO was was closed down and it was really hot! A nice neighbor helped run the wing when Andrew came to get me, and I paid for my first retrieve. This was all to the accompaniment of much laughter on the ground when he proclaimed over the radio that the featherweight PW was making the cylinder head temp go up because I was reluctant to release until I was **positive** I had altitude to make it back to Sunflower.

Back on the heading to Guymon – well, not really the correct heading, but back to the May 28th story. There just wasn't any lift to the west of Kingman so I continued to track South with the knowledge that if I went too far south there would be a time factor in daylight hours available to make it to Guymon in little Tinkerbell. There, winds aloft were light so even a 60 kt groundspeed between thermals was going to require additional time if we were to make it.

Why, I'm not sure, but I had to stumble around the windmill farm area as on past flights. When we were about to Attica and eyeballing the known Harper/Anthony possibilities I heard a call, "LW your gear is down!" At that instant I was fumbling through the gymnastics of making a relief effort and was circling up close to cloud base. The lift had improved and it was easier to do the business in the easy lift up high. I called on the radio, "where are you **Bob**?" He said, "I'm right below you." I looked down and he was about 1,000 feet below and headed south at what looked like 100 kts plus. I'm pretty sure that was the last radio communication I had with any club members.

The railroad is such a great landmark that the southwesterly track was easy navigation. Once I finally got past there, I made it east/south of Hazelton and Kiowa, deciding that clouds had filled enough to head more to the west/southwest.

I could easily see Alva, keeping in mind the increase in military jet training in that area. When I was north of Alva I turned to a true westerly direction thinking that I could still turn for home at this point. In the PW if you can make it that far you might just as well go so Tinkerbell and I headed off into the sunset. A positive factor was being able to see the river bend where Freedom, Oklahoma should be with the highly visible dry-wash Cimarron River for a landmark, and a big bridge at the tiny junction for Freedom, OK.

Salt Flats west of Freedom, OK

Waynoka is also south, and about centered between Alva and Freedom. I had stopped once in Waynoka on a drive back from the Louisiana Gulf for a wedding of one of my swimmers who was stationed at Barksdale. I detoured to the gulf and then over to the Waynoka/Freedom combination just because it sounded cool and I had the time. I wanted to see the airfield that was once home to the TAT (Trans-Continental Air transport) combination of Ford Tri-motor flights with night transit by rail in Pullman sleeper cars. I had taught about this airline in the history section of many Aerospace Education classes. The airline would haul the passengers from the grass airfield to the train station in specially constructed Pullman trailers. From Waynoka they would ride the train to Clayton, New Mexico and then board another Tri-Motor to the west in the morning. Once I got to Waynoka I followed signs and drove out of town to a small asphalt strip and that was about it. So, I drove back into town and it was a pretty sleepy summer day. I finally stopped at an old brick, downtown-type, car dealership. You know the kind, one or two cars inside in the showroom were about all they had.

The one employee helped me out and took me to the courthouse, leaving the dealership unlocked. For all I know he was the owner or manager, I can't remember, but he was a heck of a nice guy. At the courthouse we picked up the key to the museum and he drove me to what was once the edge of town and the train station, which was now the museum. He took about an hour to let me wander the displays. The old airstrip is no longer there. If I remember correctly it had been turned into farm ground.

Well, so I had a short nostalgic burst and then looked forward to passing the brilliance of the salt beds west of Waynoka. The aquamarine and teals of the evaporation pools are visible from quite a distance. It takes a while to transit the salt beds along the river going east to west, and there were evenly spaced thermals to work to help me out. Between Freedom and Guymon there are only two airports, Buffalo, OK and Beaver, OK and they both were north of my course line. Out in that part of the country there isn't an abundance of wheat and one begins to look around for potential landout spots. With considerable reading emphasis on dehydration, I had started the day with three plastic water bottles and a 100 oz. Camelback. Knowing my water was getting low, I was starting to factor in that a walk to a farmhouse would have to be taken into account if I couldn't find some lift. The farms are further apart out there as well. When I landed I realized I was down to just a couple of sips from the Camelback.

Low spots on the flight were about 2,400 AGL down by the windmill farm west of Harper, and then about 2,600 AGL just SW of Buffalo out in the boonies. Past that I hit a couple of good climbs to 10,000 MSL and as the evening clouds got widely separated I detoured slightly to a big feedlot and got a Hail Mary, blue thermal that carried me over Guymon to the airport west of town. A C-210 had just landed and was turning around on the far end of the runway. I had made all my calls but the airwaves were mysteriously silent after I was south of Buffalo. The instructor and his student/son met me after they taxied in. I asked if they had heard me and they had the same question. They hadn't seen me until they turned around at the far end. My battery had run low during that final portion of the flight, something to consider for those planning a long XC. Greg Downing is the airport manager and he loaned me the courtesy car and directed me to a great burger and fries meal, downtown at The Pub. He left me access to the FBO for when I returned from eating. I should have avoided the airport coffee later though. I figured I would need it for the disassembly and trailer loading. So, I was blessed with air-conditioning and a long sofa until about 1:30 am when **Tony** made it to the airport with the trailer. Not that I could sleep – I was way too jacked up on adrenaline. **Tony** had landed out at Arlington, done the retrieve, and then grabbed the RAV 4 to head west for me. We demonstrated to **Tony** the extreme ease of loading a PW-5 into the trailer. He was impressed – at least he was impressed we had landed at an airport to make it all easier! I remember a tired comment about how, "this trailer was designed for storage, not for cross countries". I drove back to Sunflower with **Tony** getting some shuteye about the last half of the drive, quite an accomplishment in the little SUV. We got to Sunflower about sunrise and I tied down the trailer. **Tony** crawled into his vehicle to get a small amount of sleep and I drove on home with a short stop in McPherson to stretch and eat. It seems I am so wound-up after the long XC's that my mind just keeps replaying different portions of the flight. I really didn't sleep when I got home. That night I crashed, and to tell the truth I was worthless for a full two days just hanging out in the AC.

The Oudie showed 251 nm and the badge distance was 218 miles. The flight was six hours and six minutes off tow. A major lesson is to get down to Sunflower earlier! Another is that I need to stop thermalling as soon as the thermal weakens. With the penetration of the PW-5 I always want to milk the thermals as high as I can. I waste time that could be used for distance if I would become more aggressive about exiting the thermals sooner. I also think that the hydration issue is something I need to manage. I took plenty of water, but the data shows that age impacts the hydration as well as oxygen use on long, hot flights. Add in a long hike and it could become critical.

