Top Finishing Rookie Team, Sunrayce '97

Now Online: Photo Gallery of Team Lux at Sunrayce 99!

Click here for the minutes of the last meeting. Click here for the notes on basic design concepts.

Team Meetings are every Monday Night @ 8:30PM in Mason Labs 107 - Everyone is welcome!

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A Brief History of Team Lux

Team Lux was founded in 1994 by undergraduate engineering students Asif Mahmud and Susan Wetstone and Professor Werner Wolf. The objective was to incorporate several student design projects into a solar car for Sunrayce '95, a 1250-mile road race from Indianapolis, Indiana to Golden, Colorado. Subsequently, many parts of the car were designed and built. However, the group fell short of building the entire car in time for the race.

In the fall of 1995, the team reorganized to compete in Sunrayce '97. John R. Frank, then a sophomore physics major, lead the team to design, build and race Yale's first solar car, Lux Aeterna. Investing thousands of hours of dedicated work, Team Lux completed Lux Aeterna in time for the unveiling on April 16, 1997. In June, the members of Team Lux raced Lux Aeterna in Sunrayce '97, a 10-day race from Indianapolis to Colorado Springs. Lux Aeterna finished in ninth place out of 36 university teams, far surpassing other rookie team entries. With the inauguration of Yale's first solar car and its subsequent participation and top-ten finish in Sunrayce '97, Team Lux set a milestone for student engineering at Yale.

Where We Stand Now

Team Lux is now comprised of an almost entirely new group of undergraduate students primarily from, but not limited to, the engineering and applied physics majors. We have spent time analyzing the strengths and weaknesses of Lux Aeterna, and are dedicated to the construction of a new car. Lux Perpetua will compete this June in Sunrayce '99, from Washington, DC to Epcot Center in Orlando, Florida. No longer rookies, we are building off the experience of the first race. With the new car, which will roam the streets of New Haven not too long from now, Team Lux will only have one purpose: to win Sunrayce '99!

Yale and Team Lux: From Costly Experiment to Role Model

Team Lux has affected all engineering and science faculties at Yale, directly and indirectly. Early on, it was recognized that Team Lux had great potential to strengthen Yale Engineering. The team was provided with an office and workspace in Mason Lab (Mechanical & Chemical Engineering) and in the Morse Teaching Center (Electrical Engineering). The Chemistry Department invited Team Lux to use the student machine shop in the Sterling Chemistry Laboratory.

Apart from granting workspace (a valuable and much-demanded commodity at Yale), many departments contributed money and material support to Team Lux. The Yale Science and Engineering Association donated $13,000. The Departments of Applied Physics, Chemistry, Chemical Engineering, Electrical Engineering, Mechanical Engineering, Physics, Geology & Geophysics, and Computer Science each contributed between $500 and $4,000. The Peabody Museum of Natural History donated a cube van and the production of decals for the solar car and the trailer. The Gibbs Mechanical Instrumentation Shop donated many hours of work to help build the chassis. The Yale Physical Plant donated a pickup truck and many other favors. Data Network Operations, Yale Telecomm, and the Science and Engineering Computing Facility gave technical support.

Team Lux is a student-initiated, student-run organization, yet the completion of the solar car would not have been possible without the help of our advisors. Dean D. Allan Bromley provided support with fundraising and public relations, and helped the team when things were not running smoothly. Professor Robert E. Apfel was the main administrative advisor to the team and facilitated communications within the university. Professor Peter J. Kindlmann advised the team on all electronic components of the car, especially the power electronics, and invited the team to use the facilities in the Morse Teaching Center. Anthony Massini instructed the members in his machine shop in the Sterling Chemistry Laboratory. His expertise and experience led to the construction of a reliable chassis and body. David Johnson volunteered to weld frame parts, provided advice on all topics of auto mechanics, and accompanied the team to the regional qualifiers and Sunrayce '97. Without the continuous support and motivation of our advisors, Lux Aeterna would not have been built.

With the outstanding finish of Lux Aeterna in Sunrayce '97, Team Lux has proven itself to be the premier undergraduate engineering project at Yale. The time and money which have been invested in the team have not gone to waste. New engineering majors are drawn to the university because of Team Lux. Bringing the engineering students together with each other and the faculty, Team Lux is strengthening the fabric of the Yale undergraduate engineering and applied sciences departments.

Original text by Lutz Berners
Edited and updated by Jeff Perlman and Dominic Matar

Write to Team Lux at teamlux@yale.edu

Meet Team Lux

Project Director: Kevan Moffett

Body Group

Frame, Steering, Stopping, and Suspension Group

Electrical Systems Group

Business Management

Publicity Group

Advisors

D. Allan Bromley, Sterling Professor of the Sciences and Dean of Engineering

Robert Apfel, Robert Higgins Professor of Mechanical Engineering

Peter J. Kindlmann, Adjunct Professor of Electrical Engineering

Anthony Massini, Instructor, Sterling Mechanical Instrumentation Laboratory

David Johnson, Gibbs Mechanical Instrumentation Shop

Gary Povirk, Assistant Professor of Mechanical Engineering

Alumni

Body Group

Group Leader: Jonathan Burt

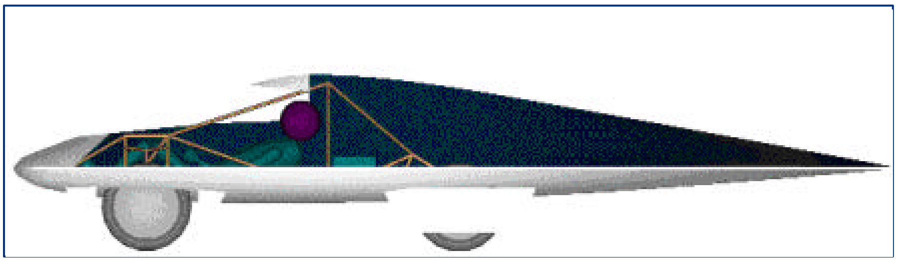
Andrew Dennis	Kevan Moffet
Jeremy Klaperman	Jeffrey Perlman
Dominic Matar	Alexander Selkirk

