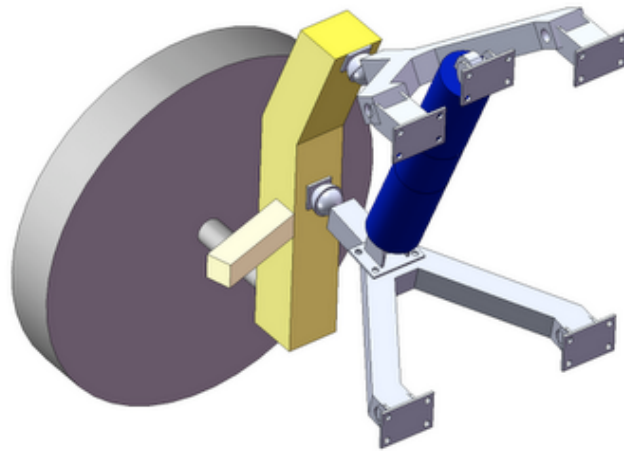# FRONT SUSPENSION OVERVIEW

Our Initial Concept

Suspension in solar cars is not designed to provide a smooth ride. Soft suspensions waste energy by absorbing the motion of the car as it travels over a bump. Therefore, solar cars have a very stiff suspension, which is designed to prevent damage to the frame in the event of a large jolt. For the front wheels almost all solar cars use double A-arm suspension, shown below. The double A-arm system has normally completely independent suspension in the front or rear and are commonly used in sports and racing cars. It is a more compact system that lowers the vehicle hood resulting in grater visibility and better aerodynamics.

In our design we are using a Short-Long Double A-arm suspension. The upper arm is shorter to induce negative camber as the suspension rises. When the vehicle is in a turn, body roll results in positive camber gain on the outside wheel. The outside wheel also rises and gains negative camber due to the shorter upper arm. The suspension design attempts to balance these two effects to cancel out and keep the tire perpendicular to the

ground. This is especially important for the outer tire because of the weight transfer to this tire during a turn. The picture below shows the short-long arm set up for the suspension in a normal car. Note the difference between the double A-arm suspension in a normal car when compared to the double A-arm suspension in a solar car. Solar car design uses long uprights mating onto high mounted wishbones reduces the thickness of the wheel fairings which lowers drag.
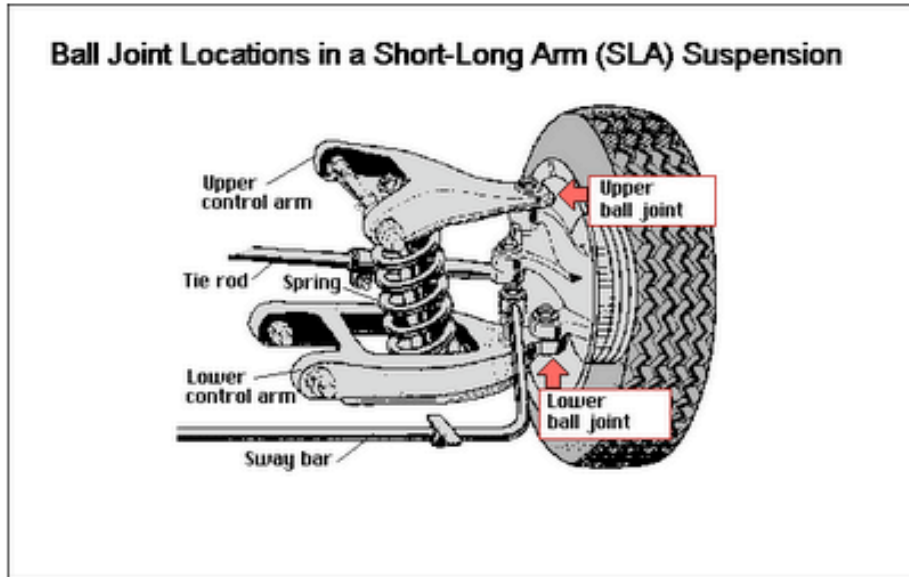