Finally, I was reminded of how great our club is. I was helped in terms of advice on the weather and route, getting the glider out of the barn, gaining a spot in the grid, getting a good launch and tow, and having a diehard retrieve occur. Thanks again to everybody who helped me achieve a fun and challenging cross country.

Tinkerbell at Guymon

Rope Break

By **Tony Condon**

I've been instructing in gliders for about 9 years now. Most of those who have flown with me know that my pretakeoff emergency briefing is "Below 200 feet, straight ahead; Above 200 feet, ahead or behind". June 7th was the first time I've had to exercise the "Straight Ahead" part of that briefing.

I was doing a couple instructional flights with **Don Jones**. He was flying the takeoff, to the north, when through not fault of his own, we suddenly found the towplane speeding away from us. I quickly glanced at the altimeter and saw 1700 feet. Nearly in unison, **Don** and I both said "We're too low" and then **Don** added "You've got it". Aw thanks **Don**!

As we all know, the options off the end of the runway are good. From our position I could see a wheat field and an open dirt field to the right, just south of Red Rock Road. I told **Don** I was going to the dirt. "You can't get hurt in the Dirt" is my usual landout mantra. The wheat was, of course, fully grown and in my opinion a real groundloop hazard. **Don**'s only comment was that it would be muddy. I said "Yea, oh well" or something to that effect as I opened the airbrakes.

The landing was held off as long as possible and the stop was sudden. **Don** was spot on about the muddy part. The Grob plowed a bit of a furrow as the gear dug in, the nose pitched down, and we plowed through the mud. The spray pattern was impressive, but everything and everybody was A-OK. Now what? I called **Matt**

Landing site on the left, photo **Rafael Soldan**. **Don** in our field on the right

Gonitzke immediately as he had run our wing. No one (except the towpilot) had even noticed that we had landed. **Matt** was a bit surprised that I was calling him.

The retrieve effort was, in short, epic. **Don** and I are probably forever indebted to **Matt Gonitzke**, **Kevin Ganoung**, **Sebastien Pepin**, **Jerry Martin**, and the farmer who lives just North of the field on Red Rock Road. Long story short, we used a bunch of auto tow rope and pulled the glider out of the field, starting with a couple pickups on the old taxiway and evolving to the farmers tractor pulling through the wheat field south of our landing field. He farms that field so we had no objections to him driving through it. We broke the rope a few times pulling back through the mud. Most of us got muddy, some of us REALLY muddy. Eventually we were to the old taxiway and then the next challenge was ahead of us. About an hour of maneuvering the glider through the maze of junk on the taxiway, cutting away some branches and then we finally were to the runway. Another hour with the hose and the glider was finally white again and it was ready for duty the next day. I think this was truly an adventure that none of us will forget. It was a good reminder for us to always have a plan and when the situation calls, execute the plan.

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Spline Mapping to Maximize Energy Exploitation of Non-Uniform Thermals

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Abstract

A method is described for modeling and maximizing the use of thermals by small unmanned aerial vehicles. A spline model is used to map thermals of arbitrary structure with no *a priori* knowledge of their shape. A candidate thermal exploitation method is developed to showcase the capability of this flexible mapping technique. Simulation results show the utility of the proposed approach both for simple Gaussian thermals and non-uniform thermals and compare climb rate for map-based thermalling and more traditional spiral climbing techniques.

Nomenclature

$\mathbf{c}$	basis spline coefficients
g	acceleration due to gravity
$\mathbf{h}$	observation model
k	spline order
n	number of knots supporting basis splines
r	turn radius
w	updraft velocity measurement
$\dot{z}$	sink rate
$C(w)$	contour at level w
K_t	Kalman gain
$N_{,k+1}$	basis spline of order k
$\mathcal{P}_k$	space of piecewise polynomial functions of order k
$\mathbf{P}$	state covariance
Q	process noise
R	measurement covariance
S	spline function
V_a	airspeed
$\mathbf{X}$	system state
ϕ	bank angle
λ	knot location

Introduction

Thermal soaring has been practiced by pilots of manned sailplanes since the invention of the variometer in the 1920s. Recently, the proliferation of small UAVs has sparked an interest in automated soaring methods. Work by Allen established that substantial gains could be made by exploiting thermals [1]; flight tests by Allen, and later Andersson demonstrated that autonomous aircraft could extend endurance by harvesting energy from thermals [2, 3]. Edwards demonstrated the use of thermalling in cross-country flight by an autonomous aircraft, placing third in competition with piloted RC aircraft [4].

Thermalling controllers to date have generally used variations of Reichmann's method to fly a constant radius circle around the center of a thermal, drawing from techniques used by piloted sailplanes to maximize climb rate [2, 5–7]. Thermal modeling in autonomous aircraft is rudimentary, typically estimating the strength and size of a radially-symmetric thermal with the objective of establishing a nominal turn rate for circling [2, 6]. Edwards does propose a method to estimate the size and orientation of an elliptical thermal [4], but no treatment has been given to an arbitrarily shaped thermal and no controllers developed to exploit such knowledge. Manned sailplane instrumentation is similarly rudimentary. While recent instrumentation presents climb rate along the flight path and sectors of maximum lift while thermalling, the pilot must mentally construct a model of the lift environment [8], as no automatic modeling capability is provided.

This paper presents a method using splines to map the air motion in a thermal without assuming a thermal structure, allowing a more fully descriptive model of a thermal to be constructed. A Kalman filter method is also presented which allows the map to be efficiently constructed by a sailplane in climb and allows the model to remain current with changes in the thermal. Further, a thermal exploitation method is presented which uses contours of constant lift from the thermal map as flight paths for the sailplane. The effectiveness of the contour path thermalling method is established by comparing climb rates with Allen's and Andersson's circling methods.