The Lux Perpetua body

- will be low to the ground and have curved edges to make it more aerodynamic. Large, bulky, angular cars create air resistance. Aerodynamic cars generate less air resistance and can go faster.
- will have good cross-wind stability, so that, if wind hits the car from either side, it will remain stable on the road and will continue to move forward quickly.
- will have efficient solar cells. Solar cells are the individual units which capture solar energy. Each solar cell is small, about 3.5 inches by 3.5 inches, and there will be about 1200 of them on the surface of the car!
- will be exactly the right size so that the frame can fit snugly inside it.

The body was designed almost entirely on a computer. It will be made mostly of synthetic materials such as fiberglass, honeycomb core, and epoxy resin. These materials are much more light-weight than steel which is used for the bodies of traditional gas-powered cars. Honeycomb core is the same material used to build many spaceships.

Lux Perpetua



Team Lux is currently building a solar powered car called *Lux Perpetua*, which will use solar cells and high-power batteries (hopefully nickel-metal hydride) to convert solar energy into energy used to run the car. *Lux Perpetua*, like it's predecessor Lux Aeterna, will use no gas, will run on the power of a hairdryer, and will be able to go as fast as sixty-five miles-per-hour!

- View the *Lux Perpetua* Structural Report
- Go to the *Lux Perpetua* Online Photo Exhibit

Lux Perpetua will compete in Sunrayce '99, a ten-day race for solar cars which takes place in June, 1999. It begins in Washington, DC and finishes in Orlando, Florida. Sunrayce is a bi-yearly event. Yale's first solar car, Lux Aeterna, competed in Sunrayce '97, in which it finished first place for a rookie team and ninth place overall (out of fifty-four entering teams).

Next year, *Lux Perpetua* will hopefully also compete in the World Solar Challenge, a bigger and more challenging race in which solar cars will race across the Australian continent.

Team Lux consists of thirty-one Yale students, mostly undergraduates. The students are responsible for designing the car, raising money for it, and then building it themselves. Overall, the solar car will cost about $108,000 to build and race. However, the cost would be much greater (close to $300,000) if most of the parts were not donated by the companies that manufacture them. For more information on our sponsors, click here.

The solar car itself has three main components, each handled by a small, dedicated subset of the entire team:

- The Body = the outside of the car.
- The Frame = the inside structures which support the body and protect the driver.
- The Electrical Systems = structures like the battery and motor, which convert solar energy into the energy used to power the car.

Additionally, there are several other functions necessary to keep the team together and running smoothly:

- Business Management = the seeking and supporting of our sponsors as well as the logistics of running the team.
- Publicity = the newsletters, flyers, handouts, t-shirts, web site, etc.

Team Lux Yale Undergraduates Racing with the Sun

Lux Perpetua

Structural Report for Sunrayce ?9
January 11, 1999

Project Director

Alexander Selkirk

Prepared by:

Edward West

Jonathan Burt

Kevan Moffett

Jodi Weinstein

Alex Selkirk

Purpose

This report analyzes the behavior of the vehicle under various loading conditions in compliance with Sunrayce ?9 regulations. The analysis shows in detail the deformation and stresses in the chassis, the protection of the driver, and the viability of the various mechanical systems.

Design

Lux Perpetua is a four-wheeled solar powered vehicle designed to compete in Sunrayce ?9. The structure consists of an aluminum space frame and a composite material body shell.

Mechanical Systems Analysis

Specifications

Figure 1: Goodyear Tire with Weld Racing Wheel and Hub

-

Wheels and Tires

Lux Perpetua will be using either 14" machined aluminum wheels designed by New Generation Motor specifically for solar car racing, or, steel 17" wheels designed by Weld Racing for dragsters. The advantage of using the Weld wheels would be time savings, in that we would not have to design or build a hub or a spindle, as these parts are commercially available.

Both of these choices have been proved Sunrayce worthy. Lux Aeterna, Yale's previous Sunrayce entry, used a combination of the two.

If we elect to use the Weld wheels, Goodyear D1121 tires will be used. If the New Generation Motor wheels prove to be a better choice, Bridgestone Ecopia model tires will be used. Both of these choices have been proved by both our racing and testing experience.

Figure 2: Enginetics 700B Brake Caliper

Brakes

To comply with Regulation 5.10, *Lux Perpetua* has one Enginetics Model 700B on each of the front wheels. Each caliper has two separate pistons, and, when mounted as floating calipers, they are adequately powerful to bring the car safely to a stop in compliance with regulation 5.11, even in the event of single master cylinder failure. The two Enginetics master cylinders are designed for use with the 700B calipers, and will be operated with a single brake pedal. Each of the master cylinders will be connected to one piston on the right side, and one piston on the left side, to ensure even brake pressure from potentially hazardous master cylinder failure.

