INTRODUCTION

LEADING PROGRAM
ROLE OF MENTOR
HANDS-ON DESIGN
SYLLABUS

MATERIALS LIST
REGISTRATION
LINKS & PARTS

Webmaster

SYLLABUS

PHILOSOPHY

Students are encouraged to attack the overall design problem in a piece wise fashion, that is, to experiment with the various components individually. Once students have a greater understanding of the workings of the various parts of the vehicle, assembling these components into a functional car becomes a simplified task. These investigations make up approximately the half of the course. In the other half, students build, test and optimize the components, from the first half of the course.

Class 1

JSS PROGRAM INTRODUCTION

Mentor Visit

- Show video & flyer
- JSS Schedule
  - Program Dates
  - School race date
- Define Goals and Constraints
  - Kit materials
  - Race rules
  - Vehicle specifications
- Brainstorm ideas for components / whole vehicle

Teacher Guidance

- Form teams of 2 to 4 students
- Select Car numbers
- Select Team Leader
- Select Team name and color
- Continue brainstorming in class

Additional Resources for you to use:

- Introduction and Design Power Point Presentation

Student Work

Student Study Materials:

Student Handout #1: *Program Introduction*

What your team should do this day:

- Brainstorm overall car concepts and sketch them
  - How might your model solar car look?
- How do motors make things move?

        - Find examples of machines, toys, vehicles, etc. with mechanical components
    - Come up with lists of questions that need answers before selecting a design
    - Select Team number, name and color
    - Continue brainstorming in class

Requirements for Completion of this Segment:

1. **Select Team Name**
2. **Select Team Colors**
3. **Select Team Number**

Class 2

DESIGN PROCESS

Mentor Visit

- Discuss Hands-on design & Design Process
    - Relate to professional engineering
    - Relate to work and / or hobbies
- Discuss vehicle components
    - Chassis
    - Wheels / Bearings
    - Motor
    - Transmissions
    - Energy Source
    - Body Shape
- Brainstorm ideas for components / whole vehicle

Teacher Guidance

- Finalize teams of 2 to 4 students
- Finalize Car numbers
- Finalize Team Leader
- Finalize Team name and color
- Continue brainstorming in class

Additional Resources for you to use:

- Introduction and Design Power Point Presentation

Student Work

Student Study Materials:

Student Handout #2: *Design Process*

What your team should do this day:

- Brainstorm overall car concepts and sketch them
  - How might your model solar car look?
- How do motors make things move?
  - Find examples of machines, toys, vehicles, etc. with mechanical components
- Come up with lists of questions that need answers before selecting a design
- Select Team number, name and color
- Continue brainstorming in class

Requirements for Completion of this Segment:

1. **Finalize Team Name**
2. **Finalize Team Colors**
3. **Finalize Team Number**
4. **2 or more rough sketches / ideas for your car**

Class 3

CHASSIS

Principles, Prototypes, & Experiments

Mentor Visit

Design Review

- Teams present car concepts and the questions that need answers before selecting design
- Class discussion of how to answer these questions, what experiments to conduct, performance measures
- Demonstrate / discuss physical principles
  - Stiffness and strength to weight ratio

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Strength of materials
  - Orientation of materials
- Assist students in obtaining building materials and tools
- See that all team members are contributing

Additional Resources for you to use:

- Chassis Power Point Presentation

Student Work

Student Study Materials:

Student Handout #3: *Chassis*

What your team should do this day:

- Conduct experiments to answer design questions
  - Build a prototype chassis
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build a chassis**
2. **Show notes from investigations 3-1 & 3-2**
3. **2 or more rough sketches / ideas for chassis**

Class 4	WHEELS, AXLES, & BEARINGS **Principles, Prototypes, & Experiments**

Mentor Visit

Design Review

- Teams present car concepts and the questions that need answers before selecting design
- Class discussion of how to answer these questions, what experiments to conduct, performance measures
- Demonstrate / discuss physical principles
  - Friction: losses in sliding parts
  - Friction: between wheels and track (traction)
  - Inertia and acceleration

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Inertia and acceleration
  - Methods of mounting wheels
  - Coasting test for friction and wheel alignment
- Assist students in obtaining building materials and tools
- See that all team members are contributing

Additional Resources for you to use:

- Chassis Power Point Presentation

Student Work

Student Study Materials:

Student Handout #4: *Wheels, Axles, & Bearings*

What your team should do this day:

- Conduct experiments to answer design questions
  - Build a prototype chassis and mount prototype wheels, axles, and bearings
  - Build something that rolls
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build a chassis with wheels that rolls**
2. **Show notes from investigations 4-1 & 4-2 & 4-3**
3. **2 or more rough sketches / ideas for wheels, axles and bearings**

Class 5

MOTORS & TRANSMISSIONS

Principles, Prototypes, & Experiments

Mentor Visit

- Class discussion of experimental results
- Demonstrate / discuss physical principles
  - Transmission (gear) ratios
  - Motors
  - Torque and Force
- Continue class discussion of how to answer additional questions, what experiments to conduct, performance measures

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Construct different transmission types and ratios
- Start planning for school race
- See that all team members are contributing

Student Work

Student Study Materials:

Student Handout #5: *Transmissions*

What your team should do this day:

- Conduct experiments to answer design questions
  - Experiment with various transmission types
  - Mount motor and transmission on test chassis
  - Build something that moves under its own power
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build something that moves under its own power**
2. **Show notes from investigations 5-1 & 5-2 & 5-3**
3. **2 or more rough sketches / ideas for transmissions**

Class 6

GEAR & WHEEL CALCULATIONS

Principles, Prototypes, & Experiments

Mentor Visit

- Class discussion of experimental results
- Demonstrate / discuss physical principles
  - Calculate distance traveled per motor revolution (taking into account gear ratio and wheel size)
- Continue class discussion of how to answer additional questions, what experiments to conduct, performance measures

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Study effect of wheel diameter on transmission ratios
- Start planning for school race
- See that all team members are contributing

Student Work

Student Study Materials:

Student Handout #6: *Calculating Gearing Ratios*

What your team should do this day:

- Conduct experiments to answer design questions
  - Experiment with various wheel diameters
  - Experiment with various transmission types
  - Mount motor and transmission on test chassis
  - Build something that moves under its own power
- Come up with additional lists of questions to be answered before design

can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build something that moves faster under its own power**
2. **Show notes from investigation 6-1**
3. **2 or more rough sketches / ideas for transmissions**

Class 7

MOTORS, ELECTRICITY, & SOLAR PANELS

Principles & Experiments

Mentor Visit

- Class discussion of experimental results
- Demonstrate / discuss physical principles
  - Electric Motors
  - Electricity
  - Photovoltaics (Solar Panels)
- Continue class discussion ofhow to answer additional questions, what experiments to conduct, performance measures

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Measure solar panel output (voltage, current)
  - Demonstrate motor output (speed-torque relationship)
  - Study effects of voltage / current input on motor output
- Continue planning for school race
- See that all team members are contributing

Student Work

Student Study Materials:

Student Handout #7: *Solar Panels*

What your team should do this day:

- Conduct experiments to answer design questions
- Choose designs for
  - Solar panel mount
  - Build something that moves under solar power
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build a chassis with wheels that moves under solar power**
2. **Show notes from investigations 7-1**
3. **2 or more rough sketches / ideas of your solar panel**

Class 8

BODY SHELL, & AERODYNAMICS

Principles & Experiments

Mentor Visit

- Class discussion of experimental results
- Demonstrate / discuss physical principles
  - Aerodynamics and car body shape
- Continue class discussion ofhow to answer additional questions, what experiments to conduct, performance measures

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Measure air drag on different body shapes
- Continue planning for school race
- See that all team members are contributing

Student Work

Student Study Materials:

Student Handout #8: *Body & Shell*

What your team should do this day:

- Conduct experiments to answer design questions
- Choose designs for
  - Chassis
  - Solar panel mount
  - Body / Shell
  - Build something that moves under solar power
- Come up with additional lists of questions to be answered before design can be selected
- Sketch final car designs to choose from

Requirements for Completion of this Segment:

1. **Build a chassis with wheels that moves under solar power**
2. **Show notes from investigations 8-1 & 8-2**
3. **2 or more rough sketches / ideas of your body shell**

Class 9

SELECT OVERALL DESIGN & PREPARE PRESENTATION

Make final plans

Mentor Visit

Design Review

- Explain the process of reviews and selling of ideas
- Help Teams prepare to present car designs to class and receive comments / suggestions
- Generate design criteria for vehicles
  - Lightweight
  - Sturdy
  - Good acceleration
  - High top speed
  - Aerodynamic
  - Low friction
  - Steers straight
  - Can accommodate guide wire
  - Easy to build
  - Aesthetics
  - Etc…
- Help each group select one design to build
  - List pros and cons
  - Combine best features from various concepts

Teacher Guidance

- Assist students in selecting designs to build
- Help teams prepare presentations
- Help teams split up building tasks
  - Obtain materials
  - Build car components
  - Etc…
- Continue planning for school race
- See that all team members are contributing

Additional Resources for you to use:

- Design Review Word Document

Student Work

Student Study Materials:

Student Handout #9: *Design Reviews*

What your team should do these days:

- Review concept sketches and select one design to be built

- Plan how to build it as a team
  - Discuss building materials and methods
  - Split up building tasks
- Consider aesthetics
- Consider Rules and Specifications

Requirements for Completion of this Segment:

1. **Show notes from investigation 9-1 &**
2. **Make final drawing of car design**
3. **Make a list of materials for your final car**
4. **Prepare for design review in front of calss**

Class

10

DESIGN REVIEW PRESENTATION

Present Ideas in front of Class

Mentor Visit

Design Review

- Teams present car designs to class and receive comments / suggestions
- Evaluate the approach of each and give feedback

Teacher Guidance

- Help teams make presentations
  - Overhead projector
  - Transparencies produced
  - Etc...
- Continue planning for school race
- See that all team members are contributing

Additional Resources for you to use:

- Design Review Word Document

Student Work

Student Study Materials:

Student Handout #9: *Design Reviews*

What your team should do these days:

- Involve everyone in presentation
- Sell your ideas
- Have support information for decisions

Requirements for Completion of this Segment:

1. **Present Design for class review**

Class	CONSTRUCTION OF VEHICLES
11 12 13	**Build & Test Components**

Mentor Visit

- Check progress of cars
- Find out problem areas and give design advice
- Remind teams to make provision for guide wire eyelet
- Review race rules with teams
- Check that vehicles comply with race rules
- Will the designs work?
  - If a design cannot be successfully built, go back to list of concepts from Brainstorm session and select another
- Review design criteria for vehicles
- Discuss performance measures
- Plan optimization experiments
  - Review design criteria for vehicles
  - Discuss performance measures

Teacher Guidance

- Assist students in building vehicles and using tools
- Review physical principles with students as needed
- Continue planning for school race
- See that all team members are contributing

Additional Resources for you to use:

- Build a sprint car Power Point Presentation

Student Work

Student Study Materials:

Student Handout #10: *Build*
Student Handout #11: *Optimizing your Design*

What your team should do these days:

- Build Vehicle
  - Wheels
  - Chassis
  - Mount wheels and axles on chassis
  - Build transmission and connect to motor
  - Body

- Solar panel mount
- Aesthetics including car number and name

- Begin testing vehicle

Requirements for Completion of this Segment:

1. **Build components for your car**
2. **Assemble components of your car**

Class 14 Race Day

PRE-RACE PREPARATIONS

Last Minute Adjustments

Mentor Visit

- See that all cars are working
- Assist teacher in race preparations
- Set up the track
- Display race heat order

Teacher Guidance

- Assist students in getting to race site with cars
- Have starting signal ready
- Make sure teams understand rules for conducting the race

Student Work

Student Study Materials:

Event Rules: ***Race Rules***

What your team should do this day:

- Complete optimization experiments
- Rework components as necessary
- Set up race team in positions
  - Finish line person
  - Start line person
  - Repair equipment & specialists
- Race your creation

Requirements for Completion of this Segment:

1. **Race your car**
2. **Show team spirit**
3. **Be helpful to team-mates & other teams**
4. **Follow the race rules**

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

COURSE INTRODUCTION *Handout 1.0*

THE DESIGN PROCESS

You will experience first-hand the process of design. When you design your car, you will start with some ideas in your head and turn them into real-life models that work. Design is different than normal problem-solving because:

- you don't know what the problems are (you discover and solve problems as you go along - everyone's challenges will be different)
- there is never one right answer

Designers have to deal with tradeoffs. For example, when a car designer uses a larger engine for greater performance, it usally sacrifices fuel efficiency. In a sports car, performance and speed are very important. But in a city car, fuel efficiency is more important. So it is up to the designer to decide which are the most important goals.

Even though there is no one right answer, some answers may be better than others for a particular application. Obviously, in Junior Solar Sprint, the faster carswill win. But remember strategy can be a big factor - there are variables like the amount of sunshine that may influence your decisions.

GETTING STARTED

You will receive short handouts on a variety of subjects from how to build the wheels to how the solar cell works. These handouts will cover the following topics:

- **CHASSIS:** How to build the fram of the car.
- **WHEELS & BEARINGS:** How to make wheels that turn.
- **TRANSMISSIONS:** How to transfer power from the motor to the wheels.
- **MOTORS & POWER SOURCE:** How the solar panel and motor work.
- **BODY SHELL:** How the shell effects car performance.

In general, when you design, it is good to keep the different parts in mind, but don't worry about the details of each component until you are ready for them.

Each handout subject will be contain 5 sections:

1. **PURPOSE**
2. **IDEAS**
3. **CONCEPTS**
4. **SUGGESTED MATERIALS**
5. **EXPERIMENTS AND INVESTIGATIONS**

The concept section will raise issues that will help you decide how to make the right decisions and build the winning car.

Experiment as much as possible early on and don't worry about making mistakes. It is always the case with design that you don't know what the problems are until you encounter them. Use what you build for investigations as prototypes for your car to test and evaluate the idea. So get your hands dirty and get started! Good luckand have fun.

INTRODUCTION

LEADING PROGRAM
ROLE OF MENTOR
HANDS-ON DESIGN
SYLLABUS

MATERIALS LIST
REGISTRATION
LINKS & PARTS

Webmaster

MATERIALS LIST

The following is a list of the materials needed to support the investigations for each team during the course of the class:

Investigation 3-1:

- 2 - 1" dowels about 6 inches long.
- 1 - 8.5" x 11" sheet paper.
- 1 - 8.5" x 11" sheet of poster board (cardboard).
- 1 - 8.5" x 11" sheet of corrugated cardboard.
- 1 - 8.5" x 11" sheet of foamcore board.
- 1 - 8.5" x 11" plastic sheet.
- Small weights.

Investigation 3-2:

- Plastic or wood 12" ruler.

Investigation 4-1:

- 12 coins.
- Text book.
- B-B's (optional).

Investigation 4-2:

- Piece of wood (8"x6"x.25").
- Ruler.
- 1 - 4" x 4" sheet of formica.
- 1 - 4" x 4" sheet of metal.
- 1 - 4" x 4" sheet of wood.
- 1 - small block of plastic.
- 1 - small block of metal.
- 1 - small block of wood.
- Small bottle of oil (could be shared).
- Tube of graphite (could be shared).
- Small bottle of liquid soap (could be shared).
- Paper towels.

Investigation 4-3:

- Piece of wood (same as 4-2).
- Block of wood (or books).
- Masking tape for marking locations.
- 2 or 3 old prototype cars with different types of wheels.

Investigation 5-1:

- Piece of wood (6"x6"x.75").
- Hammer.
- 4 - 2" long finish nails.

- 3 different sizes of spools.
- 1 - Rubber band.

Investigation 5-2:

- Plastic gear set (3 different sizes).
- Plastic gear mounting board or system.
- 2 or 3 axles for mounting gears.

Investigation 5-3:

- Motor (from team kit).
- 3V battery.
- 1 small pulley (for motor).
- 1 - 8.5" x 11" piece of foamcore board.
- Hot glue or tape.
- 1 drinking straw.
- 6" piece of .125 dia rod.
- 3 different pulleys (hole in center for the rod).
- Rubber band.

Investigation 6-1:

- Motor (from team kit).
- 3V battery.
- Prototype car (chassis & wheels with transmission).
- Lightweight foam tape (door insulation).

Investigation 7-1:

- Motor (from team kit).
- Solar panel (from team kit).
- 1 drinking straw.
- 1 protractor.
- 1 propeller.

Investigation 8-1:

- 2 .5" dia dowels - 18" each.
- Empty pop can.
- 1 - 8.5" x 11" sheet of paper.
- Tape.

Investigation 8-2:

- Piece of wood (same as 4-2).
- Block of wood (same as 4-2).
- Masking tape for marking locations.
- 1 sloted derby block car.
- 1 - 6" x 6" sheet of foamcore board.

The following is a list of materials needed for testing and race day:

- Fishing line.
- Broom.
- Yellow ribbon.
- Spounges or foam for cars to run into.
- Start line pad (plastic).
- Finish line pad (plastic).
- Duct Tape.
- Race order sheet.
- Megaphone.
- Start gun (optional).
- Covers for cars at start line.
- Balloons.
- Flags and banners.
- 2 rolls of heavy roofing paper.

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

COURSE INSTRUCTIONS

A brief presentation will be made on the material each week. Your responsibility is to go through the Student Handout information for each week (usually 2 handouts), perform the investigations and do what is outlined. Your team must complete the assignements listed and review what you have done with a teacher or mentor before moving on to the next set of handouts.
Remember that any extra time you have should be used to experiment with your ideas for your design in that subject area. Build prototypes to prove out your ideas with the materials you can find and bring in.

Class 1

JSS PROGRAM INTRODUCTION

Student Study Materials:

Student Handout #1: *Program Introduction*

What your team should do this day:

- Brainstorm overall car concepts and sketch them
  - How might your model solar car look?
- How do motors make things move?
  - Find examples of machines, toys, vehicles, etc. with mechanical components
- Come up with lists of questions that need answers before selecting a design
- Select Team number, name and color
- Continue brainstorming in class

Requirements for Completion of this Segment:

1. **Select Team Name**
2. **Select Team Colors**
3. **Select Team Number**

Class

DESIGN PROCESS

2	**Student Study Materials:**
	
	[Student Handout #2: *Design Process*]
	
	What your team should do this day:
	
	○ Brainstorm overall car concepts and sketch them
	    ● How might your model solar car look?
	○ How do motors make things move?
	    ● Find examples of machines, toys, vehicles, etc. with mechanical components
	○ Come up with lists of questions that need answers before selecting a design
	○ Select Team number, name and color
	○ Continue brainstorming in class
	
	Requirements for Completion of this Segment:
	
	1. **Finalize Team Name**
	2. **Finalize Team Colors**
	3. **Finalize Team Number**
	4. **2 or more rough sketches / ideas for your car**

Class 3	CHASSIS **Principles, Prototypes, & Experiments**
	Student Study Materials: [Student Handout #3: *Chassis*] **What your team should do this day:** ○ Conduct experiments to answer design questions ● Build a prototype chassis ○ Come up with additional lists of questions to be answered before design can be selected ○ Continue sketching concepts **Requirements for Completion of this Segment:** 1. **Build a chassis** 2. **Show notes from investigations 3-1 & 3-2** 3. **2 or more rough sketches / ideas for chassis**
Class 4	WHEELS, AXLES, & BEARINGS **Principles, Prototypes, & Experiments**
	Student Study Materials: [Student Handout #4: *Wheels, Axles, & Bearings*]

What your team should do this day:

- Conduct experiments to answer design questions
  - Build a prototype chassis and mount prototype wheels, axles, and bearings
  - Build something that rolls
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build a chassis with wheels that rolls**
2. **Show notes from investigations 4-1 & 4-2 & 4-3**
3. **2 or more rough sketches / ideas for wheels, axles and bearings**

Class 5

MOTORS & TRANSMISSIONS

Principles, Prototypes, & Experiments

Student Study Materials:

Student Handout #5: ***Transmissions***

What your team should do this day:

- Conduct experiments to answer design questions
  - Experiment with various transmission types
  - Mount motor and transmission on test chassis
  - Build something that moves under its own power
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build something that moves under its own power**
2. **Show notes from investigations 5-1 & 5-2 & 5-3**
3. **2 or more rough sketches / ideas for transmissions**

Class 6

GEAR & WHEEL CALCULATIONS

Principles, Prototypes, & Experiments

Student Study Materials:

Student Handout #6: ***Calculating Gearing Ratios***

What your team should do this day:

- Conduct experiments to answer design questions
  - Experiment with various wheel diameters
  - Experiment with various transmission types

- Mount motor and transmission on test chassis
- Build something that moves under its own power
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build something that moves faster under its own power**
2. **Show notes from investigation 6-1**
3. **2 or more rough sketches / ideas for transmissions**

Class 7

MOTORS, ELECTRICITY, & SOLAR PANELS

Principles & Experiments

Student Study Materials:

Student Handout #7: *Solar Panels*

What your team should do this day:

- Conduct experiments to answer design questions
- Choose designs for
  - Solar panel mount
  - Build something that moves under solar power
- Come up with additional lists of questions to be answered before design can be selected
- Continue sketching concepts

Requirements for Completion of this Segment:

1. **Build a chassis with wheels that moves under solar power**
2. **Show notes from investigations 7-1**
3. **2 or more rough sketches / ideas of your solar panel**

Class 8

BODY SHELL, & AERODYNAMICS

Principles & Experiments

Student Study Materials:

Student Handout #8: *Body & Shell*

What your team should do this day:

- Conduct experiments to answer design questions
- Choose designs for
  - Chassis
  - Solar panel mount
  - Body / Shell
  - Build something that moves under solar power
- Come up with additional lists of questions to be answered before design

	can be selected ○ Sketch final car designs to choose from **Requirements for Completion of this Segment:** 1. **Build a chassis with wheels that moves under solar power** 2. **Show notes from investigations 8-1 & 8-2** 3. **2 or more rough sketches / ideas of your body shell**
Class 9	SELECT OVERALL DESIGN & PREPARE PRESENTATION **Make final plans**
	Student Study Materials: **Student Handout #9: *Design Reviews and Considerations*** **Student Handout #10: *Design Review Planning Form*** **What your team should do these days:** ○ Review concept sketches and select one design to be built ○ Plan how to build it as a team • Discuss building materials and methods • Split up building tasks ○ Consider aesthetics ○ Consider Rules and Specifications **Requirements for Completion of this Segment:** 1. **Make final drawing of car design** 2. **Make a list of materials for your final car** 3. **Prepare for design review in front of calss**
Class 10	DESIGN REVIEW PRESENTATION **Present Ideas in front of Class**
	Student Study Materials: **Student Handout #10: *Design Review Planning Form*** **What your team should do these days:** ○ Involve everyone in presentation ○ Sell your ideas ○ Have support information for decisions **Requirements for Completion of this Segment:** 1. **Present Design for class review**
Class	CONSTRUCTION OF VEHICLES **Build & Test Components**

11 12 13	**Student Study Materials:** **Student Handout #11: *Tools & Materials*** **Student Handout #12: *Safe Use of Hand Tools*** **Student Handout #13: *Optimizing your Design*** **What your team should do these days:** ○ Build Vehicle • Wheels • Chassis • Mount wheels and axles on chassis • Build transmission and connect to motor • Body • Solar panel mount • Aesthetics including car number and name ○ Begin testing vehicle **Requirements for Completion of this Segment:** 1. **Build components for your car** 2. **Assemble components of your car**
Class 14 Race Day	PRE-RACE PREPARATIONS **Last Minute Adjustments**
	Student Study Materials: **Student Handout #14: *Race Rules*** **What your team should do this day:** ○ Complete optimization experiments ○ Rework components as necessary ○ Set up race team in positions ■ Finish line person ■ Start line person ■ Repair equipment & specialists ○ Race your creation **Requirements for Completion of this Segment:** 1. **Race your car** 2. **Show team spirit** 3. **Be helpful to team-mates & other teams** 4. **Follow the race rules**

Chimacum School District No. 49

Junior Solar Sprint

Junior Solar Sprint

TEACHERS INTRODUCTION

Thank you for paticipating in the Junior Solar Sprint (JSS) Program. This program is quickly expanding and evolving! This year we are providing some new background information that we hope you and your students will find helpful. This Teacher and Mentor Guide includes a suggested lesson plan for you to work from. We encourage you to modify it to suit your own circumstances.

"An Introduction to Building a Model Solar Car" is a reference provided for students; teachers and mentors may find it useful either as background information or to generate ideas for their program. Keep in mind that one of the mentor's roles is to provide teachers with technical support, so teachers should feel free too call mentors with any questions.

In designing this program we set the following goals:

- Present science concepts in a fun and exciting way.
- Give students a chance to interact with engineers and scientists.
- Stimulate creative thinking through a hands-on design project.
- Help students to experience the satisfaction of creating a working machine and the excitement of entering it in a competition.

In this guide, we have incorporated suggestions from last year's teacher and mentor participants. The sections which follow are meant to be guidelines and suggestions. It is important to keep in mind that there is no single correct way to successfully complete this program. Remeber that design is a creative process: professional engineers have variations in style and might not exactly follow the design procedure described in this document. If you have other ideas which are not mentioned here, you should feel free to use them (and let us know what they are so that we can continue to improve this guide). We realize that mentors have different levels of time flexibility and comfort with classroom teaching. Also, no two schools have exactly the same level of teacher expertise, student participation, or time scheduling flexibility.

Chimacum School District No. 49

Junior Solar Sprint

Junior Solar Sprint

INTRODUCTION

LEADING PROGRAM
ROLE OF MENTOR
HANDS-ON DESIGN
SYLLABUS

MATERIALS LIST
REGISTRATION
LINKS & PARTS

Webmaster

LEADING THE PROGRAM

Benefiting from Experienced Designers. In some classrooms it makes sense to involve in the project parents who are scientists or engineers. These parents can advise in car-building sessions or arrange workplace tours for the class. Another possibility is to have students who participated in last year's program discuss their experiences with the class. They can demonstrate their car and explain design challenges they faced.

Curriculum Areas Where JSS Can Be Used. This program can be incorporated into may classroom curriculum areas, such as:

- Physics/Physical Science
- Transportation
- Alternative Energy
- Electricity
- Mechanics
- Earth Sciences

Incorporating the program into a pre-existing curriculum enables teachers to devote class time to the project while enhancing their existing curriculum.

Working at Home vs. Working at School. There are many scheduling alternatives: completing the program during class time, completing the program at school but after school, having Saturday working sessions, and having students take cars home to work on them. Each has its own advantages and disadvantages. We suggest having the students work at home only in programs where the students are likely to work in their groups at home. This alternative will be less ideal in schools and programs where the students working in the groups don't know each other or live far from one another. If the program is done primarily at school, it is important to reserve a space where students can store their materials safely.

INTRODUCTION

LEADING PROGRAM
ROLE OF MENTOR
HANDS-ON DESIGN
SYLLABUS

MATERIALS LIST
REGISTRATION
LINKS & PARTS

Webmaster

HANDS ON DESIGN

Working in Groups. The recommended size for groups in this project is 2-4 students. We advocate that this project be completed by students working in groups rather than students working individually for several reasons. First, individual cooperation, like competition, involves skill and practice and is important in the professional engineering workplace. Second, working in a group is very often a strongly positive part of the project for students who have less confidence with hands-on work if group members help one another. Third, having the students share amongst themselves the search for and use of materials makes this portion of the project less costly and less intimidating for everyone.

We realize in some classroom situations, setting up work teams is difficult. A common problem is that one student takes ownership of the project and the others have negligible contributions, making for resentment on all sides.

We do have some suggestions for avoiding this type of problem. Some teachers find that students unfamiliar with working in groups are more enthusiastic when working on a team that the students have selected. In other cases, it makes sense for teachers to designate groups themselves so that they can effectively balance student skills among groups. Another suggestion; encourage the groups to divide the tasks and provide incentive for everyone in the group to understand what is going on. For example, have the groups present their designs to the class, and require that each member of the group speak about some aspect of the design. Also, provide some incentives for the quiet people to speak up and the assertive people to listen. Both speaking an listening are important teamwork skills.

Design Reviews as a Teaching Tool. A particularly successful classroom activity, called the "design review" in the professional workplace, requires students to explain their designs to the entire class at certain designated points in the design process. Some examples are discussed in the curriculum section. This activity is helpful for everyone. The portion of the class listening to the presentation learns about other approaches to designing the car. The members of the group presenting have to understand their own project well enough to explain it. They receive useful feedback from their classmates, their teacher, and their mentor. Students gain valuable insight from constructively criticizing one another's work. It is important, in the design review, to make sure that everyone gets a chance to give comments and receive suggestions.

Answering Questions and Stimulating Thinking. One of the goals of this project is to stimulate students to think and formulate their own questions. The next step in this process is to help students acquire the confidence to research their own answers, so that students do not make design selections because "This is what my teacher told me to do." Students should be encouraged to ask questions because they are thinking, rather than to avoid thinking.

Developing Individual Student Skills and Creativity. We suggest thinking about ways to help individual students develop skills in areas which may not be their strengths. Encourage tentative students to speak up and not be intimidated by assertive students. Encourage aggressive students to relax and listen to what others have to say. Since developing creativity is in itself a goal, give students room to be creative. Evaluate the project in multiple areas such as technical performance, aesthetics, and craftsmanship so that more students can be excited by at least one option. Encourage students who are not used to working with their hands to experiment and make mistakes. Encourage students who are used to working with their hands to be good teachers, patient and not overly helpful.

Testing the Cars: Learning from Mistakes. Students, like engineers, will learn from their mistakes! We expect things to go wrong the first (few) times. For this reason, engineers usually build one or more prototypes (test cars) to test out parts of their designs before building the actual device.

Testing is an important part of the design process, and it often takes more time than anticipated. For students working on this project, it is useful to build one or more prototypes of components to help evaluate and test initial designs. Once a final version is built, it has to be tested as well.

Recognition. It is important to give students positive feedback and recognition for their work. This can be done, for example, by holding races for the whole school to watch, or by having a school display of cars or drawings.