Thermal Modeling

Tensor Product Splines

Splines can be used to efficiently model complex functions of unknown shape, allowing complex non-linear functions to be described as a piecewise polynomial. Partitioning a function by a number of "knots," a different polynomial is defined on each segment with continuity of the k^{th} derivative at the knots, where k is the order of the spline. If the spline is written as a linear combination of functions, known as basis splines (or B-splines), then it represents a linear mapping and can be used in linear estimation algorithms. In this form the spline is written [9]:

$$S(x) = \sum_{i=-k}^{n} c_i N_{i,k+1}(x) \in \mathcal{P}_k \quad (1)$$

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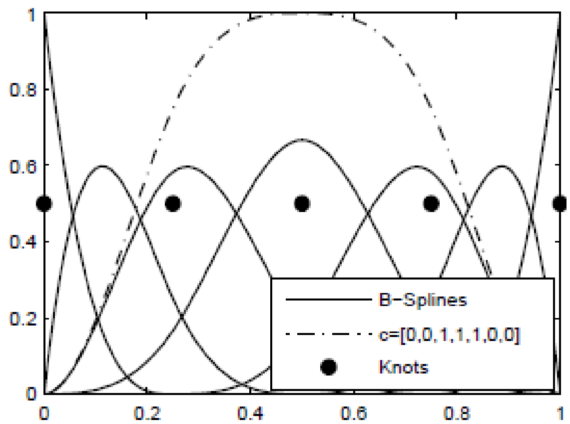

Fig. 1: Basis splines and one example spline with knots [0, 0.25, 0.5, 0.75, 1], order 3.

where N is the value at point x of a set of basis splines of order k defined on the set of knots $\lambda_j, j = 0 \ldots n+k-1$. Calculation of N is accomplished using a triangular scheme, described by Diercx [9]. The modeling of complex functions by linear combinations of basis splines is demonstrated in Fig. 1.

The concept of a spline can be generalized to more dimensions through use of the tensor product spline. In the tensor product spline, knot intervals are defined along each coordinate direction and the domain is then divided into cells defined by the Cartesian product of the knot intervals. In two dimensions this forms a rectangular mesh, with x and y knot intervals. The spline may be represented on each rectangle by the product of two polynomials, one along each coordinate direction [9]:

$$S \in \mathcal{P}_k \otimes \mathcal{P}_l$$

If $\mathcal{P}_k(x)$ and $\mathcal{P}_l(y)$ are written as basis splines as in Eq. 1, then the resulting bivariate spline is the tensor product of the two spline functions, which can be written [9]:

$$S(x,y) = \sum_{i=-k}^{n} \sum_{j=-l}^{m} c_{i,j} N_{i,k+1}(x) M_{j,l+1}(y)$$

With knots λ_i in x and μ_j in y fixing N and M, the values $c_{i,j}$ will define the shape of the spline function. The bilinearity of the tensor product [10] ensures that the final spline function is linear, thus $c_{i,j}$ can be estimated using any linear estimation procedure.

Thermal Modeling with Splines

The tensor product definition of a bivariate spline makes the thermal mapping process conceptually very simple: knots are defined on an interval bounding the region containing the thermal, and the order of the model is specified. The coefficients defining the spline's shape can then be estimated from measured updraft velocity to approximate the observed shape of the thermal. In order to keep the updates simple while allowing the thermal to change with time, a Kalman filter is used to estimate the shape of the thermal. The states of the Kalman filter are taken to be the spline coefficients, $c_{i,j}$ and the observation model is the tensor product of the two spline bases,

$$\mathbf{h}(x) = N_{i,k+1}(x) \otimes M_{j,l+1}(y) \tag{2}$$

The process noise is chosen to represent the expected change in the thermal parameters with time. With no state transition, the prediction step simply represents the increase in the uncertainty of the thermal map with time:

$$\begin{aligned} \hat{\mathbf{c}}_{t|t-1} &= \hat{\mathbf{c}}_{t-1|t-1} \\ \hat{\mathbf{P}}_{t|t-1} &= \hat{\mathbf{P}}_{t|t-1} + Q_t \end{aligned}$$

With the observation model defined as in Eq. 2 and the measurement noise chosen to represent the error in the measurement of vertical air motion, the Kalman filter update step proceeds:

$$\begin{aligned} K_t &= \hat{\mathbf{P}}_{t|t-1}\mathbf{h}^T(\mathbf{h}\hat{\mathbf{P}}_{t|t-1}\mathbf{h}^T + R_t)^{-1} \\ \hat{\mathbf{x}}_t &= \hat{\mathbf{c}}_{t|t-1} + K_t(w - \mathbf{h}\hat{\mathbf{c}}_{t|t-1}) \\ \hat{\mathbf{P}}_{t|t} &= (I - K_t\mathbf{h})\hat{\mathbf{P}}_{t|t-1} \end{aligned}$$

This filter allows the map to be rapidly updated, requiring storage of only the coefficient array $\mathbf{c}$ and its covariance matrix. The memory requirements are fairly modest, $\mathbf{c}$ has only $n = (k+g+l+h-2)$ elements, where k and l are the orders of the splines in the x and y directions, g and h are the number of knots in the x and y directions respectively. The update step does not even require matrix inversion, as $(\mathbf{h}\hat{\mathbf{P}}_{t|t-1}\hat{\mathbf{h}}^T + R_t)$ reduces to a scalar value.

The use of a Kalman filter means that the vertical wind velocity component, w can be incorporated as a raw measurement from a variometer with no prior filtering (i.e. a vario time constant of 0). The ability to directly incorporate this noisy measurement allows the elimination of filters which cause significant lag in most variometers, with the disadvantage that a good estimation of the vertical wind component requires a number of samples near a point to converge. In this paper a direct measurement of the wind field using the method described by Langelaan [11] is assumed, however measurements from a netto variometer could be used instead.

Path Planning

With a more complete understanding of the lift environment surrounding the sailplane comes the need for a method to leverage this information in harvesting energy from the thermal. This section proposes a path planning scheme which uses contours of the thermal map as candidate paths for the sailplane. A technique is also presented to balance exploration of the lift environment with exploitation of known areas of strong lift.

