PRINCIPIA SOLAR CAR

ONE MIND • ONE LIGHT • INFINITE RAYS

MARCH 2018 EDITION


# THE SOLAR FLARE

# INTRODUCING RA X

## A LETTER FROM THE EDITOR

Hello solar friends and family!

It has been a while since we've sent out a newsletter and the team has a lot to tell you about. In the past couple of years, we've been hard at work designing, fabricating, and racing our newest car, Ra X (pronounced "rah ten"). In the summer of 2016, Ra 9 ran her last race in the American Solar Challenge, finishing 2nd in the track race and 5th in the cross country race from Brecksville, OH, to Hot Springs, SD.

After coming back from the race, the team buckled down to design what we hoped would be our best car yet. Kenneth Stack (aerodynamics leader) and I (mechanical leader) teamed up to design a body and chassis that fit well together and were optimized for weight and aerodynamics. Meanwhile, Jackson Walker and Nick Flanders (electrical leaders, former and current) worked hard to make circuit boards and electrical systems that were cleaner and more efficient than designs past.

As 2016 came to an end, we spent a long Saturday doing a layup to make the carbon fiber car body, and in the spring of 2017 we finished the chassis design in time to get the steel frame manufactured by the start of the summer. That summer, we scrambled to put the car together in time to race in the 2017 Formula Sun Grand Prix, hosted at the Circuit of the Americas track in Austin, Texas. We used that race as a practice race to prepare for our ultimate goal: the 2017 World Solar Challenge.

Last September, nine students and eight faculty members and supporters left for the great Australian outback, where we raced over 3000km from Darwin to Adelaide. Unfortunately, leaky shocks and some bad battery modules set us back on our race, and constant clouds during days two and three forced us to put our car in our trailer and seek out nicer weather down the road to complete the rest of the journey. While we didn't make it the entire way on sunshine, our team has learned from our setbacks and has come out of this experience stronger and better prepared for our next race!

I hope that you enjoy the rest of this newsletter as the team details some of the great adventures we've had. Thank you for your continued support of the Principia Solar Car Team. We couldn't do any of this without you!

Nicole Gerber

*Cover photos:*
*Top right: Nick Flanders, electrical team leader, gets ready to drive*
*Bottom left: Nicole Gerber, mechanical team leader, works on the rear suspension*
*Bottom right: The team poses behind the solar car at the finish line*

*The team preps the car for the race track*


*The solar car lines up to leave the starting line in Darwin*

*The team visits a river on an afternoon off in Darwin*

*Driver Nick practices for the "Figure-of-8" test*

*A group gathers to read the Bible Lesson*


*A few team members set the array up for evening charging*


*The whole team gathers around the car at the finish line in Adelaide*

*The solar car drives through a storm*

# WELCOME TO THE OUTBACK

# AN AUSTRALIAN EXPERIENCE

## BY AVA LESKO

This past fall, the Principia Solar Car Team embarked on an incredible journey through the outback of Australia, relying on solar rays and Spirit to cross the finish line. We began with a 17-hour flight from the bluffs to the outback across the massive Pacific. For many of us, this was the farthest we had ever traveled away from home. Once we arrived and felt the humidity of Darwin, we were greeted by the dedicated team members that had been there for a few weeks.

Throughout the first week, the team spent time at Hidden Valley race track working on projects to make the car more mechanically sound, as well as improving the electronics for racing. We had the opportunity to use the race track for testing the car in preparation for qualifying. At the culmination of the week, the team went through static and dynamic scrutineering, where engineers look thoroughly at the car's mechanical and electrical systems to make sure that all regulations are met for competition. After passing inspection, the team embarked on a 6-day journey from Darwin to Adelaide, aiming to rely on solar power the whole way.

One of my favorite experiences from this trip was finding the right place to stay each night. Each day, the car has 8 hours of driving time and must be off the road by 4pm, so it is the team's job to track where we will be going and find potential spots along the way. Each time a need arose to either stop early or find a spot as soon as possible, the right place was shown to us and it ended harmoniously.

One specific time, the team needed to pull the car over to fix a motor and we were led to pull onto a side road. Soon into the repair, someone noticed that a large road train was headed towards the car. As a safety leader and with the help of radio communication, I was able to stop the road train in time for it to move around the car safely. This experience was a blessing for the team and we were able to get back on route safely after.

After 6 challenging days, the team crossed the finish line in sunny Adelaide. It was a magical feeling of accomplishment, in spite of all the challenges encountered along the way. In Adelaide, we had the opportunity to meet with all of the other teams, see their cars, and exchange tales from the race! We also attended an awards ceremony at the end to celebrate all of our collective accomplishments. The atmosphere during the time in Adelaide was specifically inspiring to me because I could feel the presence of a future of intelligent leaders. It was a feeling of confidence, that with these great minds in charge of the future of transportation, we would be in good hands.

In Adelaide, the team had the opportunity to visit the Cleland Wildlife Park, which was certainly a highlight for me. We were able to visit kangaroos and emus up close! Overall, this experience taught me about working effectively as a team, despite ups and downs, and to appreciate and learn lessons from the people around us.