http://www.aa1car.com/library/ball_joints.htm



http://www.engr.arizona.edu/newsletters/carspecs/specsasc.html
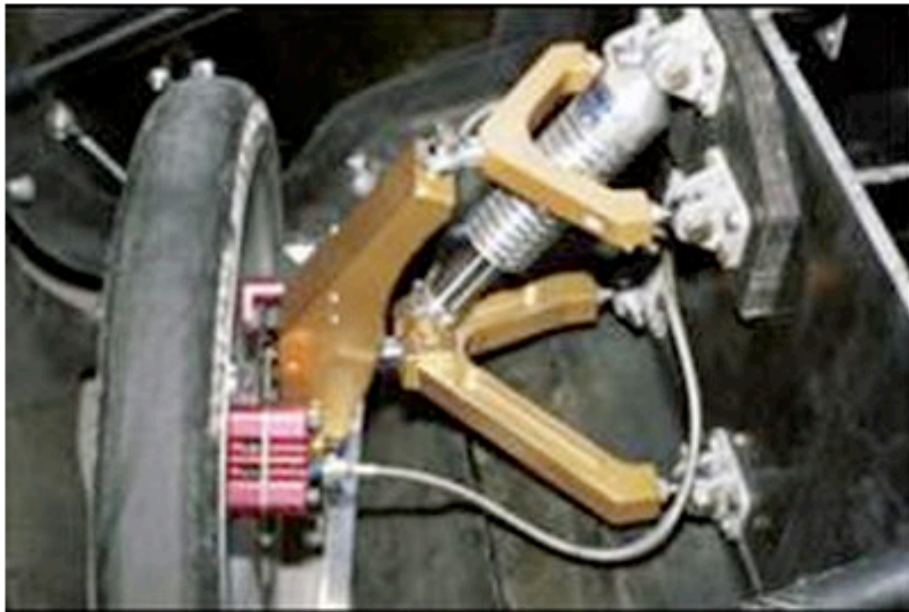
# SUSPENSION GEOMETRY TERMS

The main challenge in designing a suspension system is optimizing the geometry. To understand this there are a few key terms to consider:

***Caster***
Caster angle is the angle in side elevation between the steering axis and the vertical. It is considered positive when the steering axis is inclined rearward (in the upright direction) and negative when the steering axis is inclined forwar

Positive caster induces a self correcting force that provides straight line stability, but increases steering effort.  Caster ranges from approximately 2 degrees in racing vehicles up to 7 degrees in sedans. The bigger the angle the stronger the self centering action. If the angle is negative the steering is very light and very nervous. For our design we have chosen to use a caster that is approximately 7 degrees. This means the ball joint in the upper control arm will be positioned about an inch behind the ball joint in the lower control arm. See solidworks drawings of the completed Suspension Assembly for more details.
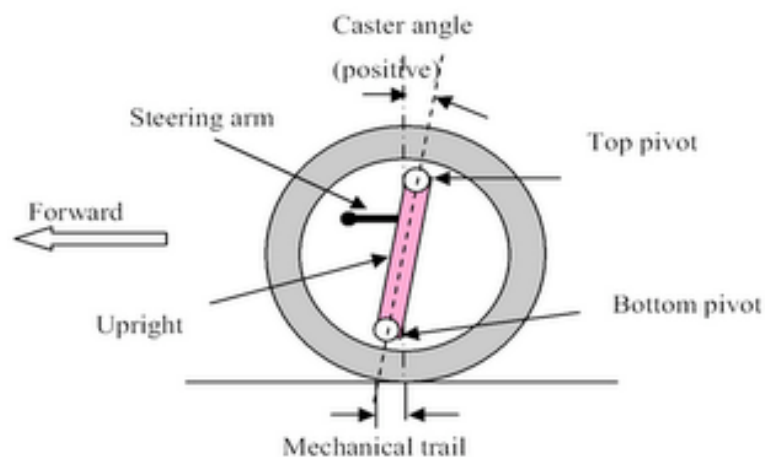
## Camber

Camber angle is regarded as the inclination of the wheel plane to the vertical. Negative camber inclines the top of the tire toward the centerline of the vehicle and positive camber inclines the top of the tire away from the centerline.

A small amount of negative camber of up to 1.5 degrees it is recommended to induce camber thrust. Changes in camber should be kept at minimum during chassis roll in order to reduce the loss of camber thrust and the change in wheel track load distribution during cornering. Negative camber will produce a better contact patch shape, producing additional lateral force without a large increase in slip angle and tire heating. A small amount of negative camber is desired such that on corners the outside wheel does not go into an excessive negative camber angle. **In most solar cars and in our design, the camber is 0 degrees to maximize efficiency. One main challenge of designing the suspension system is to keep the camber at 0 degrees as the wheel moves up and down over bumps.**
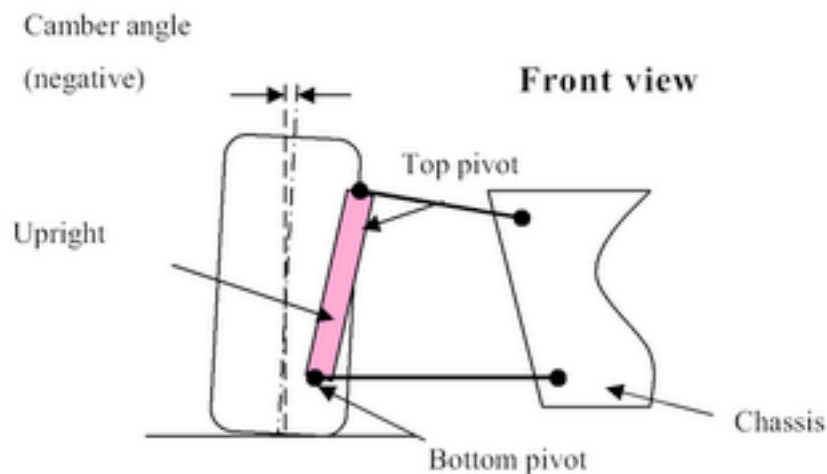