Contour Selection

As the aircraft constructs and updates the thermal map, a level set can be taken which describes a closed path around the estimated thermal structure that has a constant vertical wind speed. In order to optimize the aircraft climb rate, a cost function is defined to be the mean climb rate achieved during one orbit of a contour at level w (parameterized in polar coordinates by θ):

$$J(w) = \oint_{C(w)} (w - \dot{z}(\theta))\, d\theta$$

Making the assumption that the aircraft is in steady-state turning flight as it traverses the path, the sink rate $\dot{z}(\theta)$ can be related to the

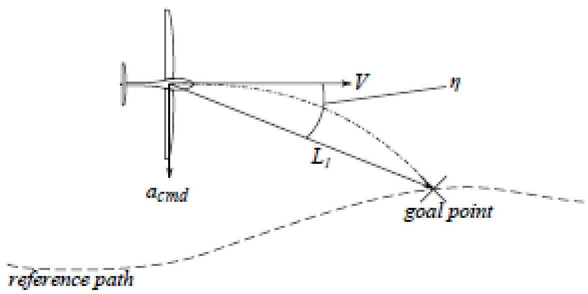

Fig. 2: Illustration of Park's nonlinear guidance law.

flight path curvature through the sailplane polar at a given bank angle, allowing the cost function to be evaluated relatively easily.

$$\begin{aligned}\dot{z} &= \dot{z}(\phi, V_a)\\ \phi &= \tan^{-1}\left(\frac{V_a{}^2}{r(\theta)g}\right)\end{aligned}$$

The term $r(\theta)$ is computed by locally fitting a circular arc at each point on the trajectory. With a cost function defined, the optimal path can be selected through the use of an optimization function to minimize the cost (coordinates here are defined positive down so a negative climb rate indicates an altitude gain).

Path Control

With a path defined, a controller is needed to keep the aircraft following the desired contour. The controller used here is a high level controller, developed under the assumption that lower level control (roll angle, airspeed control, etc) is already provided for on the UAV platform. To prevent unrealistic aircraft motions, the roll rate was restricted to $225°/s$ (high, but not completely unreasonable for a small UAV platform), and the roll rate tended to remain below $45°/s$. The controller implemented in this investigation is developed from the guidance method presented by Park [12], which generates a lateral acceleration command from the bearing to a reference point located on the desired path at a fixed distance from the vehicle as illustrated in Fig. 2.

The goal point progresses along the reference path so that it is always located at a distance L_1 from the aircraft. The lateral acceleration a_{cmd} is then given by:

$$a_{cmd} = 2\frac{V_a{}^2}{L_1} sin(\eta) \tag{3}$$

This guidance law gives good convergence and excellent tracking when compared with PID controllers [12], but presents several problems in this application. First, it cannot be guaranteed that there will be a point on the path that is distance L_1 away, especially when the contour is recalculated. Second, a closed path is more easily parameterized in polar coordinates. For these reasons, Park's guidance law is modified to use a constant look-ahead angle instead of distance. Use of the modified controller proceeds as:

1. The desired contour and aircraft position are shifted to put the path centroid at $(0,0)$. The path and aircraft position are then transformed to polar coordinates.

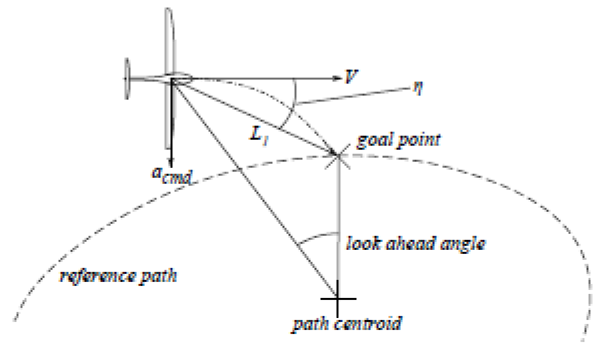

Fig. 3: Park's nonlinear guidance law modified for circular trajectories.

2. The goal point is selected to lie on the desired contour at a look-ahead angle of 15 deg.

3. L_1 is calculated as the distance from the aircraft position to the goal point.

This modified process is pictured in Fig. 3.

The lateral acceleration command is then computed as in Eq. 3. This guidance method gives accurate tracking and rapid convergence for paths that are not too complicated, but can fail for paths with overly skewed dimensions or for paths that loop back on themselves. The thermal models investigated in this paper did not present such problems. However, if real thermals prove to be sufficiently complex, this path following method may need to be revisited.

Windfield Exploration

Mapping the windfield to improve climb rate suffers from the quandary inherent in simultaneous mapping and exploitation of any resource - insufficient mapping of the wind field potentially leaves an area unexplored which could improve climb rate, but a thorough exploration takes time which degrades average climb rate. In an attempt to balance these competing objectives, a dither is applied to the aircraft goal location's radial distance from the path centroid. In this investigation a sinusoidally varying dither is applied with amplitude of 20 meters and period of 15 seconds. A dither amplitude based on the local uncertainty in the thermal map may deliver higher performance, but a fixed dither is used here for simplicity. This dither allows the aircraft to explore a region close to the current trajectory.

Simulation Results

In order to evaluate the benefit of modeling and path planning in thermals, several simulations were run for both planning and circling thermal exploitation techniques. Two types of simulation were run — a simulation to compare optimal climb rate achieved by planning and circling paths given *a priori* knowledge of the entire wind field, as well as a kinematic simulation of an aircraft flying in thermals with no prior windfield knowledge. In all simulations a perfect inner loop controller is assumed to test only the effectiveness of the outer loop guidance method. Measurements of vertical air motion were corrupted with zero mean Gaussian noise with standard deviation of 0.5 m/s in order to simulate the noise in the aircraft's sensors [11].

Table 1: Thermal initialization parameters for simulation.

Parameter	Min	Max	Mean	σ
Thermal Center (m)	-10	10	0	3
Thermal Strength (m/s)	-1.33	5.33	2	1
Number Of Cores	0	5	-	-
Core Strength (m/s)	-0.333	1.333	0.5	0.25
Core Radius (m)	0	97	30	20
Core Center (m, N or E)	-53	53	0	27

Table 2: Results for thermalling in an *a priori* known wind field.

Mean Climb Rate for Contour Planning Glider:	2.21 m/s
Mean Climb Rate for Circling Glider:	2.08 m/s
Minimum Improvement in Climb Rate:	-44%
Maximum Improvement in Climb Rate:	66%
Mean Improvement in Climb Rate:	6.2%
5th Percentile Improvement:	-12.8%
95th Percentile Improvement:	34.4%

Path Optimization with *a priori* Windfield Knowledge

To assess the potential of the contour planning method independent of the thermal model quality, a simulation was developed to plan both circular and contour paths on an *a priori* known windfield. The simulation compares contour paths with paths generated by optimizing a circular path centered at the thermal centroid, calculated using Allen's lift-weighted centroid method. Due to the complexity of the interaction between wind field structure and climb rate, a Monte Carlo approach was taken where each run was seeded with a random thermal composed of a Gaussian thermal with half-sine "cores" superimposed to form a more complex wind field. The thermal parameters and their ranges are given in Table 1.