*Ava Lesko joined the team in the fall of 2016, and came to the World Solar Challenge as her very first race! She is currently a sophomore majoring in chemistry.*


*Ava directs a road train around the solar car as it's pulled over for repairs*

*Kangaroos at the Cleland Wildlife Park*

# THE GOOD PEOPLE OF AUSTRALIA

## BY STEVE SHEDD

During five Solar Car races across Australia and on a 10-week Abroad there, I've learned that the people in Australia are honest, friendly, and very willing to help. This was still the case last October in our World Solar Challenge, where two examples really stood out to me.

On the fourth day of racing across the continent of Australia, our Solar Car (Ra X) had to make another unscheduled stop for repairs. Since the car was just over the crest of a small rise, the caravan radioed Solar Car alumni Chad Reid and Tom Brownell in the truck to pull off to the side of the road and signal to traffic that they should be careful ahead. With repairs completed, Ra X was now ready to roll, but the truck couldn't go because the wheels got stuck in the mud on the unpaved shoulder of the Stuart Highway.


*A Gilbert's Transport Service driver pulls the truck out of the mud*

*O-rings replaced from one of the air shocks*

*Mik and Van, Bull's Garage workers, help Nicole with the shocks*

So, they radioed me and asked me to get a tow truck. I drove 15-20 miles back up the highway to the nearest gas station. They told us where the nearest tow truck was and we called them, only to learn that the fee was $1,650 and they couldn't come until tomorrow. This was unacceptable as our tools, parts, luggage, tents, etc. were all in the truck and we needed them with us that evening wherever we ended up.

I headed back toward the truck to see what else could be done. When I got within radio range, I found that they had already been helped by a road train driver with three trailers. He drove up the highway to a pull-off spot, unhooked his trailers, made a U-turn, and drove back to our truck. He lined his rig up with our truck and attached a chain to our vehicle in order to pull it onto the pavement. He then drove back to his trailers where I met him and took the picture. I offered to pay him for his trouble, and he said absolutely not – he was very happy to help. He had just saved Solar Car $1,650 and LOTS of trouble.

The next day the caravan radioed me to go to the next control stop (Coober Pedy) and try to find a place that had a vise. Nicole Gerber had to rebuild the two rear shocks that had been replaced and we didn't have a vise with us.

Coober Pedy is a small town of 1,700 people where they mine 80% of all the opals in the world. There are only 2 gas stations in town and the first one I tried said that yes they had a vise and that we could use it. The caravan rolled into the control stop just before 3:30 PM and I brought Nicole and her parts to the gas station – Bull's Garage. I would have guessed that a pneumatic shock would have about 3 o-rings in it – but I would be very wrong – as you can see in my picture.

The two fellows at the garage helped Nicole for a full 5 hours – 3 hours past their closing time! I tried hard to pay them for their immense help, and they said no – they were very glad they could help. These are just two examples of how wonderful the people are in Australia.

*Steve Shedd has been a faculty advisor, fundraiser, photographer, and solar car supporter for many years. On most races, he drives the lead vehicle directly in front of the solar car.*


HIDDEN VALLEY
WESTERN SYDNEY UNIVERSITY
WORLD SOLAR CHALLENGE
NOVUM
SIEMENS

# MY TIME AS A SOLAR CAR DRIVER

## BY ANDREW HUDDLESTON

The process of designing and building a solar car is a strenuous and difficult one, but it is not without its moments of pure elation. The first time the car turns on, the first time the car rolls and makes a turn, and the first time the car gets on the open road are a few times that come to mind when I think of fantastic moments as a member of the project from the beginning of construction to racing the car. However, none of those moments compare to the numerous times that I have been behind the wheel.

I have been a member of the Principia Solar Car Team since the beginning of my freshman year in 2015. Since then, I have been a part of the mechanical team and have had a hand in the design and construction of Ra X and its components. I was also a member of the race team in the 2016 American Solar Challenge and the 2017 Formula Sun Gran Prix. In the fall of 2017, I not only had the opportunity to join the race team in the 2017 World Solar Challenge in Australia but was given the privilege to be one of the drivers of Ra X during the race through the Australian outback. Being a driver quickly became one of my favorite parts of solar car.

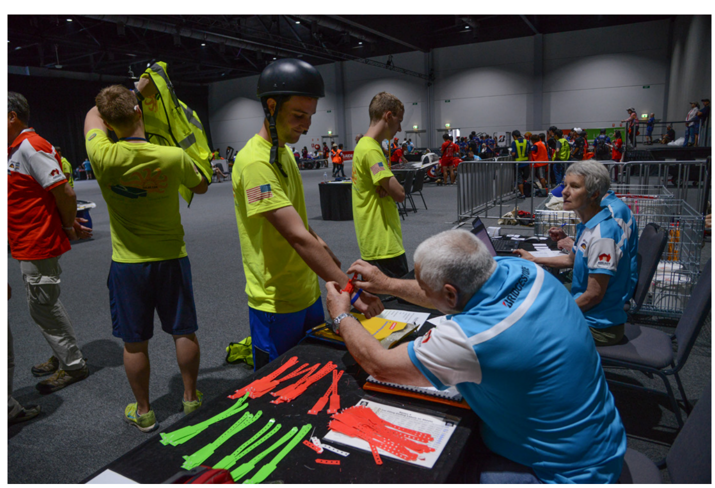
Driving a solar car is not as straightforward as driving a family-sized SUV, a fact which I was quick to discover. First and foremost, riding in the car isn't what most people would consider to be "comfortable." Due to the design of the suspension, every crack and rock on the road is easily felt. This is because we made the suspension very stiff in order to optimize efficiency. There also isn't much space for the driver. Ra X was built to be as slender and aerodynamic as possible, which in turn made the space for the driver considerably tight. There is just enough room to get in and out, and to comfortably turn the wheel 90 degrees in either direction. Driving Ra X really gave me an appreciation for the leather seats and cup holders in my old "compact" car.