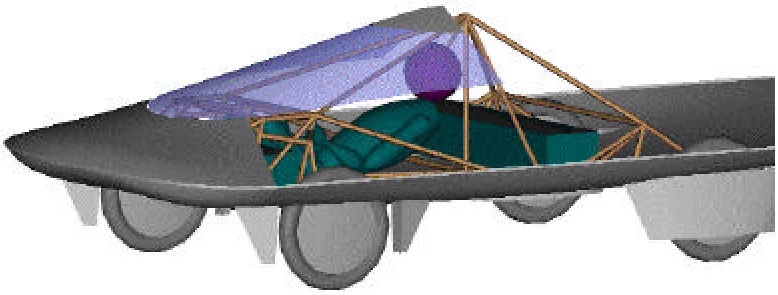


Figure 3: Canopy - view without array

Canopy

Lux Perpetua's wrap-around canopy is made from Celcast acrylic with a UV blocking agent. This provides excellent clarity and protection from sunlight. Forward, side and rear vision criteria as well as eye height set forth in Regulation 5.4 are met. Rear view mirrors will be attached to the canopy.

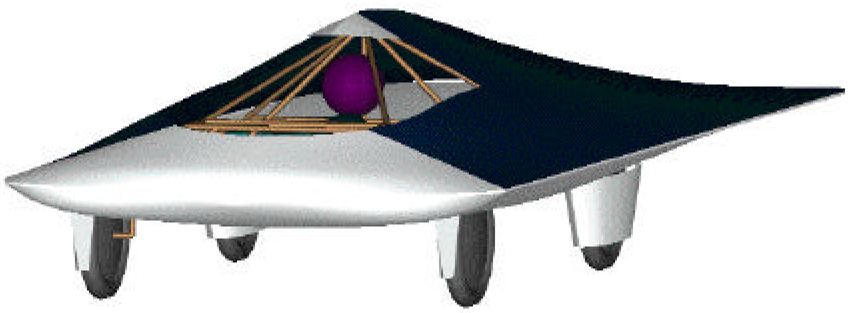


Figure 4: *Lux Perpetua* with Body

Body

The entire outer shell of the body will be constructed with .375" thick 1.8lb and 3.0lb HRH-10 Nomex core sandwiched between 2 layers (each) of 2oz fiberglass and 1.8oz bi-directional Kevlar, bonded with epoxy resin. It will be internally reinforced and attached to the aluminum space frame using a grid of .4" thick fiberglass-Nomex ribs and spars. We elected to use Kevlar-Nomex panels, as opposed to carbon-Nomex panels because of the conductive properties of carbon fiber and the favorable qualities (no dangerous splinters and absorption of impact energy) of Kevlar in a crash.

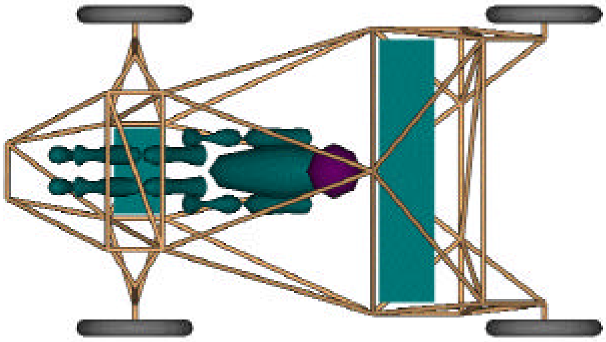


Figure 5: Top View (Structural)

Chassis

The chassis is a space frame made of 1.25" outside diameter by .060" wall W7A 10A aluminum metal matrix composite tubing welded together with 5356 welding rod by a professional welder at Brewer's Dauntless Shipyard. In accordance with Regulation 5.3.5, the frame totally encloses the driver, providing protection and ample crush space in case of an accident. The roll cage, made of the same material, is specially designed to provide volume enough for a full-face auto-racing helmet. The seat is a custom designed hammock style seat that fulfills Regulations 5.3.1 and 5.3.6. It will be constructed of a combination of canvas and Kevlar fabric. The seatbelts are to be bolted (not threaded into) tabs welded onto structural members of the space frame at or very near nodes in compliance with Regulation 5.3.6. The Stilleto rack and pinion steering system will be enclosed above the structural member above the driver's knees. This prevents the driver from contacting the moving parts of the cockpit to fulfill Regulation 5.6. Driver's egress requirements as stated in Regulation 5.3.8 are met.

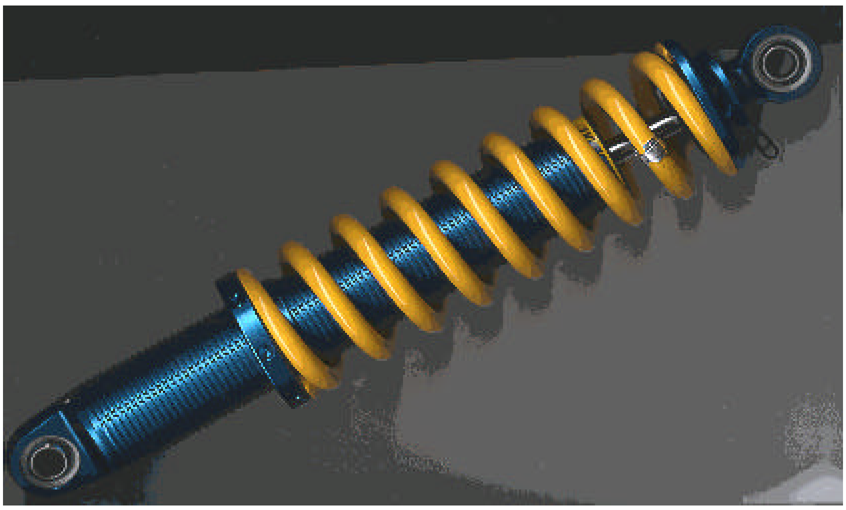


Figure 6: Afco Shocks

Suspension

The front suspension uses standard A-arms and Afco aluminum coil spring shocks. The A-arm geometry was designed to minimize lateral scrub and bump steer. The A-arms are manufactured from 5/8" outside diameter .125" wall chrome-moly tubing. The joints between the A-arms and frame and between the A-arms and outer linkage are Alinabal steel rod ends. The uprights are custom machined aluminum, and the steel spindle is press-fit, bonded, then through bolted to the upright to ensure adequate attachment.