To evaluate the climb rate achieved on a given path, the difference between aircraft sink rate (adjusted for load factor) and thermal rise rate is integrated around the path to determine mean climb rate. MATLAB's nonlinear optimization tools were then used to find the path maximizing climb rate. For the contour planning path, the contour level and aircraft speed are used as optimization targets. The circling method used circle radius and aircraft speed as independent variables. The simulation uses aerodynamic characteristics for an RnR Products SBXC sailplane, a 4.5 m span radio controlled sailplane commonly used in autonomous soaring experiments [2, 5, 6]. In 54% of cases the mapping approach showed better performance than the baseline. Results are summarized in Table 2 and flight paths for a typical case are shown in Fig. 4.

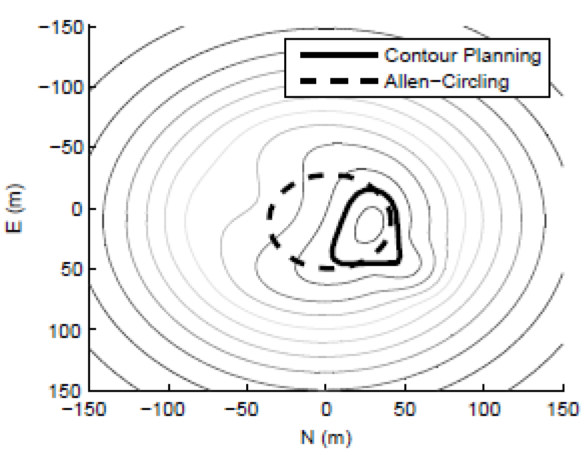

Fig. 4: Flight paths for circling and contour planning methods given *a priori* knowledge of the windfield.

Thermalling in an Unknown Windfield

A second simulation is used to evaluate the stability of the spline mapping and contour planning method as it explores and exploits a thermal. For comparison two other gliders are also simulated to compare the climb rate and flight paths for the different methods. One of the other gliders circles using Allen's method [2] and the second uses Andersson's controller [5]. For this simulation, thermals are modeled using Gedeon's single and four cell thermals of random strength and size [13]. The gliders are started at the same location at one corner of a box surrounding the thermal, with an initial heading into the box at a random angle between 0 and 90 degrees. The simulation is then run for four minutes to give the aircraft time to find and center the thermal. Figure 5 illustrates the flight paths flown by the three gliders during one such thermal encounter with a type 1 (single cell Gaussian) thermal and Table 3 summarizes the performance of the three methods.

In examining the bulk simulation results it is immediately apparent that the planning method converges to the thermal much more robustly than Allen's method. If the aircraft only grazes the thermal, often Allen's method will turn the wrong way or fail to turn in time to intercept the thermal and flies away from the area of lift. It should be noted that in both cases the aircraft controllers are only trying to thermal — there is no thresholding or logic for a thermal/cruise decision in the simulations. With the addition of such logic some of this advantage may be negated as the cases grazing the thermal in cruise may not trigger an attempt at thermalling for either method. Even so, ther-

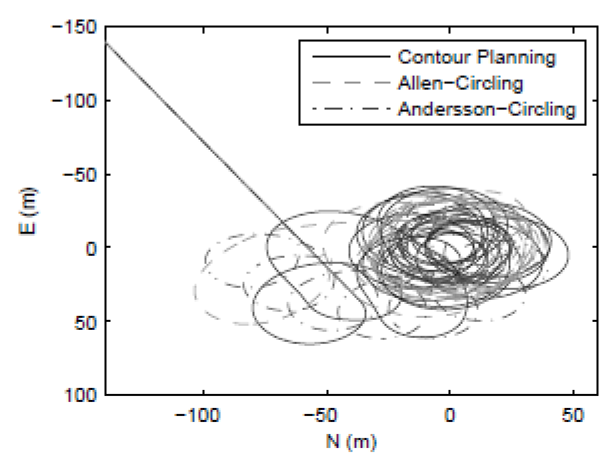

Fig. 5: Flight paths for three thermalling techniques during a four minute simulation of an encounter with a type 1 thermal, $C_0 = 3.2$ m/s, R = 114.46 m.

Table 3: **Results for exploitation of type 1 thermals, averaged over 113 simulations**

Climb Rate for the Full 240 Second Simulation			
	Contour Planning	Allen	Andersson
Min (m/s)	0.19	0.23	0.16
Max (m/s)	3.12	2.87	3.26
Mean (m/s)	1.47	1.42	1.46
Mean Climb Rate in the final 30 Seconds of Simulation			
	Contour Planning	Allen	Andersson
Min (m/s)	0.28	0.26	0.25
Max (m/s)	3.47	3.47	3.65
Mean (m/s)	1.64	1.60	1.74

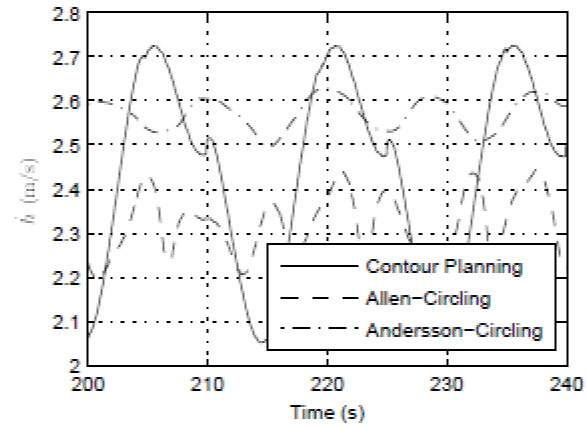

Fig. 6: Climb rate during the final 40 seconds of simulation in type 1 thermal, $C_0 = 3.2$ m/s, $R = 114.46$ m.