## Kingpin Axis Inclination

Kingpin Inclination or steering axis inclination is the angle in front elevation between the steering axis and the vertical. It is used to reduce the distance measured at the ground between steering axis and tire's centre of pressure in order to reduce the torque about the steering axis during forward motion. A right kingpin inclination will reduce the steering effort and will provide the driver with a good 'road feel". Raising the KPI too much will increase the lateral forces on the cars increase making it more receptive to roll and instability. The exact KPI depends on the length of the hub and

axle, the width of the tire, and the two mounting locations for each ball joint.

**Based on these variables, the steering axis inclination is roughly 10 degrees for our design.**
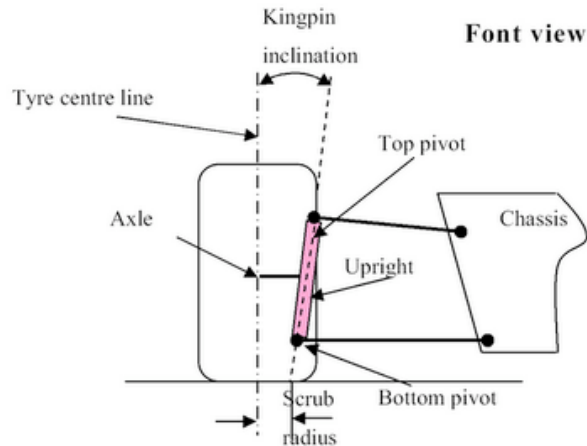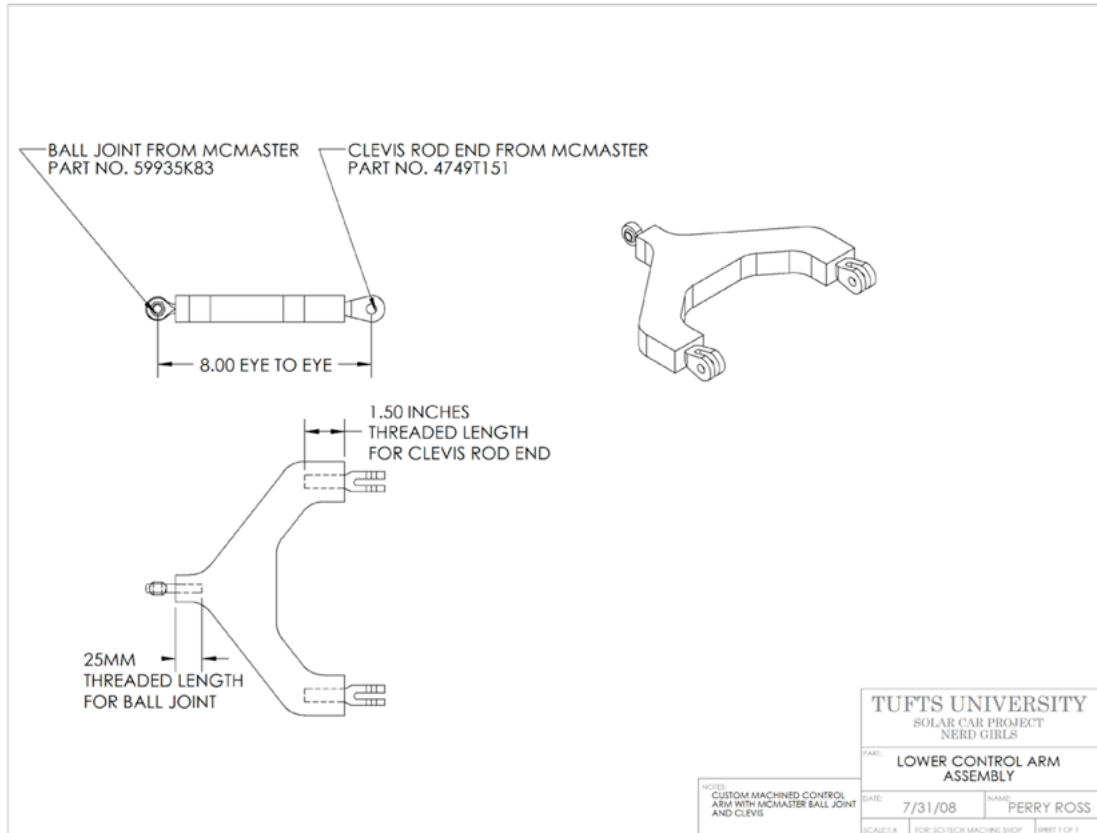