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

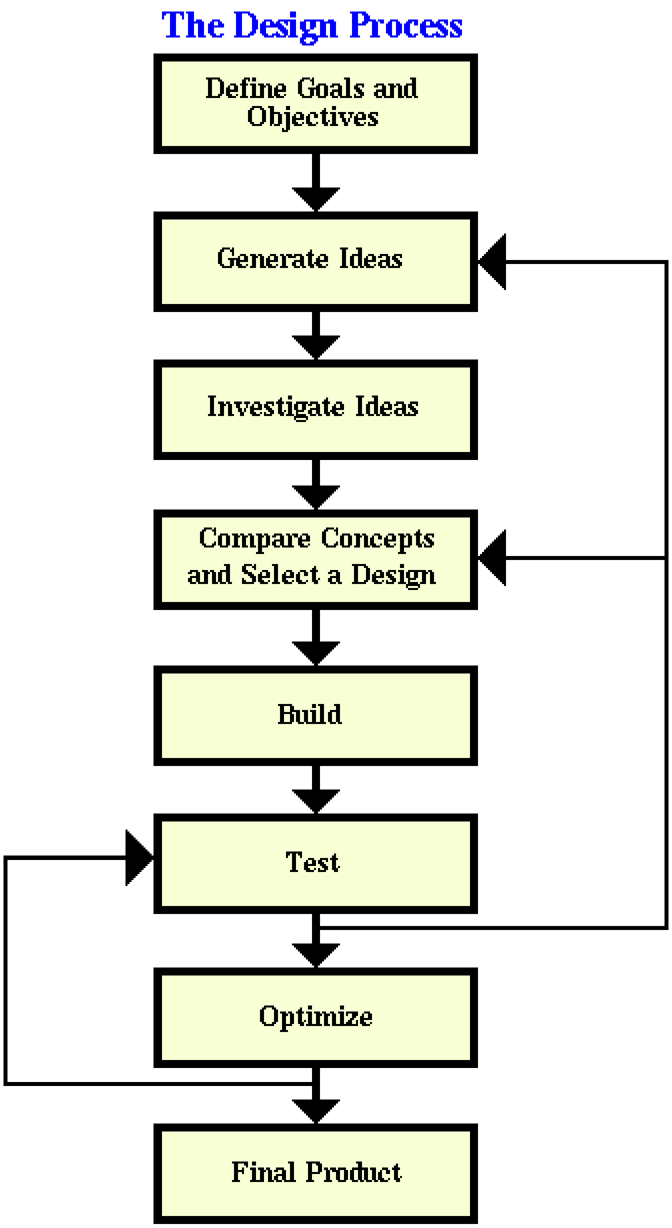
EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

DESIGN PROCESS *Handout 2.0*

What is design? Design is the process of creating something new to perform a specific function. In this program, students will be given a specific mechanical design problem and asked to create a machine that solves it. To effectively channel creativity, professional design engineers impose a structure on the design process. The process used by many engineers is presented here for teachers and students to use in designing their solar vehicles.

For more information on each process step, select the process box below.



The process presented here may be used at any and all levels of model car design, from the design of individual components to the complete car as a system. The key principle in the process is to start all designs with many ideas, then investigate and evaluate several of them before locking into a design.

Part of the challenge in design is learning to combine good ideas from several people into a winning design. Students should be encouraged or required to use a notebook to record their ideas and sketches. Ideas not written down or sketched are quickly forgotten. In addition to providing a means to store and communicate ideas, putting thoughts down on paper often aids in idea generation and clarity.

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

CHASSIS *Handout 3.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]
   The car's chassis is its frame. It holds all of the main componenets, or parts, together.

2. **IDEAS:** [index]
   Some possible ideas for a solar car chassis are shown below. Try different ideas.Try different materials.

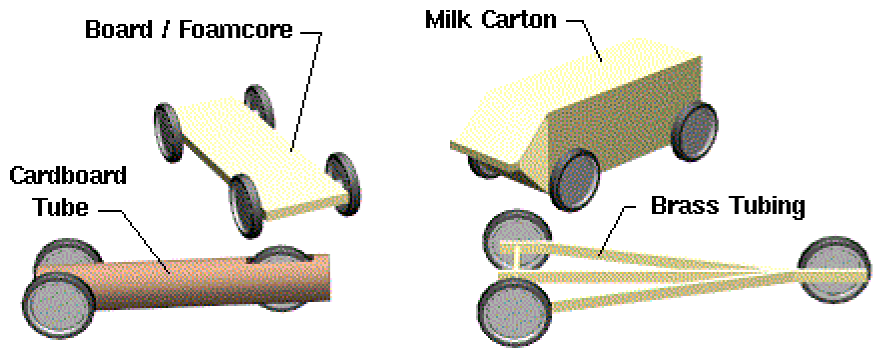


Figure 1: Examples of chassis

3. **CONCEPTS:** [index]
   a. ***Weight and Stiffness***
   One thing you will discover when you build your solar car is that designing and building involves tradeoffs. There is no one ideal design. This is true with the chassis of your car.
   One obvious consideration is that you don't want your car too heavy. It is easier for your motor to push a light car than a big, heavy one. In solar cars, efficiency is very important, and you don't want to waste energy.

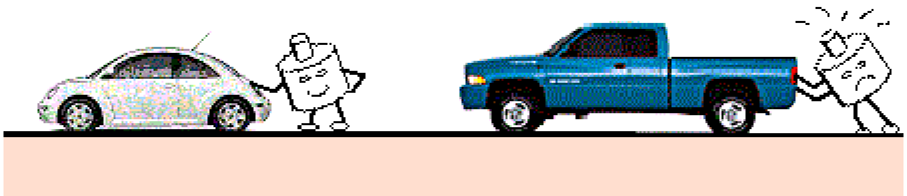


Figure 2: Weight affects ease of movement

   But something you must also keep in mind is that a light car can be pushed easily by wind, too. Even if the wind does not blow the car over, it may make it harder to go in a straight line. (This depends not only on the weight, but on where theweight is, and the shape of the body, too. We will talk more about the body and aerodynamics in a later section.)

   b. ***Materials***
   In most cases it is more difficult to make the car light enough (you can alwaysadd a little ballast, or weight, anyway) so in this section we will

emphasize lightweight materials and construction. The first step to a lightweight chassisis in choosing the right materials. Balsa wood, for example, is a commonly chosen material because it is lightweight. But more importantly, is fairly stiff for its weight.
What is the difference between strong and stiff? Strong means it will not break easily. Stiff means it will not bend easily.

Figure 3: Stength verses Stiffness

For the solar car, stiffness is very important. Stiff, light materials include styrofoam, foam core, balsa wood, corrugated cardboard, and some plastics.

c. ***Shape***
Some heavier materials are also appropriate if they are constructed correctly. Try Investigation 3-1 below to investigate how the shape of a material can effect its stiffness.
Engineers can stiffen flexible materials using shapes as shown in Investigation 3-1 or use less of a heavier material with just a change of shape. Look at a cardboard box. Why is the inside corrugated?

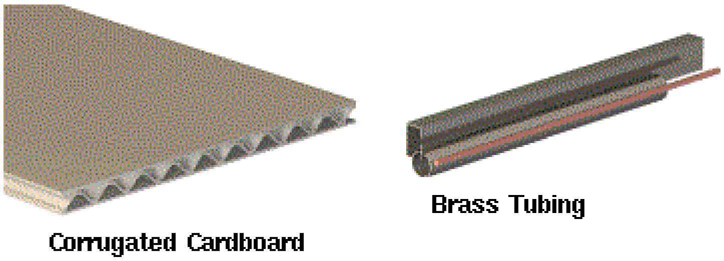


Figure 4: Examples of stiffening by shape

Other materials are made stiffer or stronger by sandwiching them between other materials. Look at foam board and plywood.

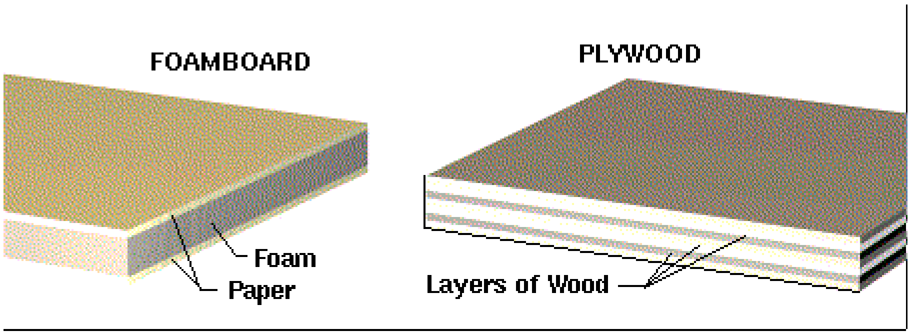


Figure 5: Examples of stiffeining by Layering

d. ***Orientation***
As you saw with the folded pieces of paper, orientation is also very important in determining stiffness. Try Investigation 3-2 below to see how the

orientation of the material affects its stiffness.
Imagine you wish to stiffen your chassis by adding ribs. You glue two strips of material to the bottom of the chassis as shown in figure 6 trying to strengthen to the chassis.

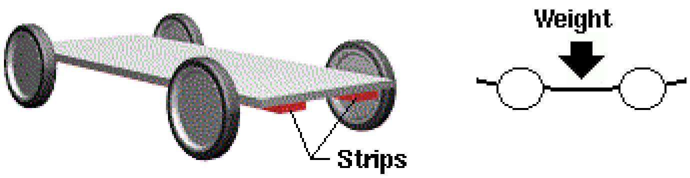


Figure 6: Stiffening chassis by layering

Unfortunately, that didn't seem to do the trick - the chassis still sags. Your partner insists that adding strips of material will help, but you know that this is not necessary. You have a better idea! What is your idea?

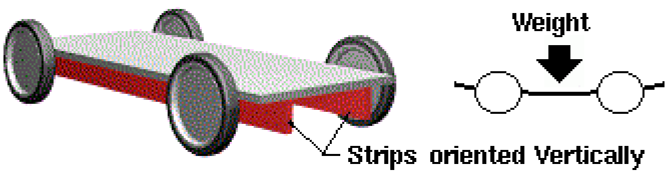


Figure 7: Stiffening chassis by orientation

Well, if you turn the strips sideways, as shown in figure 7, (remember whichway the ruler was stiffer in Investigation 3-2), you add the weight again and your chassis is much stiffer.. without adding much material!
So, as you can see, if you are smart about your material selection, and you remember the importance of shape and orientation of materials, you will have much more control over the weight of your solar car.

14. **MATERIALS:** [index]
Any material that is light and stiff would be appropriate. Some hollow tubing is very stiff for its weight. Arts and crafts stores, hobby stores and hardware stores are good sources. Some stores have scrap materials like cardboard. Or, look around your house for scraps. Some materials we found are useful are:
    - Stiff insulating foam board
    - Foam core board
    - Balsa wood
    - Brass tubing
    - Cardboard tubes
    - Shoe box
    - Soda bottle
    - Rigid plastic
    - Corrugated cardboard
    - Plexiglass

15. **EXPERIMENTS & INVESTIGATIONS:** [index]
    - See Investigation 3-1
    - See Investigation 3-2

CHASSIS *Investigation 3-1*

[Back to CHASSIS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

3-1	Structures Investigation

Materials Needed:

- 2 - 1" dia dowels or sticks
- Sheet of ordinary paper
- Sheet of ordinary cardboard (1/16" thick)
- Sheet of corrugated cardboard
- Sheet of Foamcore board
- Plastic sheets
- Small weights (up to 1lb)

Procedure: (see Figure 8)

1. Place the dowels about 6" to 8" apart.
2. Place the various materials across the dowels and place weights at various positions.
3. What positions do the weights have the least effect on the shape of the material?
4. Try two thicknesses of the same material and repeat the application of weights.
5. Is the extra strength worth the added weight to you? Can you combine materials to achieve the desired performance?
6. Vary the shapes of the materials by folding into a U or a fan (keep the size and weight of the material constant) and repeat the application of weights.
7. What effect does folding have? Does direction matter?
8. Try the corrugated cardboard with ribs running across and with the dowels.
9. Why is corrugated cardboard used more frequently for things than the same thickness of simple cardboard?

Heavy paper can also be used and shapes can be produced using scissors, tape and/or glue.

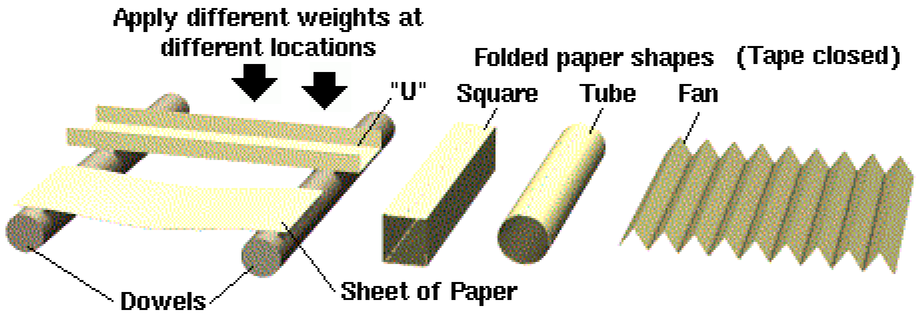


Figure 8: Stiffness investigation setup

Observations:

The dowels or sticks represent your axles and wheels and they allow the materials to flex and bend much as real wheels and axles do with the chasses of the car. The differences in the loads that a miniature car frame can carry with materials of different strength and shape are demonstrated here. Use this type of test to evaluate the materials you are considering in the design of your car.

[Back to CHASSIS & JSS]

CHASSIS *Investigation 3-2*

[Back to CHASSIS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

3-2 Orientation Investigation

Materials Needed:

- Plastic or wood ruler

Procedure: (see Figure 9)

1. Take the ruler and hold it at each end.
2. Try to bend it in both directions - across thin and wide.
3. Which way does the ruler bend more?
4. Do not brend the ruler so far that it breaks.

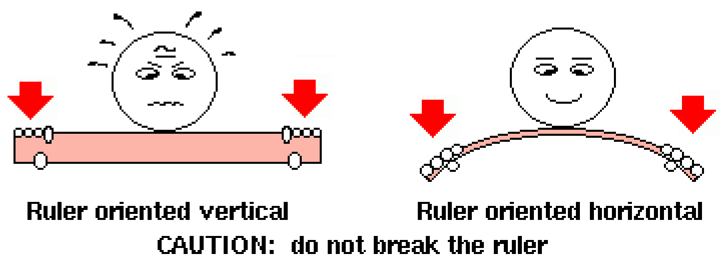


Figure 9: Orientation investigation setup

Observations:

The ruler will bend more in the thin direction. It bends very little in the wide direction.

[Back to CHASSIS & JSS]

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

WHEELS, AXLES & BEARINGS *Handout 4.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]
   Wheels support the chassis and allow the car to roll forward. Bearings support the wheels while allowing them to rotate.

2. **IDEAS:** [index]
   Wheels can be large, small, narrow, wide...here are some ideas to start you thinking.

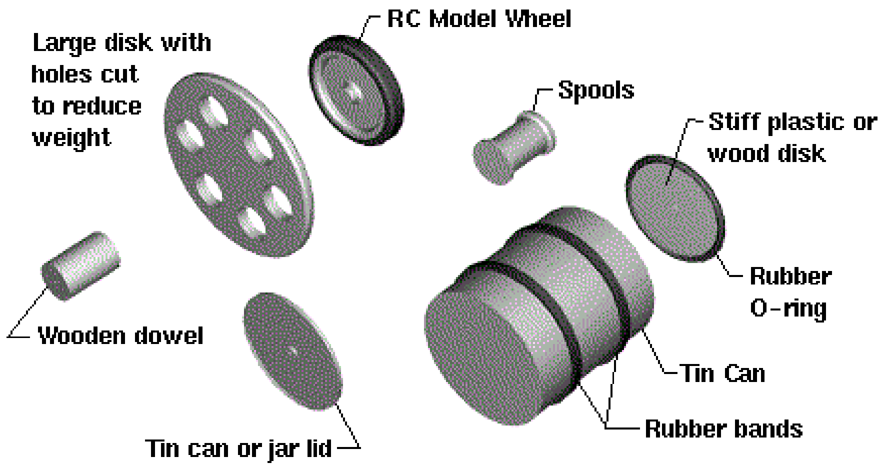


Figure 1: Examples of wheels

3. **CONCEPTS:** [index]
   a. ***Friction***
   Friction keeps things from sliding against each other. When you build your cars, there are some parts you want to slide easily, and other parts you do not want to slide at all.
   b. ***Tire Traction***
   When you have two things that must roll against each other, like a wheel rolling along the road, friction keeps them from slipping. The type of friction is also called "traction," and is important to remember when building your wheels. Why do mountain bikes have big, fat, knobby tires? If you have to bike up a muddy hill covered with leaves, your tires will slip if they don't have enough traction. And the big knobs of rubber can grip onto the dirt and rocks and keep the tires from slipping on

Figure 2: Mountain Bike

(Another reason for the thick tires, too, is because they are more rugged and can take the abuse from the trail!)

Now, the question is, why don't racing bicycles have fat, knobby tires if these wheels have good traction? Once again, there is a tradeoff in designing a wheel. Mountain bike tires have two main disadvantages. The first disadvantage is the thick, knobby rubber which gives them such great traction also makes them inefficient. Every time a rubber "knob" is compressed and bent by the road, energy is lost. Where does this energy go? If you have ever felt an automobile tire after it has been on the road, you probably noticed that it was hot. The energy it took to compress the rubber and air in the tire was lost to heat.

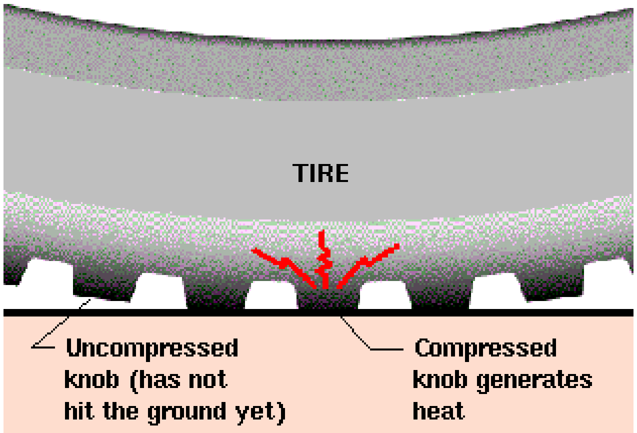


Figure 3: Knobs on a Mountain Bike Tire

The other main disadvantage of mountain bike tires is their weight. Weight in tires is actually more difficult to move than weight in the chassis. Weight in the chassis has to be moved forward, but the weight in the wheels has to be moved forward and around the circle. The heavier the wheel, the more energy it takes to get the wheel turning. Surprisingly, the bigger the wheel diameter (even if it is the same weight), the more energy it takes to get the wheel turning.

Figure 4: Racing Bike

So, racing bicycles do not have mountain bike tires, because traction is not as important. But what is important is efficiency, so that the bicyclist does not need to expend a lot of energy. The bicycle designers have made a conscious decision to use different tires designed for efficiency and not traction.

c. ***Weight Distribution & Traction***
Imagine your rear-wheel-drive solar car has trouble -- its back wheels are slipping. Your partner suggests adding some rubber bands around the wheels to increase traction, and you agree.
The rear wheel still slips some. Your other partner wants to add some weight to the car, like this:

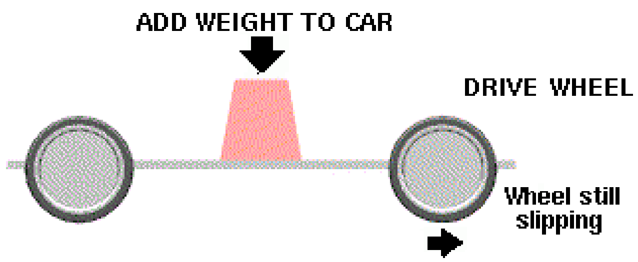


Figure 5: Adding weight to middle of car

But it does not work. You tell him you have a better idea. You move the existing weight, and now it works! Why?

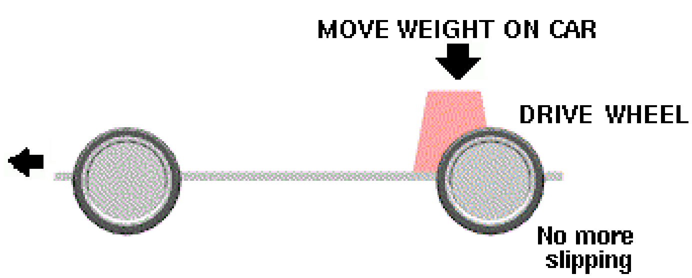


Figure 6: Move weight over drive wheel of the car

Remember that all of the force is transmitted through the driven wheels, so the moved weight increased the traction where it was needed. Weight distribution is

very important, since you can increase traction just by moving existing weight from one part of the car to the other.
Have you ever heard that front wheel drive cars are better in snow and ice than rear wheel drive vehicles? Front wheel drive cars aren't heavier. But the engine is very heavy and is located above the front wheels. This helps traction in front wheel drive cars because the weight is right above the driven wheels.

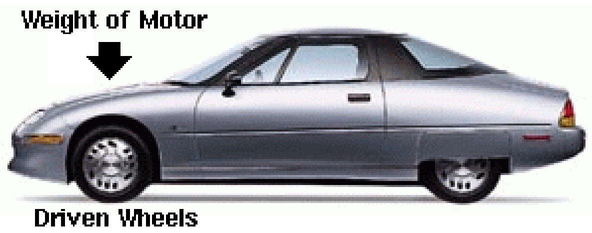


Figure 7: Front Wheel Drive weight distribution

So, in summary, traction is important for transmitting the forces from the wheels to the road. If any of your wheels are spinning rather than rolling, you probably need more traction. Traction can increased by adding a non-slip material around the wheels (like a tire) or by moving weight over the driven wheels. But, remember, it is also important to have efficient wheels, which are usually thin and lightweight.

d. ***Axle***
The axle is the component on which the wheel turns. It must be strong, straight and polished to reduce friction losses. Is a smaller diameter axle better? Why do "Hot Wheels" toy cars have such tiny axles and to so fast and far? The larger the diameter of the axle the farther away from the center they contact the bearings. Like a book dragging on the table all the way out at the corners, a large axle will be harder to turn.

e. ***Axle Bearings***
When you have two things rubbing against each other and you want them to move freely, friction slows things down and wastes energy. For example, try sliding a coin and an eraser across the table. The reason the coin slides much more easily is there is less friction between the coin and the table than there is between the eraser and the table.
One case where friction is very undersirable is in the wheel axle. The axle must be supported and attached to the chassis, but still must be able to turn. Components which allow the relative motion of two parts are called bearings. Some ideas for bearings are shown in Figure 8.

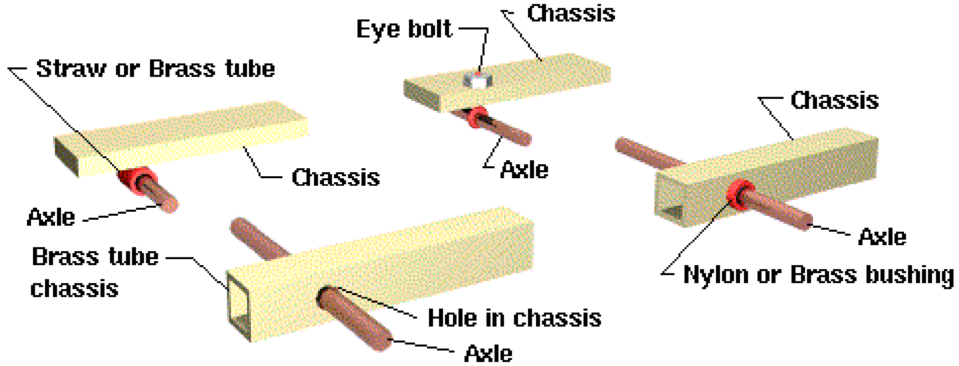


Figure 8: Examples of Bearings

Look at a bicycle or a roller blade. Hold it above the ground and spin one of the wheels. Between each wheel and its center axle is a type of bearing called a "ball bearing." The bearing holds the wheel on the axle, but reduces the friction between them, so the wheel can spin for a long time without slowing down. Choose axle and bearing materials that have low friction against each other. Surface finish is critical. Make sure all the running surfaces are as smooth as possible.

f. ***Thrust Bearings***

These are whatever keeps the axle from falling out the side of the car. If the edges of the wheels rub on the body they will have a lot of friction (See Figure 9). If there is something around the axles that let the center portion of the wheel touch first, the friction will be lower.

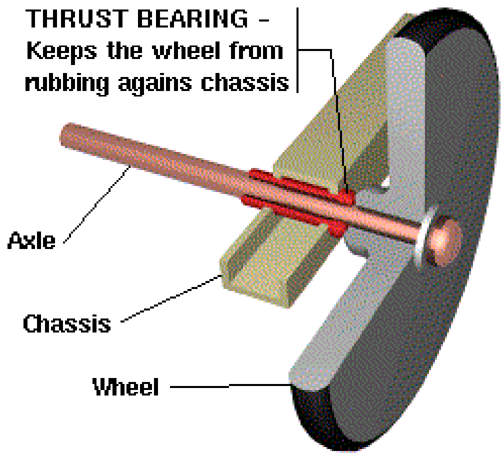


Figure 9: Thrust Bearings

g. ***Lubrication***

Lubrication helps parts slide against each other, so it is used in bearings to reduce friction.
Let's try a small experiment. Rub your hands together very lightly and quickly. Your hands should feel warm. Where is the heat coming from? There is friction between your hands, and some of the energy you expend rubbing is turned into heat. If you put a lot of hand lotion or cream between your hands and rub, your hands slide more easily and should not get as warm. That is because the lotion acts as a lubricant.
Different lubricants work better with different materials. In the case of machines, one generally uses oil or grease to help the parts slide together easily. On a water slide, the water acts as a lubricant. If you bake cookies, a little oil or butter on the cookie sheet keeps the cookies from sticking.
Some appropriate lubricants for the solar car bearings may be a light oil, light grease, or graphite powder (crushed pencil lead). Try various lubricants and see which ones work best in your car.

h. ***Wheel Alignment***

Another problem that wastes energy is poor wheel alignment. When the wheels on your vehicle are not lined up properly, the car may want to turn making some of the wheels must slide sideways. One way this might happen is sketched in Figure 10.

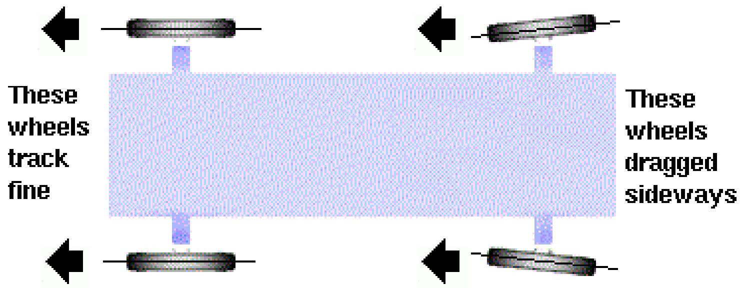


Figure 10: Wheel Alignment problem

When the driven wheels try to pull the car one way, but the rest of the car wants to roll the other way, the traction in the wheels (normally a good thing) wastes quite a bit of energy.

Also, make sure that the axle goes through the center of the wheel. One suggestion is to use a compass, rather than tracing a circle out of a material. The compass will show you where the center of the circle is.

Taking time to align the wheels carefully the first time will make a huge difference in how well your car runs. Testing your chassis with the wheels on it will be very important in identifying problems with the alignment.

44. **MATERIALS:** [index]

For wheels: Look around for anything round, or things which can be cut into circular shapes...look at home, arts and crafts stores, and hardware stores. Hobbie stores sell model wheels, but they are more expensive and are not designed for building a solar car. They may be too heavy. Some materials we found are useful are:

- Thin plywood
- Foam core
- Balsa wood
- Stiff plastic sheet
- Styrofoam
- Cardboard tubes
- Tin can
- Thread spool
- Plastic pipe
- Tape Spool
- Brass tube
- Wood dowels
- Toy/model wheels

For traction: Things that are rough or rubber-like usually add friction. Some materials we found are useful are:

- Rubber o-rings
- Rubber bands
- Rubber sheet
- Cloth tape
- Silicone or caulking

For axle: The axle must be stiff, narrow, and round. Some materials we found are useful are:

- Nails
- Brass rod
- Brass tubing
- Coat-hanger wire

For bearing: Bearings should be smooth and work well with the axle. Some materials we found are useful are:

- Screw eyes or bolts
- Brass tubing
- Hard material with hole drilled in it
- Brackets with screw holes pre-drilled
- Holes drilled in chassis
- Nylon bushings

45. **EXPERIMENTS & INVESTIGATIONS:** [index]
    - See Investigation 4-1
    - See Investigation 4-2
    - See Investigation 4-3

WHEELS, AXLES, & BEARINGS *Investigation 4-1*

[Back to WHEELS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

4-1 Friction Investigation 1

Materials Needed:

- 1 large textbook
- 12 coins (similar size)

Procedure: (see Figure 11)

1. Put the heavy hardcover book flat on the table.
2. Rotate it slowly back and forth and get a feel for how hard it is to turn.
3. Put a stack of 3 coins on the table and balance the book on them.
4. Rotate it slowly back and forth again and note how hard it is to turn. (do not let the edges of the book touch the table)
5. Put a stack of 3 coins under each corner of the book.
6. Rotate it slowly back and forth again and note how hard it is to turn.
7. Repeat the last 2 steps each time moving the coin stacks closer to the center.
8. Is the flat book harder to turn because of more surface area in contact with the table?

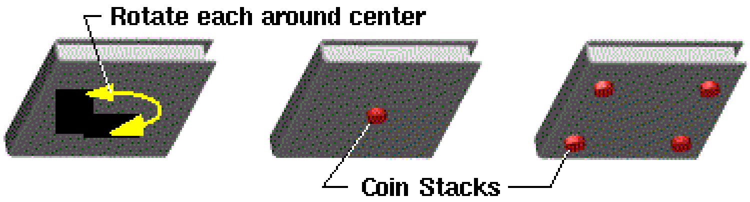


Figure 11: Friction investigation setup

Observations:

Where things are rubbing together makes a difference. Much like a lever, the farther from the center (pivot) a force is, the more effect it has. It is easier to stop spinning objects by grabbing the outside edge than a point near the middle. Therefore, a friction force far from the center slows a spinning object (such as a wheel) more quickly than the same force close to the center.

[Back to WHEELS & JSS]

WHEELS, AXLES, & BEARINGS *Investigation 4-2*

[Back to WHEELS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

4-2 Friction Investigation 2

Materials Needed:

- Plank of wood
- Ruler
- Sheets of materials
- Small objects made of various materials
- Lubricants: oil, graphite, soap, etc.

Procedure: (see Figure 12)

1. Put the first sheet on the plank.
2. Place the first object on this wheet/plank setup
3. Tilt the plank until the object begins to slide on the sheet - note the height with the ruler.
4. Repeat this process with combinations of the sheets and objects you have.
5. Now repeat this process for all the object and sheet combinations with different lubricants noting the heights in the chart.
6. Which combination of object and sheet had the least amount of friction? (moved at the lowest height)

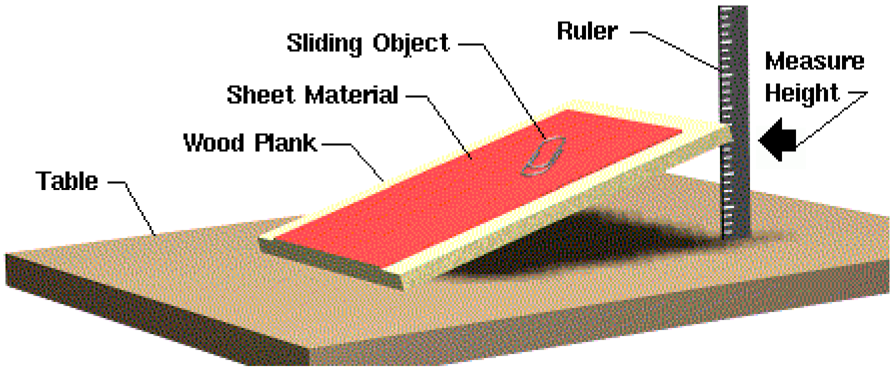


Figure 12: Friction investigation setup

To choose the best materials for axles and bearings find samples of the different materials you may want to use and test the friction between them.
Keep in mind that it can be difficult to un-lubricate something if it doesn't work, so test a scrap piece of material using this friction test before lubricating your car components if you are not sure.