A subtler change from driving a street car to racing a solar car is how much the driver is required to pay attention to, especially the battery voltage and the current that the motor is drawing from the battery pack. The driver doesn't just have to worry about keeping the car on the road, but also driving as efficiently as possible. A Principia solar car driver on a race will be constantly updated on the strategy that they should be implementing during the race. This usually involves a target speed the driver should aim for, or maybe a target current draw (i.e. the number of amps the driver should try not to go above). Again, being as efficient as possible is key to driving a solar car. This entails going as fast as the strategy team wants while using as little of the battery as possible. I found this to be a challenging but extremely rewarding balancing act. At first it was very difficult for me to maintain the speed I wanted without wasting more of the battery, but as I spent more time behind the wheel, I found it to be a fun challenge.

Being in that tiny uncomfortable car surrounded by the Australian outback as far as the eye can see is an experience like none other. There was a moment while racing that the challenge turned from tough to interesting and the ride changed from rough to peaceful. In that moment, there was no other place I would rather be.

*Andrew Huddleston has been a part of the team for three years and primarily works on the mechanical team when he's not driving the solar car.*


*Andrew lines up to enter the track in Darwin*



*Drivers weigh in and get their bracelets at scrutineering*

# NEW MEMBERS

My name is Antonio Rojas Acuña and I am a sophomore at Principia College. I am studying civil engineering. I have always liked the engineering career, and I dream of one day building amazing structures when I become a professional. I am from Bogotá, Colombia. I lived almost all my life there until we found out about Principia, where I came to become a better Christian Scientist. I joined the solar car team because I am very interested in learning all about solar panels. Later on, I want to be able to implement my knowledge about solar energy into the structures I will build so that they will be more sustainable. On the solar car team, I am interested in working with both the mechanical and electrical teams.

My name is Hanna Farson. I am a Freshman and I am undecided on my major, but I am leaning towards history or religion. My family currently lives in Godfrey, IL. However, I grew up in Zaventem, Belgium; Tripoli, Libya; and Washington D.C., among other places. I enjoy reading and was a gymnast for 15 years. I joined the team because I wanted more opportunities to meet people and I enjoy building things. I am currently on the mechanical team and I recently learned how to bleed the brakes of Ra X. I am not really sure what I am going to do in the future but I am hoping that it takes me back overseas.

My name is Grace Ndayishimiye. Right now, I am a freshman looking into majoring in chemical engineering. I am originally from Kigali, Rwanda, and some of my favorite things to do in my free time are volunteering and reading a lot of books. I love helping other people and being of service. I joined the solar car team because I am intrigued by how the team comes up with the design for the cars and how they put together all the different aspects of the solar car. I am really interested in working on the mechanical and body teams and learning more about the composite materials that go into the car. Right now, I'm working with the body team to find a better plastic to use for the canopy of the car.

# NEW MEMBERS

My name is Annika Marthaler and I'm a freshman majoring in computer science. I'm from Cambria, California, and I love running, cooking, and backpacking. I joined the team because I loved the collaboration and trust of the team and how they work so hard to uphold high standards of teamwork and craftsmanship to represent Principia College. I also find the advancing field of solar technology to be fascinating. I like being able to understand how each part of the car contributes towards a finished product, but I enjoy the design aspect the most. I am excited to go wherever God has planned for me, and right now that's being a student here at Principia.

My name is John Woodall, I'm a freshman and a mass communications and digital media production major. I play the saxophone in jazz band and I enjoy photography and filmmaking. I joined the team because I love working together with other people to create something. I think how things work mechanically is intriguing and I love the hands-on experience of getting to build and finding creative solutions to problems. I like being able to be a part of helping make the solar car team better. In the future, I want to be a filmmaker and create content that will inspire other people.

My name is Rachel Smith and I am a one year enrichment student from Toowoomba, Australia. I joined the solar car team because when I go back home, I will be studying electrical engineering and my university doesn't have a solar car team. I play violin, swim, and enjoy spending time on the weekends in the solar car shop. Last semester I learned to use Altium software for PCB design, and this semester I would like to learn more about the silicon solar cells and how they harness energy from the sun. In the future, I would like to work with GPS systems in farming, and the skills I am learning in solar car will help me with anything I choose to do.

# THE MAKING OF RA X: COMPOSITE LAYUP

## BY BILLY BROOKE

A car is not complete without a body. The body of the car is what gives the car its good looks, what allows the car to cut through the air with minimal effort, and what we mount the solar cells onto. Unlike the body on your typical car or truck – which is mass manufactured and made out of either steel or aluminum – the body of a solar car is custom made using aluminum honeycomb sandwiched between sheets of carbon fiber in a process called a layup.