Our rear suspension, which is currently under construction, will utilize similar chrome-moly tubing in a tetrahedral configuration, and Afco aluminum coil spring shocks in a simple trailing arm arrangement, for both simplicity and lateral scrub minimization.

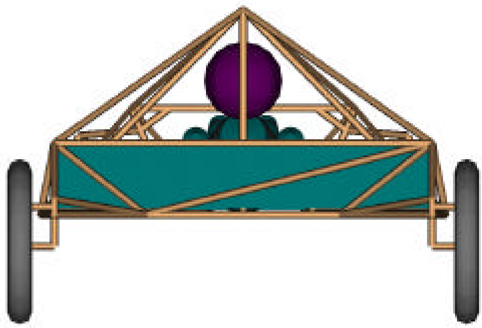


Figure 7: Rear view of frame with battery box

Battery Box

The batteries will be strapped down individually to the frame in two planes and to the belly pan of the car, and the battery box will be placed over them. Because of their placement behind the driver, we have been particularly careful and conservative in the design of the battery box. There is a structural plane of the space frame behind the driver's back, which will be fit with a ? Kevlar-Nomex panel (on the battery side).

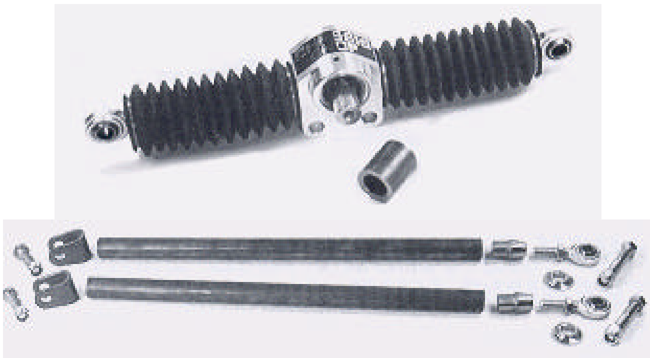


Figure 8: Rack and Pinion Steering, Tie Rods

Steering

After experimenting some with alternative arrangements on our prototype, we have decided to use a commercially available rack-and-pinion steering system. All moving steering parts are covered to prevent contact by the driver as set forth in Regulation 5.6 and steering stops fulfill Regulation 5.7.

<u>Analysis</u>

Due to the complexity of the mechanical component and their complex interplay, we feel that (with the exception of the chassis) computer modeling or hand calculations would give us inconclusive results at best as to the race-worthiness of the car and it s components. Because of this, empirical testing of, first, the individual components, then, the assemblies, and, finally, the car as a whole. Our car is not currently in testable condition, though careful testing is slated for the coming months.

Because of the proven viability of a number of the mechanical components, we are going to focus most of our testing efforts on the parts that we fabricate ourselves.

Wheels and Tires

New Generation Motor solar car wheels have been proven race-worthy many times, by ourselves, and by a large portion of Sunrayce ?7 teams. Weld wheels and hubs, in addition to being designed for dragsters and being race proven in drag racing events across the country (where the loads are much greater than any solar car race), were tested and raced by Yale s entry in Sunrayce ?7. The same is true for the Goodyear D1121 and Bridgestone Ecopia tires.

Brakes

As braking is one of the most important safety features of any car, extensive testing of our braking system is planned. The most obvious way to test braking is by deceleration testing of the completed car. We won t feel that our car is race ready until we are in compliance with Regulation 5.11 with one master cylinder disabled. We will modify our braking system as necessary to pass this stringent test.

Chassis

The chassis is tested by finite-element analysis later in this report.

Battery Box

The batteries will be strapped down individually to the frame in two planes and to the belly pan of the car, and the battery box will be placed over them. Because of their placement behind the driver, we have been particularly careful and conservative in the design of the battery box. There is a structural plane of the space frame behind the driver's back, which will be fit with a ? Kevlar-Nomex panel (on the battery side).

Steering

After experimenting some with alternative arrangements on our prototype, we have decided to use a commercially available rack-and-pinion steering system. All moving steering parts are covered to prevent contact by the driver as set forth in Regulation 5.6 and steering stops fulfill Regulation 5.7.

Suspension

The suspension is where most of our empirical testing effort shall be focused. For the suspension, we feel it is best to be on the stronger, heavier side of the spectrum. Suspension failure has sidelined multiple Sunrayce teams, and can be quite dangerous.

The front suspension uses standard A-arms and Afco aluminum coil spring shocks. The A-arm geometry was designed to minimize lateral scrub and bump steer. The A-arms are manufactured from 5/8" outside diameter .125" wall chrome-moly tubing. The joints between the A-arms and frame and between the A-arms and outer linkage are Alinabal steel rod ends. The uprights are custom machined aluminum, and the steel spindle is press-fit, bonded, then through bolted to the upright to ensure adequate attachment.