*Scrub Radius*

The scrub radius, or kingpin offset, is created if the projected KPI angle doesn't align with the footprint center of the tire. The wheel forces will try to pull the center of contact patch of the front wheels forward, thus the wheel will rotate about the point of the kingpin axle projected to the ground. Scrub radius is measured at the ground is the horizontal distance in front elevation between the point where the steering axis intersects the ground and the centre of tire contact. It is positive when the center of tire contact is outboard of the steering axis intersection point on the ground. Scrub radius is measured at static conditions (zero degree camber).

The scrub radius in our design should be as close to 0 as possible. A value of .003 inches is our goal. The exact geometry to provide this still needs to be finalized.

# SUSPENSION PARTS LIST

*Upper and Lower Control Arms with Mounting Pieces*



BALL JOINT FROM MCMASTER PART NO. 59935K83

CLEVIS ROD END FROM MCMASTER PART NO. 4749T151

8.00 EYE TO EYE

1.50 INCHES THREADED LENGTH FOR CLEVIS ROD END

25MM THREADED LENGTH FOR BALL JOINT

TUFTS UNIVERSITY
SOLAR CAR PROJECT
NERD GIRLS

LOWER CONTROL ARM ASSEMBLY

NOTES: CUSTOM MACHINED CONTROL ARM WITH MCMASTER BALL JOINT AND CLEVIS

DATE: 7/31/08  NAME: PERRY ROSS

SCALE:1:4  FOR: SCI-TECH MACHINE SHOP  SHEET 1 OF 1

The control arms are parts that need to be custom machined from aluminum to fit our specifications. We are having the control arms made at the machine shop at Sci-Tech. Once machined, the control arms will attach to the frame using a clevis pin. **The control arms will attach to the upright using a ball joint to allow motion in all directions. The clevis rod end (Part Number 4749T151) and ball joint (Part Number 4749T151) are standard parts that have been selected from McMaster.** The mounting holes for these pieces still need to be dimensioned to fit the ball joint and clevis rod end. The specific clevis rod ends still need to be selected and analyzed using FEA for loading conditions specified in The Winning Solar Car.

The length of the lower control arm must reach from the outside of the inner panel of the frame to the inside of the upright. In the Winning Solar Car, the author recommends using 9" for the length of the lower control

arm. We have seen anywhere from 6" to 15" for this length. **Because we are using a monocoque frame the length is somewhat restricted . We have chosen 8"  measured from the center of the ball joint to the center of the clevis pin for this distance.**

The upper control arm is shorter than the lower control arm and will be slightly offset from the frame and reach to the top of the upright. The length of the upper control arm must be designed to minimize the scrub radius, while keeping the caster and kingpin inclination within a reasonable range. The upper control arm geometry will be finalized once the hub and spindle designs are complete.
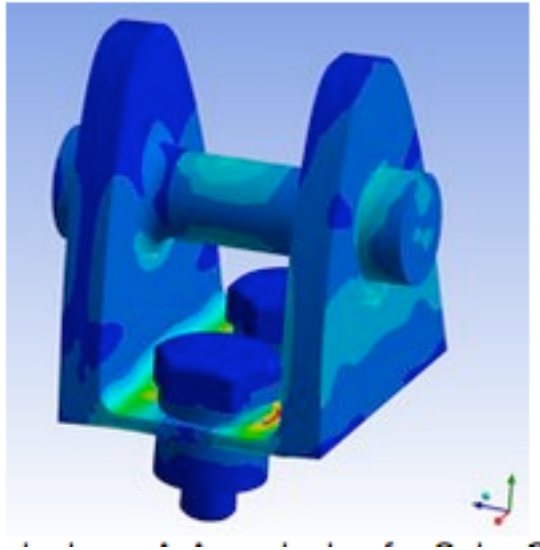The bracket that attaches the clevis rod end to the frame will need to be a custom machined part. Four of these clevis brackets will mount to the frame at each wheel.
These attachment joints still need to be designed and must be tested using FEA. Also we need to determine the best way to mount these to the frame.