The layup process is not specific to the Solar Car world. Layups are done in many different industries, from aerospace, to automotive, to boat manufacturing. A layup is any process in which a fibrous material (i.e. Kevlar, carbon fiber, fiberglass) is bonded to another material (anything from steel to carboard), usually using epoxy – a special type of glue which, while similar to Gorilla or super glue, is intended for more permanent industrial applications than its more consumer-oriented cousins. The method typically used is infusing the fibrous material with the epoxy, shaping it onto whatever surface the layup is being done on, and then allowing it to cure. We do our layups on molds – parts shaped like the car that we use as three-dimensional templates. The molds are coated with a release film (functionally the same as the Pam cooking spray used when baking) so that the layup doesn't stick to the mold. Once we have applied the film release, we put the first layer of epoxy-infused carbon fiber onto the mold, followed by an aluminum honeycomb core, and then the last layer of epoxy-infused carbon fiber. The carbon fiber that we use is similar to cloth; by itself the cloth is flexible and relatively thin, but with the epoxy and the honeycomb core, each component gains some of the best properties of the other – the carbon fiber becomes much more stiff, making it able to withstand being buffeted by the wind without losing its shape, and the core gains the strength of the carbon fiber. Once that part of the process is finished, the entire layup is covered with a piece of plastic, put under vacuum, and left to cure.

Because of the car's size, if we did a layup of the entire body all at once, the process would take more than a full day to complete. So, we split it into multiple layups: the upper body, the lower body, and the wheel covers (called fairings). Even then, with each layup done individually and the prep completed the day before (cutting the cloth and core to size and preparing the mold surface), it still took us just over twelve hours to get the lower body layup under vacuum.

After all of the work it took to make the body of the car, it was a treat to see the finished product race down the road. It highlighted one of the reasons I enjoy being a member of this team – I am able to actively contribute to a final product that is able to compete on the world stage.

*Billy Brooke works on the electrical team and is our team's safety head. He joined the team his freshman year and is majoring in Principia's mechanical engineering program.*

*Jake Williams carefully pours epoxy to weigh for a layup*

*The team removes the upper body from the mold for the first time*

# THE MAKING OF RA X: FRAME CONSTRUCTION

## BY JAKE WILLIAMS

The solar car has two main parts to it: the body and the frame. The body of the solar car is the outside shell that is exposed to the air. It is aerodynamic, but it doesn't have to support any components of the car. The structural strength of the car comes from the frame (or chassis) – the steel skeleton of the car that holds the driver, the battery pack, and all of the suspension components.

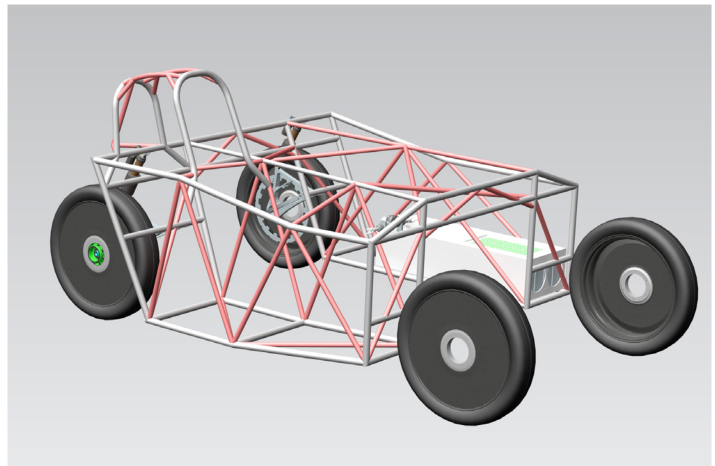
The frame is made from tubes of 4130 chromoly steel, the same material that race cars use in their frames. We use this material because it is light and very strong, both qualities that are important in the design of a solar car. We need to reduce the weight as much as possible to be more energy efficient. The completed frame weighs 45 lbs, which is slightly heavier than Ra 9's 40 lb. frame. This is because Ra X has two large compartments: one for the driver and one for the battery pack. Both sections need support, which adds more weight to the car, hence the heavier frame.

To design the frame we used NX 10, a 3D design software donated to the team by Siemens. This software allowed us to make multiple wireframe models in order to see which model best fit the driver, steering, suspension and other car components. We used NX to create a model of the car and review the model with other members of the team to make sure we hade enough room for all of the components. NX also allowed us to test the strength of our car by applying forces to different parts and running simulations to make sure the chassis would protect the driver in the event of a crash.

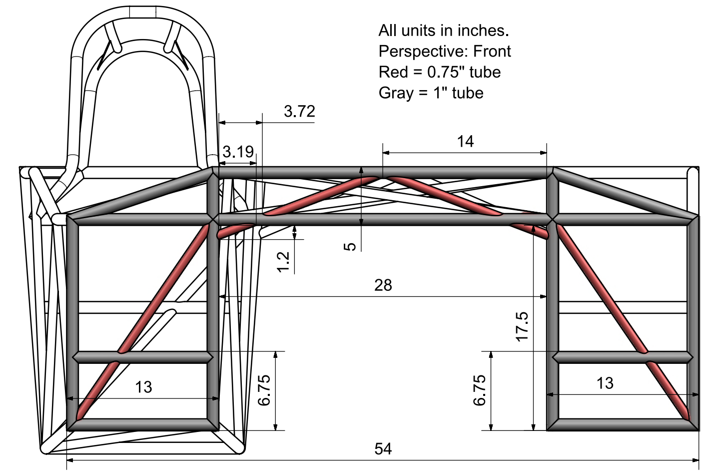
When it came to time actually construct the frame, we went to Jerry Haas Race Cars, a local drag race chassis manufacturer. They were a great resource because of their experience and knowledge about frames made of this material. We worked with John DeFlorian there to check over all our designs and get advice for any improvements in safety or efficiency. Once they begain construction, we got to stop by every few weeks and see more and more of our design come to life.