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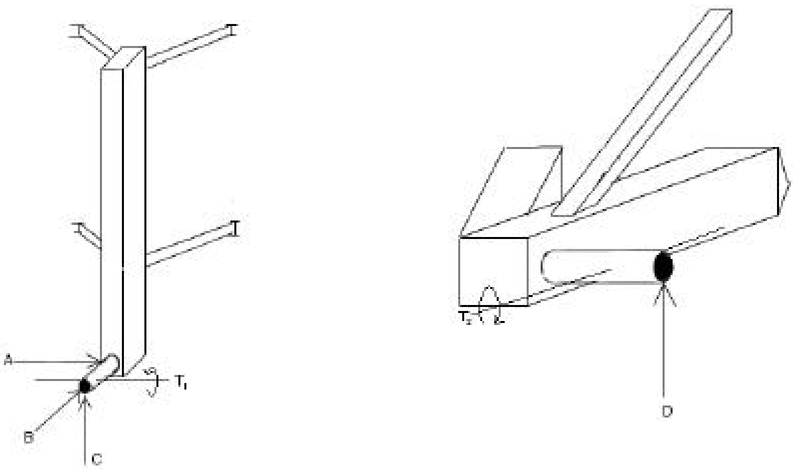


Figure 9: Simplified Suspension Model

Figure one shows the basic configuration of the front suspension and figure two shows the rear. We shall test these assemblies by affixing them to a test frame at the normal attachment points, apply loads at A, B, C, and D, and apply torques at T_1 and T_2

Front suspension tests will be conducted as follows:

Test one: 1020 lbs at A

This simulates striking a curb at speed.

Test two: 400 lbs at B, and 4,000 in*lbs at T_1

This simulates hard cornering.

Test three: 640 lbs at C

This simulates the load that a 4G bump, distributed across all wheels equally, would produce on one front wheel.

Rear suspension tests will be conducted as follows:

Test one: 960 lbs at D

This simulates the load that a 4G bump, distributed across all wheels equally, would produce on one front wheel.

Test two: 400 lbs at E, 4000 in*lbs at T_2

This simulates hard cornering.

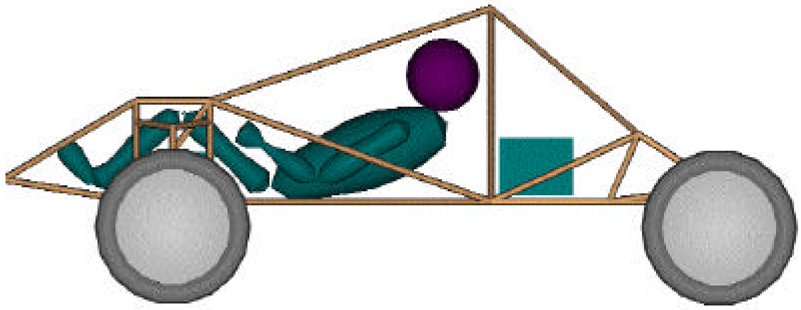
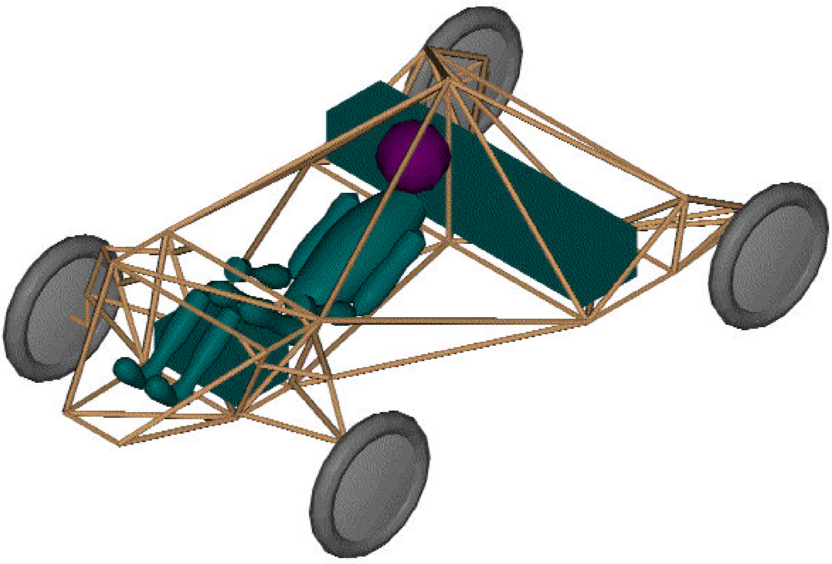


Figure 10: Side View



Frame, Steering, Stopping, and Suspension Group

Group Leader: ***Edward West***

Lutz Berners	Scott McNab
Tricia Donnelly	Jeffrey Perlman
Michael Feinberg	James Wagner
Maxime Ko	Jodi Weinstein

The Lux Perpetua frame

- includes parts like the tires and wheels, brakes, steering wheel, and seat. It also has a roll cage which surrounds the driver to protect him in an accident. The roll cage can withstand the weight of two solar cars on top of it without allowing the driver to be crushed.
- will have tires which are specially designed for solar cars.
- will be made almost entirely of aluminum, which is light-weight and strong.
- was designed and tested on a computer.
- was designed to mimic the performance of an ultra light-weight race car.
- will weigh less than sixty pounds overall, and less than twenty pounds without the wheels and their attachments!

For More detailed information on the frame of Lux Perpetua, check out the structural report.This does not include the extensive FEA work done by the frame group, but those pictures aren't nearly as much fun.

Electrical Systems Group

Group Leader: ***Alexander Potter***

David Anjelly	Colbert Davis	Dominic Matar	Jeffrey Perlman
Jason Arroyo	Oleg Elkhunovich	Mark Meras	Colin Reingold
Lutz Berners	Michael Feinberg	Marek Michalowski	Ji-Jon Sit
Ethan Bregman	Seth Gilbert	Kevan Moffet	Liang Yang
Henri Chen	Eric Hartman	Charles Park	

The Lux Perpetua electrical systems include:

- the **solar array**, which consists of the individual solar cells on the surface of the car, which convert energy from the sun to electrical energy.
- the **batteries**, which are responsible for providing the car with the energy it needs to move. A normal car goes until it runs out of gas; a solar car goes until its batteries run out of stored energy.
- the **motor**, which is highly efficient and mounted in one of the rear wheels (manufactured by New Generation Motors).
- a **computer** with access to the global positioning system (GPS), which can pinpoint the exact location of the car on a particular road in any city in any state.
- an **inclinometer**, which measures the steepness of the road's hills and then feeds the measurements into the computer.