SHEET Material and Description	OBJECT Material and Description	HEIGHT AT WHICH OBJECT SLID (by lubricant)			
		None	Soap	Oil	Graphite

Observations:

The lower the friction, the sooner the object will start to slide and the smaller the angle will be. One interesting feature of this investigation is that the weight of the object is not important. A steel paper clip will start sliding at the same angle as a heavy steel object. Picking two materials that "run" well together will mean that less power will be used to overcome the friction and more will go towards driving the car faster.

[Back to WHEELS & JSS]

WHEELS, AXLES, & BEARINGS *Investigation 4-3*

[Back to WHEELS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

4-3 Rolling Resistance Investigation

Materials Needed:

- Ramp (plank)
- Several prototype cars
  - Without motors
  - Various axle and bearing components
  - Approximately the same weight

Procedure: (see Figure 13)

1. Mark a start line on the plank.
2. Place the first car and let it roll down the ramp.
3. Mark the location it rolled to.
4. Repeat steps 2-3 3 times for each car or until the car repeatable rolls to the same place.
5. Repeat steps 2-4 for each car.
6. Did the cars travel in straight lines?
7. Which car went further?
8. Try improving your chassis/wheel car with different axles or bearings or lubricants and see how they alter the final distance the car travels.

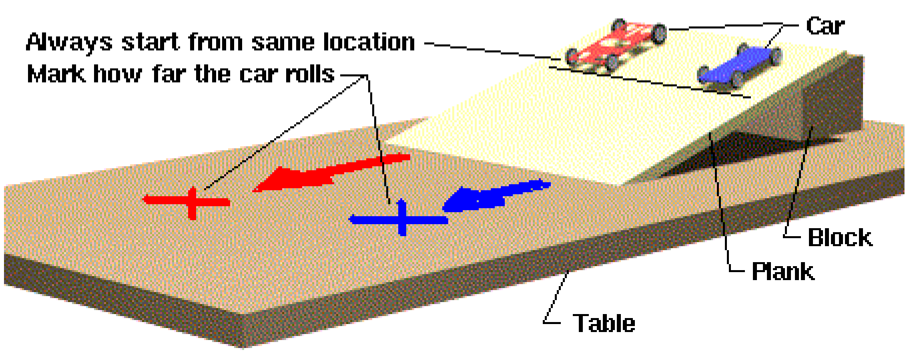


Figure 13: Rolling resistance investigation setup

Observations:

Using this roll down test you can find the bearing and wheel configuration with the lowest rolling resistance (do not change the aerodynamics [shape] of the car during this test because that will also affect the results.) Finding the best combination is an important step in building a fast car.

[Back to WHEELS & JSS]

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

TRANSMISSIONS *Handout 5.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]

   A transmission transfers the power from the motor to the wheels. While doing so, it may make the wheels spin at a different speed than the motor.

2. **IDEAS:** [index]

   There are different ways to transfer power from the motor to the wheels. Some more popular techniques are shown in Figures 1 through 4 like direct drive, friction drive, beld or chain drive and gears. Some transmissions are easier to build than others, and not all are appropriate for a solar car.

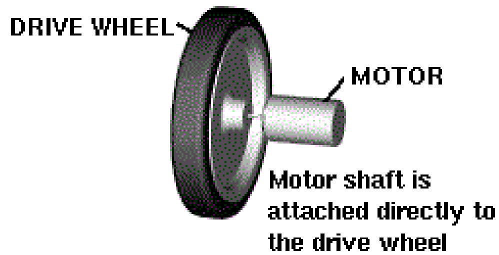


Figure 1: Direct Drive Transmission

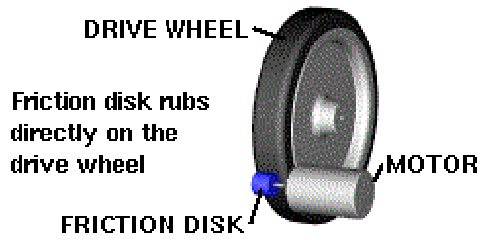


Figure 2: Friction Drive Transmission

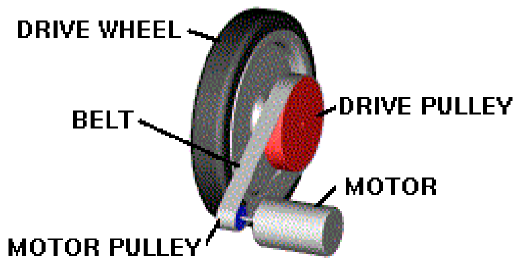


Figure 3: Belt Drive Transmission

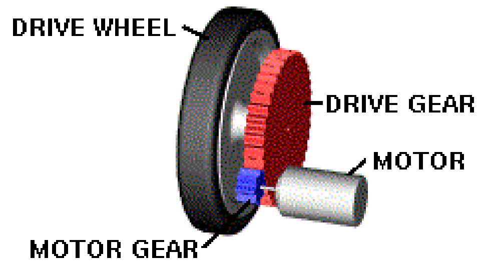


Figure 4: Gear Drive Transmission

3. **CONCEPTS:** [index]

   a. ***Speed vs. Force***

   The most simple type of transmission is direct drive, which means the motor is connected directly to the axle of the driven wheel. Direct drives are not common in vehicles; one of the few vehicles that uses direct drive is a unicycle. Every time your feet make one revolution, the wheel makes one revelution.

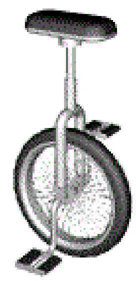


Figure 5: Unicycle

   b. ***Speed***

Imagine two of your neighbors have a unicycle race. Bruce's unicycle has a regular wheel, and Karen's has a very large wheel. If they both pedal the same rate (number of revolutions per minute), which one of them will win?

In both cases, each revolution of the pedal means one revolution of the wheel. BUT, one revolution of Karen's wheel will roll twice as far as bruce's. So Karen would win if they pedaled at the same rate. If Bruce wanted to win, he would have to pedal twice as fast as Karen.

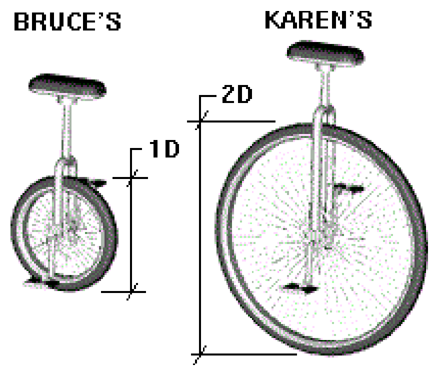


Figure 6: Different wheel sizes

Have you ever seen pictures of very old bicycles that have huge front wheels? These bicycles allowed the rider to go faster without pedaling like a maniac!


Figure 7: Old time bicycle

As mentioned before, most vehicles are not direct drive, so let's look at another type of vehicle: a 3-speed bicycle. A bicycle uses a chain drive. It allows you to move the pedal, and the chain transfers the energy from the pedals to the rear wheel (see Figure 8).

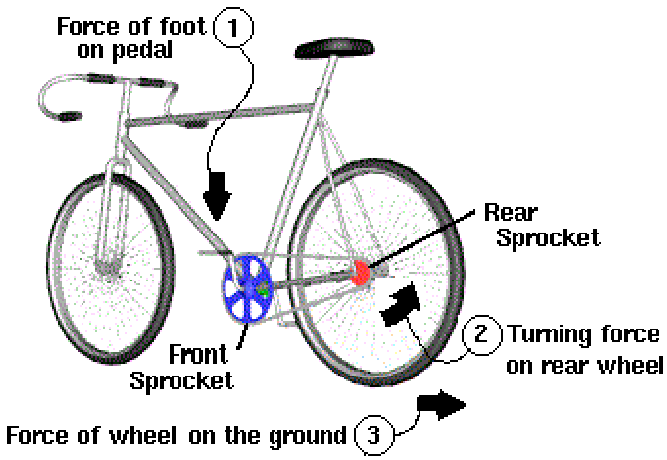


Figure 8: Forces on a Bicycle

The chain glides over different sized sprockets, depending on the speed of the rider. Which sprocket combination will make the rider go the fastest, given the same pedaling rate, or "cadence"? (Hint: how many times will the back sprocket [and therefore the back wheel] turn with each rotation of the front sprocket?)

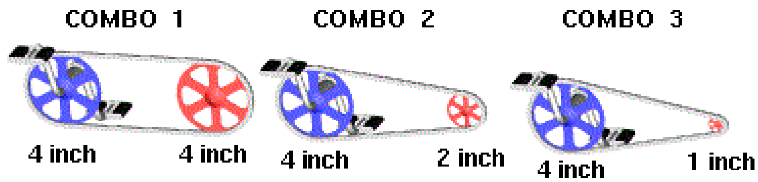


Figure 9: 3-Speed bicycle sprocket combinations

Each rotation of the front sprocket will make the back wheel rotate once in Combo 1, twice in Combo 2, and four times in Combo 3. So, combination 3 will go the fastest. (These sprocket combinations can also be called "gear ratios", because the new speed is calculated as the ratio of the driven (front) sprocket over the driven (back) sprocket.)

So how does this affect the way the biker would use the bicycle? Well, when the rider starts out, he uses first gear (Combo 1). As he pedals faster, the bike starts going faster. After a while, his legs are moving very fast, so he switches to second gear (Combo 2). No his legs only go half as fast as a second ago, but the bike is still going fast. He can increase his cadence again and make the bike go even faster. Once his cadence is very high again, he can shift up to third gear (Combo 3).

If the rider is going 5 mph in first gear, how fast is he going in third gear with the same pedaling rate or cadence?

Well, the jump from first to second gear doubles the speed, and the step from second to third gear doubles it again. So, the rider is going four times as fast as in the first gear. He is going 20 mph, but his legs are moving at the same rate as at the very begining!

The term "3-speed" bike is not entirely correct, because a biker can go more than just three different speeds. As we saw in the previous example, our bike rider was able to continuously speed up from 5 mph to 20 mph. But the name comes from the fact that given one cadence, the three gear ratios will give you three different speeds. Of course, your legs can pedal at many different rates, but "3-speed" bike sounds better than "3-gear-ratio" bike.

c. ***Force***

You may ask, then, why isn't it the best to go for the highest speed possible? Well, you can't get something for nothing! So what are you giving up when you gain speed? Let's investigate.

Imagine two bikers approaching a very steep hill. Jeff and Dave are both in third gear, because they are going very fast. Dave downshifts into second gear. But Jeff decides to stay in third gear, because he knows that third gear is for going fast, and he wants to go up this hill very fast.

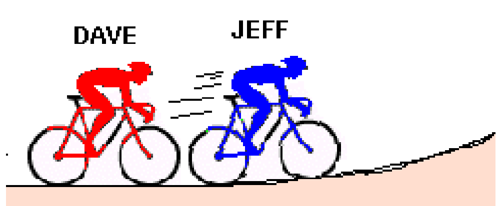


Figure 10: Dave downshifting at a hill

Dave is going half the speed now, because he just downshifted. Jeff smirks as he blows by Dave. But Jeff hits the hill, and he suddenly realizes that his legs can't go very fast anymore -- it becomes very hard to pedal! He gets slower and slower, and finally stops pedaling because it's too hard. Dave passes, slowly but surely, and makes it to the top of the hill while Jeff stops part way up.

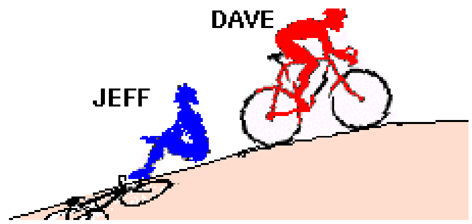


Figure 11: Jeff stops and Dave makes it

What happened? If only Jeff could have kept pedaling at the same rate, he would have beat Dave by a mile! Let's look at each pedal stroke. Each time Dave and Jeff pedal once, Dave's back wheel goes around once (let us say it travels 10 ft), but Jeff's back wheel goes around twice (20 ft).

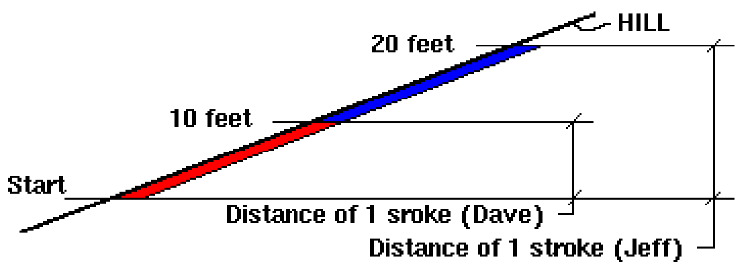


Figure 12: Distance Traveled per Stroke Comparison

Dave realizes that he only has to expend half the energy per pedal revolution than Jeff does, because Jeff goes twice as far each time. That is why Jeff started getting very tired, because his pedals were difficult to push. In other words, his pedals required more force than Dave's did.
So does Dave expend less energy going up the same hill?
Dave expends have the energy per pedal revolution, but this is only because he goes half the distance per revolution. Dave has to bedal twice as many time sto get up the hill. So, the energy expended by both Dave and Jeff going up the entire hill would be the SAME in either case.

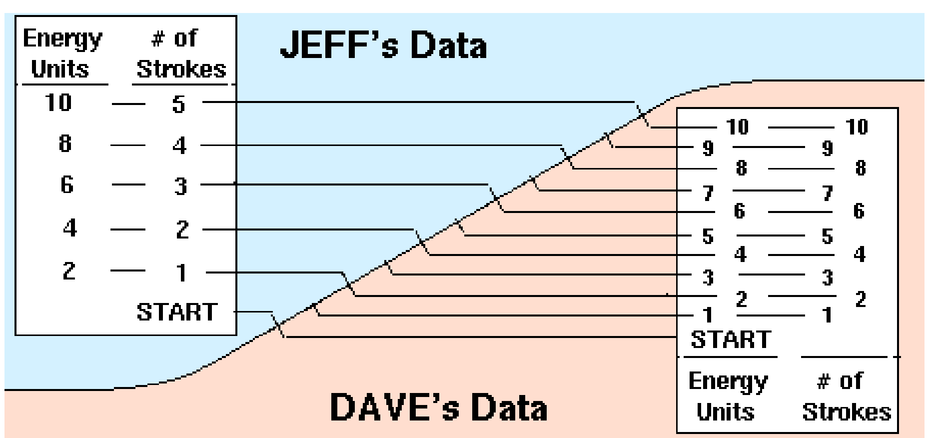


Figure 13: Energy units comparison

So, the bottom line is, when we gain a speed advantage, we are losing the force advantage. The pedals are more difficult to turn. You can gain either speed or force advantage, but not at the same time.

d. ***Selecting Proper Gear Ratios***
So, how can you choose the best gear ratio? Experimentation is probably the easiest way to find out. Try some of the Investigations below or build a test bed to try different combinations and note your findings.
The ideas is that your motor, like your legs when you ride a bike, will like to go a certain speed. They also have a limit as to how much force they can exert. First you must find the speed at which the motor gives the most power (this is usually half the speed at which the motor will rotate if there is no load, or force, exerted on the motor shaft). Try to keep the motor turning at approximately that speed as you experiment with different gear ratios.
It helps if you build your car in such a way that you can change the gear ratios easily as you experiment. Remember, the ideal gear ratio may change some if you change different characteristics of your car (size, weight, wheel size, etc.). Just remember, if your car is not going very fast it can either be that the wheel speed is too slow, or (like Jeff riding uphill) the force required to turn the wheel is too high. Try a different gear ratio!

32. **MATERIALS:** [index]
The materials you choose vary greatly depending on the type of transmission you build. Remember that your car must start on its own power from the solar panel with no pushing so make good decisions.
Belt Drive: If you decide to build a belt drive you will need both pulleys and belt materials. Make sure your pulleys are pulled away from each other so that the belt is tight. One suggestion: one way to change the gear ratio on a pulley drive is to add or remove masking tape around a pulley which changes its diameter. Another thing to remember is that the pulleys must be securely attached to the motor axle and the other to the driven wheel. Some materials we found useful are:
    - Slide of inner tube
    - Rubber band
    - O-Ring
    - Spools
    - Drawer pulls
    - Videocassette reels
    - Reclaimed pulleys (Electronics parts)
    - Washers

Friction Drive: Make sure you have enough traction on the friction disk, or it will slip (See the materials section in Student Handout 4). Also, make sure the friction gears are pressed against each other snugly to ensure traction. Another thing to remember is that the gears must be securely attached to the motor axle and the other to the driven wheel. Some materials we found are useful are:
    - Parts out of model cars
    - Rubber bands
    - Circular wood or plastic cutouts
    - Spools

For Gears: Make sure the wheel axle is mounted securely in relationship to the motor axle to keep the teeth meshed on the gears. If they are not snug, the teeth may slip and you will loose power. Some materials we found are useful are:
    - Gears out of electronics
    - RC model car gears
    - RC model car gearboxes

In all cases, you will need wheel-like parts to put on the motor axle shaft and the wheel, and you can get ideas from Student Handout 4 on wheels.

33. **EXPERIMENTS & INVESTIGATIONS:** [index]
    - See Investigation 5-1
    - See Investigation 5-2
    - See Investigation 5-3

TRANSMISSIONS *Investigation 5-1*

[Back to TRANSMISSIONS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

5-1 Pulley System Investigation

Materials Needed:

- Board
- Hammer
- Nails
- Large & small spools
- Rubber band

Procedure: (see Figure 14)

1. Hammer two nails into a board far enough apart to lightly stretch the rubber band between them.
2. Place the large spool over one of the nails and one of the smaller ones over the other nail. They should turn freely.
3. Slip the rubber band around both spools so when one spool is turned the other moves.
4. Place a mark on the top edge of each spool and one on the board corresponding.
5. Beginning at the mark, turn the large spool through one complete turn.
6. How many times did the small spool turn?
7. In which direction did each spool turn?
8. Repeat the investigation for different sizes of spools and note the results.
9. What can you do to change the directions of the spools?
10. Does the length of the drivebelt make a difference?

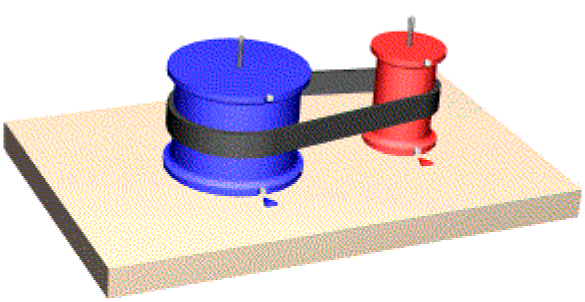


Figure 14: Pulley investigation setup

MOTOR Spool (you turn)			DRIVE Spool (pulley turns)			RATIOS	
Diameter (inches)	# of Revolutions	Direction (cw/ccw)	Diameter (inches)	# of Revolutions	Direction (cw/ccw)	$\frac{DIA_m}{DIA_d}$	$\frac{REV_m}{REV_d}$
2.0	1	cw	1.0	2	cw	2:1	1:2

Observations:

Drive belts are a form of pulley system that can be used to turn wheels. Observe the diameters of the spools and see if there is a correlation between the diameters and the number of terms ratios. Be sure and note in your data if you twist the rubber band (figure 8 type configuration) so you can make proper deductions about direction. Compare spool combinations at different distances apart also.

[Back to TRANSMISSIONS & JSS]

TRANSMISSIONS *Investigation 5-2*

[Back to TRANSMISSIONS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

5-2 Gear System Investigation

Materials Needed:

- Plastic gears of different sizes (3)
- Mounting board
- Axles

Procedure: (see Figure 15)

1. Mark one tooth of each gear.
2. Count and record the number of teath on each gear.
3. Mount the largest and smallest gears of different sizes so their teeth mesh and their marks are aligned at the intersection point.
4. Turn the small gear to the right (CW) 1 revolution.
5. Record the direction and number of revolutions the large gear travels.
6. Return the gears to the start position and this time turn the large gear to the right (CW) 1 revolution.
7. Record the direction and number of revolutions the small gear travels.
8. Repeat steps 3 through 7 using the largest and middle sized gears.
9. Repeat steps 3 through 7 using the smallest and middle sized gears.
10. Try some variations in revolutions or other sizes.

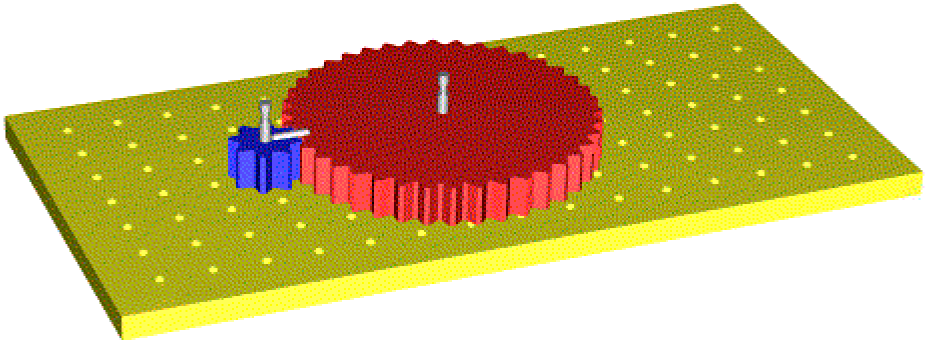


Figure 15: Gear investigation setup

MOTOR Gear (you turn)			DRIVE Gear (gear turns)			RATIOS	
# of Teeth	# of Revolutions	Direction (cw/ccw)	# of Teeth	# of Revolutions	Direction (cw/ccw)	$\frac{Teeth_m}{Teeth_d}$	$\frac{REV_m}{REV_d}$
10	1	cw	20	2	ccw	2:1	1:2

Observations:

The mechanical advantage in gears is determined by the ratio of the number of teeth on the gears. The pitch of a gear describes the number of teeth that can be put on a 1-inch diameter gear. Gears with different pitches will not fit together well, so the same pitch must be used throughout the transmission. Gears in 48 and 64 pitch are the ones most often used in slot cars. You can buy gears for the 1/24 scale slot cars at hobby shops.

[Back to TRANSMISSIONS & JSS]

TRANSMISSIONS *Investigation 5-3*

[Back to TRANSMISSIONS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

5-3 Transmission Ratio Investigation

Materials Needed:

- Motor
- 3V power source (battery)
- 1 small pulley (motor axle)
- 3 larger pulleys (output axle see setup)
- Cardboard or foamboard (chassis)
- Axle shaft (output axle)
- Rubber band or belt (pulley)
- Axle bearings (see setup)
- Hot glue or tape

Procedure: (see Figure 16)

1. Build the test transmission as shown in the setup figure (mount the motor to a piece of material so it can be moved to align with the different pulleys and stretch the belt drive).
2. Move the beld to different pulleys and see the results of the different ratios.
3. Which ratios give the highest speed?
4. Which ratios make the output axel easiest to stop with your finger?
5. Try different bearings on the output axle.
6. Does the bearing material affect the speed or ease of stopping the output axle?
7. Try adding or removing weight from the output shaft to see the efect on the system.

Notice how flat rubber bands tend to crawl up the edges of a pulley - try a "crowned" pulley (convex profile) as shown in Figure 16. It is counter-intuitive, but does work, and is used often in machines.

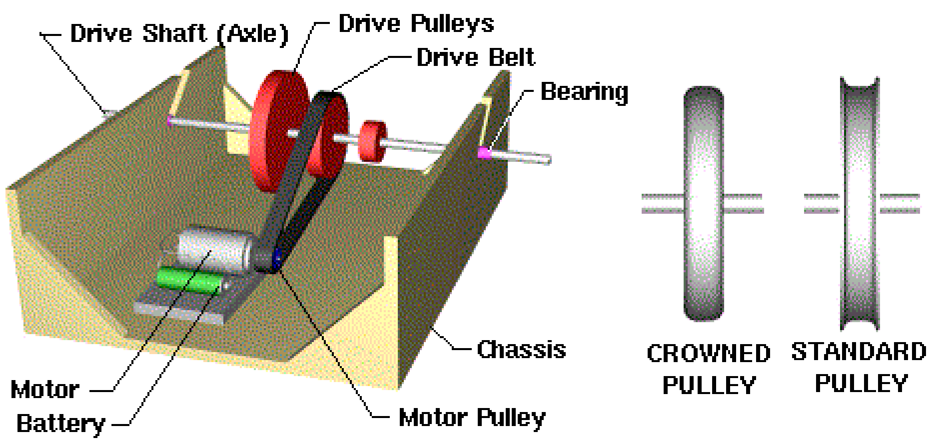


Figure 16: Transmission investigation setup

D_m Diameter of Motor Pulley		D_d Diameter of Drive Pulley	RATIO $\frac{D_m}{D_d}$	Rank each from 1 to n....	
				Highest Speed (Turns Fastest)	Highest Torque (Hardest to stop)
	Small				
	Medium				
	Large				

Observations:

Building a car without any knowledge of the best transmission ratio is risky because the car will not perform to its full potential (if it moves at all). This investigation uses a belt and pulley system, but the ratio of the pulley diameters applies to all the other types of transmissions as well (gears, friction drive). You can use this type of investigation in your final car as well to arrive at the best transmission for your design.

[Back to TRANSMISSIONS & JSS]

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

GEAR RATIO CALCULATION *Handout 6.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]
   To identify how to calculate gearing ratio requirements for your car rather than just by experimentation.

2. **IDEAS:** [index]
   The complete requirements for gearing ratios includes the wheel size since it affects the speed vs force conditions. The two transmission ratios and wheel size combinations shown below will produce cars with similar performance in terms of acceleration and top speed.

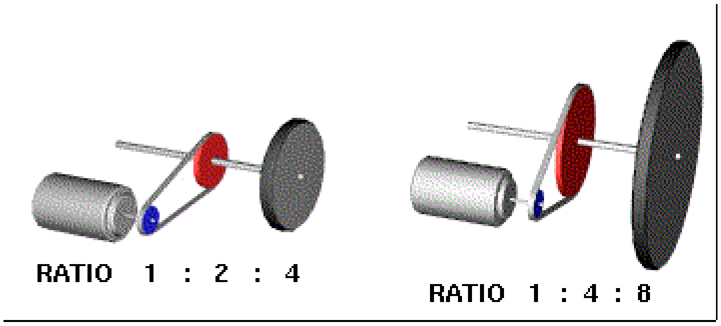


Figure 1: Transmission wheel combinations

The faster the axle rotates in the bearing the more friction and drag it will have. A large wheel will allow the axle to rotate more slowly (if the car is to go at the same speed), and will waste less power in the bearings.
In nature, an analogy for wheel size would be leg length. Just as a horse and hamster will travel different distances if each takes one step per second, cars with large and small wheels will travel different distances with each wheel rotation.

3. **CONCEPTS:** [index]
   a. ***Known Values***

Motor Speed	w_m	**8300** rpm	(revolutions per minute) under load 0.278 in-oz torque at that speed
Vehicle Speed	**V**	**300** cm/sec	winners cover the track in 6.5 seconds. Track distance = 20m (65.6 ft), V=20m/6.5sec -or- 3m/sec

   b. ***Gear Ratio Known***
   If we have a set of pulleys or a couple of mating gears then we already have the gear ratio. Now we just need to find out what size drive wheel(s) we need to be competitive. Figure 2 shows how a pulley or gear system might look.

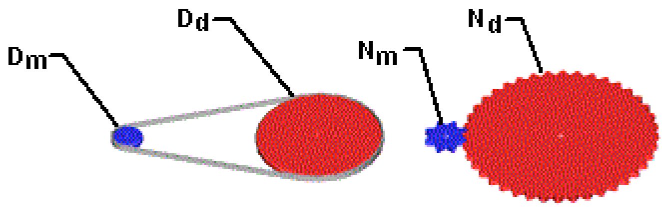


Figure 2: Pulley and Gear Systems

The variable **D** is the diameter of the pulley, and variable **N** is the number of teeth on the gear. The subsript **d** refers to the gear or pulley attached to the drive axle and the subscript **m** refers to gear or pulley attached to the motor. For sample purposes we have supplied values for these - use your own values to do the calculations on your own transmission.

The variables for a Pulley System

D_m = **1.25** cm D_d = **0.25** cm

The variables for a Gear System

N_m = **40** teeth N_d = **8** teeth

The variables for a YOUR System

[___]$_m$ = [_____] [___]$_d$ = [_____]

Step 1: Determine the gear ratio.

For a Pulley System the gear ratio is

R = D_m / D_d or **R** =**1.25** cm / **0.25** cm or **R** =**5**

For a Gear System the gear ratio is

R = N_m / N_d or **R** =**40** / **8** or **R** =**5**

For YOUR System the gear ratio is

R = [___]$_m$ / [___]$_d$ or **R** =[___] / [___] or **R** =[___]

Step 2: Find out the speed of the wheel in rpm.

For a Pulley or Gear System wheel speed is

w_d = w_m / **R** or w_d = **8300** rpm / **5** or w_d = **1660** rpm

For YOUR System wheel speed is

w_d = w_m / **R** or w_d = [_____] rpm / [___] or w_d = [_____] rpm

Step 3: Find out wheel speed in revolutions per second.

For a Pulley or Gear System wheel speed in rps is

$w_d = w_d$ / **60** spm or w_d = **1660** rpm / **60** spm or w_d = **27.6** rps

For YOUR System wheel speed in rps is

$w_d = w_d$ / **60** spm or w_d = **[____]** rpm / **60** spm or w_d = **[____]** rpm

Step 4: Calculate the wheel circumference.

To determine the wheel diameter we first need to know the circumference of the wheel (the distance the car will travel each time the wheel turns one full revolution).

For a Pulley or Gear System the circumference is

$C = V / w_d$ or C = **300** cmps / **27.6** rps or C = **11** cm

For YOUR System the circumference is

$C = V / w_d$ or C = **[__]** cmps / **[__]** rps or C = **[__]** cm

Step 5: Determine the wheel diameter.

Now we can find out what diameter wheel, D_w we need. The wheel diameter is determined from the cicumference.

For a Pulley or Gear System the diameter is

$D_w = C$ / **pi** or D_w = **11** cm / **3.14** or D_w = **3.5** cm (1.4 in)

For YOUR System the diameter is

$D_w = C$ / **pi** or D_w = **[__]** cm / **3.14** or D_w = **[____]** cm

Step 6: Check calculations.

Now check to make sure the diamter of your wheel is bigger than the diameter of the drive gear. If it is, you're up and running. If it is not, you need to chose smaller pulleys or gears.

c. ***Wheel Size Known***

If we already have a wheel size we want to use we must find a suitable gear ratio to drive it. For sample purposes we have supplied values for these - use your own values to do the calculations on your own transmission.

The variables for a Wheel

D_w = **8** cm (3.1 in)

The variables for a YOUR Wheel

D_w = **[____]**

Step 1: Calculate the wheel circumference.

For a Pulley or Gear System wheel circumference is

$C = D_w$ * **pi** or C = **8** cm * **3.14** or C = **25** cm

For YOUR System wheel circumference is

C = D_w * **pi** or **C** = [__] cm * **3.14** or **C** = [____] cm

Step 2: Find the wheel speed in revolutions per second.

For a Pulley or Gear System wheel speed in rps is

w_d = **V** / **C** or w_d = **300** cmps / **25** cm or w_d = **12** rps

For YOUR System wheel speed in rps is

w_d = **V** / **C** or w_d = [__] cmps / [__] cm or w_d = [___] rps

Step 3: Find the wheel speed in revolutions per minute.