Even though we watched the frame being produced section by section, seeing the result of our hard work as the entire frame was put together was incredibly rewarding. When we had finally finished the car and saw it driving, we knew it was safe because of all of the effort we put into designing and testing the frame.

*Jake Williams has been a valuable member of the mechanical team for the last two and a half years. He has been on three races, two in the US and one in Australia.*



*The 3D model of the chassis, designed in Siemens NX*





*One of the drafts given to the welders as a construction guide*

*John DeFlorian of Jerry Haas Race Cars welds the roll cage*

# MECHANICAL

## AN IN-DEPTH LOOK AT THE SUSPENSION, SHOCKS, TIRES, AND MORE

### BY SKYLYR CIEPLY

There are three main ‘divisions’ of the solar car – electrical, mechanical, and body. Each of these are highly important to the success of the car but the two most important to the functionality and actual motion of the car are the mechanical and electrical teams. The mechanical components of the car are the chassis, wheels, brakes, suspension, steering, and the connections between them all.

Our suspension is a double leading ‘A’ arm in front and a trailing arm in back. These designs were chosen to minimize the amount of space these components took up in the car and because they offer good handling and grip of the road. The leading and trailing arms, as well as several other suspension pieces, are milled out of 7075 aluminum, a change from the steel suspension of previous cars.

During the World Solar Challenge, we used FOX Float X2 air shock absorbers for our suspension. These shocks are made for dirt bikes and are equipped to handle heavy loads. The decision to use air shocks was determined to be a questionable one fairly early on in the race because of several malfunctions which required the repair of the shocks. The rear shocks failed more than once, most likely due to a high rate of lateral torque on the shaft of the shock absorber which then caused the air to leak and the car to sink down low and actually scrape on the ground, wearing holes in the two rear fairings.

Fairings are the body panels that cover the wheels for greater aerodynamic efficiency. We attach them to the car with a combination of magnets and tape. The magnets are placed inside of both the fairings and the car body which makes alignment easy, as each fairing will “snap” into place on the body. We then tape around the seam of the fairings where they meet the body, adding extra strength to the connection. Almost every time that we need to work on the wheels, tires, brakes, motor or suspension, the fairings have to be taken off of the car.

This year, the World Solar Challenge was sponsored by Bridgestone which meant that all the teams were given a stock of Bridgestone tires made specifically for solar cars. This was a nice touch, but the tires were truly unpleasant to change. We changed tires just about every night. With two sets of rims, both fitted with tires, we were prepared for quick changes on the road, should any of the tires blow out. The tires we use are very narrow and have little tread for low rolling resistance. This means the suspension and brakes need to be set up very well so that the small contact patch stays grippy.

The car uses Wilwood go-kart brake calipers which are certainly sufficient for our 500-lb car. One of the most useful things I have learned from being on the solar car team is how to install and bleed a brake system. I love cars and I think that being able to work on your own car is a very useful skill. I really enjoy when I can apply the things I learn in solar car to my regular life. Being on the mechanical team has been a really great experience, and I would encourage anyone interested in mechanics to join!

*Skylyr Cieply joined the team in the fall of 2016 and came to the World Solar Challenge in the fall of 2017. His knowledge and love of cars makes him a valuable addition to the mechanical team.*

*The mechanical team puts the motor onto the car*

*Nicole Gerber assembles the front suspension*

# ELECTRICAL

## A COMPLETE BREAKDOWN OF THE FOUR ELECTRICAL SYSTEMS

### BY NICK FLANDERS

The electrical systems in our solar car are comprised of four sections. The first of these sections is the solar array. The array is made up of groups of solar cells which collect energy from the sun to be stored in the battery pack. One of the major regulation changes that our team has had to work with is the reduction in solar array size. Ra 9, our previous car, was allowed 6m$^2$ of solar cells. However, Ra X only has 4m$^2$ of SunPower silicon cells. This equates to 260 cells which completely cover the top surface of the car. This reduction in energy that we can collect has forced us to be more careful with how we use our energy and finding other ways to improve our overall efficiency. Our current silicon cells have a lower efficiency than the expensive gallium cells which Principia has used in the past, but these silicon cells work better in a wider variety of solar conditions. Solar cells are incredibly delicate, so we take great care to protect them at all times!