Clevis Rod End
http://www.mcmaster.com/

FEA stress analysis on A-Arm clevise for Solar Car suspension
http://ansys.com/industries/env-uoft-solarcar.htm

## *Upright*

The upright in a solar car is very different from any other automobile. The upright, or kingpin, is much taller to raise the suspension system inside the shell of the car which reduces drag. In most cars the upper and lower control arm will mount above and below the axle. In a solar car the lower control arm mounts level to the axle and the upper control arm mounts at at point roughly level to the top of the wheel.
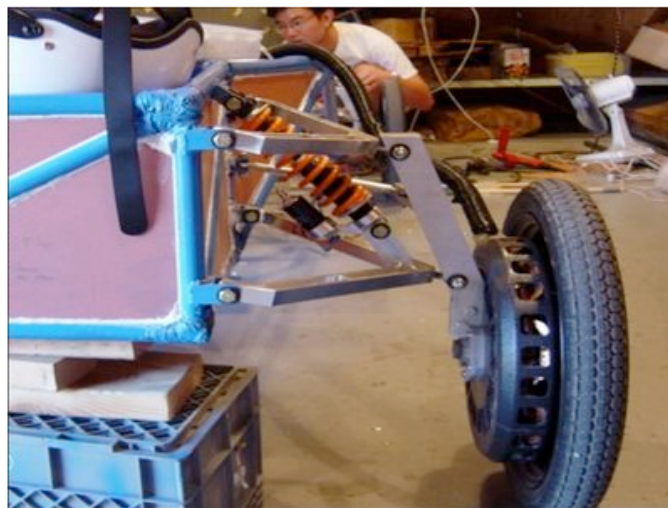
### *Shock Absorber*

When comparing different models for shock absorbers there are several different important terms to consider. Listed below are the definitions of some of the key parameters that need to be considered when specifying shocks

   Sprung weight - the weight supported by the springs. For example, the vehicle's body, transmission, frame, and motor would be sprung weight. This has been determined by the center of weight calculations

   Unsprung weight - the weight that is not carried by springs, such as the tires, wheels, and brake assemblies. This has been determined by estimating the weight of the wheel assemblies.

   Stroke - the distance the shock can compress. This parameter is determined by the shock manufacturer. **For the Risse Racing shocks that were purchased several years ago the full stroke distance is 2 1/2 inches. However will aim to have the displacement only be 1 1/2 inches to prevent the shock from bottoming out**

   Pre-load Stroke - the amount the shock compresses when it is subjected to the weight of the car. This should be between 1/4 to 1/2 inch. **Based on our spring rate of 350 lbs/in the preload stroke is .43 inches.**

   Leverage Ratio - the wheel displacement divided by the shock displacement. This relates how much the wheel travels to how much the frame will move. **The leverage ratio for our design is 1.5.**

We have found a set of four Risse Racing shocks that were purchased by a team in 2002. Since these shocks were not chosen for our design, we are sending them back to the company to be calibrated to fit the specific needs for our design.

### July 25th, 2008
*Courtney Mario*

I spoke with Kevin from Risse Racing (530-246-8700) to get a few things cleared up about shocks.  The spring rate is monitored with air pressure, typically ranging from 50psi to 350psi.  For solar cars, the shock travel is typically 2.5" and the spring rate ranges anywhere from 100 lb/in to 500 lb/in.  With regards to a damping ratio, instead of giving them an exact value, it's better to tell them the spring rate, corner weight (weight on each wheel), and force/velocity profile and they will use these values to find an accurate damping ratio.  The leverage ratio is typically around 2, and should be no higher than 3.  Our pre-load distance for the shock, which will define the spring rate based on the corner weight for the wheels, should be between 0.25" to 0.5".

**July 28th, 2008**
*Perry Ross*
Based on the information from Risse Racing and using a corner weight of 150 lbs we have been able to set the following parameters listed below:

**Spring Rate - 350 (lb/in)**
**Damping Ratio - .07 (lb*s/in)**
**Pre-Load - .42 in**
**Shock Mounting Angle - 45 degrees**
**Leverage Ratio - 1.5**

Please refer to  SpringRateSimplifiedCalculations_8_04_08.xls for the exact calculations

**February 2nd, 2009**
*Kayla Burke and Rachael Hogan*
We decided to use Aluminum 6061:
http://www.mcmaster.com/#aluminum/=fgrr7