For a Pulley or Gear System wheel speed in rpm is

w_d = **60** spm * w_d or w_d = **60** spm * **12** rps or w_d = **720** rpm

For YOUR System wheel speed in rpm is

w_d = **60** spm * w_d or w_d = **60** spm * [__] rps or w_d = [___] rpm

Step 4: Determine the gear ratio.

For a Pulley or Gear System the ratio is

R = w_m **/** w_d or **R** = **8300** rpm / **720** rpm or **R** = **11.5**

For YOUR System the ratio is

R = w_m **/** w_d or **R** = [___] rpm / [___] rpm or **R** = [___]

Step 5: Design the transmission.

Since the drive pulley or gear can be no larger than the drive wheel, we need to select a pulley or gear accordingly.

For a Pulley System we might select a drive pulley of 6 cm in diameter.

D_m = D_d **/** **R** or D_m = **6** cm / **11.5** or D_m = **.52** cm

For a Gear System we might select a drive gear of 69 teeth.

D_m = D_d **/** **R** or D_m = **69** teeth / **11.5** or D_m = **6** teeth

For YOUR System select a drive pulley or gear that is appropriate

D_m = D_d **/** **R** or D_m = [__] / [__] or D_m = [___]

d. ***Notes***

In these calculations friction and wind drag were not considered. In a JSS car friction and drag will effect performance. To compensate we need to make the wheel diameter smaller, or the gear ratio bigger if we are going to get the best performance. This fine tuning of the car performance will need to come from experience gained by testing the car, but these calculations will give you an idea of where to start.

Notice that we came up with two different combinations of gearing and wheel size. There is an infinte number of combinations that will work well. What you come up with for your car depends on what you have available to you for constructing your car.

22. **MATERIALS:** [index]
    See Student Handouts 4 and 5 for information on materils for Axles, Wheels, Bearings and Transmssions.

23. **EXPERIMENTS & INVESTIGATIONS:** [index]
    - See Investigation 6-1

CALCULATING GEARING RATIOS *Investigation 6-1*

[Back to GEAR CALC & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

6-1 Effect of Wheel Size Investigation

Materials Needed:

- Prototype car
  - Chassis
  - Wheels
  - Motor
  - Temporary power source (3V battery)
- Lightweight foam tape

Procedure: (see Figure 3)

1. Experiment with the varying of wheel diameter by building up the diameter of the drive wheel(s) on your prototype car using various materials.
2. How much larger would the wheels need to be to make the car's top speed twice as fast?
3. Three times as fast?
4. How can large wheels hurt the performance of your car?
5. How does the size of the wheels affect acceleration?

Try using materials like weather-stripping foam tape to increase the diameter of the wheels.

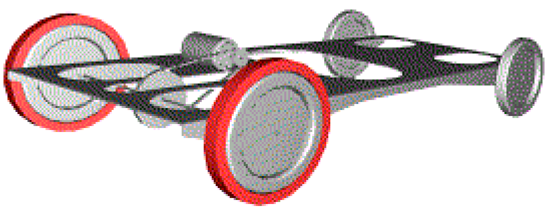


Figure 3: Investigation setup - add to size of the drive wheels

Observations:

Wheel size is as important a factor in the car's design as the transmission ratio; in fact, they are closely related. Try to calculate what distance your car travels per one revolution of the motor. The transmission ratio will tell you how many revolutions the wheel axles will turn per motor revolution, and the size of the wheels will tell what linear distance the car will travel per wheel revolution.

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

SOLAR PANELS *Handout 7.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]
   The purpose of the solar panel is to capture energy from the sun and to turn this energy into electrical energy. The electric motor then uses this electrical energy to power the wheels of the solar car.

2. **IDEAS:** [index]
   The basic configuration of solar panel and motor.

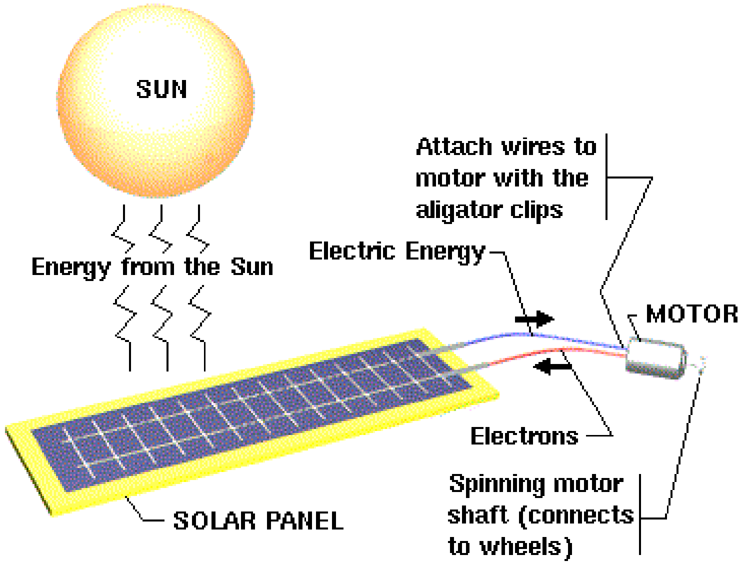


Figure 1: Solar Panel motor configuration

3. **CONCEPTS:** [index]
   a. ***How a Solar Panel works***
   When you look at the diagram above, you might ask, "How does the solar panel turn the sun's energy into electric energy?"
   The solar panel is made of a sandwich of two materials called *semiconductors*. Each material is made of millions of atoms. As you might already know, atoms have a positively charged *nucleus*, and negatively charged *electrons* which spin around the nucleus. When these two materials are put together in a sandwich, an interesting thing happens: electrons become pulled from the bottom half. But there's a problem. The electrons are all attached to atoms, and the atoms won't let go very easily. This is where the sun's energy helps out. If we shine sunlight on these materials, the sunlight has enough energy to knock the electrons off of the atoms. The electrons will then be free to be pulled to the top of the sandwich.

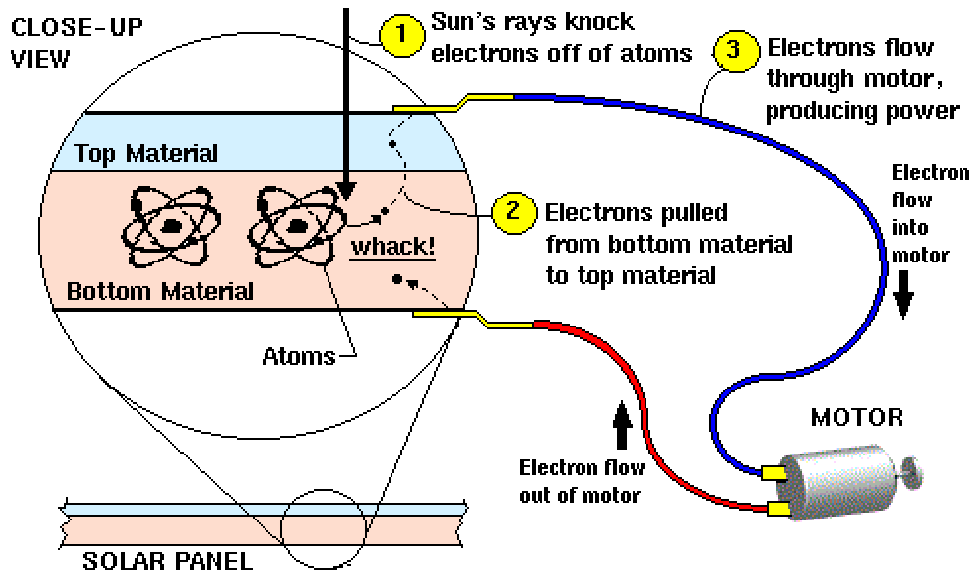


Figure 2: How a solar panel works

Now if we connect wires to a motor, electrons will flow through the wire into the motor (making it spin) and back through another wire to the solar panel where they can fill the "holes" left in the atoms who lost their electrons.

b. ***Power***
How does such a solar panel create power? To understand power more clearly, let's look at a mechanical example to illustrate the main ideas. For example, imagine a water wheel, like the one in Figure 3.

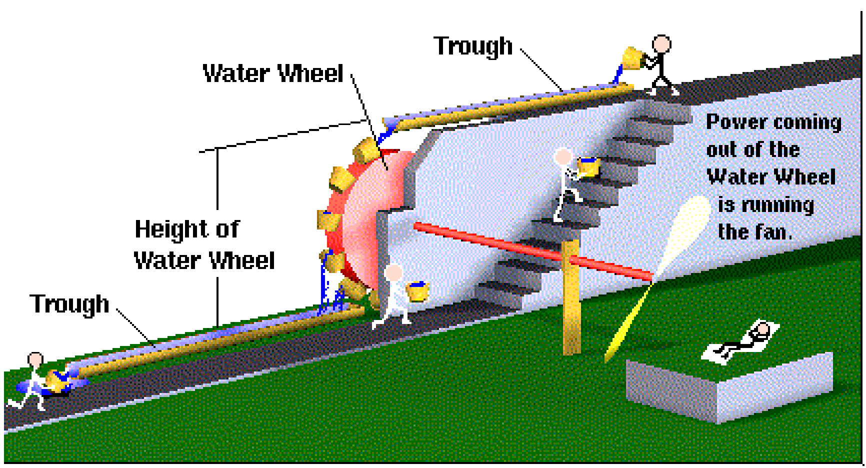


Figure 3: Mechanical example of power system

This does not look very much like a solar panel and motor, but we will see that in many ways they are actually quite alike. In this example, the people have to climb stairs to carry buckets of water up a hill, and then pour the water into a trough. The water flows down over a "water-wheel", which has buckets attached to it that catch the water. The weight of the water in the buckets is what makes the wheel spin. Now, we can use the power of the spinning wheel to run a machine, like the big fan in the picture.

For the water-wheel, the *power* coming out depends on two things:

1. How *high* the water falls.
2. How *much* water (how many buckets) is poured over the wheel.

In fact, the power you get is:

Power = Height x Amount of water

The larger the height of the wheel, the more power we get, and the more buckets of water we pour over the wheel, the more power we get.
No let's think about the solar panel and the motor. Imagine that the electrons are buckets of water, the wires are like the troughs, and the electric motor is the water wheel. In the solar panel, then, the sun's energy is used to carry the electrons up on electric "hill" inside the solar panel, then they are "poured" down through the motor. So, if we drew the picture again for the solar panel, it would look like this:

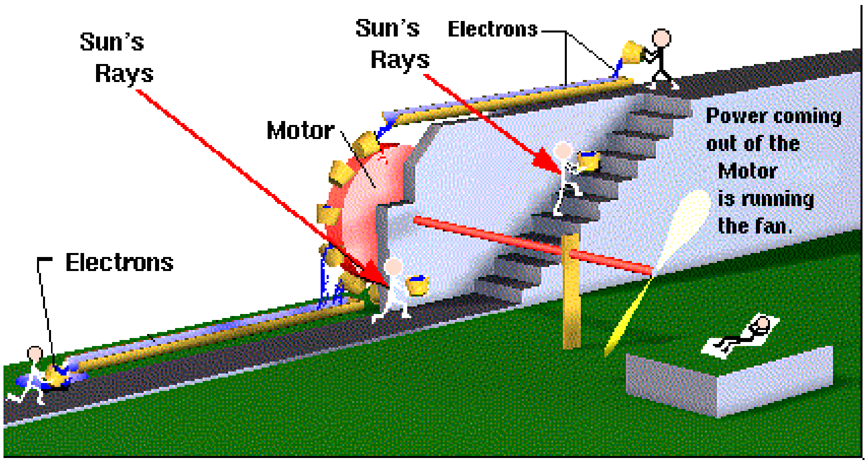


Figure 4: Solar version of Mechanical model

In the solar panel, a very similar equation for power is true as for the water wheel. But instead of height, we have what is called *voltage*, and instead of buckets of water, we have *electric current* (or the number of electrons flowing through the motor).
The *power* coming out of the solar panel is the product of the *voltage* and *the current* (the number of electrons flowing):

Power = Voltage x Current

c. ***Maximizing Power***

How can we build the solar car so it gives us the most power from the solar panel? One way is to try to get the solar panel to produce more current. To produce current, more electrons need to be forced to move inside the panel. If more sunlight hits the solar panel, more electrons are knocked away from atoms in the solar panel and more current is then produced!
How can we do this? One way is to tilt the solar panel towards the sun. The more of the sun's rays hit the panel, the more current will flow and the more power will be produced. Look at the two cars in Figure 5:

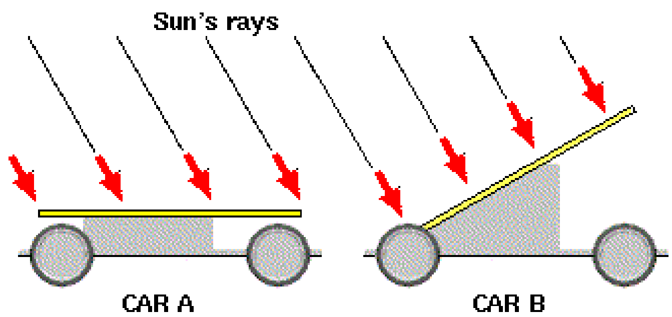


Figure 5: Orientation of the Solar Panel

Which one would have more power? In this case, car B would, because it has more sunlight hitting it than does car A.
Of course, the best way to tell if this will affect your car is to try it with the solar panel mounted at different angles -- experiments are the best way to find out.

Another idea that you might want to experiment with is using a reflector to capture more sunlight with the solar panel.

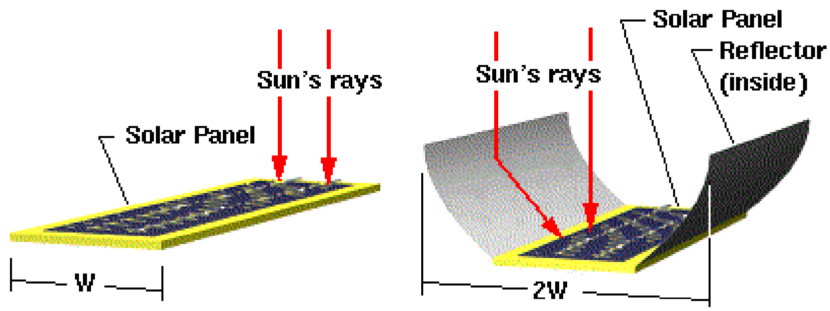


Figure 6: Reflectors on a solar panel

On the right, a reflector that is twice as wide as the solar panel could be made to direct twice as much sunlight to it. This would double the current coming out of the solar panel and double its power!
The disadvantage is that the car would be heavier with a reflector, and a heavier car will be harder to move. Also the reflectors might add air drag or get caught in side winds causing the car to tip over. But, as usual, the only way to find out is to build one and see!

14. **MATERIALS:** [index]
The Solar Panel and Motor will be supplied to you with wires for connection. You made add more wiring if you need it or even add an on-off switch if you like.

15. **EXPERIMENTS & INVESTIGATIONS:** [index]
    - See Investigation 7-1

SOLAR PANELS *Investigation 7-1*

[Back to SOLAR PANELS & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

7-1 Sun's Angle Investigation

Materials Needed:

- Solar Panel
- Motor
- Straw
- Protractor
- Propeller
- Sunshine

Procedure: (see Figure 3)
Do this at 3 different times of day (ie 8am, 11am, 2pm).

1. Attach the propeller to the motor shaft.
2. Connect the motor to the solar cell.
3. Go outside and hold the solar cell level.
4. Count how many times per minute the propeller turns.
5. Hold straw so it is parallel to the sun's rays and casts no shadow (other than a ring).
6. Measure the angle of the straw to the level plane (solar cell) using the protractor.
7. Note the angle, propeller turns and weather conditions at each trial.
8. Repeat these steps on 3 separate days.

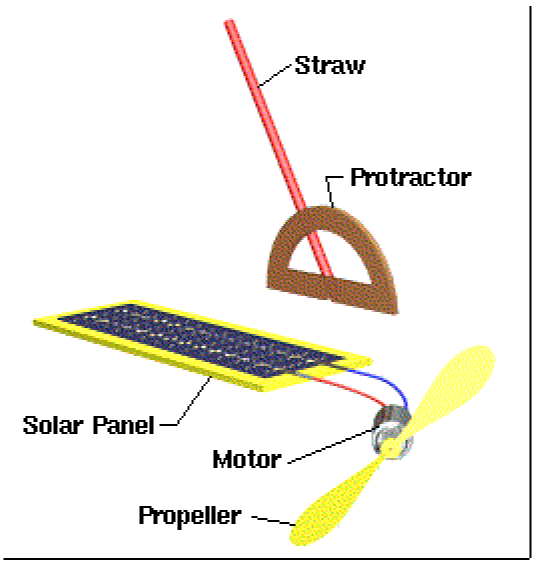


Figure 7: Sun's angle investigation setup

Calculate the average turns over the 3 days for each of the times the observations were taken.

Record the Number of Turns observed and the Sun's Angle at different times of day:							
Date	8am		11am		2pm		Weather Conditions
	Turns	Angle	Turns	Angle	Turns	Angle	
Average							

Observations:

The angle of the sun is different at different times of the day and affects the power to your motor. Weather conditions also affect the power available. Make deductions based on your results, when the race will be held and your strategy in the design of your car.

[Back to SOLAR PANELS & JSS]

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

BODY & SHELL *Handout 8.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]
   The body or shell of a real car has several purposes. It protects the passengers from wind and rain, it provides added safety in case of a crash, and it improves how the car looks. But it also changes how the car performs because a well designed shell can reduce the force of air on the car as it moves.

2. **IDEAS:** [index]
   Some ideas for shells are given below.

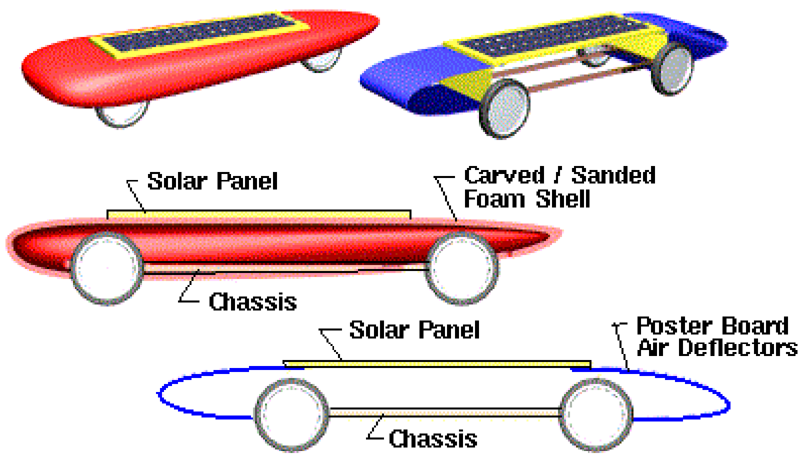


Figure 1: Shell or body concepts

3. **CONCEPTS:** [index]
   a. ***Aerodynamics***
   Aerodynamics: a branch of dynamics that deals with the motion of air and other gaseous fluids and the forces acting on bodies in motion relative to such fluids. Air is a gas and produces a resistance force to objects that move through it. To see how much force air can have, you can try some simple experiments. While driving in a car, carefully try holding your hand flat, and sticking it out of the window. Feel how much force the air has on your hand. What happens to the force when you tilt your hand?

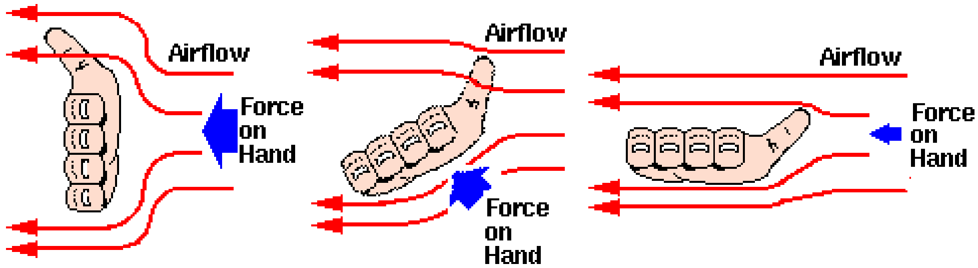


Figure 2: Force of air on your hand

   b. ***Frontal Area***
   When looking at the front of an object that is moving through the air, you can

see the "frontal area" that the air must move around. The smaller the frontal area the less air has to be moved around the object so the less force is required to move through the air.

To illustrate this concept try riding a bike down a hill, compare how fast you can go while sitting upright, or by leaning forward. If you crouch down, the air can go over you instead of hitting you in the chest, so you should be able to go faster. In other words, the force of the air on your body when you crouch down is less, so you are more aerodynamic.

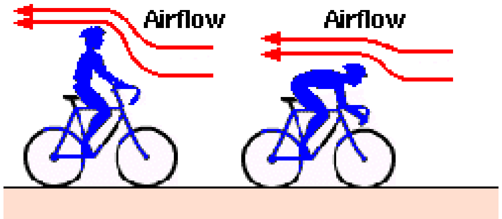


Figure 3: Bicyclist and frontal area

c. ***Shaping***

The shape of the object affects the way the air goes around it. The air wants to stay in a nice smooth flow around the object, however, fast changes in shape create "holes" in the air that disrupt this flow and increase the "drag" or resistance of the air on the objects movement.

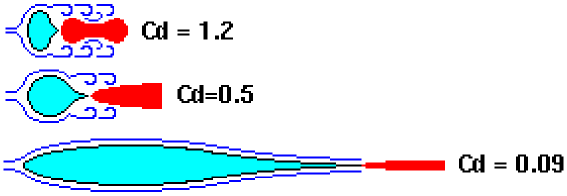


Figure 4: Shapes and airflow

Look at things that move through the air, and notice how they are shaped. For example the two cars shown below, notice how the air flow around them is affected by the shape.

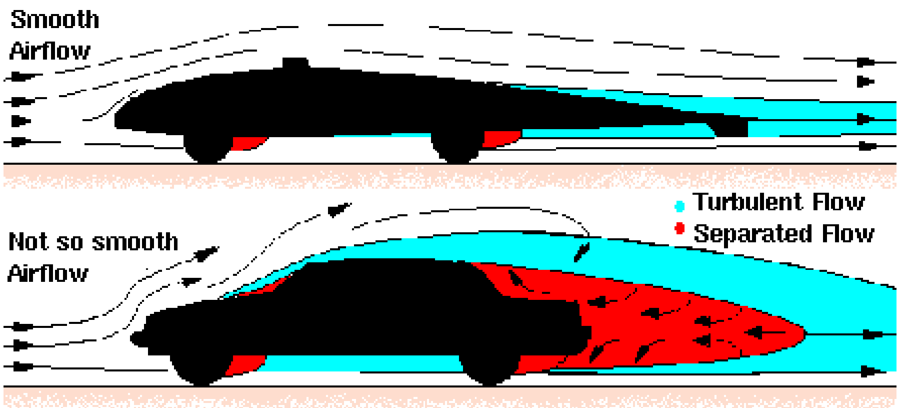


Figure 5: Smooth verses disrupted flow

Fast cars are shaped so that, when moving quickly, they can move more easily through the air. As another example, you may have seen tractor-trailer trucks with big air deflectors on them. The reason for this deflector is to make the truck more aerodynamic, so the truck's engine doesn't have to work as hard and the truck driver saves money on gas.

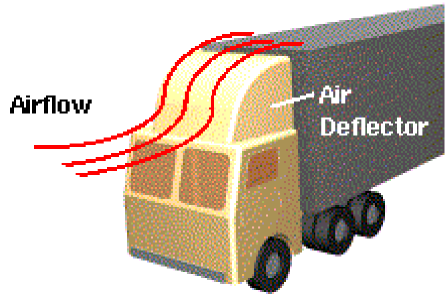


Figure 6: Semi truck and deflector

In some situations, the force of air helps you instead of hurting you. For example, what if you want to slow down very fast? How about using a parachute? Or if you want to create more pressure on the drive wheels without adding weight - you could add a wing that creates a down force on the car. Now the force of the air is helping you.

8. **MATERIALS:** [index]
So how do you reduce the force of air on your solar car? One way might be to add a body or sheel to it that deflects the air around the car. Some possible materials you might want to use are:
    - Poster board
    - Cardboard
    - Foam core
    - Stiff insulation foam (Foamula)
    - Mylar or plastic sheet
    - Paper

   Insulation foam can be carved to a shape, made smooth with sandpaper, and even painted to look nice. (Warning: some paints, likes spray paint, will "melt" foam, so always try your paint on a piece of scrap foam that you don't need before using it on the real thing.)
   Radio control modeling stores also cary an acrylic that can be heated shaped over a mold of your own construction.

9. **EXPERIMENTS & INVESTIGATIONS:** [index]
    - See Investigation 8-1
    - See Investigation 8-2

BODY & SHELL *Investigation 8-1*

[Back to BODY & SHELL & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

8-1 Aerodynamic Shape Investigation 1

Materials Needed:

- Soda can (empty)
- Sheet of paper
- Tape
- 2 - 1/2" diameter wooden dowels (3' long)

Procedure: (see Figure 7)

1. Set up dowels as shown.
2. Place the can alone on the dowels.
3. Blow on the can and observe its movements and the strength of the blow.
4. Make a cone out of the paper and tape it to the front of the can.
5. Now place the can with the cone facing the side to blow from.
6. Blow on the can and observe its movements and the strength of the blow.
7. What kind of resistance forces would this can feel if it were a moving vehicle?
8. How does the cone end can compare with the flat end can?

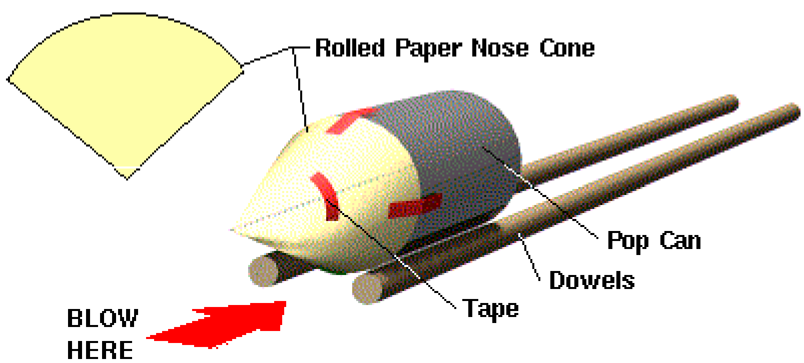


Figure 7: Aerodynamic shape investigation setup

Observations:

In this case the frontal area (area projected to the front or direction of the air movement) did not change, but the sape affected the amount of force applied to the object. How can you apply these principles to your car to make it faster?

[Back to BODY & SHELL & JSS]

BODY & SHELL *Investigation 8-2*

[Back to BODY & SHELL & JSS]

Complete the following investigation. Apply your notes and what you learn to the design of your car. Experiment with ideas on your car.

8-2 Aerodynamic Shape Investigation 2

Materials Needed:

- Ramp (plank of wood)
- Simple car chassis (derby car)
- Different shapes to attach to chassis
- Pieces of Foam core

Procedure: (see Figure 8)

1. Set up a ramp as shown.
2. Identify a starting line.
3. Release the simple car chassis until it repeatably rolls to the same place.
4. Mark the location.
5. Repeat with different frontal area (sheets of foam core of different sizes and orientation), keeping the weight of the car consistant. Try a very large frontal area.
6. Mark the locations they roll to.
7. Which tests went the farthest? Smallest frontal area or largest?
8. Repeat these steps using different steamlined shapes as you did with the nose cone on the soda can. Be careful to keep the other variables constant.
9. Why is it invalid to use different test cars (chassis)? What other physical properties can affect the amount of distance traveled?

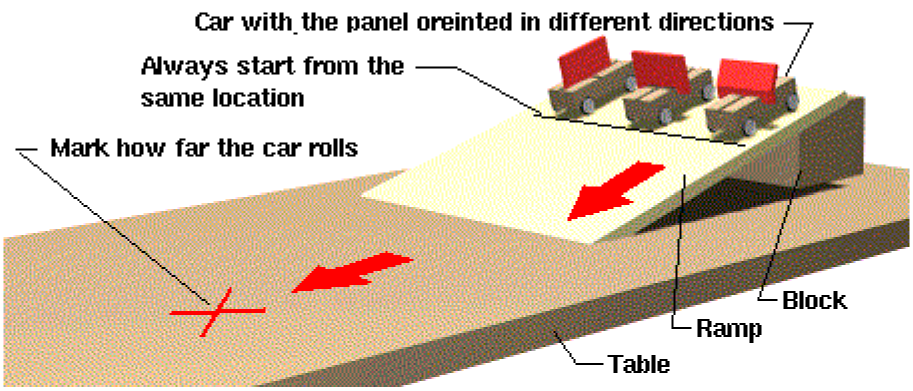


Figure 8: Aerodynamic shape investigation setup

Observations:

Roll-down tests are used by some automobile manufacturers, race car builders, and car testing organizations (among others) to test the aerodynamic drag of a car. The idea is to roll a car (with the engine turned off and out of gear) down a hill, and see how far it rolls. A car with more drag

(for example, a car with a parachute behind it) will roll to a stop faster (or in a shorter distance) than a streamlined, low drag car.
In this case the frontal area did change. Make observations on how the frontal area and shape can affect the drag or resistance the air has on your vehicle. How can you apply these principles to your car to make it faster?

[Back to BODY & SHELL & JSS]

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

DESIGN REVIEW *Handout 9.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:**

   [index] A design review is an opportunity for any organized team of developers to gather all the information together and review it - establishing a more refined approach to the problem. At this point you have learned some things, through study and investigation, that will help you narrow the options you have in producing your car. A design review is where you take establish a design (in the form of a drawing and maybe with some of the "prototypes" you have already made) and present it along with the reasoning behind the decisions you have made to others. The presentation is then followed by a question / answer and comments period where the audience gives you feed back. Your team can then take this input and finalize the design you are going to build.

2. **IDEAS:** [index]

   Some ideas for this presentation.
   - A final sketch or drawing of the car (overhead)
   - Examples in the form of sketches or prototypes
   - Samples of the materials you plan on using
   - Samples of processes you plan on using
   - Experiences in trying things that you learned from

3. **CONCEPTS:** [index]

   a. ***Presentation***

   Hold a team meeting to review all of the information you have learned about chassis, wheels & bearings, transmissions, solar panels, motors and bodies. Decide as a group what your final approach will be in each of these areas (for example a pulley & belt transmission) and record them on paper with small sketches of what you want to build. You can also use prototype projects you have already completed. Also record the reasons why you are making these choices. You might also record any statements on strategy that are affecting your design decisions such as "we expect a cloudy day - so we will build a transmission that will make the car move with very little sunlight."

   If you plan on doing anything special with a material in producing your car include statements on how you plan on doing the work.

   The presentation for you Solar Sprint car should be about 5 minutes long. Make assignments in your group to produce a sketch (with critical dimensions) or drawing of your final concept. Have a transparency of the picture produced.

   Identify one of your team members to make the presentation and another to act as a recorder of the comments that you receive. These notes can be very helpfull in making final decisions after the design review with your peers.

   When making the presentation, remember that you are not only sharing your ideas but trying to sell your audience on them. Make the presentation fun and exciting. Showcase your ideas and see what kind of reactions you get.