A lot of time has been put into the design of our solar array. Our curved, aerodynamic body makes array construction very challenging. Unlike a flat array, whose solar cells receive equal sunlight throughout the day, a curved array will receive different amounts of sunlight in different places depending on the position of the sun in the sky. Since our chains of cells are going to be connected in series, each chain will be limited by its weakest link. In other words, if part of a chain is in the sun and another part is in the shade, the outputted current and voltage would equal that of a chain wholly in the shade. To prevent this from happening, we are mapping out areas of equal sunlight on the car, taking into account the sun's path in the sky and our race route. The curved shape will also make construction difficult because cells might slide while we wait for them to set in the silicon elastomer donated to us by Dow-Corning. We may overcome this by constructing the array in flat panels, which would be designed to fit the curved shape of the car.

We hope to use nickel metal hydride batteries from GM-Ovonic, which contain the metal nickel (Ni) instead of lead (Pb). Lead acid batteries were used in Lux Aeterna, but nickel metal hydride batteries have twice the energy density (they can store twice as much energy in the same mass). If each battery captures more solar power, then we don't need as many batteries. Using fewer batteries will make the car 150 pounds lighter, and much faster. However, nickel metal hydride batteries are more expensive and we have yet to raise $24,000 to pay for them!

The largest focus of the electrical systems group is the data acquisition system of the car and racing strategy. The computer will use the global positioning system data and the information from the inclinometer to calculate exactly how fast the car can go at any given time to maximize efficiency. That is, the inclinometer can tell us how much energy is needed to climb a hill (because a steep hill will naturally take more energy to climb), and the global positioning system can tell us how many hills we have left to climb. The computer will allow us to go as fast as possible up a hill and still have enough energy left to climb the next hill before the batteries run out of energy.

Lux Aeterna

Yale's First Solar Powered Race Car

Ninth Place & Top Rookie Entry in Sunrayce '97

Lux Aeterna was a great success. Exceeding all expectations, Team Lux finished in the top ten in Sunrayce '97 and was the best rookie entry by far, even leaving in their wake many experienced teams. The project is an example of Yale Engineering at its finest, not to speak of student leadership and teamwork.

Despite some imperfections, our first car had no outstanding weaknesses, and consequently it's only significant failure throughout the all of Sunrayce '97 was a blown tire on the third day.

This could never have happened without the help of our sponsors to whom we are eternally grateful.

Specifications

- **Name**: Lux Aeterna [eternal light]
- **Number**: 480 [the wavelength of blue light in nanometers]
- **Dimensions**:
- **Weight**:
    - Frame and body:
    - +batteries:
    - +driver
- **Solar cells**: 920 3.2 Amp solar cells connected in series; manufactured by Siemens
- **Motor**: 9 horsepower axial flux in-wheel motor; manufactured by New Generation Motors .
- **Batteries**: 7 Lead-Acid Batteries, specs per battery: 52 Ahr @(C3), 12 V, 18.8 kg; manufactured by Delphi
- **Chassis**: Composite Aluminum
- **Wheels**:
- **Body**: honeycomb nomex; supplied by Hexel
- **Telemetry**: modular data acquisition system to measure voltages, currents, and temperatures throughout the vehicle; manufactured by DGH.

A Timetable of Lux Aeterna

Spring 1996	planning & conceptual design of all car parts
Summer/Fall 1996	construction of prototype chassis & body
Fall 1996	display of prototype at the Yale Club of New York City and at the Yale Club of Washington, D.C. testing & evaluation of prototype planning of final car logistics planning
Winter 1997	construction of final chassis
Spring 1997	construction of body construction of solar array road testing of final chassis and body final assembly of all car parts final decisions on logistics unveiling and press conference
May 1997	regional qualifiers for Sunrayce 97 in Milford, MI evaluation of performance at qualifier and final adjustments
June 1997	Sunrayce 97: Indianapolis to Colorado Springs

Members of the Sunrayce 97 Team

Directors: John R. Frank '98, Lutz Berners '99

Jeffrey Anker '98	Leah Barton '97	Paul Ellison '00
Damon Erickson '98	Seth Gilbert '99	Long Huynh '97
Tess Krebs '97	Wojtek Przylecki '99	Dan Riegel '98
Alexander Selkirk '99	Margaret Spencer '00	Bennett Sprague '97
Nabyl Tejani '97	Liang Yang '99	

Advisors

D. Allan Bromley, Sterling Professor of the Sciences and Dean of Engineering
Robert Apfel, Robert Higgins Professor of Mechanical Engineering
Peter J. Kindlmann, Adjunct Professor of Electrical Engineering
Anthony Massini, Instructor, Sterling Mechanical Instrumentation Laboratory
David Johnson, Gibbs Mechanical Instrumentation Shop

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Team Lux fueled up for big solar race

BY BLAIR GOLSON
YDN Staff Reporter

Published 4/23/99

Thirty members of Yale's solar car team are ready to emerge from the garages, laboratories and steam tunnels under Hillhouse Avenue.

They want some sun.

Their ride: Lux Perpetua, the brand-new, superlight, superfast and superefficient solar car that Team Lux members hope will bring glory to Yale -- and their sponsors -- in this summer's inter-collegiate race from Washington D.C. to Orlando, Florida.

For the last two years, a motley crew of undergraduate engineers, physicists, publicists, and artists has laid waste to free time, higher grades, and precious sleep to build a solar with such a low power output that it puts hairdryers to shame.