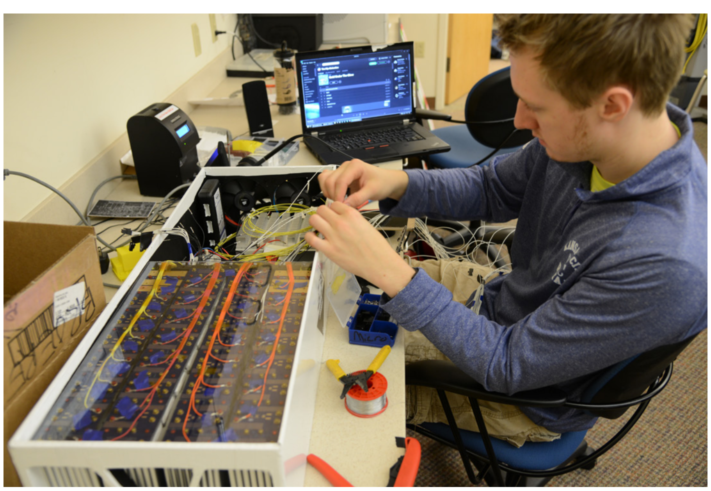
The second section is the car's battery consists of 20 kilograms of Lithium-ion Polymer battery cells. These batteries hold the energy that we gather from the solar cells and deliver the energy to the motor to propel the car forward. These batteries are closely monitored by a Battery Protection System, which is a small computer which performs constant checks on the status of the batteries, such as their voltage and temperature. This computer keeps the batteries in safe operating condition since they are the most dangerous part in the solar car.

The third section is the motor. Ra X uses a Mitsuba gen. 3 Variable Magnetic Field Motor, which is mounted on the wheel directly behind the driver. This is one of the largest improvements from Ra 9 to Ra X. This new motor has the ability to "shift gears" similar to a manual transmission car. This will allow the solar car to travel at higher speeds while remaining highly efficient. This new technology has been an exciting project for the team to work with and implement into Ra X.

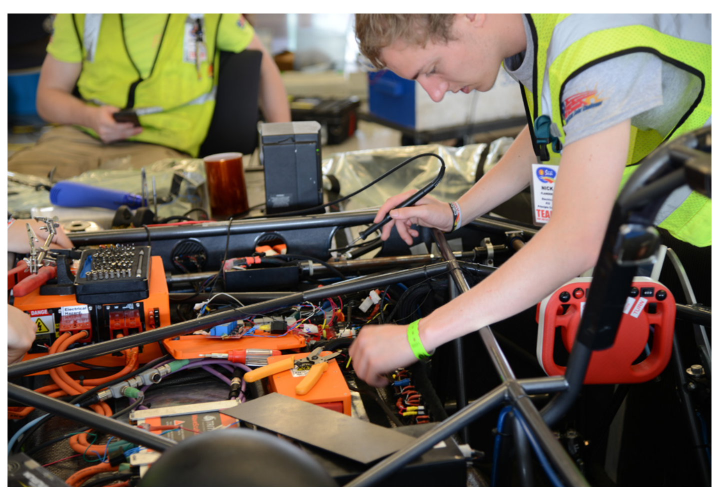
The last section is the control electronics. These electronics handle sending all the signals between all the major systems of the car, so all the systems can work together seamlessly. One of the most important aspects is handling the inputs from the driver such as the accelerator and regenerative braking pedals, and sending that information to the motor or other systems. Also included in this section is the organization of and broadcasting of telemetry, which is the data which informs us of the car's status at any time. This includes information such as how full the batteries are, the speed of the motor, and how much energy we are getting from the array.

Learning the details of the electronics has been a wonderful experience for me. One of the best parts of my experience on the team is having the opportunity to teach others about the things that I have learned. The solar car program has helped me learn a variety of new skills and pushed me to build more than I previously thought I could. My time here has also shown me the awesome things that we can create and accomplish when we work well as a team.

*Nick Flanders is the electrical team leader and has worked closely with his fellow team members to design the electrical systems for Ra X. He has been on the team for three years.*



*Jackson Walker (C '17) works on the battery pack*

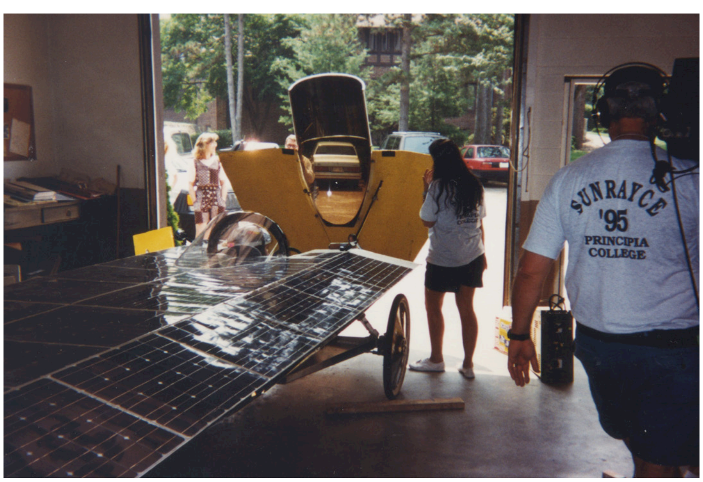


*Nick fixes some wiring in the solar car*

# A LOOK AT THE PAST



The original Principia Solar Car Team prepares the first car, Ra I, to race in the 1995 Sunrayce. Featured here are Linda and David Cornell, Elias and Melanie Shedd, Loraine Lundquist, Harold Simpson, Larry Charlston, and Seth Hieronymus. In these photos, they are filming a documentary about Principia's first solar car.