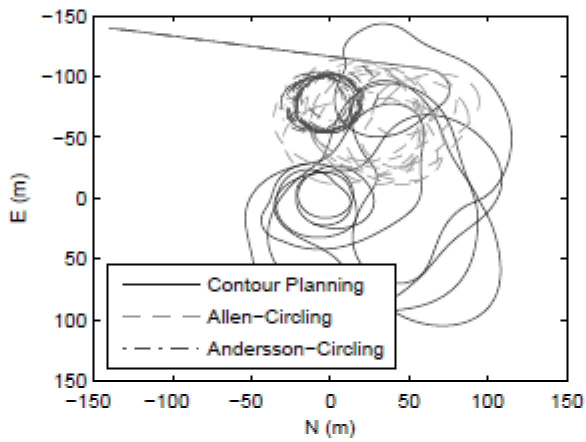

Fig. 7: Flight paths for three thermalling techniques during a four minute simulation of an encounter with a type 2 thermal, $C_0 = 4.4$ m/s, $R = 42.93$ m.

mal mapping conveys a clear advantage in stability of convergence. In comparing Andersson's controller and the contour planning method, it is seen that Andersson's controller has very robust convergence characteristics within the thermal itself, but is very sensitive to thermal/cruise logic. If the aircraft is not definitely in the thermal when the controller begins operation then the controller will converge slowly to the center, if it converges at all. In order to ensure that the controller had a chance of succeeding it was necessary to add a logic switch to prevent Andersson's controller from operating until the aircraft had entered the thermal.

If the examination is restricted only to the cases where all aircraft successfully intercepted the thermal, the contour planning glider out climbed the Allen-circling glider by an average of 3.5%. Some of the climb advantage can be attributed to the reduced time required to center a thermal (under one turn in some situations), but, as can be seen in Fig. 6, the final climb rate is also superior, the mean climb rate in the final 30 seconds of simulation was 2.5% better for the planning glider than for the circling one. Comparing the mapping and Andersson-circling gliders, the total climb achieved is nearly identical, with the planning circling glider achieving a total climb less than 1% better on average. Comparison of the final climb rates indicates that the planning glider has an advantage in more rapid centering: despite a lower mean climb rate, the Andersson-circling glider achieved a climb rate in the final 30 seconds of simulation 5.7% better on average than did the planning glider. With a simple, Gaussian type thermal, this is to be expected as this thermal model plays to the strengths of the Andersson-circling technique. Both the planning glider and Andersson-circling glider have some room to improve climb rate in the simple Gaussian thermal. The gains used for Andersson's controller could be tuned more finely than those used here, allowing more rapid convergence. For the planning glider, a more sophisticated dithering algorithm would improve the final climb rate as the simple dithering algorithm takes the aircraft into non-optimal areas even after the thermal model has converged.

The periodic notch that can be seen in the planning method climb rate occurs at the replanning intervals. When a new contour is determined the aircraft is often some distance away from the contour and begins an aggressive maneuver to intercept the proper trajectory, temporarily increasing its sink rate.

The thermalling techniques were also tested for the type 2, four cell thermal [13]. Again, the mapping glider converges to the thermal much more consistently than the other gliders. Examining only the cases where all methods converged, the methods have nearly identical mean climb rates over the course of a four minute simulation. Examining the final 30 seconds of climb shows that the steady-state climb rate is superior for the Allen-circling glider, with a steady state climb rate averaging 3% better than the mapping technique. The reason for the discrepancy between mean and steady-state climb rates for the four cell thermals becomes apparent when examining the flight paths in Fig. 7. With no clear maximal point in the thermal, the contour planning glider traverses an irregular trajectory as it maps the thermal. Unlike the simple Gaussian thermal which is rapidly mapped and has a clear and easily determined structure, the complexity in the type 2 thermals occasionally leads to phantom peaks in the model such as that visible in Fig. 8. Chasing these irregularities naturally leads the planning glider to fully explore the thermal and limits the uncertainty in the model, but also degrades the mean climb rate. Table 4 presents the differences in climb for several simulations using the type 2 thermal structure.

Comparing the contour planning glider and the Andersson-circling glider, the mean climb rate is similar for the two techniques. The planning glider achieves a mean climb rate 1.4% better than the Andersson-circling glider, and in the final 30 seconds of simulation the climb rate

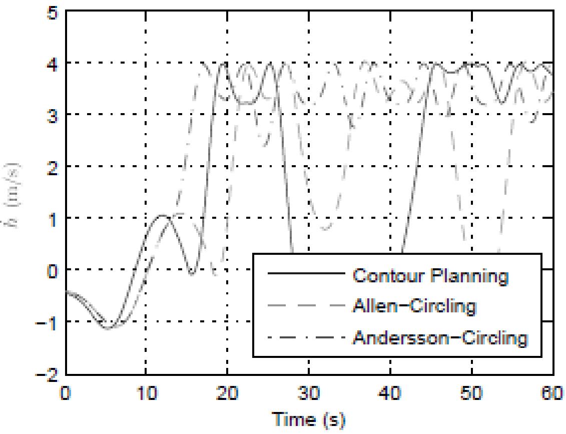

Fig. 8: Climb rate during the first 60 seconds of simulation in Konovalov type 2 thermal, $C_0 = 4.4$ m/s, R = 42.93 m.

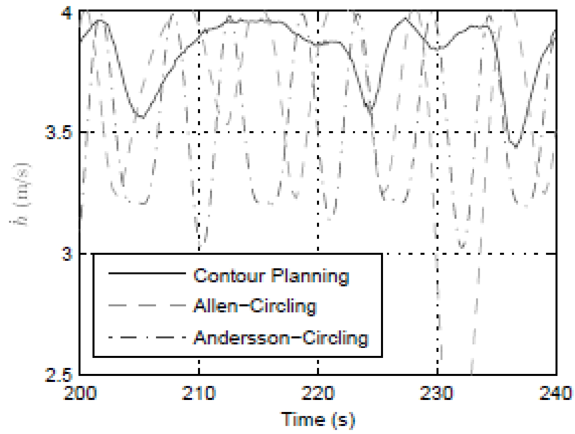

Fig. 9: Climb rate during the final 40 seconds of simulation in Konovalov type 2 thermal, $C_0 = 4.4$ m/s, R = 42.93 m.

Table 4: Results for exploitation of type 2 thermals, averaged over 127 simulations.