Remember that the commments and questions are not personal. It is just others trying to understand what you are saying or giving you ideas they have. In the end, you will, as a team, make the final decisions on what you are going to build. The Design Review is a tool to try and help you produce a better vehicle.

b. ***The audience***

When a team is presenting their design you need to be attentive. Do not interrupt the presentation and only express an idea or ask a question when called upon. The audience members need to be supportive of ideas they think are good, but also ask questions to clarify what you do not understand. You should freely express concerns about ideas that might have problems such as something you learned in an investigation that had different results. You are responding to the presentation to help the presenting team produce a better more competitive car.

You also need to listen intently because you can learn things from other presentations that might help your team do better. Take notes when you hear something that impresses you or is a good idea.

Remember, the better all the cars are the better the race and the more fun for all - you, your team-mates, the other racers and the audience that comes to see the results of all your hard work.

c. ***Considerations for a Solar Car***

A solar car, whether full sized or a smaller model, must perform with very little energy available from the solar panel. Since the energy is limited, the designer must do everything possible to make the car efficient so that the maximum amount of energy is used to make the car go. In a car like Sunraycer, we had to consider many things. With the solar panel area limited, we wanted to have the most efficient solar cells possible. The electrical load on the solar panel had to be continuously adjusted by electronic controls to maximize the power under any condition of sunlight. The motor for driving the wheels had to be very efficient, too. In the Junior Solar Sprint, everyone must use the same solar panel and motor so these are not a matter of design for this application. What are the design points which have the greatest impact? They are aerodynamic drag, rolling resistance, drive train efficiency and weight.

Aerodynamic Drag is very non-linear with speed. At very slow speeds, below 10mph, it doesn't have too much effect, but as the speed increases to more than 30mph, aero drag gets important. The magnitude of drag depends on the frontal area of the car; (ie., maximum cross section looking at the car from the front, multiplied by the coefficient of aero drag, which depends on the car's shape, multiplied again by the velocity squared). It is this velocity squared term that makes the drag increase quickly with velocity or speed. So the designer should make the frontal area of the car as small as possible and make the body as streamlined as he or she can. A poorly designed shape might have a coefficient of 0.5 (drag), and a very good shape might be as low as .02 (drag). So you can see that the drag could range over four to one! Make a smooth tear-drop shape as well as you can considering that the solar panel has to be included. Use the wheels with disc structure, not spokes. If spokes are used, they should be covered on both sides. Be sure the underbody is smooth, too, not open like a regular car. Make openings for the wheels (if the body covers the wheels) as small as possible. If the wheels are not enclosed in the body, consider wheel pants.

Rolling Resistance is another energy waster. It is the energy lost in the wheel bearings and in the tire deformation. The tires on the Junior Solar car are probably solid rubber so tire pressure is not a factor, but the rubber should not be very soft and the tires should be smooth (no tread) and very narrow. The bearings should be given careful attention. The Axles should be straight straight and the bearings (if they are sleeved bearings) should be made from low friction materials like Teflon, Nylong or oilite (bronze). The lubrication should be very light - no grease.

The Drive Train can waste energy too. Gears can be particularly wasteful if they are not precision made. Some form of belt drive may be best but be sure the belt doesn't slip, and that it is not overly tight. The drive ratio is very critical. You will want to experiment to see which drive ratio gives the best results with your car. It may be that different ratios are best for different sun conditions. You may want to be able to quickly change ratios to do best on a cloudy dat from that ratio that is best on a sunny day.

The weight of the Junior Solar car is a very important design consideration. Since the car is probably accelerating most of the run, the weight is more important than if the car was traveling at a constant speed. Also, the weight is a direct multiplier on rolling resistance. Twice the weight means twice the rolling resistance for the same wheels, tires, and bearings. So use light-weight materials, built-up construction, or other lightening techniques. Remember though, that there must be enough weight on the drive wheels so that they don't spin.

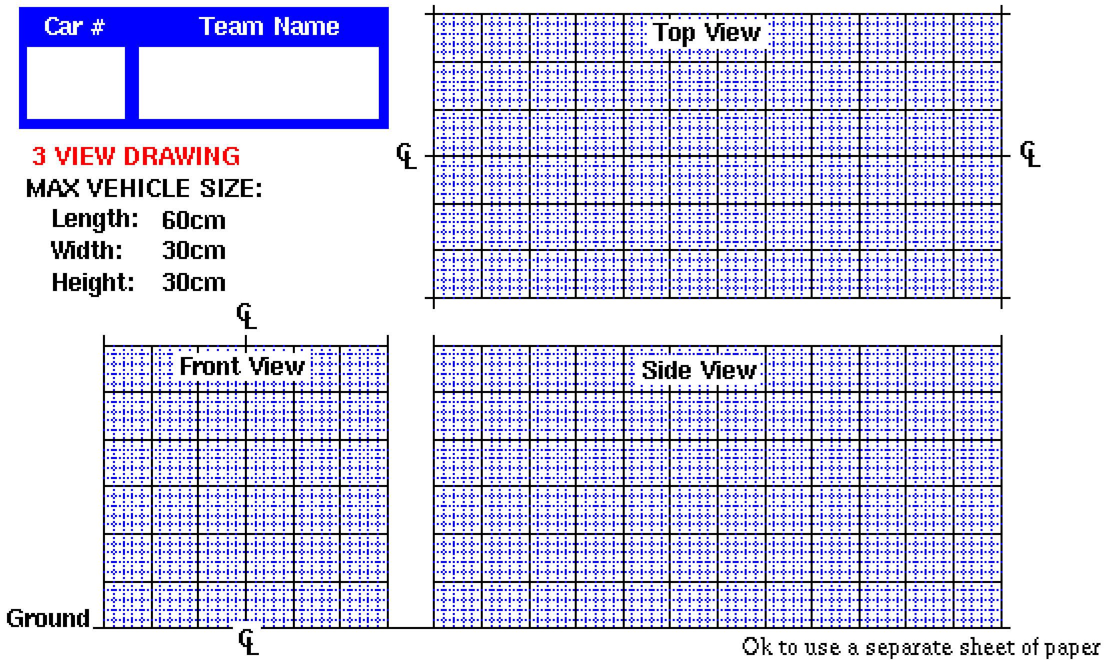
8. **MATERIALS:** [index]
   - Take a look at each of the materials sections in handouts 1 through 8 for ideas.
9. **EXPERIMENTS & INVESTIGATIONS:** [index]
   - See Investigation 9-1

DESIGN REVIEW *Investigation 9-1*

[Back to DESIGN REVIEW & JSS]

Fill out this form and prepare a 5 minute presentation on your design to a group of peers or your class - make the presentation and field questions.

1. **DRAWINGS:**



2. **COMPONENTS:**

A. **TRANSMISSION:** Presented By:____________________
- What type:
- What materials:
- Who will build:
- How will we test:

B. **CHASSIS:** Presented By:____________________
- What type:
- What materials:
- Who will build:
- How will we test:

C. **WHEELS & BEARINGS:** Presented By:____________________
- What type:
- What materials:
- Who will build:
- How will we test:

D. **BODY SHELL & ARRAY:** Presented By:____________________
- What type:
- What materials:

- Who will build:
- How will we test:

3. **MATERIALS:**
   - Any special Materials to be used:
   - Any special Processes to be used:

4. **NOTES:**

[Back to DESIGN REVIEW & JSS]

DESIGN REVIEW

Team Number:	Team Name:	Team Members:
		1. ____________________ 2. ____________________ 3. ____________________

1. **Sketch / Drawing** **Responsible:**______________________________
   a) Top View
   b) Side View
   c) Front View
   d) Section Views as needed

2. **Chassis / Body** **Responsible:**______________________________
   a) Type: Uni-Body Frame-Body Other:______________
   b) Frame Material: ____
   c) Body Material: ____
   d) Wheel Mounting Plan: ____
   e) Motor Mounting Plan: ____
   f) Solar Cell Mounting Plan: ___________________________________
   g) Track Guide Wire Plan: ___________________________________
   h) Special Considerations: ___________________________________

3. **Wheels / Bearings** **Responsible:**______________________________
   a) Number of Wheels: 2 3 4
   b) Wheel Material & Size: ___________________________________
   c) Axle Type: Front: Fixed Rotating Other:____________
   Rear: Fixed Rotating Other:____________
   d) Axle Material & Size: ___________________________________
   e) Bearing Material & Size: ___________________________________
   f) Special Considerations: ___________________________________

4. **Transmission** **Responsible:**______________________________
   a) Type of transmission: Direct Gears Pulley Friction Other:__________
   b) Materials: ____
   c) Attachment to Motor Shaft: ___________________________________
   d) Attachment to Drive Wheel/Axle: ______________________________
   e) Special Considerations:____

5. **Other** **Responsible:**______________________________
   a) Finish / Paint Job: ____
   b) Number Marking: ____
   c) Name Labeling: ___________________________________
   d) Solar Cell Orientation: ____
   e) Special Considerations:____

Chimacum School District No. 49

Junior Solar Sprint

Junior Solar Sprint

HOME COURSE TEACHER HISTORY ABOUT

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

BUILD *Handout 10.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]

   This is the phase of the project where you actually build your final car. You may use parts you have already constructed for investigations and trials up to this point.

2. **IDEAS:** [index]

   Following the design review, as a team, decide about the details you will construct, who will bring the materials, put things together etc. As you are able do some testing. You may want to do this with batteries or ask the instructor to use a solar panel to test with.

   You may want to review the following before you get started to insure you know what the rules are which you must conform to:

   - Event Rules

   Take a few minutes to review the following so that you can get more ideas and also build your car in a safe environment:

   - Tools & Materials
   - Safety Issues

3. **CONCEPTS:** [index]
   - None

4. **MATERIALS:** [index]
   - None

5. **EXPERIMENTS & INVESTIGATIONS:** [index]
   - None

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

OPTIMIZE DESIGN *Handout 11.0*

PAGE INDEX

- PURPOSE
- IDEAS
- CONCEPTS
- MATERIALS
- INVESTIGATIONS

1. **PURPOSE:** [index]
   Once you have constructed your car and performed some testing you will want to make adjustements to improve performance. Apply what you have learned in the investigations and prototypes you have constructed to solve problems. Get the whole team involved in brainstorming solutions - even ask other teams or observe what others have done to solve your problems. Remember, your car must be ready for the race so time is a critical consideration.

2. **IDEAS:** [index]
   Some ideas for this process.
   - Try to identify the source of the problem.
   - Compare your car to prototypes you have constructed.
   - Evaluate how long it will take to make corrections.
   - List out your options with pros - cons & time then determine what to do, and do it.
   - Re test your car after any change to see what the change did.
   - Only make one change at a time.

3. **CONCEPTS:** [index]
   a. ***Observation***
   During your testing, make notes of what works best. Test the car on the track (or a close replica) attached to the guide string and make what adjustments you are able to in the current design. Look for parts that are rubbing, alignment of wheels, loose wires or parts, or weak points in the structure. Watch what happens as the car goes down the line and then isolate what the problem is that needs to be corrected. Work as a team and be sure and evaluate completely all input from every team member.

   b. ***Determine Options for Correction***
   Once you have identified the problem brainstorm the teams options for fixing it. Take advantage of the prototypes you built during the first few weeks of the project, and the things you learned during the design reviews. Make a complete list of the options you have including the difficulty of each, how much time it will take and the availability of parts/materials. Then as a team start eliminating them until you get the top one or two then as a team decide which approach to take.

   c. ***Make the change and evaluate results***
   Once you make the change to your car re-test it and find out if the fix improved the car or not. Try to do the test exactly the same way as before and make sure nothing else went wrong during the rework. You should only do one thing at a time so you know what is affecting the performance of your car. As you optimize the car, you will be more successful in the race.

4. **MATERIALS:** [index]

- Not Applcable.

5. **EXPERIMENTS & INVESTIGATIONS:** [index]
   - None.

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

TOOLS & MATERIALS *Things you may want to use*

Some of the materials and tools needed for the project are provided in the kits. Others are the responsibility of the schools and/or students. The lists which follow are not required lists; they are suggestions. Feel free to be creative and come up with other ideas. For more detailed lists of materials look at Student handouts 3 thru 8.

1 Items Included in the Kit

- Solar Panel
- Motor
- Student Guide (online)
- Computer Based Instructions

2 Suggested Materials

- Cardboard sheet
- Cardboard tubes
- 1/8 inch rods
- Wire Hangers
- Foam Core Board
- High Density Foam
- Styrofoam
- Straws
- Washers
- Stiff Wire
- Solder tape
- Wire Nuts
- Alligator Clips
- Electrical Wire
- Wood
- Tin Cans

3 Suggested Hand Tools

- Safety Glasses
- Scissors
- Wire Cutters
- Pliers
- Tape (masking, duct, electrical, scotch)
- Hot Glue
- Elmers Glue
- Rulers
- Pencils
- Electric Drill
- Hacksaw
- Utility Knife
- File
- Sand Paper

- Hand Jig Saw
- Soldering Iron

JSS Student Contract & Expectations

Weekly assignments
You will be expected to review all student handouts and complete the investigations for each week. At the conclusion of each section is a list of things you must review with one of the teachers and/or mentors before you move on to the next section. You must also create some prototypes of components as you work each week and this is part of your assignment for completing that weeks work.

Attendance
Students who sign up to participate in this event are making a commitment to attend all of the classes that are outlined in the schedule. Your team and the other competitors are counting on you to be there. If you cannot make a session, please let a teacher or team member know and make up the missed assignment at home.

Teams
Students will be organized into teams of 2 or 3 people each. You are to work on the assignments as a team and involve all the members in the study, investigation and development of your car. Find out the strengths of the team members and make assignments that will take advantage of them. Remember - it takes a whole team to be successful and get your car to run.

Outside of session time
There is no such thing as failure in this event unless you quit. We are asking that you evaluate the amount of time this requires and make a commitment and keep it. It will take some time outside of the sessions that are scheduled to do things like locate and collect materials to build your car out of. Depending on the complexity of your design, you may have to spend some time outside of class to construct parts of your car or use equipment that we do not supply at the school. Please be careful and only operate equipment under adult supervision.

Behavior
We expect everyone to follow normal school rules for behavior while involved in this event. Please be courteous to other teams and help others when you see they are in need. If everyone shares and helps one another, all the teams will be competitive and make for a lot more fun on the final race day. You will be expected to adhere to all the rules stated in the Event Rules.

Permission & Agreement
As the student I pledge adherence to the contract and rules as stated above in order to qualify to participate in the SDRES Junior Solar Sprint.
As the Parent/Guardian of the above named student, I give my permission for him/her to participate in the Junior Solar Sprint program after school.

Students Signature ______________________ Date________________

Parents Signature _______________________ Date________________

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

EVENT RULES *Rules & Specifications*

Section 1 Objective

The object of the Junior Solar Sprint competition is to design and build a vehicle powered by a solar panel that will complete a race track in the shortest possible time.

Each team will be given a solar panel and a motor. Using any other materials, teams will design and build a solar powered vehicle that will race on a 20 meter (65.6 feet) long track. The winner of the competition will be the team whose vehicle is the top finisher in a series of head-to-head races.

Section 2 Materials

The vehicle you construct is to be of your teams own design and made from any materials you desire using only the solar panel as a source of energy and the motor that is provided as noted below.

1. Solar Panel (No modifications allowed - must be returned after the race).
2. Electric Motor (No modifications allowed - team may keep this item).
3. Any other materials you collect or choose to use.

Section 3 Vehicle Specifications

The vehicle you construct must meet the following requirements.

1. **Car Size** The car must be no larger than 60cm in length, by 30cm in width, by 30cm in height.
2. **Power Source** Only sunlight may be used as an energy source - NO BATTERIES permitted.
3. **Attachments** Everything must be attached to the car so that it does not come off when on the track. The start cover must not touch the car.
4. **Guide Wire** The vehicle must include a method to attach the car to the guide wire on the track easily without disconnecting the guide wire.
5. **Car Body** The solar cell cannot be used as the body of the car. Axels, wheels, and motors cannot be attached directly to the cell.
6. **Markings** The car number must be displayed on the car and at least 3cm by 3cm in size and visible from either the front, side or top. Decals provided by the school must also be displayed on the car.
7. **Safety** The car must be safe to participants and spectators. No sharp edges, projectiles or the like are allowed.

Section 4 Track Specifications

The track you will run your car on will meet the following requirements.

1. **Length** Distance from the start line to the finish line is 20 meters (65.6 feet).
2. **Width** Distance between Race lanes will be 1 meter (3.1 feet).

3. **Guide Wire** Will be located at the center of the race lanes and not more than 1.5cm above the track surface.
4. **Surface** Will be a hard, flat, smooth surface. Building felt layed down on the tennis courts at the high school.

Section 5 Conduct of the Race

The race will be run under the following conditions.

1. **Inspections** Vehicles will be inspected by the judges prior to the race and may be inspected between heats at the judges discression.
2. **Starting** At race time, your team will attach the vehicle to the guide wire behind the starting line with all of its wheels touching the track surface and an opaque start cover over the solar panel but not touching it or the vehicle. On the GO signal from the official your team start person will remove the cover allowing the vehicle to collect power and start.
3. **Pushing** An early push startmay result in either disqualification, forfeiture or a re-run of the heat and will be determined on by the starting judge.
4. **Winner** All vehicles will be started when the official signal is given. The winner of the heat will be the first vehicle to cross the finish line or the vehicle farthest down the track and will be determined by the finish judge.
5. **Team Members** Once the cars are ready to start, one team member will be at the start to remove the cover on the signal and one team member will be at the finish line to catch the car, all other team members inside the track area must stay behind the yellow clear zone line marked on the ground Team members may not accompany or touch the vehicle on the track unless instructed to do so by the starting judge.
6. **Collecting Cars** Vehicles stalled on the track may be retrieved only after the end of the race has been declared by the finish line judge.
7. **Fixing Cars** Teams may work on their cars between races to fix problems but must stay out of the yellow track zone. Remember that if you are called to the next race and your car is not ready you will forfeit the race - at the start line judges determination.
8. **Lane Changes** Lane changing or crossing may result in disqualification at the determination of the judges.
9. **Format** All vehicles will race all other vehicles. A record will be kept of wins and losses and a winner determined based on the best win-loss record. A runoff will be used in case of a tie.

Section 6 Awards

Awards will be presented at the conclusion of the race to all participants and teams in recognintion of special achievements. This may be done at the next school assembly.

INSTRUCTIONS

1 -INTRODUCTION
2 -DESIGN PROCESS
3 -CHASSIS
4 -WHEELS
5 -TRANSMISSIONS
6 -GEAR CALCS
7 -SOLAR PANEL
8 -BODY & SHELL
9 -DESIGN REVIEW
10-BUILD
11-OPTIMIZE

EVENT RULES
LAB QUICK LIST
TOOLS & MATERIALS
SAFETY ISSUES
TEAMS
STUDENT CONTRACT

Webmaster

SAFETY ISSUES *Safe use of hand tools*

Hand tools are easy and safe to use when they are used properly. Please inform yourself about safe use of hand tools by reading ahead, and by consulting with your teacher or mentor. Below, we describe some commonly used hand tools and some dangerous situations that can result if they are not used properly.

1 Safety Glasses

Safety glasses, the most important safety aid, are inexpensive, and available at any hardware store, or from your shop teacher.

2 Hot Glue Gun

Very useful for quickly fastening different materials together with a reasonably strong bond, hot glue guns can cause **minor burns** if the gun nozzle or hot glue touches the skin.
Store tools safely. Unplug electrical tools when not in use for a long period of time.

3 Soldering Iron

Useful for making electrical connections. Soldering irons can cause **minor burns** if the soldering tip, or hot solder, touches the skin.
Wear safety glasses to protect against hot solder.
Store tools safely. Unplug electrical tools when not in use.

4 Electric Hand Drill

Hand drills are useful for placing holes in materials, and might be used in the fabrication of wheels, for example.

Wear safety glasses. If too much force is applied, drill bits can break, launching fragments into the air. Material removed by the drill bit can also become airborne. Students using hand drills should work a safe distance from students that are not wearing safety glasses.
Clamp work securely. A spinning drill bit can grab the workpiece and yank it around if it is not properly clamped in place, resulting in hand injuries, especially if the workpiece has sharp edges. A small vice or clamp is used for this purpose.
Note what is underneath the piece being drilled. Be sure that the drilling is done into a secure block of scrap wood or into clear space.
Store tools safely. Unplug electrical tools when not in use.

5 Hacksaws & Jigsaws

Hacksaws & jigsaws are useful for cutting a variety of materials.

Wear safety glasses. Removed material could become airborne.
Clamp work securely. This removes any inclination to hold the workpiece near the cutting zone, and allows better control of the tool. A small vice or clamp is used for this purpose.
Note what is underneath the piece being cut. Be sure that the cutting is done into a clear space.
Keep hands away from the cutting zone. The blade can jump and cause minor hand injuries.

Store tools safely. Unplug electrical tools when not in use.

6 Wire Clippers

These tools are useful for cutting wire and thin shafts. If both sides of the piece are not securely held, they may shoot out.

Wear safety glasses. The material could become airborne.
Clamp work securely. Clamping one or both ends of the material being cut with a pair of pliers or clamp reduces the chance of a piece becoming airborne. Orient the tool so that any loose piece is aimed at the floor.

7 Utility or "Exacto" Knives

Useful for cutting cardboard, foam, balsa wood etc.

Wear safety glasses. A blade could break and fly upwards.
Cut away from yourself. Do not direct the blade toward any part of your body or other hand as a simple slip can cause a minor cut.
Store tools safely. Avoid leaing exposed blades on table surfaces. Use a handle with a retractable blade if possible.

Chimacum School District No. 49

Junior Solar Sprint

HOME COURSE TEACHER HISTORY ABOUT

INTRODUCTION

LEADING PROGRAM
ROLE OF MENTOR
HANDS-ON DESIGN
SYLLABUS

MATERIALS LIST
REGISTRATION
LINKS & PARTS

Webmaster

MENTOR ROLE

The role of the technical mentor is to provide teachers and classes with science and/or engineering expertixe. How this occurs depends much on the individual involved.

Examples of mentor contributions in the past include:

- Present JSS program to the class.
- Bring students on a lab or workplace tour.
- Lead design and build sessions.
- Run Saturday or after school sessions.
- Provide technical support for teachers and volunteers.
- Build demonstrations.
- Assist students at race area.
- Discuss science and engineering professions.

Class time participation of the mentor ranges roughly from 5 to 20 hours. If the mentor is a student or has a very flexible work schedule, he or she may be able to spend even more time with the class. It is also common for mentors and teachers to have frequent telephone or email contact.

In addition to providing instruction and expertise for the JSS project, mentors share their professional science or engineering experiences with the class. This may or may not include tours of their lab or workplace.

Mentors have different levels of comfort with classroom teaching. Some may enjoy teaching class, while others may prefer to remain on the sidelines and answer questions.

It is suggested that teachers consider providing their mentors with a copy of the class's science and/or math (non JSS) curriculum and schedule for the units covered during the JSS program so the mentors have the opportunity to relate what they are presenting to the teacher's current lessons.

It is particularly useful for the mentor to come in and help students evaluate one another's designs if a class period is set aside for this purpose. In this type of session, a design review, the mentor can ask and answer questions of the students and make suggestions for design enhancements.

NREL/BK-820-30829
Revised 8/23/01

Junior Solar Sprint

Teacher and Mentor Guide

Written by:
Diana Bauer, Diane Brancazio, and David Brancazio

Acknowledgments

We would like to thank the many individuals who helped us through the brainstorming, writing and rewriting stages in the creation of this guide. Their insights greatly enriched the guide. Teachers and mentors Kathleen Allen, Bruce Anderson, Regina Cadillac, Ken Cray, Milly Feloney, Steve Fernandez, Andrew Heafitz, Bill Hutchinson, Frank Madden, Matt Mangan, Randy McGilvary, Mike Pfrommer, Bob Phinney, Ned Rice, Sumner Richards, Chris Saunders, John Stasik and Mike Walsh all provided inspiration at points along the way.

We would also like to thank Patricia Rose and Richard Stephens from the U.S. Department of Energy for their support, Dave Chamberlain of DOE's Boston Support Office, Linda Lung of the National Renewable Energy Laboratory for their dedication, encouragement, and suggestions, and Bob Larsen and Marti Hahn of Argonne National Laboratory for their dedication and creativity.

This work was sponsored by a grant from the U.S. Department of Energy.

Comments and suggestions concerning this document should be directed to:

Diane and David Brancazio
45 Pemberton St. #1
Cambridge, MA 02140

Table of Contents

Subject **Page(s)**

Introduction 4

The Role of Technical Mentor 5

Teaching Hands on Design:
Comments and Suggestions 6

Leading the Program: Comments and Suggestions 8

The Design Process 9

Define Goals and Constraints 10

Suggested Syllabus 13

Introduction

Thank you for participating in the Junior Solar Sprint (JSS) program. This program is quickly expanding and evolving! This year we are providing some new background information that we hope you and your students will find helpful. This Teacher and Mentor Guide includes a suggested lesson plan for you to work from. We encourage you to modify it to suit your own circumstances.

"An Introduction to Building a Model Solar Car" is a reference provided for students; teachers and mentors may find it useful either as background information or to generate ideas for their program. Keep in mind that one of the mentor's roles is to provide teachers with technical support, so teachers should feel free to call mentors with any questions.

In designing this program we set the following goals:

- Present science concepts in a fun and exciting way.
- Give students a chance to interact with engineers and scientists.
- Stimulate creative thinking through a hands-on design project.
- Help students to experience the satisfaction of creating a working machine and the excitement of entering it in a competition.

In this guide, we have incorporated suggestions from last year's teacher and mentor participants. The sections which follow are meant to be guidelines and suggestions. It is important to keep in mind that there is no single correct way to successfully complete this program. Remember that design is a creative process: professional engineers have variations in style and might not exactly follow the design procedure described in this document. If you have other ideas, which are not mentioned here, you should feel free to use them. We realize that mentors have different levels of time and flexibility and comfort with classroom teaching. Also, no two schools have exactly the same level of teacher expertise, student participation, or time scheduling flexibility.

The Role of Technical Mentor

The role of a technical mentor is to provide teachers and classes with science and/or engineering expertise. How this occurs depends much on the individuals involved.

Examples of mentor contributions from 1993 Junior Solar Sprint include:

- Present JSS programs to the class.
- Bring students on a lab or workplace tour.
- Lead design and build sessions.
- Run Saturday or after school sessions.
- Provide constructive design feedback.
- Provide technical support for teachers and college-student volunteers.
- Build demonstrations.
- Assist students at area race.
- Discuss science and engineering professions.

Class time participation of the mentor ranges roughly from 5 to 20 hours. If the mentor is a student or has a very flexible work schedule, he or she may be able to spend even more time with the class. It is also common for mentors and teachers to have frequent telephone contact.

In addition to providing instruction and expertise for the JSS project, mentors share their professional science and engineering experiences with the class. This may or may not include tours of their lab or workplace.

Mentors have different levels of comfort with classroom teaching. Some may enjoy teaching class, while others may prefer to remain on the sidelines and answer questions.

It is suggested that teachers consider providing their mentors with a copy of the class's science and/or math (non-JSS) curriculum and schedule for the units covered during the JSS programs so the mentors have the opportunity to relate what they are presenting to the teacher's current lessons.

It is particularly useful for the mentor to come in to help the students evaluate one another's design, if a class period is set aside for this purpose. In this type of session, a design review, the mentor can ask and answer questions of the students and make suggestions for design enhancements.

Teaching Hands on Design:
Comments and Suggestions

Working in Groups. The recommended size for groups in this project is 2-4 students We advocate that this project be completed by students working in groups rather than students working individually for several reasons. First, individual cooperation, like competition, involves skill and practice and is important in the professional engineering workplace. Second, working in a group is very often a strongly positive part of the project for students who have less confidence with hands-on work if group members help one another. Third, having the students share amongst themselves the search for and use of materials makes this portion of the project less costly and less intimidating for everyone.

We realize that in some classroom situations, setting up work teams is difficult. A common problem is that one student takes ownership of the project and the others have negligible contributions, making for resentment on all sides.

We do have some suggestions for avoiding this type of problem. Some teachers find that students unfamiliar with working in groups are more enthusiastic when working on a team that the students have selected. In other cases, it makes sense for teachers to designate groups themselves so that they can effectively balance student skills among groups. Another suggestions: encourage the groups to understand what is going on. For example, have the groups present their designs to the class, and require that each member of the group speak about some aspect of the design. Also, provide some incentives for the quiet people to speak up and the assertive people to listen. Both speaking and listening are important teamwork skills.

Design Reviews as a Teaching Tool. A particularly successful classroom activity, called the "design review" in the professional workplace, requires students to explain their designs to the entire class at certain designated points in the design process. Some examples are discussed in the curriculum section. This activity is helpful for everyone. The portion of the class listening to the presentation learns about other approaches to designing the car. The members of the group presenting have to understand their own project well enough to explain it. They receive useful feedback from their classmates, their teacher, and their mentor. Students gain valuable insight from constructively criticizing one another's work. It is important, in the design review, to make sure that everyone gets a chance to give comments and receive suggestions.

Answering Questions and Stimulating Thinking. One of the goals of this project is to stimulate students to think and formulate their own questions. The next step in this process is to help students acquire the confidence to research their own answers, so that students do not make design selections because "This is what my teacher told me to do". Students should be encouraged to ask questions because they are thinking, rather than to avoid thinking.

Developing Individual Student Skills and Creativity. We suggest thinking about ways to help individual students develop skills in areas which may not be their strengths. Encourage tentative students to speak up and not be intimidated by assertive students. Encourage aggressive students to relax and listen to what others have to say. Since developing creativity is in itself a goal, give students room to be creative. Evaluate the project in multiple areas such as technical performance, aesthetics, and craftsmanship so that more students can be excited by at least one option. Encourage students who are not used to working with their hands to experiment and make mistakes. Encourage students who are used to working with their hands to be good teachers, patient and not overly helpful.

Testing the Cars: Learning from Mistakes. Students, like engineers, will learn from their mistakes! We expect things to go wrong the first (few) times. For this reason, engineers usually build one or more prototypes (test cars) to test out parts of their design before building the actual device.

Testing is an important part of the design process, and it often takes more time than anticipated. For students working on this project, it is useful to build one or more prototypes of components to help evaluate and test initial designs. Once a final version is built, it has to be tested as well.

Recognition.
It is important to give students positive feedback and recognition for their work. This can be done, for example, by holding races for the whole school to watch, or by having a school display of cars or drawings.

Leading the Program: Comments and Suggestions

Benefiting from Experienced Designers. In some classrooms it makes sense to involve in the project parents who are scientists or engineers. These parents can advise in car-building sessions or arrange workplace tours for the class. Another possibility is to have students who participate in last year's program discuss their experiences with the class. They can demonstrate their car and explain design challenges they faced.