# A NEW WORLD OF OPPORTUNITIES

## BY ANTONIO ROJAS ACUÑA

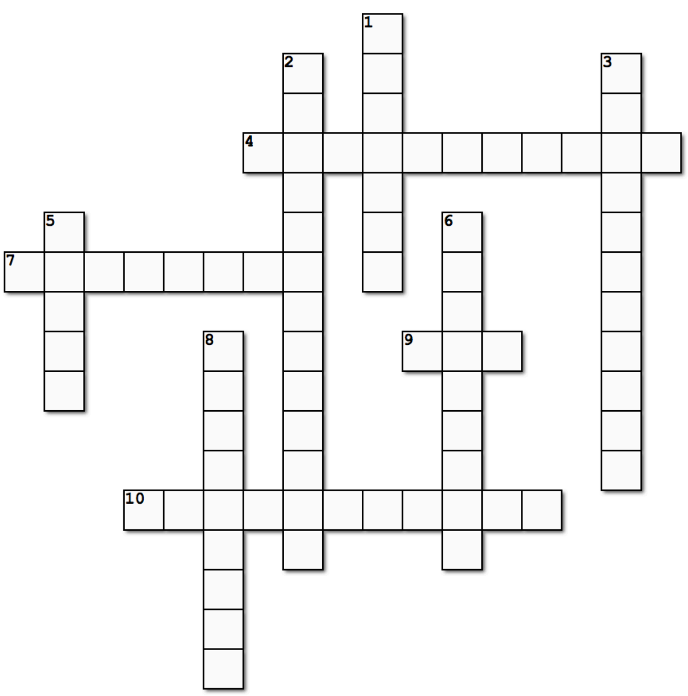
This last year at Principia I have been learning a lot about 3D printing. This is because I had to design and print a functional machine for my dynamics class last semester. It was absolutely fascinating to learn to use Fusion 360, a 3D designing software. I was just starting to understand the possibilities of what I could do and print with this amazing tool when I joined the solar car team.

The first time I walked into the solar car shop, one thing grabbed all my attention. Surprisingly, this was not the solar car, but an interesting machine that was sitting in the corner of the shop. This was a very big, advanced and precise mill: a Tormach CNC 1100. In that moment, I found my first opportunity to ask a question. I could not stop talking about this machine. This was a whole new world of opportunities to design and make useful tangible objects. I didn't even know a machine like this one existed before I joined the team. Now I have a great interest in learning all about it, I want to be able to help the solar car team by making the parts that need to be very precise and are hard to craft by hand.

This mill works with a series of "instructions" which have to be very specific. These instructions include the rotation speed of the tool, the speed at which the tool moves, and every movement in the x, y, and z-axis that the machine has to make. So creating this code can be very tedious, but very satisfying. I am so happy that I decided to join the solar car team. It brought to me many great new learning opportunities and also great new friends.

*Antonio Rojas Acuña is a new team member this year and we are very excited to have him on the team! Read more about him in his biography on page 10.*


*Our new milling machine can be used to make lighter parts*




### Solar Car Crossword

Across:
4. Type of rear suspension
7. Hopping mammal found in Australia
9. Name of the current solar car
10. Where energy gets stored in the car

Down:
1. Type of solar cell we use
2. Type of metal used on the frame
3. Material the car body is made from
5. Name of the process used to make the car body
6. Design style of the current car
8. Large Australian vehicle with several trailers

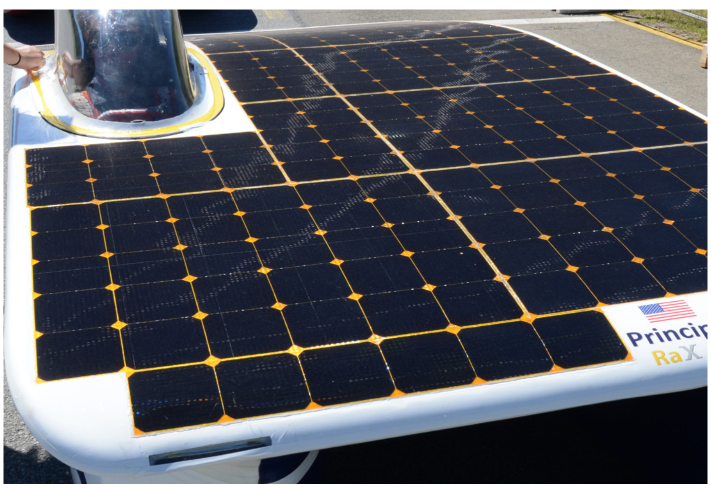
*1. silicon 2. chromoly steel 3. carbon fiber 4. trailing arm 5. layup 6. catamaran 7. kangaroo 8. road train 9. ra x 10. battery pack*

# TECHNOLOGICAL ADVANCEMENTS

## BY KENNETH STACK

I have been a part of the solar car team since I joined as a freshman in 2010. In that time I have noticed significant improvements between Ra 7s, Ra 9 and Ra X. The electrical, mechanical and aerodynamic systems all receive upgrades with each iteration because of new technology, better choices, and continued practice. There are many differences among the cars for a variety reasons, so for simplicity I will just share some of the biggest improvements over the years and the primary ways they came about.

Some changes are because of new technological advancements. The silicon solar cells and encapsulation we use now capture almost 3% more of the sun's energy than when I joined the team. The motor we currently use is 20 lbs lighter than the motor used on Ra 7s and is at least 95% efficient. The batteries in Ra X weigh the same as those from Ra 7s but can store about 40% more energy. Electrical systems like the motor controller and battery management system also have increased capabilities and durability because better technology has become available.