Climb Rate for the Full 240 Second Simulation			
	Contour Planning	Allen	Andersson
Min (m/s)	-0.02	0.06	-0.47
Max (m/s)	4.0	3.46	3.82
Mean (m/s)	1.47	1.46	1.45
Mean Climb Rate in the final 30 Seconds of Simulation			
	Contour Planning	Allen	Andersson
Min (m/s)	-0.02	0.08	-0.44
Max (m/s)	4.16	3.88	3.92
Mean (m/s)	1.62	1.67	1.55

achieved by the planning glider is 4.5% better than the Andersson-circling glider. The flight path trace bears this out - the Andersson-circling glider immediately starts turning in the edge of the thermal, achieving an initial climb rate advantage. Once the planning glider has sufficiently mapped the thermal it can catch up by flying a path in a more consistent portion of the thermal, seen in the smaller variation in climb rate depicted in Fig. 9.

The climb rates achieved by the Andersson and Allen techniques in the two thermals illustrate the sensitivity these two techniques have to assumptions built into their algorithms about thermal structure. Using the parameters specified by the authors of these controllers [2, 5], the two controllers exhibit "preferred" thermal sizes. As specified, the Andersson controller prefers a small thermal, flying tight circles which gives it good performance in the type 1 thermals with a clear and narrow core. The Allen controller prefers a larger thermal, making it better suited to centering the wide core of the type 2 thermals, where the Andersson controller ends up stuck on the edge and achieves a lower climb rate. The planning controller runs a course in between, delivering consistent performance in several thermal structures, though not achieving maximum climb rate in either.

Thermal Modeling

Mapping a thermal while soaring is useful for more than just the contour controller presented, it could enable other controller types or the tuning of existing controllers. While quantitative evaluation of such a model is problematic, an example model constructed during one simulation run is presented below. Evolution of the thermal map for one of the type 2 thermals is illustrated in Fig. 10. Qualitatively the figure shows the algorithm presented is capable of mapping even complex thermal structures.

The broken outer ring observed in the map is the result of the aircraft not flying in that region. Since the spline model is purely descriptive, windfield features will not be modeled for areas where the aircraft did not gather data.

Conclusion

A method has been presented for mapping non-uniform thermals by aircraft in soaring flight. A path-planning method using the thermal map to maximize exploitation of thermals has also been presented.

Simulations using several thermal structures show that thermal maps can be constructed by a sailplane in climb given measurements reasonably available on board the aircraft. The utility of the map is established through the performance of the contour-following controller which achieves mean climb rates similar to existing thermalling controllers, and exhibits resiliency to differing thermal structure and size. Further improvements in the thermal map quality can be made through the implementation of algorithms to automatically place the spline knots. In addition to the thermalling controller presented in this paper, the utility of thermal mapping could be extended to an adaptive thermal size for Andersson or Allen's controllers, or displaying a better picture of the lift environment to the pilot of a manned sailplane.

While the contour following controller presented here shows promise, further examination should be made of the cost incurred by frequent control surface action needed in order to follow the more complex paths generated by the controller.

Acknowledgments

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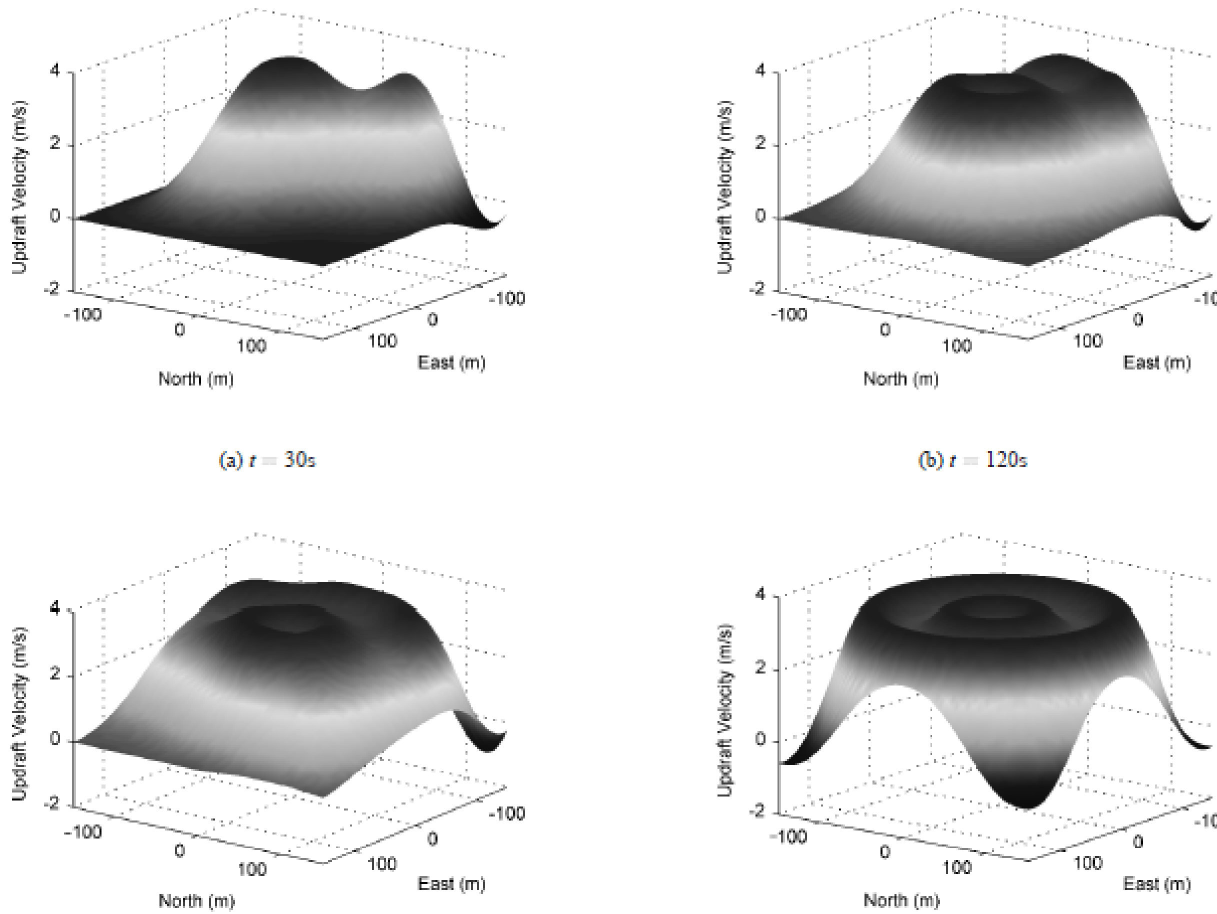

(a) $t = 30$s

(b) $t = 120$s

(c) $t = 240$s (end of simulation)

(d) True Structure

Fig. 10: Evolution of the thermal map for a type 2 thermal, $C_0 = 4.4$ m/s, R = 42.93 m. Breaks in the outer ring are in regions not sampled by the sailplane.