"Sometimes, when I wake up at 6 a.m., I really don't want to get up," said Electrical Systems Group leader Alex Potter '01. "But, when I reflect on it, I realize this is what I'm going to remember about my college days."

If the finished product functions as planned, Lux Perpetua will be capable of sustaining speeds up to 65 miles per hour for an entire day on the road. At 150 pounds, it weighs considerably less than its predecessor, Lux Aeterna -- the team's first solar car which placed 9th out of 36 teams in last year's Sunrayce.

The resources at work here -- human and otherwise -- are staggering.

The money and materials that went into Lux Perpetua totaled somewhere around $200,000. The frame is all aluminum, and the body is a kevlar-fibergalss shell filled with a honeycomb core, material similar to what NASA uses in the shuttle. Despite having to wield these seemingly daunting materials, team members say they used a lot of basic intuition in the construction of the car.

"It would have been helpful if we all had built go-carts when we were younger," Project Director Alex Selkirk '99 said.

The team works out of five different locations on campus, and has garnered, mostly through donations, a fleet of vehicles that would seem at home in a slapstick comedy.

They include: a stretched Connecticut Limo teetering on the verge on passing inspection, two large school buses-turned machine shops, a civilian ambulance that drives like a Porsche, and a Volkswagen golf that doesn't like low gears.

The team once blocked off Temple Street for an entire afternoon to unload the car's foam body-mold from an 18-wheel tractor-trailer.

The students in Team Lux hail from all different walks of Yale's scientific and artistic community. One of the newer recruits is an electrical engineering expert named Ji-Jon Sit '00.

At the middle of last term, J.J. saw some Team Lux'ers working in their lab. "Do you have any need for an electrical engineer?" he asked. "Hell, yeah!" Potter replied.

A student whom Team Lux members say teachers turn to for help, J.J is now designing the software and hardware used to relay information from the solar car to the chase vehicle which will follow Lux Perpetua during the Sunrayce in tow.

Many members of Team Lux spent the summer and spring break in New Haven, working feverishly on various aspects of the project -- frequenting Mamoun's at strange hours of the night, and kicking back beers at the end of a 12-hour stretch.

Though team members say they eagerly anticipate the race's start, many said their real satisfaction came over the course of the last two years, which sometimes seemed to crawl by inches at a time.

"The payoff comes in going through the process, seeing different parts get built, and then putting them together," Liang Yang '99 said.

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Yale Daily News ONLINE

Wednesday, October 7, 1998

Solar power fuels drive of Team Lux

By Blair Golson

Contributing Reporter

This summer, in a cross-country solar car race, Team Lux will pilot a $160,000 car that runs off the same amount of power as a hair dryer.

The car must be finished by early June, when the team will compete against other collegiate solar car teams in a race from Washington, D.C. to Florida. Team members said they hope to improve upon their performance in a similar June 1997 race -- ninth out of 55 teams.

Their success will depend upon the completion of a brand new vehicle, Perpetua, which will replace the current car, Aeterna. Designed from the ground up, Perpetua will achieve speeds of up to 65 mph while emitting nothing but heat.

When the new Perpetua hits the capitol this summer, it will be a sleeker, lighter, and more efficient craft than the original Aeterna. The frame -- made of two layers of kevlar and durable honeycomb paper -- will be covered by 920 solar cells. These cells transfer the sun's energy to the car's batteries, which in turn power the motor.

"This car is going to be ridiculously efficient," electronics leader Alex Potter '01 said. "On a sunny day you could drive it at 15 mph without ever recharging."

The group works mostly out of a small room in Dunham Lab, but Team Lux members said it has amassed a mobile headquarters that eclipses that of any other Yale group.

"We've got a full-size school bus, a 25 foot stretched Suburban, a Volkswagen Golf, and an ambulance that's almost passed inspection," Ale Selkirk '99 said.

Potter said the community aspect of Team Lux is what keeps him involved.

"It's the excitement of having the entire team on the road, and knowing that if anything goes wrong with the solar car, you've got the team there to back you up," Potter said. "I've definitely sacrificed my grades, but it's all going to be worth it when we get to the race."

The 25 undergraduate members of Team Lux are responsible for every aspect of the new car's production. However, few members came to Yale with any formal engineering background.

"Whatever I didn't learn about physics in high school, I've had to pick up on the job," Potter said.

Some students said they brought their love of engineering to the team.

"Since I was a kid, I've always loved building things," Ed West '01 said. "Team Lux is the only place on campus where I can really do that without worrying about the funding."

Selkirk said the team has received donations ranging from $15 to $50,000, primarily from corporate sponsors. But he added that the corporations provide monetary, not inspirational, support.

Unlike some colleges, who enlist engineering professors to build almost the entire car, Yale's Team Lux does not receive direct input from its faculty advisor.

"If an advisor got too involved, or started giving out course credit, it would start to feel wrong, like it was something we had to do," Selkirk said.

Other team members agreed that Team Lux is a group for dedicated students.

"Everyone is here because they want to be here," Potter said. "We don't need people coming who are just looking to fill up a couple of course credits."

MICHAEL RASIEJ/YDN STAFF Undergraduate members of Team Lux are gearing up to race their improved car, Perpetua, cross-country this summer.

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Archives News

Despite rain, Team Lux unveils its solar car

Lux Perpetua to compete in intercollegiate race

YDN Staff Reporter

CHONG-HAO FU

Published 4/24/98

In an age of increasing environmental concerns and growing demands for transportation, Team Lux, the Yale undergraduate solar car team, is searching for creative ways to exploit solar energy.

Despite rain storms, Team Lux unveiled the prototype body and frame for their new solar-powered vehicle at Beinecke Plaza yesterday afternoon.