Curriculum Areas Where JSS Can Be Used. This program can be incorporated into many classroom curriculum areas, such as:

- Physics/Physical Science
- Transportation
- Alternative Energy
- Electricity
- Mechanics
- Earth Science

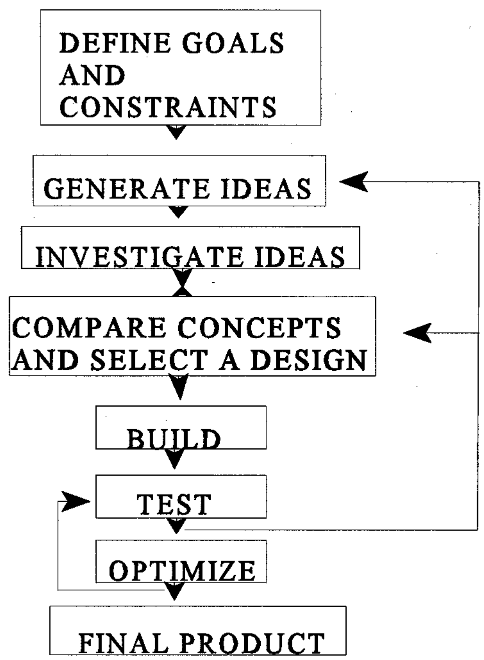
Incorporating the program into a pre-existing curriculum enable teachers to devote class time to the project while enhancing their existing curriculum.

Working at Home vs. Working at School. There are many scheduling alternatives: completing the program during class time, completing the program at school but after school, having Saturday working sessions, and having students take cars home to work on them. Each has its own advantages and disadvantages. We suggest having the students work at home only in programs where the students are likely to work in their groups at home. This alternative will be less ideal in schools and programs where the students working in group don't know each other or live far from one another. If the program is done primarily at school, it is important to reserve a space where students can store their materials safely.

The Design Process

What is design? Design is the process of creating something new to perform a specific function. In this program, students will be given a specific mechanical design problem and asked to create a machine that solves it. To effectively channel creativity, professional design engineers impose a structure on the design process. The process used by many engineers is presented here for teachers and students to use in designing their solar vehicles.

The steps are as follows:



The process presented here may be used at any and all levels of model car design, from the design of individual components to the complete car as a system. The key principle in the process is to start all designs with many ideas, then investigate and evaluate several of them before locking into a design.

Part of the challenge in design is learning to combine good ideas from several people into a winning design. Students should be encouraged or required to use a notebook to record their ideas and sketches. Ideas not written down or sketched are quickly forgotten. In addition to providing a means to store and communicate ideas, putting thoughts down on paper often aids in idea generation and clarity.

Define Goals and Constraints

To begin with, a designer needs to clearly define the problem: what is the **goal** of the design, and what **constraints** exist that will provide limits for the design.

Some possible **goals** for the design of the solar cars are:

- to make the race-winning model solar car
- to make a stylish model solar car
- to make a sturdy, robust solar car

Constraints are the limitations that are imposed upon the design by the designer or by the problem itself. In designing a model solar car some **constraints imposed by the designer** might be:

- Materials will cost less than $20 and be easy to find
- The car must be constructed in 8 weeks

In addition, there are **constraints imposed by the rules**, such as:

- The car must be powered only by the solar panel and motor provided in the kit
- The car must be within the specified size limits
- The solar panel cannot be a structural member of the car

Defining the goals and constraints helps focus the designer's time and effort on the most important areas.

Generate Ideas

Design relies on generating ideas. **Brainstorming** is an effective idea-generating technique that is usually done in groups. The goals of a "brainstorming session" is to generate as many ideas as possible in the given time. Groups often include individuals with varied backgrounds to get as many perspectives on a problem as possible. The duration of brainstorming sessions varies with the quantity and complexity of the issues to be discussed, but for a student group such as this a session lasting from 15 to 30 minutes is recommended. Students can begin with brainstorming ideas for car components.

Some possible topics for a brainstorming session are:

- Types of transmissions
- Ways to attach a solar panel to the car
- Aerodynamic body shapes
- Materials for wheels, axles and bearings

To make these sessions productive, it is useful to set a few rules before hand. One of the most important is "There is no such thing as a dumb idea". Participants are encouraged to contribute ideas they consider silly since these ideas may trigger more practical ones in their own or another participant's thinking. Another useful rule is "No one may interrupt the person who is speaking". To ensure that everyone gets a chance to contribute ideas, the leader may consider breaking the class into smaller groups and sharing the results of the individual sessions. Students should sketch their ideas as much as possible, or otherwise record them clearly.

For an effective session there should be both a **leader** and a **scribe** (the mentor or teacher can serve as one or both). The leader's role is to keep the discussion from getting off-track and maintain order in the group. The scribe's job is to record all ideas that are generated. He or she is permitted to stop the session to ask for clarification of an idea (or for a participant to draw a concept) and should compile the notes for future reference.

Students can also generate ideas outside of brainstorming sessions. A skillful designer combines new ideas with existing ones, or combines existing ideas in innovative ways. To stimulate the generation of ideas and to increase the awareness of existing technologies, related mechanical devices (such as toys and small appliances) should be examined by the students. How did other designers solve problems similar to those in model solar car design (wheels, bearings, transmissions, chassis, etc.)? What parts can be used or where can similar parts be found? Reference book such as "The Way Things Work" by David Macaulay or users's manuals for various appliances may be consulted for ideas. Trips to hardware stores, hobby shops, crafts stores, etc. To look at various tools and gadgets are also good ways to get ideas. A good designer sees to it that he or she has a wide variety of ideas to choose from.

Investigate Ideas

Once the ideas have been tossed around, students will be wondering how to choose between all of these concepts. They should be encouraged to formulate questions and experiments that will help to answer them. There is a natural tendency to go for the ideas that one likes best, or has a "gut" feeling for. These concepts may indeed be the ones that work out best, but unless they are tested against other concepts, the designer can never be sure that all ideas were investigated fully and the best design was selected.

There are many ways to investigate ideas, such as research and consulting with "experts", but the most direct and convincing way is to try it out for oneself. This is the essence of hands-on design. Often the design is broken into smaller problems which are investigating individually. In the case of a model solar car, the "smaller problems" are the individual mechanical components (wheels, transmissions, etc.). Some possible investigations are:

- What are good ways to build wheel axles and bearings?
- What is the effect of weight on a vehicle?
- How can a simple transmission be built from low-cost parts?
- What car body shapes have the lowest aerodynamic drag?

The investigations called for here are likely to be simple experiments where students get a feel for the mechanical concept behind their question. A complex investigation may be broken up and assigned to different groups or individuals; their results can later be shared with the entire class. A student investigating materials and methods for building a car chassis, for example, may take simple pieces of each material and watch how they react to various loads or forces. Another example may be to build various transmissions on a simple chassis (not necessarily the one they intend to use in their final car) and compare their relative performance and ease of construction. As part of this process, students should identify design variable, that is, attributes which can be varied to affect performance. Some of those **design variables** are:

- transmission ratio
- wheel diameter
- vehicle shape
- material selection

The goal of these investigations is to gain an understanding of all the individual parts of a vehicle. The groups will probably have a few concepts for each component; they will be narrowed down in the next phase.

Compare Concepts and Select Design

Designers are comparing concepts or doing "trade-offs" of alternative component designs throughout the design process. They weigh the various ideas against the design criteria and see which one(s) comes out best. Much of the time the designer does this in his or her head. However it is often helpful, especially when working with a group or a complex problem, to write down the pros and cons of each idea. Some examples of **pros and cons** for a particular transmission design (a gear drive in this case) are:

Pros		Cons	
+	reliable	-	harder to build and align properly
+	high efficiency	-	harder to find meshing gears
+	won't slip	-	harder to modify ratio

In addition to presenting all relevant information in a single place, the record of ideas also allows the designer to go back later and choose another design if the first one selected does not work out.

Once designs of individual components have been evaluated and one or two leaders identified, students can begin to integrate them into a complete car design. The design for the complete car will be a combination of the students' most workable components. The deciding factor in the choice between two or more workable options for a particular component may be its compatibility with the rest of the car's design. If concepts generated thus far are not sufficient, it may be necessary to refer to brainstorming notes and/or generate more ideas.

Build

Building usually takes more time than you think, especially if the students are not familiar with the materials. The teacher and mentor should ensure that there is adequate time and supervision for build sessions. Thorough prototyping of components will also help final vehicle construction go smoothly. Parts built for experimentation may also be used in the final car design.

Test

A long hallway or track and guide wires are useful for vehicle testing. Since solar power may not always be available for testing the vehicle, alternative power sources will be required. Teachers or mentors may need to help students mount batteries to their vehicles (note that car performance with batteries is unlikely to match that with the solar panel due to the internal resistance of the panel). A ramp may also be set up for “roll down” tests (motor must be disconnected from transmission) to test rolling resistance and aerodynamic drag.

The testing phase is an appropriate time for the class to discuss performance measures. Some **performance measures** for the complete car include:

- time to go 20 meters
- rolling resistance and aerodynamic drag
- total vehicle weight
- acceleration
- top speed

Intermediate contests based on one or more of these attributes may be held to identify leading designs. The winners can be decided on the basis of relative performance of multiple cars.

Optimize

Optimization occurs after the car has been assembled and tested. This is the process of fine-tuning the design for top performance. The winning car in this contest is likely to have **optimized the design variables**, that is, chosen the best ones for the given task. This is not always straightforward. Experienced designers know that this process involved trade-offs, because optimizing one variable may prevent you optimizing another. For example, a frame that is both stiff and light may be desired, but stiffer frames may be heavier. Another classic example is the transmission ratio: a car with high top speed takes a long time to accelerate. Taking the time to optimize the car will often improve the performance dramatically.

Suggested Syllabus

Notes:

This is an eight week syllabus. Teachers and mentors are free to modify the content or schedule as they see fit.

Since we do not know when mentors will be able to attend classroom sessions, we have designed this curriculum with possible mentor roles at every point in the curriculum. This role may be filled when necessary by a teacher of other science resource.

Philosophy:

In this syllabus for Junior Solar Sprint, students are encouraged to attack the overall design problem in a piece wise fashion, that is, to experiment with the various components individually.

Once students have a greater understanding of the working or various parts of the vehicle, assembling these components into a functional car becomes a simpler task. These investigations make up approximately the first half of the course. In the second half, students build, test and optimize the complete vehicle using the knowledge, and possibly some of the prototype components, from the first half of the course.

Week 1: JSS Program Introduction and Basics of Vehicle Design

Mentor Visit:

- Show video and flyer
- Discuss Hands-on design and Design process
  - Relate to professional engineering
  - Relate to work and/or hobbies
- JSS Schedule
  - School Race approx. date
  - Area Race approx. date

Discuss Vehicle Design

- Define Goals and Constraints
  - Kit materials
  - Race rules
  - Vehicle specifications
- Discuss vehicle components
  - Chassis
  - Body
  - Motor
  - Wheels
  - Bearings
  - Transmissions
  - Energy source
- Brainstorm ideas for components/whole vehicle

Teacher Guidance:

- Form teams of 2-4 students
- Continue brainstorming in class

Student Work:

- **Brainstorm overall car concepts and sketch them**
  - How might your model solar car look?
- How do motors make things move?
  - Find examples of machines, toys, vehicles, etc. with mechanical components
- Come up with lists of questions that need answers before selecting a design

Week 2: Wheels, Axles, Bearings, and Chassis: Principles, Prototypes and Experiments

Mentor Visit: **Design Review**

- Teams present car concepts and the questions that need answers before selecting design
- Class discussion of how to answer these questions, what experiments to conduct, performance measures
- Demonstrate/discuss physical principles:
  - Friction: losses in sliding parts
  - Inertia and acceleration
  - Stiffness and strength to weight ratio

Teacher Guidance

- Continue discussion of physical principles
- Lead class experiments
  - Inertia and acceleration
  - Methods of mounting wheels
  - Coasting test for friction and wheel alignment
- Assist students in obtaining building materials and tools
- See that all team members are contributing

Student Work:

- Conduct experiment to answer design questions
  - Build a prototype chassis and mount prototype wheels, axles and bearings
  - **Build something that rolls**
- Come up with additional lists of questions to be answered before a design can be selected
- Continue sketching concepts

Week 3: Motors, Transmissions and Gear Ratios: Principles, Prototypes and Experiments
Mentor Visit:

- Class discussion of experimental results
- Demonstrate/discuss physical principles:
  - Transmission (gear) ratio
  - Motors
  - Torque and Force
  - Calculate distance travels per motor revolution (taking Into account gear ratio and wheel size)
- Continue class discussion of how to answer additional questions, what experiments to conduct, performance measures

Teacher Guidance:

- Continue discussion of physical principles
- Lead class experiments
  - Construct different transmission types and ratios
  - Study the effect of wheel diameter on transmission ratios
- Start planning for School Race

Student Work:

- Continue experiments to answer design questions
  - Experiment with various transmission types
  - Experiment with various wheel diameters
  - Mount motor and transmission on test chassis
  - **Build something that moves under its own power**

Week 4: **Motors, Electricity and Solar Panels: Principles and Experiments**
Aerodynamics: Principles and Experiments

Mentor Visit:

- Class discussion of experimental results
- Discuss physical principles of:
  - Electric Motors
  - Electricity
  - Photovoltaics (Solar panels)
  - Aerodynamics and car body shape
- Continue class discussion of how to answer questions, what experiments to conduct, performance measures

Teacher Guidance:

- Continue discussion of physical principles
- Lead class experiments:
  - Measure solar panel output (voltage, current)
  - Demonstrate motor output (speed-torque relationship)
  - Study effects of voltage/current input on motor output
  - Measure air drag on different body shapes
- See that all team members are contributing

Student Work:

- Continue experiments to answer design questions
- Choose design for:
  - Chassis
  - Body/shell
  - Solar panel mount
  - **Build something that moves under solar power**
- Sketch final car designs to choose from

Week 5: **Select Overall Vehicle Design and Plan/Begin Construction**

Mentor Visit:

- Teams present car design to class and receive comments/suggestions
- Generate design criteria for vehicles:
  - Lightweight
  - Sturdy
  - Good acceleration
  - High top speed
  - Aerodynamic

- Low friction
- Steers straight
- Can accommodate guide wire
- Easy to build
- Aesthetics
- etc.

- Help each group select one design to build
  - List pros and cons
  - Combine best features from various concepts

Teacher Guidance:

- Assist students in selecting designs to build
- Help teams split up building tasks
  - Obtain materials
  - Build car components

Student Work:

- **Review concepts and select one design to be built**
  - Combine features from various designs
- Plan how to build it
  - Discuss building materials and methods
  - Split up building tasks
- Consider aesthetics
- Begin building

Week 6: Construction of Vehicles

Mentor Visit:

- Check progress of cars
- Find out problem areas and give design advice
- Remind teams to make provision for guide wire eyelet
- Review race rules

Teacher Guidance:

- Assist students to building vehicles and using tools
- Review physical principles with students as needed
- See that all team members are contributing

Student Work:

- **Build Vehicle**
  - Wheels
  - Mount wheels and axles on chassis
  - Build transmission and connect to motor

Week 7: Complete Construction of Vehicles and Begin Testing

Mentor Visit:

- Check progress of cars
- Find out problem areas and give design advice
- Check that vehicles are “legal”

- Will the designs work?
  - If a design cannot be successfully built, go back to list of concepts from Brainstorm session and select another

Teacher Guidance:

- Assist students in building vehicles and using tools
- Review physical principles with students as needed
- See that all team members are contributing
- Prepare for School Race

Student Work:

- **Finish building vehicles**
  - Complete chassis
  - Body
  - Solar panel mount
  - Aesthetics

Week 8: Optimize Vehicles

Mentor Visit: **Design Review**

- Teams present vehicles to class and receive comments/suggestions
- Plan optimization experiments
  - Review design criteria for vehicles
  - Discuss performance measures

Teacher Guidance:

- Assist students in building vehicles and using tools
- Set up test track for optimization experiments
- See that all team members are contributing
- Check that vehicles are "legal"
- Prepare for School Race

Student Work:

Test vehicle

- Decide whether or not to use existing design
- Begin optimization experiments
- Rework components as necessary to optimize vehicle
- Complete vehicles, add decorations and decals

Pre-Race

Mentor Visit:

- See that all cars are working
- Assist teacher in making preparations for school race

Teacher Guidance:

- Assist students in building vehicles and using tools
- Set up test track for optimization experiments
- Finalize preparations for School Race

Student Work:

- Complete optimization experiments

- Rework components as necessary to optimize vehicle
- Complete vehicle

Project Tools and Materials

Some of the materials and tools needed for the project are provided in the kits. Others are the responsibility of the schools and/or students. The lists which follow are not required lists; they are suggestions. Feel free to be creative and come up with other ideas.

Items Included in the Kit
Solar Panel
Motor

Items Available on NREL's Home Page: http://www.nrel.gov
Click on Gloabal and Local Partnerships, click on education programs and click on Junior Solar Sprint
"Introduction to Building a Model Solar Car"
Junior Solar Sprint software (WINDOWS and MAC)
Junior Solar Sprint software instructions
"Junior Solar Sprint Classroom Investigations"
"So... You Want to Build a Model Solar Car"
"Junior Solar Sprint Teacher and Mentor Guide"
"Junior Solar Sprint" Order form
"Inside Tips on Parts and Construction"
"Junior Solar Sprint Race Rules and Vehicle Specifications"

Suggested Materials
Cardboard sheet
Cardboard tubes
Shaft material - 1/8 inch rods
Foam core
Styrofoam
Wire hangers
Straws
Washers
Stiff wire
Solder tape (and matches)
Wirenuts
Electrical Wire
Alligator Clips

Suggested Hand Tools
Safety Glasses
Scissors

Wire Cutters
Pliers
Tape -- masking, duct, electrical, fiberglass packing tape
Hot glue
Elmers glue
Rulers
Pencils
Hacksaw
Retractable Utility knife (or Exacto)
File

Safe Use of Hand Tools

Students will be working with hand tools while doing this project, so they should first familiarize themselves with their safe use. Below, we describe some commonly used had tools and some dangerous situations that can result if they are not used properly.

Please be certain to go over this information with students, and enforce our suggested safety rules. Safety glasses are inexpensive, and available at any hardware store, or from your shop teacher. If possible, consult a shop/industrial arts teacher for more safety information, especially if students will be using tools that are not discussed here.

<u>Hot glue gun</u>
Very useful for quickly fastening different materials together with a reasonably strong bond. Hot glue guns can cause **minor burns** if the gun nozzle or hot glue touches skin.

<u>Soldering Iron</u>
Useful for making electrical connections. Soldering irons can cause minor burns if the soldering tip, or hot solder, touches skin.

> **Wear safety glasses to protect against hot solder.**

<u>Electric hand drill</u>
Hand drills are useful for placing holes in materials, and might be used in the fabrication of wheels, for example.

> **Wear safety glasses.** If too much force is applied, drill bits can break, launching fragments into the air. Material removed by the drill bit can also become airborne. Students using hand drills should work a safe distance from students that are not wearing safety glasses.
>
> **Clamp work securely.** A spinning drill bit can grab the work piece and yank it around if it is not properly clamped in place, resulting in hand injuries, especially if the work piece has sharp edges. A small vice or clamp is useful for this purpose.

Note what is underneath the piece being drilled. Be sure that drilling is done into a secure block of scrap wood or into a clear space.

<u>Hacksaw</u>
Hacksaws are useful for cutting a variety of materials.

> **Wear safety glasses.** Removed materials could become airborne.
> **Keep hands away from the cutting zone.** The blade can jump and cause minor hand injuries.
> **Clamp work securely.** This removes any inclination to hold the work piece near the

cutting zone, and allows better control of the tool.

<u>Wire Clippers</u>

These tools are useful for cutting wire and thin shafts. If both sides of the piece are not securely held, they may shoot out.

Wear safety glasses, and:

Hold both sides of the part being cut, or orient the tool so that the section being clipped is aimed at the floor.

<u>Utility or “Exacto” knives</u>

Useful for cutting cardboard, foam core, etc.

Wear safety glasses. It is possible that a blade could break and fly upwards.

Cut away from yourself. (i.e. don’t draw the blade towards your hand or any other part of your body)

Store tools safely. Avoid leaving exposed blades on table surfaces. Use a handle with a retractable blade if possible.

Note what is underneath the material being cut. Cut into scrap material to avoid scratching the surface below.

NREL/BK-820-30828
Revised 8/23/01

Junior Solar Sprint

An Introduction to Building a Model Solar Car

Student Guide for the Junior Solar Sprint Competition

Produced by:
Krisztina Holly and Akhil Madhani

Introduction

Welcome to Junior Solar Sprint! By competing in Junior Solar Sprint, you will learn how to make your own model solar car that will run entirely from the power of the sun.

Design
You will experience first-hand the process of design. When you design your car, you will start with some ideas in your head and turn then into real-life models that work. Design is different than normal problem-solving, because:

- you don't know what the problems are (you discover and solve problems as you go along -- everyone's challenges will be different)
- there is never one right answer

Designers have to deal with tradeoffs. For example, when a car designer uses a larger engine for greater performance, this usually sacrifices fuel efficiency. In a sports car, performance and speed are very important. But in a city car, fuel efficiency is more important. So it is up to the designer to decide which are the most important goals. Even though there is no one right answer, some answers may be better than others for a particular application. Obviously, in Junior Solar Sprint, the faster cars will win.

How to Get Started
You will receive short handouts on a variety of subjects from how to build the wheels to how the solar cells works. These handouts will cover the following topics:

- **chassis:** how to build the frame of the car
- **wheels and bearings:** how to make wheels that turn
- **power source:** how the solar panel and motor work
- **transmission:** how to transfer power from the motor to the wheels
- **body shell:** how the shell effects car performance

In general, when you design, it is good to keep the different parts in mind, but don't worry about the details of each component until you are ready for them. Each handout will be composed of 4 parts:

- purpose
- ideas
- concept
- suggested materials

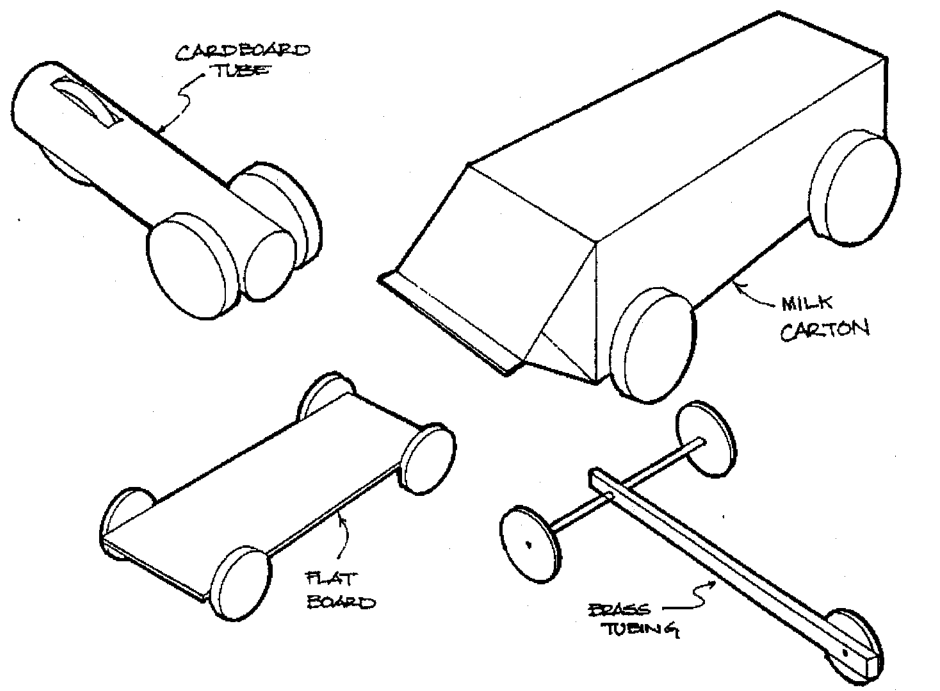
The concept section will raise issues that will help you decide how to make the right decisions and build the winning car.

Experiment as much as possible early on and don’t worry about making mistakes. It is always the case with design that you don’t know what the problems are until you encounter them. So get your hands dirty and get started! Good luck and have fun.

Chassis

Purpose
The car's chassis is its frame. It holds all of its main parts together.

Ideas
Some possible ideas for a solar car chassis are below. Try different ideas! Try different materials!



Concepts: Weight and Stiffness
One thing you will discover when you build your solar car is that designing and building involves tradeoffs. There is no ideal design. This is true with the chassis of your car.

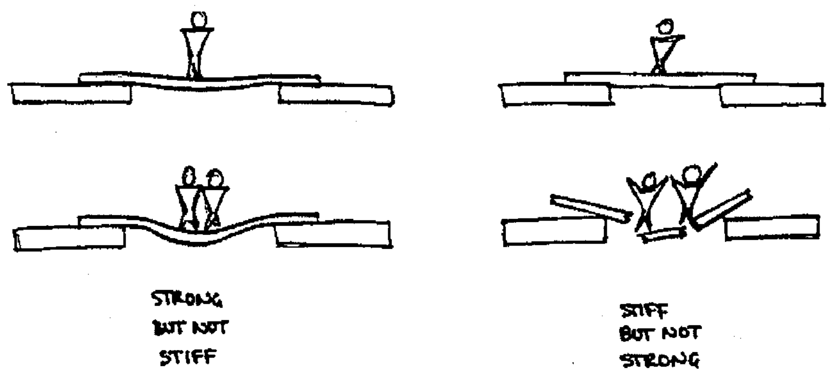
One obvious consideration is that you don't want your car too heavy. It is easier for your motor to push a light car than a big, heavy one. In solar cars, efficiency is very important, and you don't want to waste energy.

But something you must also keep in mind is that a light car can be pushed easily by the wind too. Even if the wind does not blow the car over, it may make it harder to go in a straight line. (This depends not only on the weight, but on where the weight aerodynamics in a later section.)

Materials

In most cases it is more difficult to make the car light enough (you can always add a little ballast anyway) so in this section we will emphasize lightweight materials and construction. The first step to a lightweight chassis is choosing the right materials. Balsa wood, for example, is a commonly chosen material because it is lightweight. But more importantly, is fairly stiff for its weight.

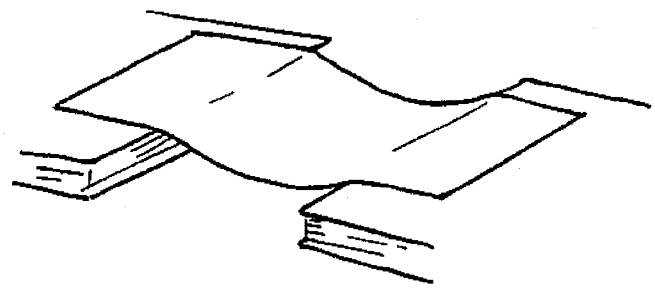
What is the difference between strong and stiff? Strong means it will not break easily. Stiff means it will not bend easily.



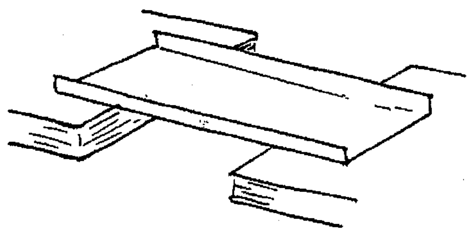
For the solar car, stiffness is very important. Stiff, light materials include Styrofoam, foam core, balsa wood, corrugated cardboard, and some plastics.

Shape

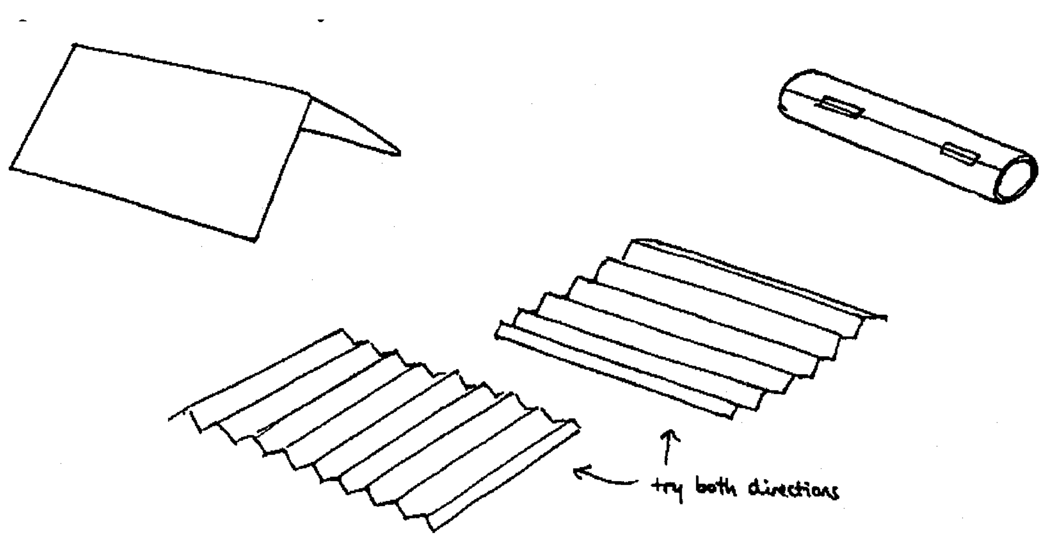
Some heavier materials are also appropriate if they are constructed correctly. Let's try an experiment. Place two books side by side and out 6 inches apart. Now place a piece of paper across the two books. What happens?



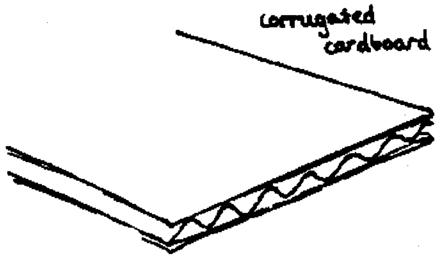
The paper is not stiff, so it bends in the middle. Now, fold the same piece of paper in thirds, lake a “u” (see drawing) and put it back across the books. Now what happens?

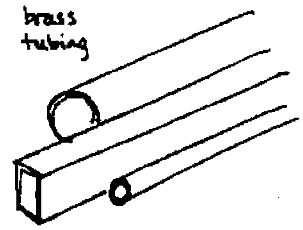


The paper is not any heavier, but it is much stiffer now because of its shape. Try other shapes and see how stiff they are:

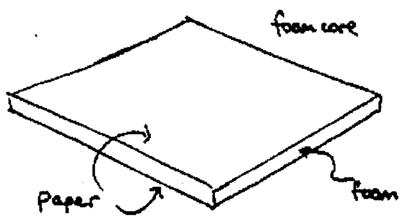


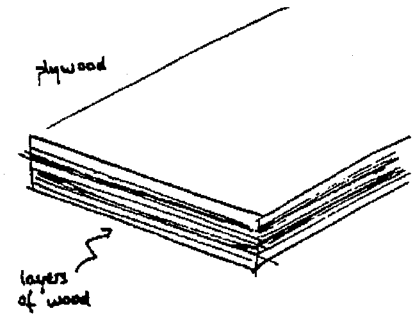
And in this way engineers can stiffen flexible material -- or use less of a heavier material -- with just a change of shape! Look at a cardboard box. Why is the inside “corrugated”?





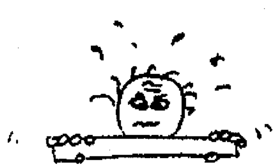
Other materials are made stiffer or stronger by sandwiching them between other materials.