*Ra X's array captures almost 25% of the energy from the sun*

*This milled aluminum trailing arm is lighter than a steel version*

Other changes in the car are a result of finding better options in parts and materials. The most recent choices in the steering mechanism and brake calipers are significantly lighter while giving the driver more precise control over steering and braking. By milling suspension components from aluminum instead of welding steel plates together, we have additional flexibility in design and we can use a lighter material. This design flexibility in conjunction with more advanced computer simulations allows us to create uniquely shaped parts that are lighter and stronger. Other pieces become lighter too as we learn to make them from carbon fiber instead of metal. These upgrades are possible by building upon the choices of previous team members.

Many improvements in the body of the solar cars have been a result of practice. The team has developed methods to fabricate composites with better results. The carbon fiber car body is lighter and more streamlined on Ra X because the team is better at spreading epoxy as well as cutting, sanding and gluing carbon fiber together. From practice we have learned how much material is necessary to achieve the strength required. Most recently we have reduced weight by using fewer and lighter materials in the composite car body. A majority of the core in the body is lightweight aluminum and can absorb excess heat from electrical components. The drastic enhancements in construction methods are because of the team's persistence to make continual progress.

All these advancements and more are part of what makes Ra X the lightest and most aerodynamic solar car that Principia has made. It is exciting to see the evolution of the car designs and technology over time. These changes are the result of continuous improvements made by team members that dedicate themselves to doing their best and passing on important lessons to the next generation. Our team would not be a success without the guidance and support of the solar car advisors, as well as the many companies and generous donors that make this possible. I look forward to seeing the improvements made in future solar cars.

*Kenneth Stack graduated in 2014 and has stayed at Principia as the aerodynamics team leader. He taught himself NX, our 3D modeling software, to design the bodies for Ra 9 and Ra X.*

# A LOOK INTO THE DESIGN OF RA X

## BY NICOLE GERBER

The most recent set of race regulations gave us the opportunity to entirely redesign the shape of our car. The earliest versions of the Ra series could have three wheels and there were no restrictions on seating angle, allowing the driver to lay completely flat. This meant that the composite body around the frame could be very thin and aerodynamic. In 2008, a new rule was instituted that required the drivers to be sitting upright, which presented a challenge for packaging the driver in a small space. Our team came up with a design for Ra 7 that placed the driver directly in front of the rear wheel, packaging them together in one aerodynamic pod, called a fairing. The windshield blends into the upper body and is referred to as a "manta" design.

When designing Ra 9, there was another new regulation that forced cars to have four wheels, in an attempt to make cars more closely resemble production vehicles. Not wanting to deviate from a symmetrical car, the team designed a body that had the driver centered in a large airfoil, with small fairings for each of the four wheels. This design is referred to as a "thick wing" design, as the center shape is a thick airfoil, like the cross section of a plane wing.

After racing Ra 9 in WSC, the team noticed that there were three main designs that had emerged as a result of the four wheel rule. One was the thick wing design that we had, which didn't have the aerodynamic advantage we were looking for. Another was a design called a "fifth pod", which is similar to the thick wing in that it places the driver in the center of four wheels that have individual fairings. However, instead of putting the driver inside of a thick airfoil, the main airfoil is very thin, with the driver in his own fairing, making for a total of five "pods".

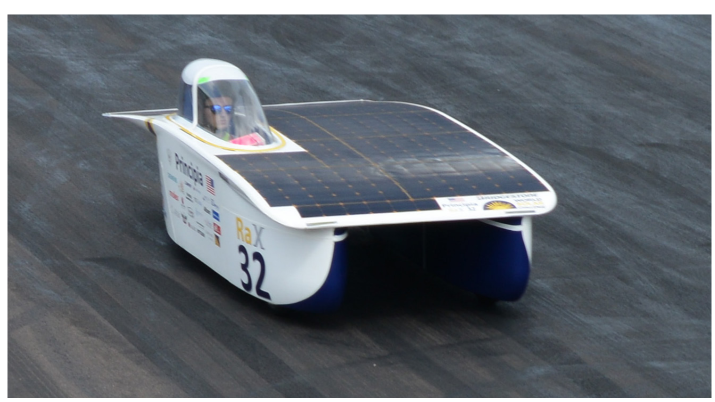
The final design we noticed was an asymmetric "catamaran" design, which features the driver on one side of the car, in between the front and rear wheel for that side. This design allows for two large fairings, one for each set of front and rear wheels, with the driver in the middle of one. Without a driver in the center, the middle of the car is very thin, resembling a catamaran boat. Having that large open space in the middle of a car is a great improvement on aerodynamics, but the asymmetry of the shape and weight of the car can lead to instability.

As we were designing Ra X, the regulations for the 2017 WSC were released. The biggest modification was the change in solar array size from $6m^2$ to $4m^2$. This difference drastically reduced how large the car needs to be. With such a small car, the asymmetric catamaran design seemed the best choice for aerodynamics. Having two sides of the car meant that the bridge between them had to be strong enough to prevent the sides from flexing. Our aerodynamics and mechanical teams put significant effort into making sure the car is sleek and stable!

*Nicole Gerber is the mechanical team leader and has spent countless hours designing the chassis, steering, and suspension of Ra X. She has been with the team for four years and five races.*


*Ra 7s, a three-wheeled "manta" design*


*Ra 9, a four-wheeled "thick wing" design*




*Ra X, an asymmetrical "catamaran" design*

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