The vehicle, dubbed Lux Perpetua is expected to compete in the intercollegiate Sunrayce '99. Sunrayce will take place next June, and the course will stretch 1500 miles from Washington D.C. to Orlando Florida.

Depending on the results at Sunrayce, Lux Perpetua may also enter the World Solar Challenge, which takes place later that fall in Australia and represents the ultimate test for solar racing.

Teams from around the world compete with the latest technology to race across the Australian continent.

Team Lux also displayed last year's solar car, Lux Aeterna, Yale's first complete solar car which took first place among rookie teams at Sunrayce '97, and finished ninth overall in a field of 36 teams.

Project director, Alexander Selkirk '99, characterizes Lux Aeterna as a "learning experience" and credits Yale's first-time success to a simple design.

"[Lux Aeterna] was built to last. That's why we did so well. We built a car that you could beat against the side of a building and still race," Selkirk said.

In order to build a sturdy car, concerns about aerodynamics and weight were pushed to the side. The new car, Lux Perpetua, hopes to improve on many of these problems.

To reduce weight, Team Lux utilizes new materials such as kevlar and carbon fibers, and more efficient batteries, in order to help Yale speed past favorites Massachusetts Institute of Technology and California State.

Unfortunately, many of the innovation in Lux Perpetua will be costly. The last solar car cost approximately $240,000, and the new car looks to be even more expensive. Fundraising has played an integral part in Team Lux success, and in addition to group engineering leaders, the group has recruited account and business managers. Team Lux draws upon the experience of past members and Yale engineering professors.

"The engineering department gives us advice, helps with funding in materials and in cash, and allows us the use of their facilities," Selkirk said.

However, unlike other schools, the solar car has remained largely a student project with only limited faculty involvement.

The group's sponsor, Robert Apfel from the Department of Mechanical Engineering said his role is mainly supportive.

"We're loosely coupled," Apfel said. "I let them do things on their own, but I'm also their biggest cheerleader."

Students involved expressed enthusiasm in the creative process involved in making Lux Perpetua.

"It's such an amazing thing to be involved with because it allows a hands-on experience that classrooms can never provide," body group leader Jonathan Burt said.

"It's something completely different from doing problem sets," Selkirk said. "When you start welding the frame together, you have to make sure your driver fits into the box that you drew. The problems are just so much more tangible."

Although the current applications for solar vehicles are somewhat impractical, a new form of hybrid vehicle, powered by a combination of batteries, solar cells, and fuel, may represent the solution to transportation problems, Apfel said.

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Basic Design Concepts

From Monday Night Meeting, 9-6-99 (Mason Lab., rm. 107)

This is a brief introduction to the three major aspects of solar car design. Of course, there's a lot more to it, but the information summarized below is what we were able to discuss at the team meeting. It will be updated soon.

Basic Frame Design

Contact: Ed West, Stiles '01, frame group leader for *Lux Perpetua*.

Two methods of frame (chassis) design: monocoque and space-frame. (*Lux Perpetua* has a space-frame.)

Monocoque: a single piece of custom-molded material. It is faster and easier to build but more but more difficult to analyze.

Space-frame: consists of welded (aluminum) tubes. Team Lux used computerized Finite Element Analysis (FEA) to determine the space-frame's stress-points, and sent the results to SunRayce (the organization which runs the nationwide solar car race we went on this summer), to demonstrate its safety. We also used the computer to simulate crashes and see how the space-frame would respond to them.

Basic Body Design

Contact: Jonathan Burt, TD '01, in charge of the design and building process for *L.P.*'s body.

Solar cars originally were much odder-looking than they are now: little marshmallow-like objects with huge solar arrays propped on top.

Two modern methods for body design:

flat array with bubble canopy: ***Lux Aeterna*** (the '97 car) had a bubble canopy with a flat array made from solar cells attached to prefabricated Nomex panels. Flat arrays are easier and less time-consuming.

curved array: ***Lux Perpetua*** (the '99 solar car) has a curved array, based on the shape of a triangle (because it is a stable shape). Curved bodies are much harder to build (because of the complications of applying flat solar cells to a curved design) but also more aerodynamic.

Stability is the most important thing in body design. The next concern is how to make the car maximally aerodynamic by avoiding drag. Types of drag include --

1) **separation drag**: When air hits the front of the car, it stagnates briefly, creating a high-pressure zone at the stagnation line. To avoid separation drag there needs to be a complementary high-pressure zone at the tail end of the car. This can be accomplished by making the tail thin and flat, so that the air passing over it stays

as close as possible.

2) **induced drag**: When air hits the front of the car, some of it spirals around the body, creating turbulence. Turbulence is especially an issue with objects, such as solar cars, which not wide. It's minimized by good nose design.

3) **Friction drag** is created by a pressure difference between the top and bottom of the car. Air movement is low at the top of the car, creating a region of high pressure, and high at the bottom of the car, creating a region of low pressure; the result is a vortex of spinning air at the back of the car, which produces friction drag.

Electrical Systems

Contact: Alexander Potter, JE '01, electrical systems group leader, and Ji-Jon (JJ) Sit, Trumbull '00, who designed *LP*'s Data Acquisition System (DAQ).

Team Lux bought some parts of the car's electrical systems ready-made, such as the motor controller and the charge controller. We (and JJ in particular) built our own Data Acquisition System, to keep track of battery voltages and other minute-to-minute things about the car as we were driving it. To avoid making the same mistakes he did, JJ recommends:

Take EE 226 and 228 freshman year if you are interested in electrical engineering as a major. That way, you won't have to wait until senior year to take the most interesting courses.

If you are interested in electrical engineering or computer science as a possible career, watch the video on Wednesday night at 8:00 p.m. in CO31 (between Dunham and Becton Labs.).