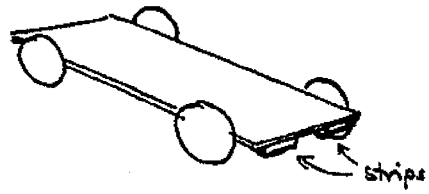
Orientation

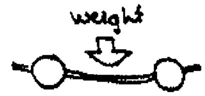
As you saw with the folded pieces of paper, orientation is also very important in determining stiffness. Take an ordinary wood or plastic ruler. Try to bend it both directions.



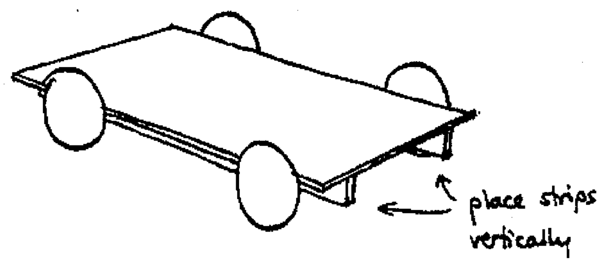
It is easier to bend it the thin way, of course.

Imagine you wish to stiffen your chassis by adding ribs. You glue two strips of materials to the bottom of the chassis like this:





Unfortunately, that didn't seem to do the trick -- the chassis still sags. Your partner insists that adding more strips of material will help, but you know that this is not necessary. You have a better idea! What is your idea?



Well, if you turn the strips sideways (remember which way the ruler was stiffer), your chassis will be much stiffer ... without adding material!

So, as you can see, if you are smart about your material selection -- and you remember the importance of shape and orientation of the materials -- you will have much more control over the weight of your solar car.

Materials

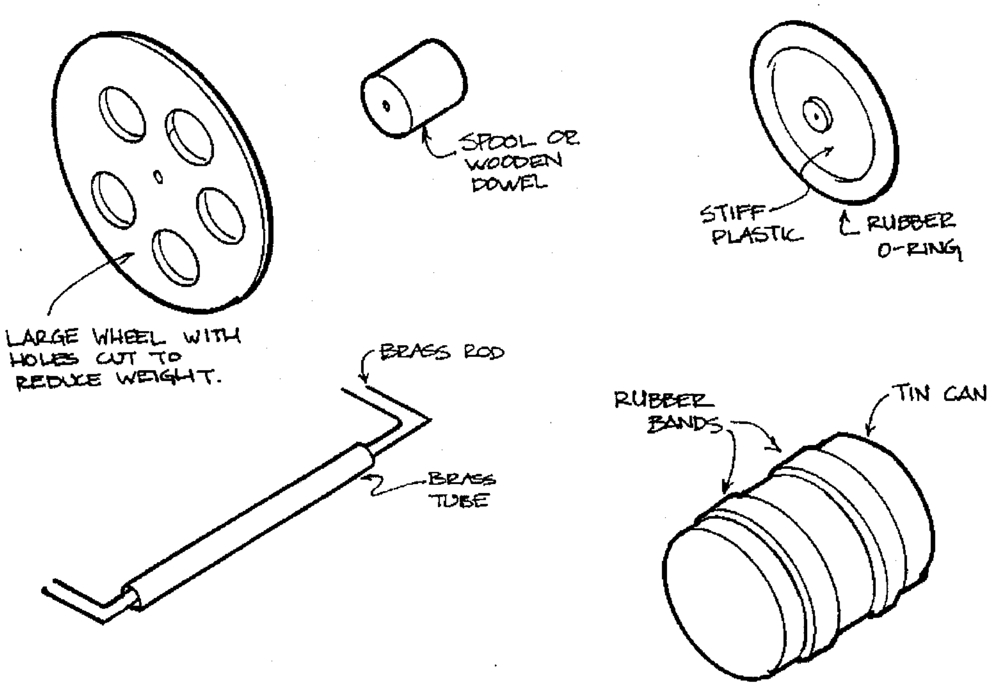
Any material that is light and stiff would be appropriate. Some hollow and tube like pieces are very stiff for their weight. Arts and crafts stores and hobby stores are good sources. Some stores have scrap materials like cardboard. Or, look around your house for scraps. Some materials we found that are useful are:

- stiff insulating foam (large hardware store or home improvement center)
- foam core (like the back of your solar panel -- try arts and crafts stores)
- balsa wood (a&c or hobby stores)
- brass tubing (a&c or hobby)
- cardboard tube (scrap from a&c store)
- shoe box
- soda bottle
- rigid plastic
- corrugated cardboard (scrap from boxes)

Wheels and Bearings

Purpose
Wheels support the chassis and allow the car to roll forward. Bearings support the wheel while allowing them to rotate.

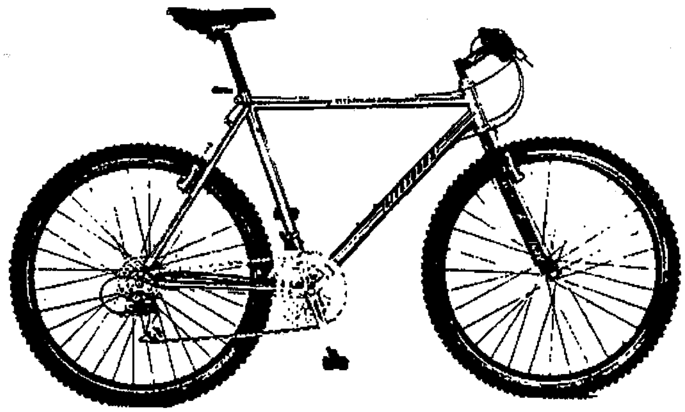
Ideas
Wheels can be large, small, narrow, wide...here are some ideas to start you thinking:



Concept: Friction
Friction keeps things from sliding against each other. When you build your cars, there are some parts that you want to slide easily, and there are other parts you don’t want to slide at all.

Tire Traction
When you have two things that must roll against each other, like a wheel rolling along the road, friction keeps them from slipping. This type of friction is also called “traction,” and is important to remember when building your wheels.

Why do mountain bikes have big, fat knobby tires? If you have to bike up a muddy hill covered with leaves, your tires will slip if they don’t have enough traction. And the big knobs of rubber can grip onto the dirt and rocks and keep the tires from slipping on the ground.

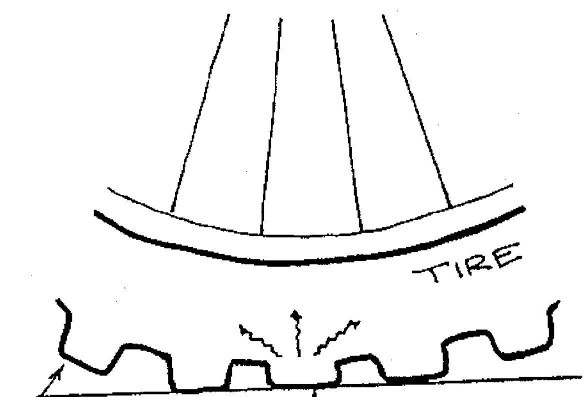


MOUNTAIN BIKE

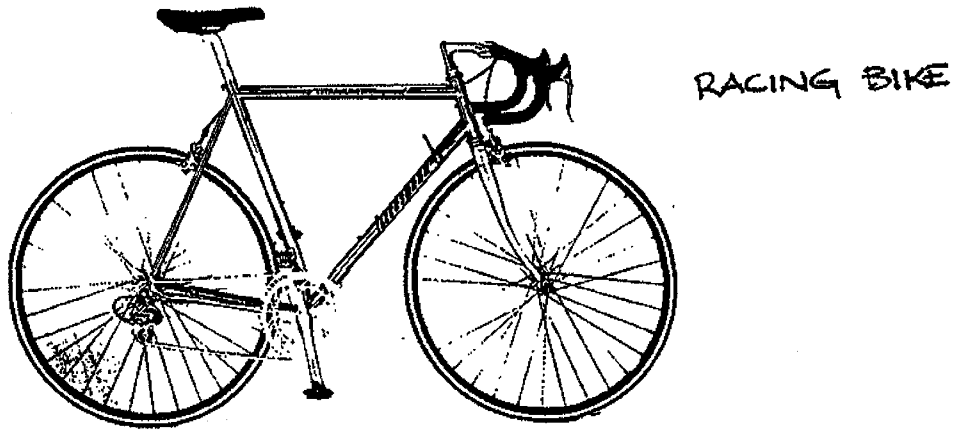
(Another reason for the thick tires, too, is because they are more rugged and can take the abuse from the trail!)

Now, the question is, why don't racing bicycles have fat, knobby tires if these wheels have good traction? Once again, there is a tradeoff in designing a wheel.

Mountain bike tires have two main disadvantages. The first disadvantage is the thick, knobby rubber which gives them such great traction also makes them inefficient. Every time a rubber "knob" is compressed and bent by the road, energy is lost. Where does this energy go? If you have ever felt an automobile tire after it has been on the road, you probably noticed that it was hot. The energy it took to compress the rubber and air in the tire was lost as heat.



The other main disadvantage of mountain bike tires is their weight. Weight in tires is actually more difficult to move than weight in the chassis. Weight in the chassis has to be moved forward, but the weight in the wheels has to be moved forward and around in a circle. The heavier the wheel, the more energy it takes to get the wheel turning. Surprisingly, the bigger the wheel diameter (even if it is the same weight), the more energy it takes to get the wheel turning.

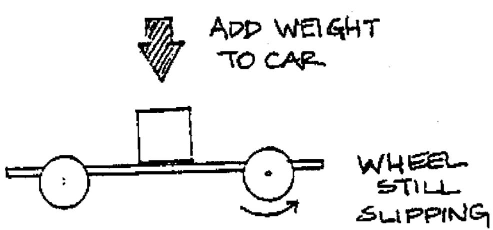


So, racing bicycles do not have mountain bike tires, because traction is not as important. But what is important is efficiency, so that the bicyclist does not need to expend a lot of energy. The bicycle designers have made a conscious decision to use different tires designed for efficiency and not traction.

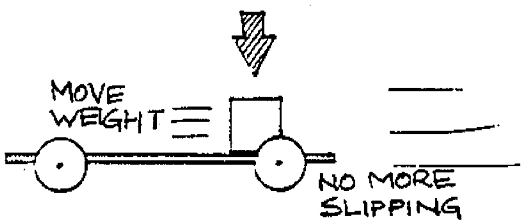
Weight Distribution and Traction

Imagine your rear-wheel-drive solar car has trouble -- its back wheels are slipping. Your partner suggests adding some rubber bands around the wheels to increase traction, and you agree.

The rear wheel still slips some. Your other partner wants to add some weight to the car, like this:

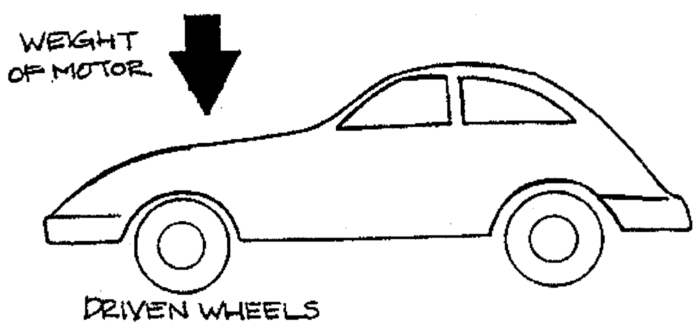


But it doesn't work. You tell him you have a better idea. You move the existing weight, and now it works! Why?



Remember that all of the force is transmitted through the driven wheels, so the moved weight increased the traction where it was needed. Weight distribution is very important, since you can increase traction just by moving existing weight from one part of the car to the other.

Have you ever heard that front wheel drive cars are better in snow and ice than rear wheel drive vehicles? Front wheel drive cars aren't heavier. But the engine is very heavy and is located above the front wheel. This helps traction in front wheel drive cars because the weight is right above the driven wheels.

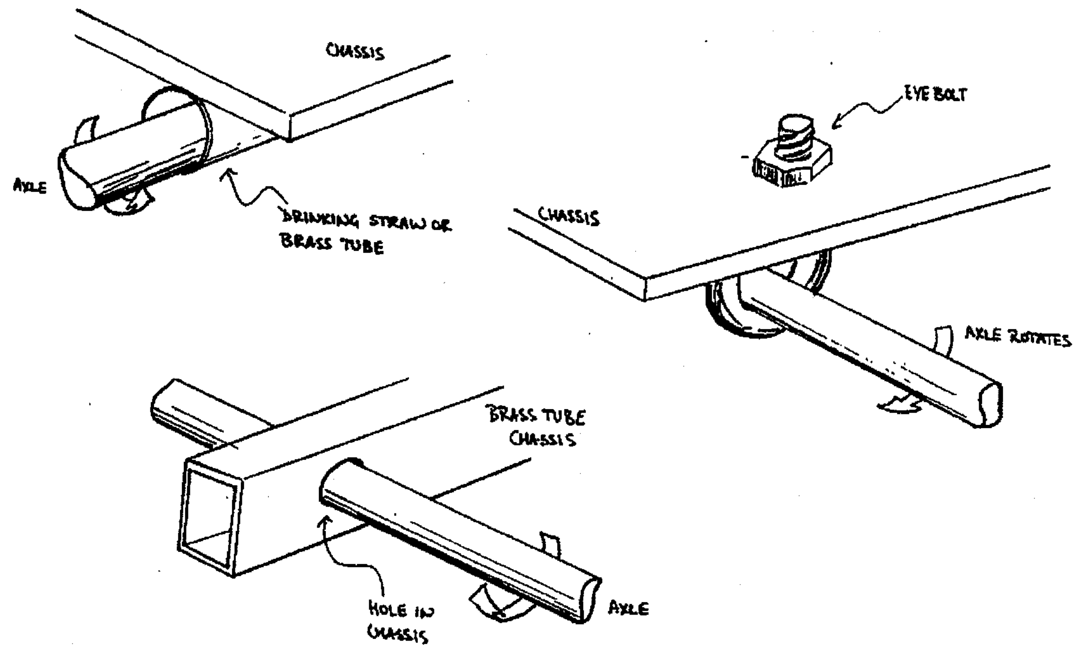


So, in summary, traction is important for transmitting the forces from the wheels to the road. If any of your wheels are spinning rather than rolling, you probably need more traction. Traction can be increased by adding a non-slip material around the wheels (like a tire) or by moving weight over the driven wheels. But, remember, it is also important to have efficient wheels, which are usually thin and lightweight.

Bearings

When you have two things rubbing against each other and you want them to move freely, friction slows things down and wastes energy. For example, try sliding a coin and an eraser across the table. The reason the coin slides much more easily is there is less friction between the coin and the table than there is between the eraser and the table.

One case where friction is very undesirable is in the wheel axle. The axle must be supported and attached to the chassis, but still must be able to turn. Components which all the relative motion of two parts are called bearings. Some ideas bearings are sketched on the next page:



Look at a bicycle or a Roller Blade. Hold it above the ground and spin one of the wheels. Between each wheel and its center axle is a type of bearing called a “ball bearing.” The bearing holds the wheel on the axle, but reduces the friction between them, so the wheel can spin for a long time without slowing down.

Lubrication

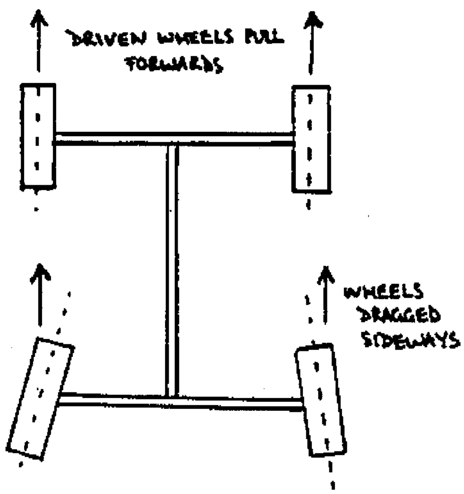
Lubrication helps parts slide against each other, so it is used in bearings to reduce friction.

Let’s try a small experiment. Rub your hands together very lightly and quickly. Your hands should feel warm. Where is the heat coming from? There is friction between your hands, and some of the energy you expend rubbing is turned into heat. If you put a lot of hand lotion or cream between your hands and rub, your hands slide more easily and should not get as warm. That is because the lotion acts as a lubricant.

Different lubricants work better with different materials. In the case of machines, one generally uses oil or grease to help the parts slide together easily. On a water slide, the water acts as a lubricant. If you bake cookies, a little oil or butter on the cookie sheet keeps the cookies from sticking.

Some appropriate lubricants for the solar car bearings may be light oil, light grease, or graphite powder (crushed pencil lead). Try various lubricants and see which ones work best in your car.

Wheel Alignment
Another problem that wastes energy is poor wheel alignment. When the wheels on your vehicle are not lined up properly, some of the wheels must slide sideways. One way this might happen is sketched below.



When the driven wheels try to pull the car one way, but the rest of the car wants to roll the other way, the traction in the wheels (normally a good thing) wastes quite a bit of energy.

Also, make sure that the axle goes through the center of the wheel. One suggestion is to use a compass, rather than tracing a circle, it you cut a circle out of a material. The compass will show you where the center of the circle is.

Taking time to align the wheels carefully the first time will make a huge difference in how well your car runs.

Materials
For wheels: Look around for anything round, or things which can be cut into circular shapes...look at home, arts and crafts stores, and hardware stores. Hobby stores sell model wheels, but they are more expensive and are not designed for building a solar car. They may be much too heavy. Some materials we found were:

- thin plywood
- foam core
- Styrofoam
- toy/model wheels
- tape spool
- brass tube
- wood dowels
- balsa wood
- stiff plastic sheet
- cardboard tubes
- tin can
- thread spool
- plastic pipe

For traction: Things that are rough or rubber-like usually add traction. A few things we found were:

- rubber o-rings (hardware store)
- rubber bands
- rubber sheet
- cloth tape
- silicone or other caulking (hardware store)

For axle: The axle must be stiff, narrow and round. Some ideas:

- nails
- brass rod
- brass tubing
- coat-hanger wire

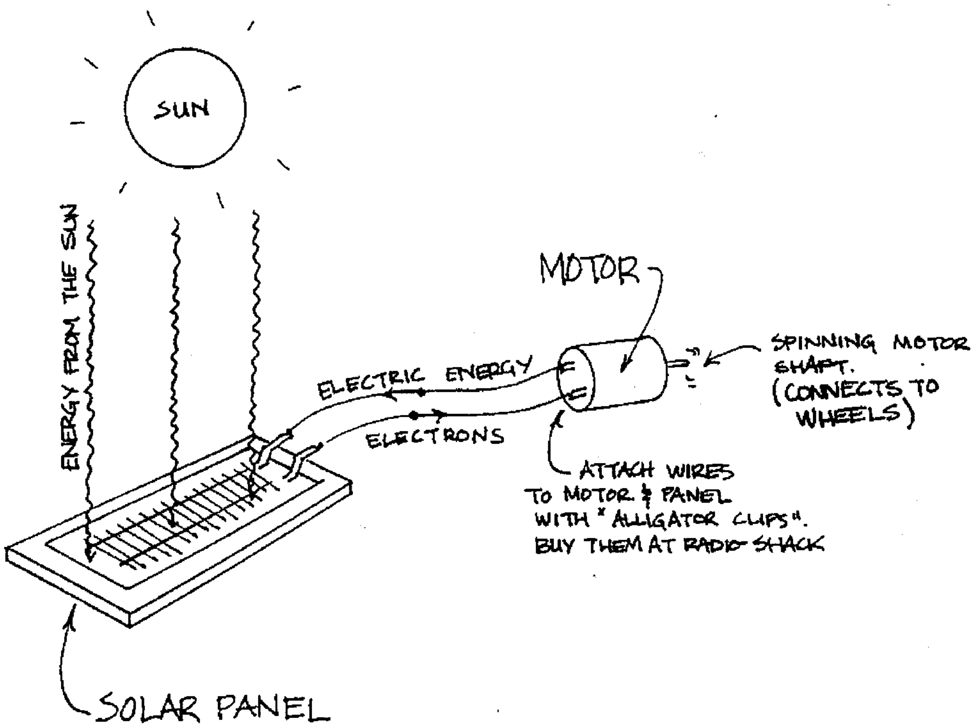
For bearing: Some ideas of things that would support the axle:

- Screw eyes/eyebolts (hardware store)
- brass tubing
- hard material (wood, aluminum, etc.) with a hole drilled into it
- brackets with screw holes pre-drilled
- holes drilled directly into the chassis

Power Source: The Solar Panel and Electric Motor

Purpose

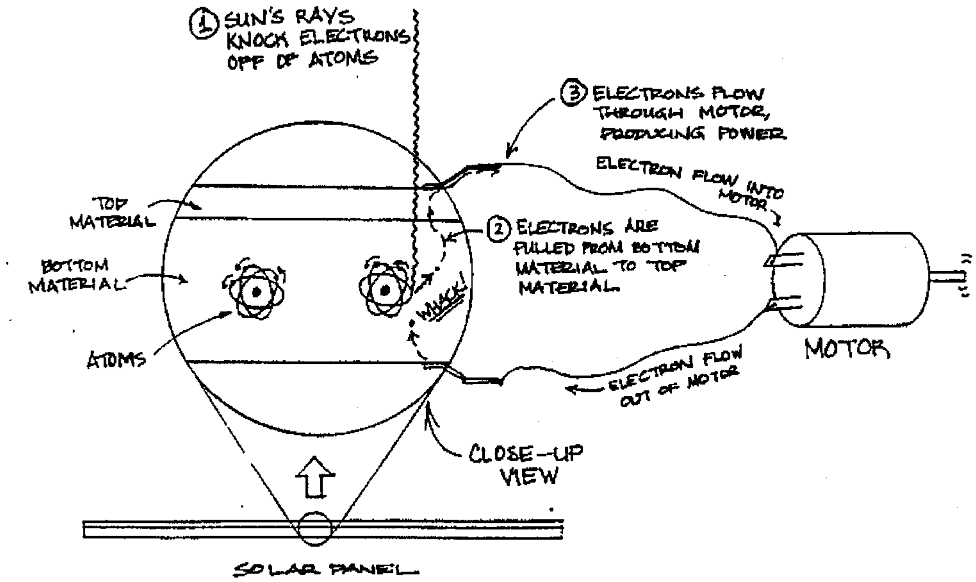
The purpose of the solar panel is to capture energy from the sun and to turn this energy into electrical energy. The electric motor then uses this electrical energy to power the wheel of the solar car.



Concept: Solar Power

How the Solar Panel Works
When you look at the picture above, you might ask, "How does the solar panel turn the sun's energy into electric energy?"

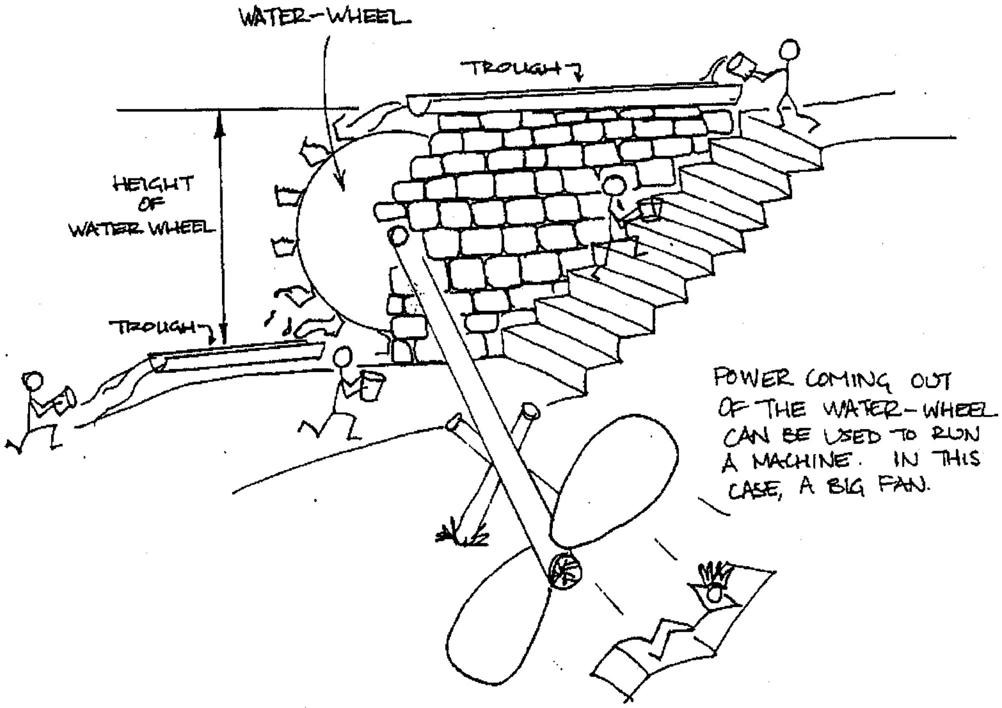
The solar panel is made of a sandwich of two materials called *semiconductors.* Each material is made of millions of atoms. As you might already know, atoms have a positively charged *nucleus*, and negatively charged *electrons, which* spin around the nucleus. When these two materials are put together in a sandwich, an interesting thing happens: electrons become pulled from the bottom half of the sandwich to the top half. But there's a problem. The electrons are all attached to atoms, and the atoms won't let go very easily. This is where the sun's energy helps out. If we shine sunlight on these materials, the sunlight has enough energy to knock the electrons off of the atoms. The electrons will then be free to be pulled to the top of the sandwich.



Now if we connect wires to a motor, electrons will flow through the wire into the motor (making it spin) and back through another wire to the solar panel where they can fill the "holes" left in the atoms who lost their electrons.

Power

How does such a solar panel create power? To understand power more clearly, let's look at a mechanical example to illustrate the main ideas. For example, imagine a water wheel, like the one on the next page:



This doesn't look very much like a solar panel and motor, but we'll see that in many ways they're actually quite alike. In this example, people have to climb stairs to carry buckets of water up a hill, and then pour the water into a trough. The water flows down over a water-wheel, which has buckets attached to it that catch the water. The weight of the water in the buckets is what makes the wheel spin. Now, we can use the power of the spinning wheel to run a machine, like the big fan in the picture.

For the water-wheel, the *power* coming out depends on two things:

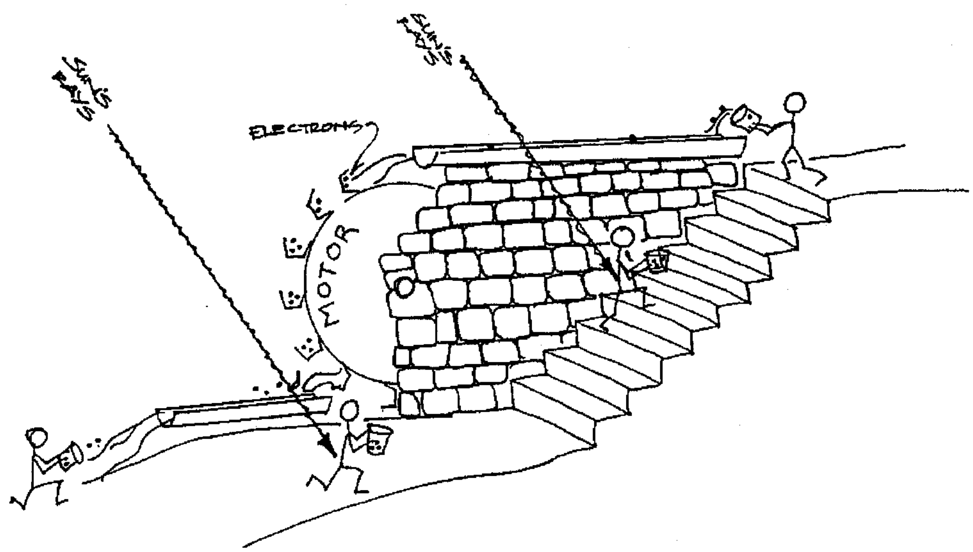
1) How *high* the water falls, and
2) How *much* water (how many buckets) is poured over the wheel.

In fact, the power you get is:

Power = Height x Amount of water

The larger the height of the wheel, the more power we get, and the more buckets of water we pour over the wheel, the more power we get.

Now let's think about the solar panel and the motor. Imagine that the electrons are buckets of water, the wires are like the troughs, and the electric motor is the water wheel. In the solar panel, the sun's energy is used to carry the electrons up an electric "hill" inside the solar panel, then they are poured down through the motor. So, if we drew the picture again for the solar panel, it would look like this:



In the solar panel, a very similar equation for power is true as for the water wheel. But instead of height, we have what is called *voltage*, and instead of buckets of water, we have *electric current* (or the number of electrons flowing through the motor).

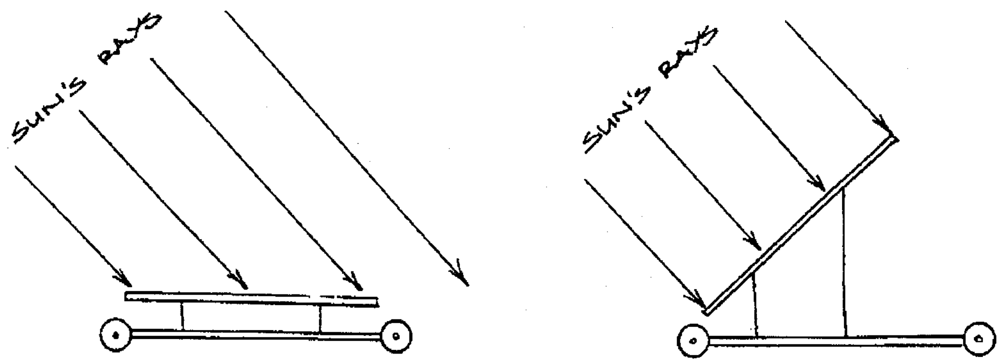
The *power* coming out of the solar panel is the product of the voltage and the number of electrons flowing (the current):

$$\text{Power} = \text{Voltage} \times \text{Current}$$

Maximizing Power

How can we build the solar car so it gives us the most power from the solar panel? One way is to try to get the solar panel to produce more current. To produce current, more electrons need to be forced to move inside the panel. If more sunlight hits the solar panel, more electrons are knocked away from atoms in the solar panel and more current is then produced!