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KSA Duty Schedule

DATE	TOW PILOT		LINE MANAGER		INSTRUCTOR	
Fri, Jul 4, 14 Holiday	Bob Hinson	316-841-5561	Shea Zuckerman	801-554-7337		
Sat, Jul 5, 14 Reg. 10 N. Practice	KC Alexander	316-308-8498	Mike Davis	316-772-8535	Rafael Soldan	706-255-9909
Sun, Jul 6, 14 Reg. 10 N. Practice	Bob Holliday	316-733-5403	Mark Ross	316-214-1464		
Mon, Jul 7, 14 Reg. 10 N. Contest						
Tue, Jul 8, 14 Reg. 10 N. Contest						
Wed, Jul 9, 14 Reg. 10 N. Contest						
Thu, Jul 10, 14 Reg. 10 N. Contest						
Fri, Jul 11, 14 Reg. 10 N. Contest						
Sat, Jul 12, 14 Cookout	Mark Schlegel	316-641-5093	Paul Sodamann	785-456-5654	Tony Condon	515-291-0089
			Kevin Ganoung	785-536-4540		
Sun, Jul 13, 14	Jack Seltman	316-636-4218	Steve Leonard	785-643-6817		
			Paul Sodamann	785-456-5654		
Sat, Jul 19, 14 Kowbell	Mark Schlegel	316-641-5093	Aaron Maurer	316-300-6741	Brian Bird	620-728-1341
			Jerome Martin	620-259-7827		
Sun, Jul 20, 14 Konsolation	Bob Hinson	316-841-5561	Dennis Brown	316-722-8351		
			Jerome Martin	620-259-7827		
Sat, Jul 26, 14 Konsolation II	Jerry Boone	620-662-5330	Dennis Brown	316-722-8351	Mike Westemeir	316-729-2551
			Shea Zucherman	801-554-7337		
Sun, Jul 27, 14	Bob Hinson	316-841-5561	Harry Clayton	316-744-2389		
			Susan Erlenwein	316-744-2389		
Sat, Aug 2, 14	Mark Schlegel	316-641-5093	Paul Sodamann	785-456-5654	Rafael Soldan	706-255-9909
			Sebastien Pepin	401-585-6833		
Sun, Aug 3, 14	Jack Seltman	316-636-4218	Neale Eyler	316-729-0659		
			Paul Sodamann	785-456-5654		
Sat, Aug 9, 14 Cookout	Bob Hinson	316-841-5561	Bob Blanton	316-683-9759	Mike Westemeir	316-729-2551
			Robbie Gra- bendike	316-686-8859		
Sun, Aug 10, 14	Brian Bird	620-728-1341	Scott Dimick	316-733-5678		
			Luke Marquardt	316-531-2621		
Sat, Aug 16, 14	Mike Logback	620-755-1786	Shea Zucherman	801-554-7337	Rafael Soldan	706-255-9909
			Aaron Maurer	316-300-6741		
Sun, Aug 17, 14	Mike Logback	620-755-1786	Mike Davis	316-772-8535		
			Dana Duckworth	316-722-2078		
Sat, Aug 23, 14	Mike Westemeir	316-729-2551	Bob Blanton	316-683-9759	Brian Bird	620-728-1341
			Robbie Grabendike	316-686-8859		
Sun, Aug 24, 14	Bob Holliday	316-733-5403	Harry Clayton	316-744-2389		
			Susan Erlenwein	316-744-2389		
Sat, Aug 30, 14 Holiday	Bob Hinson	316-841-5561	Mike Davis	316-772-8535	Andrew Peters	316-682-4287
			Jerome Martin	620-259-7827		
Sun, Aug 31, 14 Holiday	Mike Logback	620-755-1786	Mark Ross	316-214-1464		
			Aaron Maurer	316-300-6741		

KSA TOWCARD

TOW NUMBER ____________ START TACH TIME ________________

TOW PILOT ____________________

PILOT ____________________________

ADDRESS ____________________________

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SAILPLANE ____________________________

TOW HEIGHT ____________________________

TOW SPEED (MPH) ______________

DATE ____________________________

KSA TOWCARD

TOW NUMBER ____________ START TACH TIME ________________

TOW PILOT ____________________

PILOT ____________________________

ADDRESS ____________________________

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SAILPLANE ____________________________

TOW HEIGHT ____________________________

TOW SPEED (MPH) ______________

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KSA TOWCARD

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KSA TOWCARD

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PILOT ____________________________

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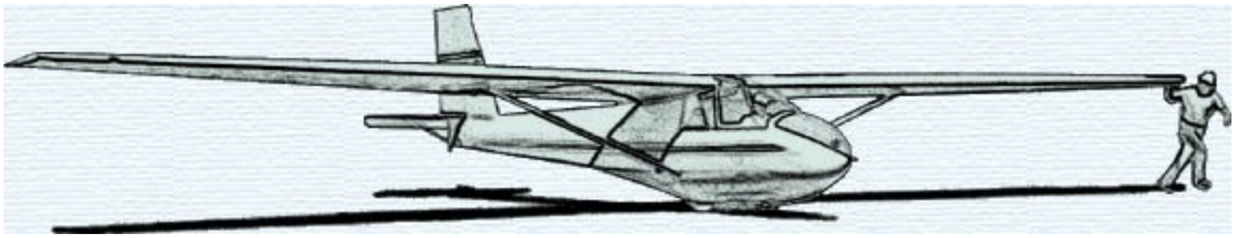
SAILPLANE ____________________________

TOW HEIGHT ____________________________

TOW SPEED (MPH) ______________

DATE ____________________________

KSA VARIOMETER
911 N Gilman
Wichita, KS 67203
abcondon@gmail.com



KSA MEETING

Cookout at Sunflower

Saturday July 12th, 2014, 5:00 PM

Bring a side dish to share!