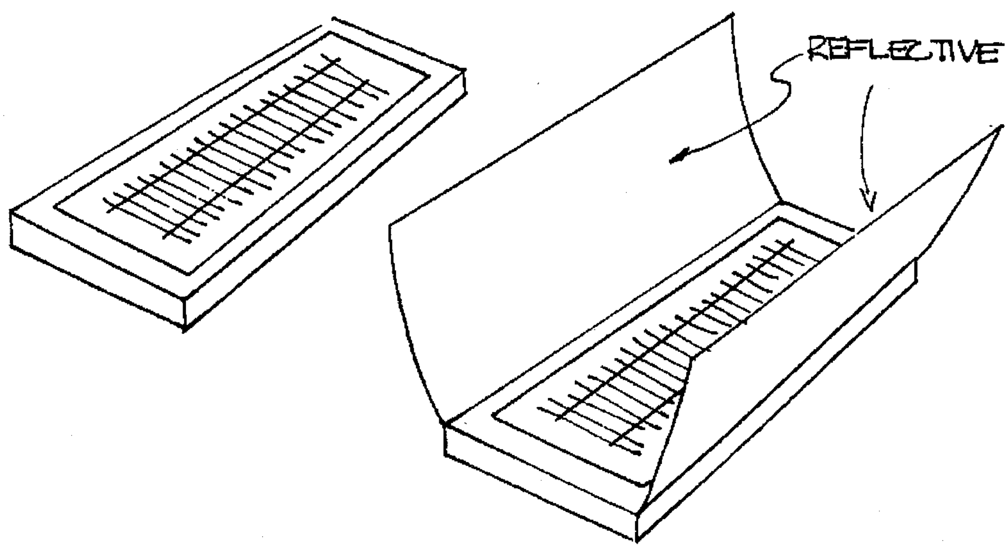
How can we do this? One way is to tilt the solar panel towards the sun. The more of the sun's rays hit the panel, the more current will flow and the more power will be produced. Think of the following two cars:

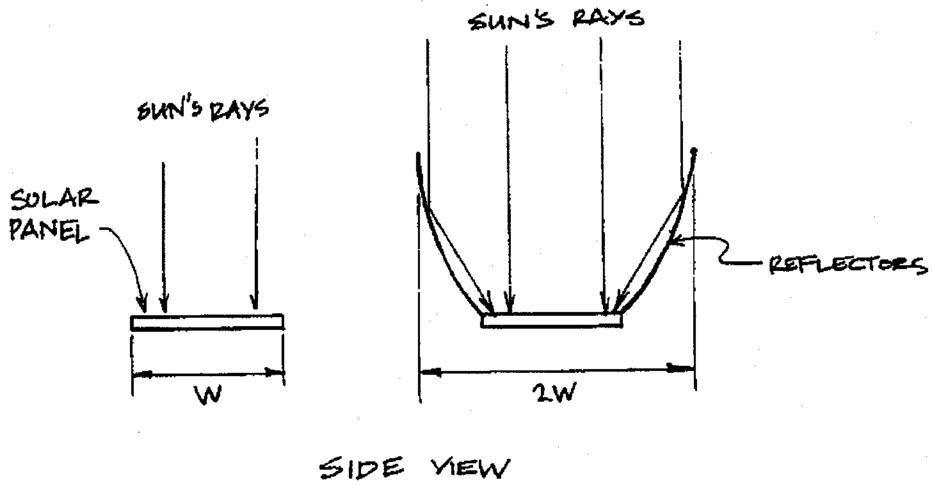


Which one would have more power? In this case, car B would, because it has more sunlight hitting it than A does:

Of course, the best way to tell if this will affect your car is to try it with the solar panel mounted at different angles -- experiments are the best way to find out.

Another idea that you might want to experiment with is using a reflector to capture more sunlight with the solar panel.





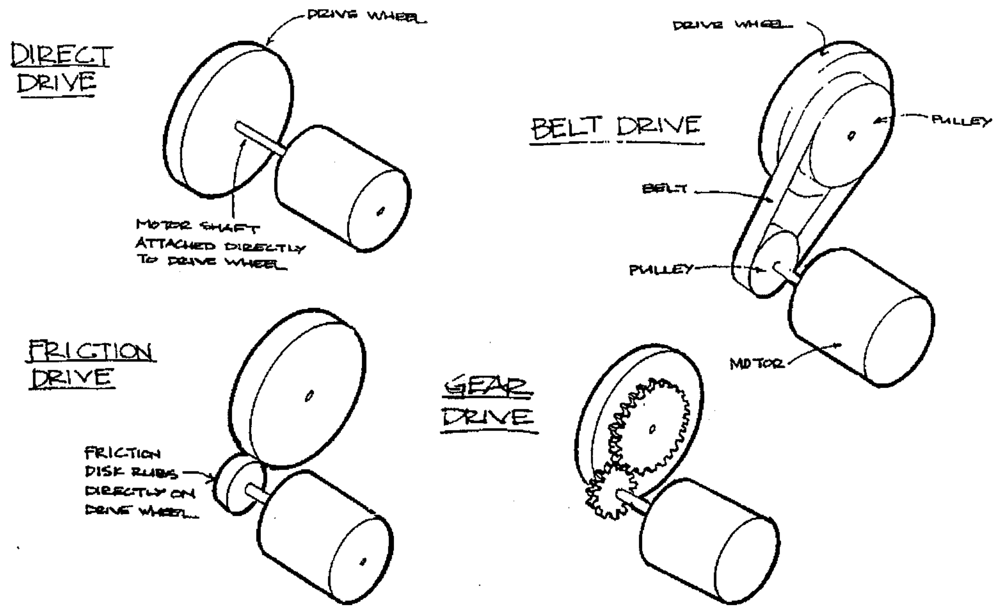
On the right, a reflector that is twice as wide as the solar panel could be made to direct twice as much sunlight to it. This would double the current coming out of the solar panel and double its power!

The disadvantage is that the car would be heavier with a reflector, and a heavier car will be harder to move. Also the reflectors might add air drag or get caught in side winds causing the car to top over. But, as usual, the only real way to find out is to build one and see!

Transmission

Purpose
A car's transmission transfers the power from the motor to the wheels. While doing so, it may make the wheels spin at a different speed than the motor.

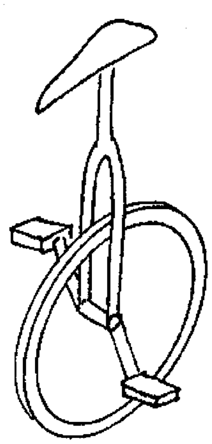
Ideas
There are different ways to transfer power from the motor to the wheels. Some popular techniques are direct drive, friction drive, belt drive, chain drive, and gears.



Some transmissions are easier to build then others, and not all are appropriate for a solar car.

Concept: Speed vs. Force

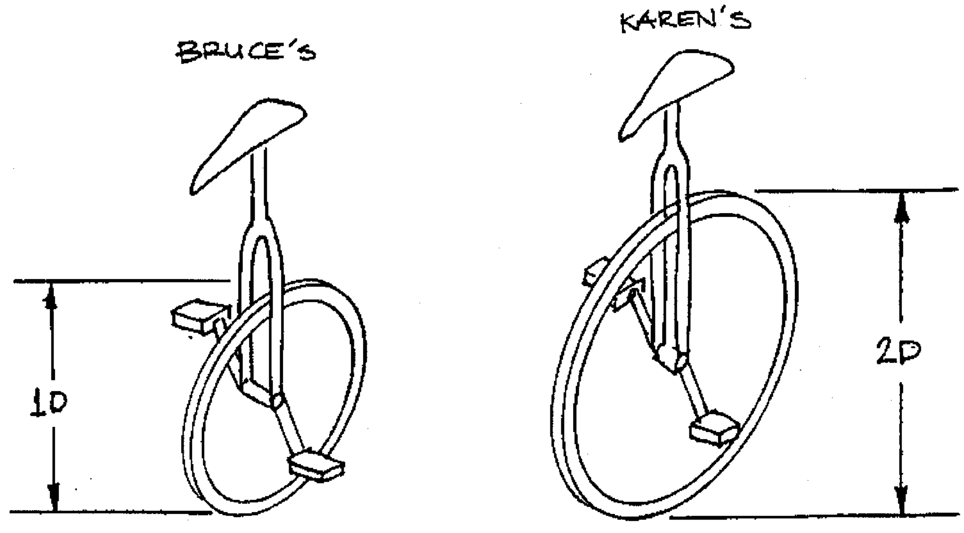
The most simple type of transmission is direct drive, which means the motor is connected directly to the axle of the driven wheel. Direct drives are not common in vehicles; one of the few vehicles that uses direct drive is a unicycle. Every time your feet make one revolution, the front wheel makes one revolution.



UNICYCLE

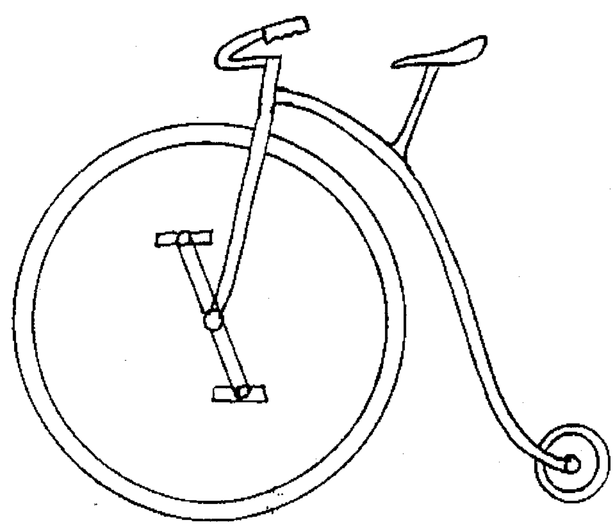
Speed

Imagine two of your neighbors have a unicycle race. Bruce's unicycle has a regular wheel, and Karen's has a very large wheel. If they both pedal the same rate, which one of them will win?



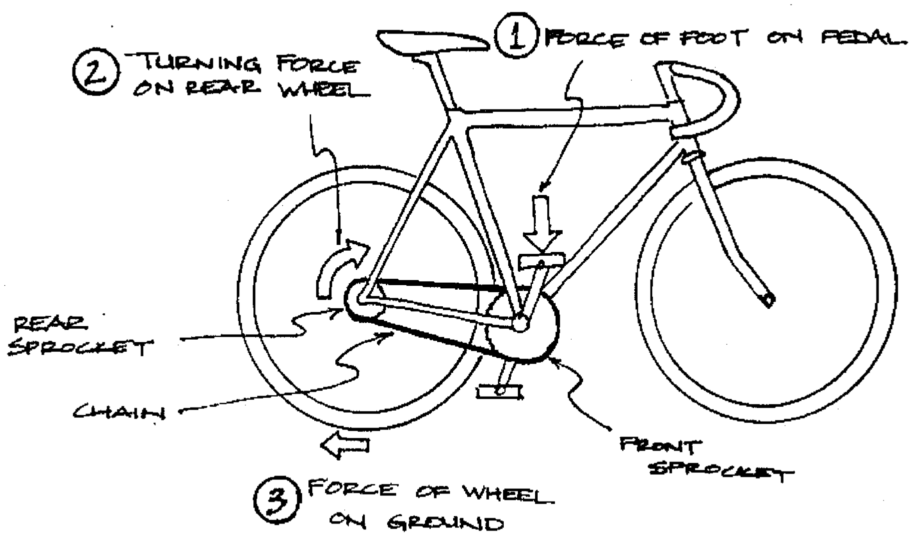
In both cases, each revolution of the pedal means one revolution of the wheel. BUT, one revolution of Karen's wheel will roll twice as far as Bruce's. So Karen would win if they pedaled at the same rate. If Bruce wanted to win, he would have to pedal twice as fast as Karen.

Have you ever seen pictures of very old bicycles that have huge front wheels? These bicycles allowed the rider to go faster without pedaling like a maniac!

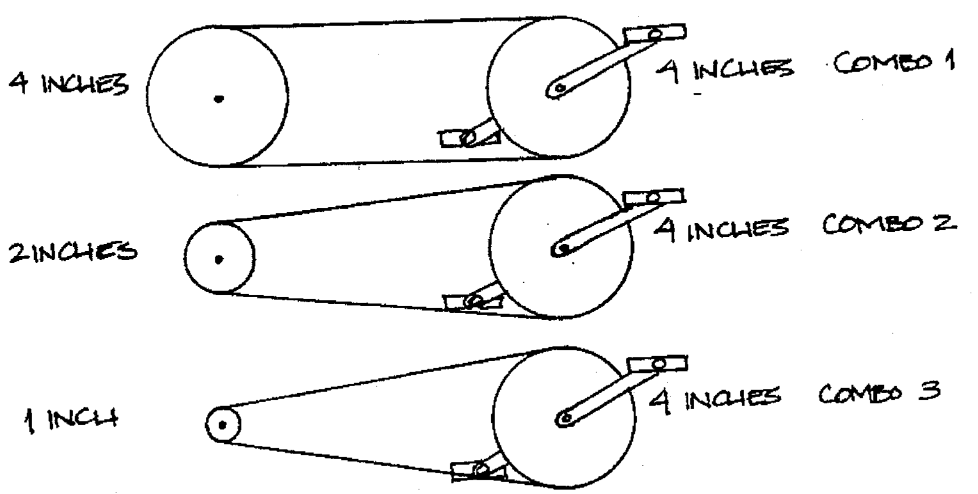


OLD BICYCLE

As mentioned before, most vehicles are not direct drive, so let's look at another type of vehicle: a 3-speed bicycle. A bicycle uses a chain drive. It allows you to move the pedals, and the chain transfers the energy from the pedals to the rear wheel.



The chain glides over different sized sprockets, depending on the speed of the rider. Which sprocket combination will make the rider go the fastest, given the same pedaling rate, or cadence? (Hint: how many times will the back sprocket (and therefore the back wheel) turn with each rotation of the front sprocket?)



Each rotation of the front sprocket will make the back wheel rotate once in combo 1, twice in combo 2, and four times in combo 3. So, combination 3 will go the fastest. (these sprocket combinations can also be called *gear ratios*, because the new speed is calculated as the ratio of the driven (front) sprocket over the back sprocket.)

So how does this affect the way a biker would use the bicycle? Well, when she starts out, she starts in first gear (combo 1). As she pedals faster, the bike starts going faster. After a while, her legs are moving very fast, so she switched to second gear (combo 2). Now her legs only go half as fast as a second ago, but the bike is still going fast. She can increase her cadence again and make the bike go even faster. Once her cadence is very high again, she can shift up to third gear (combo 3).

If she was going 5 miles per hour in first gear, how fast is she going in third gear with the same pedaling rate?

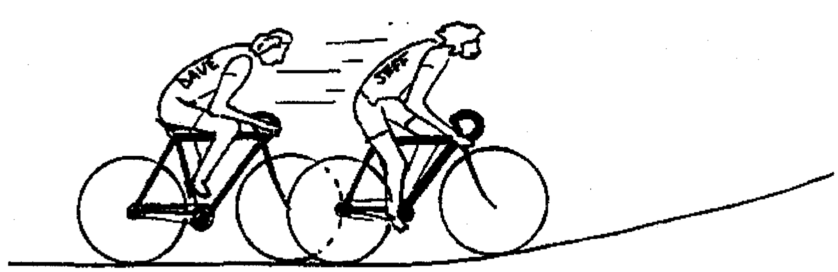
Well, the jump from first to second gear doubles the speed, and the step from second to third gear doubles it again. So, she is going four times as fast as in first gear. She is now going 20 miles per hour, but her legs are going the same rate as at the very beginning.

The term "3-speed" bike is not entirely correct, because a biker can go more than just three different speeds. As we saw in the previous example, our biker was able to continuously speed up from 5 mph to 20 mph. But the name comes from the fact that given one cadence, the three gear ratios will give you three different speeds. Of course, your legs can pedal at many different rates, but "3-speed" bike sounds better than "3-gear ratio" bike.

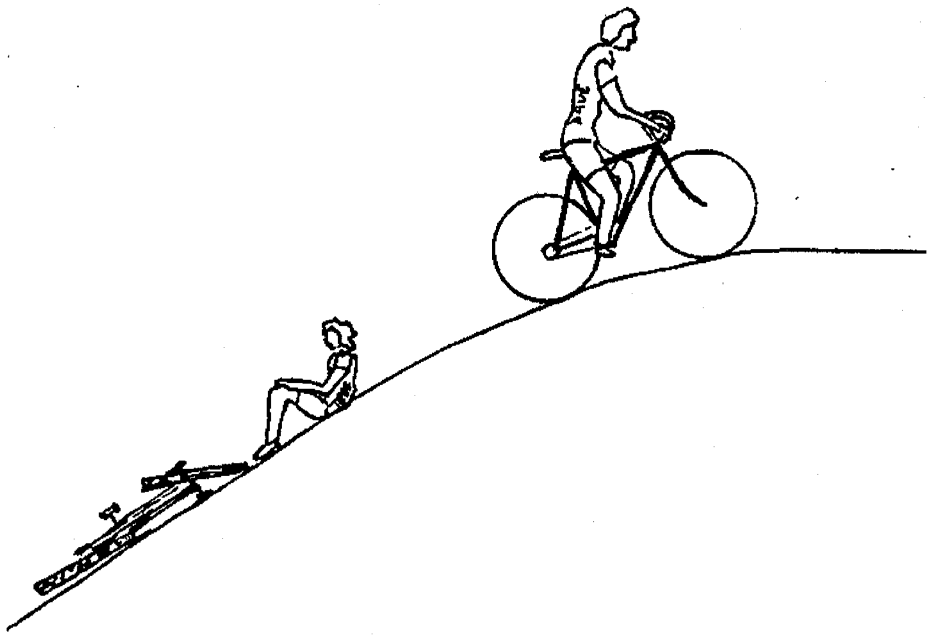
Force

You may ask, then, why isn't it the best to go for the highest speed possible? Well, you can't get something for nothing! So what are you giving up when you gain speed? Let's investigate...

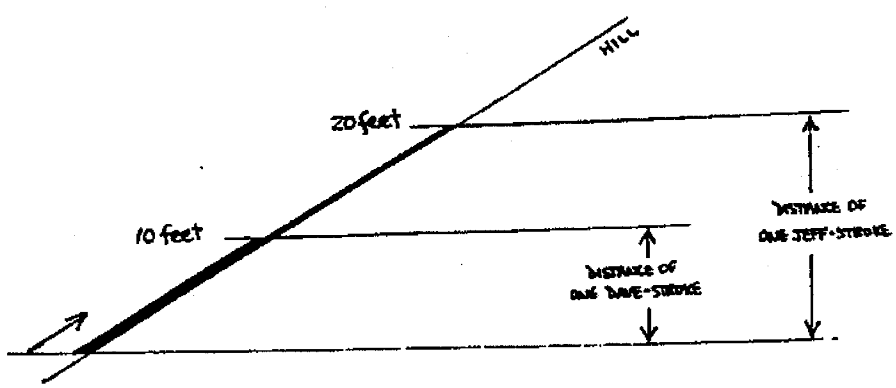
Imagine two bikers approaching a very steep hill. Jeff and Dave are both in third gear, because they are going very fast. Dave downshifts into second. But Jeff decides to stay in third gear, because he knows that third gear is for going fast, and he wants to go up this hill very fast.



Dave is going half the speed now, because he just downshifted. Jeff smirks as he blows by Dave. But Jeff hits the hill, and he suddenly realizes that his legs can't go very fast anymore -- it becomes very hard to pedal! He gets slower and slower, and finally stops pedaling because it's too hard. Dave passes, slowly but surely, and makes it to the top of the hill. Jeff now owes him a new pair of bicycling gloves!



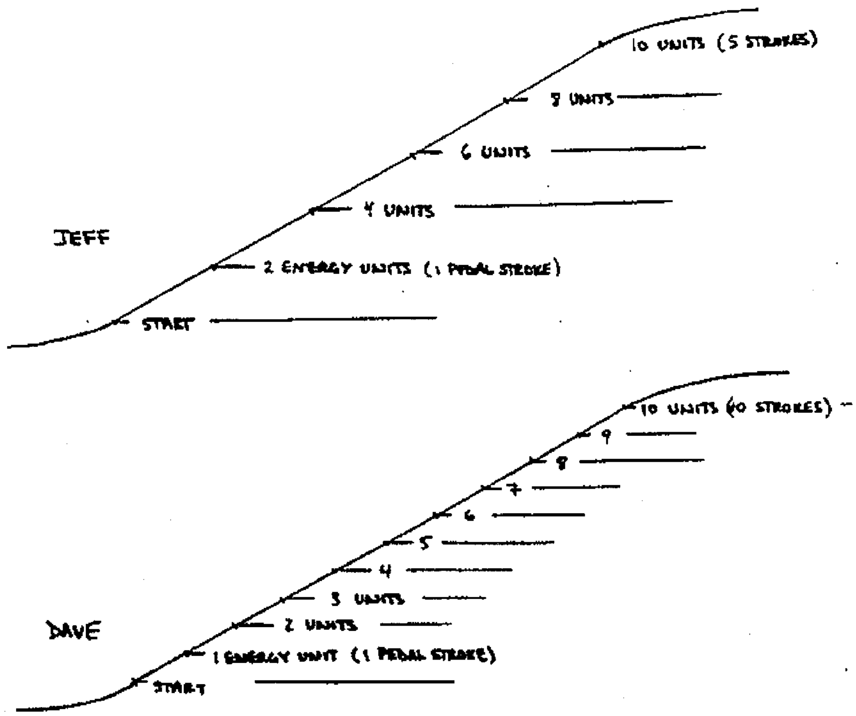
What happened? If only Jeff could've kept pedaling at the same rate, he would've beat Dave by a mile! Let's look at each pedal stroke. Each time Dave and Jeff pedal once, Dave's back wheel goes around once (let's say it travels 10 feet), but Jeff's back wheel goes around twice (20 feet).



Dave realizes that he only has to expend half the energy per pedal revolution than Jeff does, because Jeff goes twice as far each time. That is why Jeff started getting very tired, because his pedals were difficult to push. In other words, his pedals required more force than Dave's did.

So does Dave expend less energy going up the same hill?

Dave expends half the energy per pedal revolution, but this is only because he goes half the distance per pedal revolution. Dave has to pedal twice as many times to get up the hill. So, the energy expended both Dave and Jeff going up the entire hill is the SAME in either case.



So, the bottom line is, when we gain a speed advantage, we are losing the force advantage. The pedals are more difficult to turn. You can gain either speed or force advantage, but not at the same time.

Selecting the Proper Gear Ratio

So, how can you choose the best gear ratio? Experimentation is probably the easiest way to find out.

The idea is that your motor, like your legs when you ride a bike, like to go a certain speed. They also have a limit as to how much force they can exert. First you must find the speed at which the motor gives the most power (this is usually half the speed the motor will rotate if there is no load, or force, exerted on the motor shaft). Try to keep the motor turning at approximately that speed as you experiment with different gear ratios.

It helps if you build your car in such a way that you can change the gear ratios easily as you experiment. Remember, the ideal gear ratio may change some if you change different characteristics of your car (size, weight, etc.). Just remember, if your car is not going very fast it can either be that the wheel speed is too slow, or (like Jeff riding uphill) the force required to turn the wheel is too high. Try a different gear ratio!

Materials
The materials you choose vary greatly depending on the type of transmission you build. If you decide to build a belt drive, try stiff, rubbery materials for the belt - such as a slice of inner tube or an o-ring. Make sure your pulleys are pulled away from each other so that the belt is tight. One suggestion: one way to change the gear ratio on a pulley drive is to add or remove masking tape around the pulley, which changes its diameter.

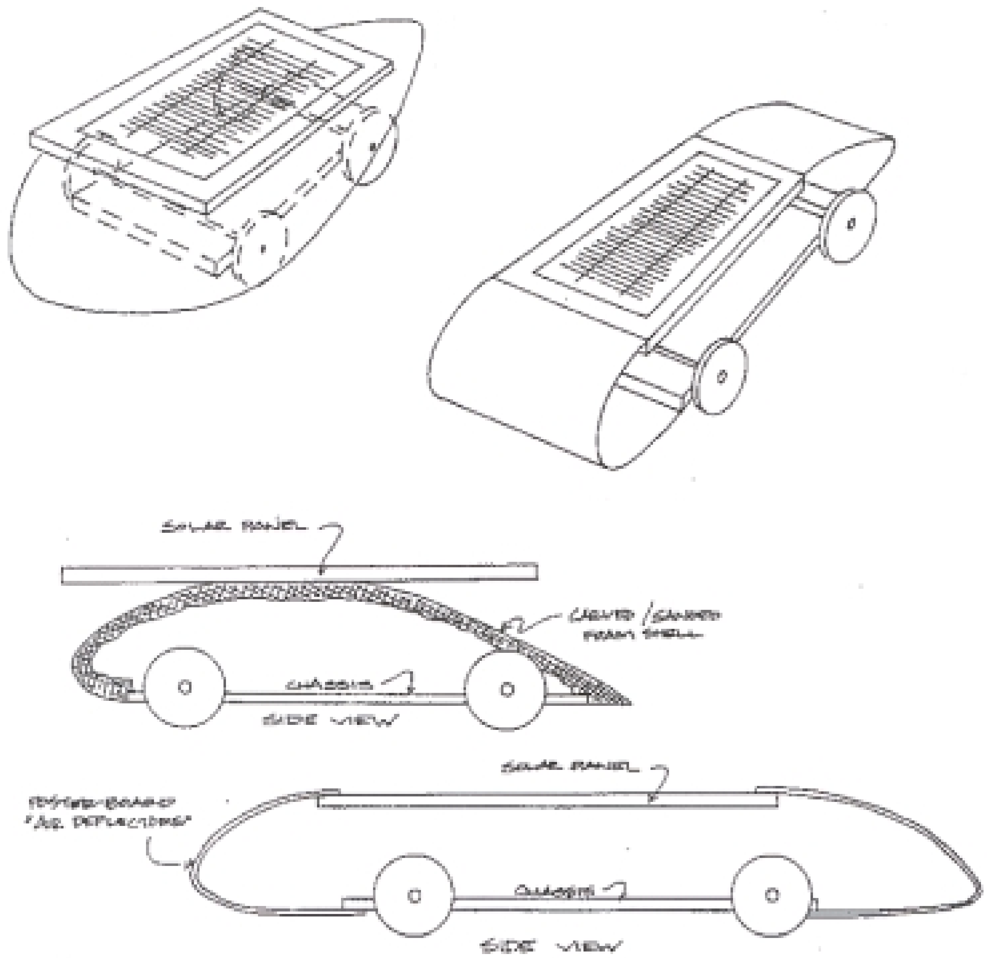
If you use a friction drive, make sure you have enough traction on the *friction disk*, or it will slip (see the materials section for wheels and bearings). Also, make sure the friction gears are pressed against each other snugly to ensure traction.

In all cases, you will need wheel like parts to put on the motor shaft and the wheel, and you can get ideas from reading the suggestions for wheel materials.

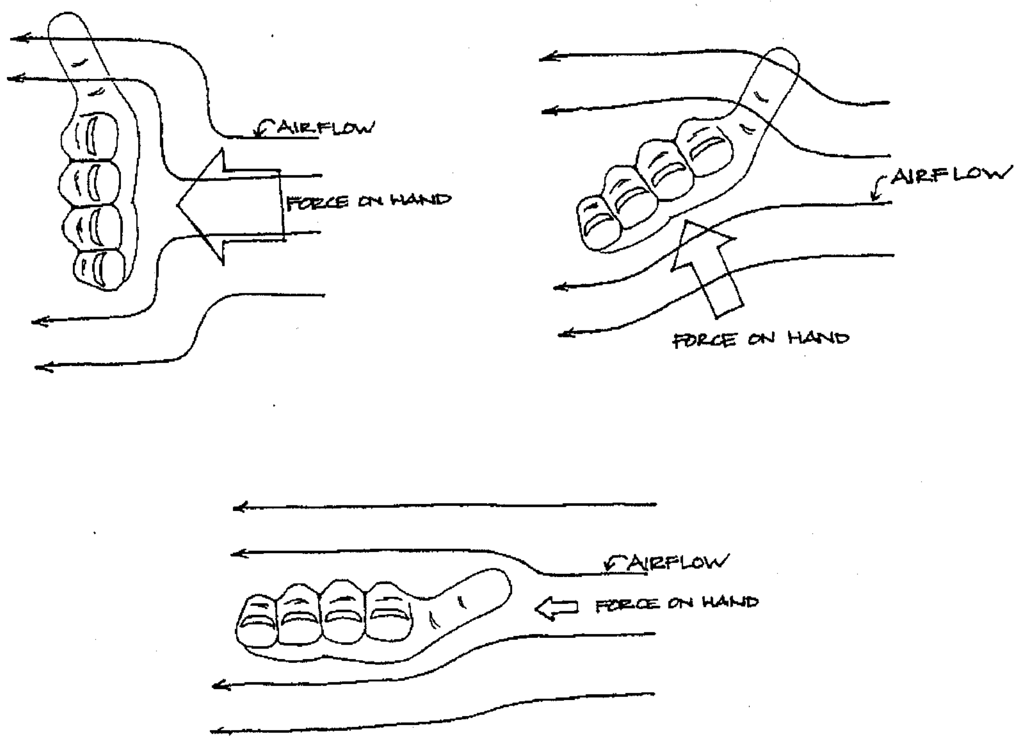
Body/Shell

Purpose
The body or shell of a real car has several purposes. It protects the passengers from wind and rain, it provides added safety in case of a crash, and it improves how the car looks. But it also changes how the car performs because a well designed shell can reduce the force of air on the car as it moves.

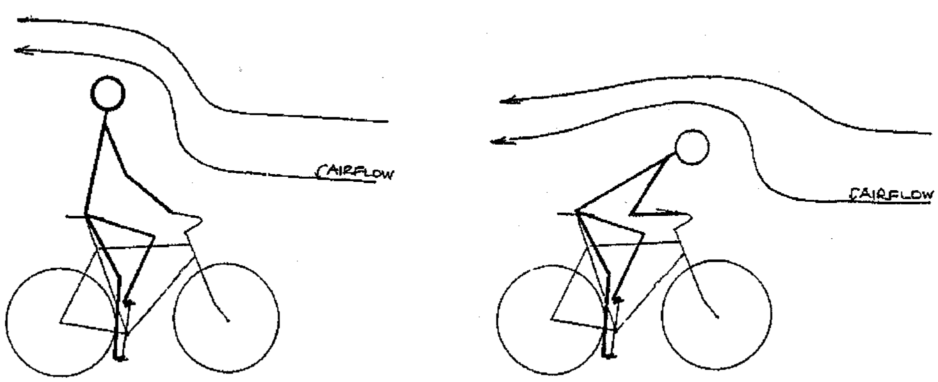
Ideas
Some ideas for shells are given below:



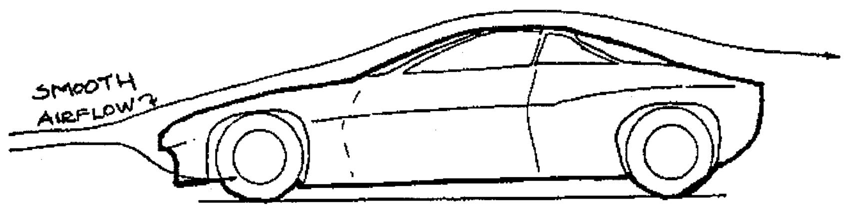
Concept: Aerodynamics
To see how much force air can have, you can try some simple experiments. While driving in a car, try (carefully!) holding your hand flat, and sticking it out of the window. Feel how much force the air has on your hand. What happens to the force when you tilt your hand?

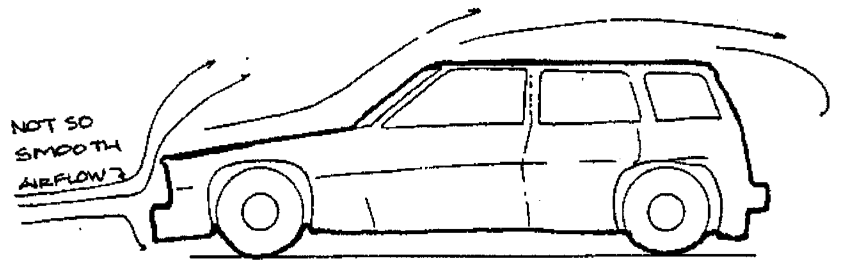


Or while riding a bike down hill, compare how fast you can go while sitting upright, or leaning forward. If you crouch down, the air can go over you instead of hitting you in the chest, so you should be able to go faster. In either words, the force of the air on your body when you crouch down is less, so you are more *aerodynamic*.

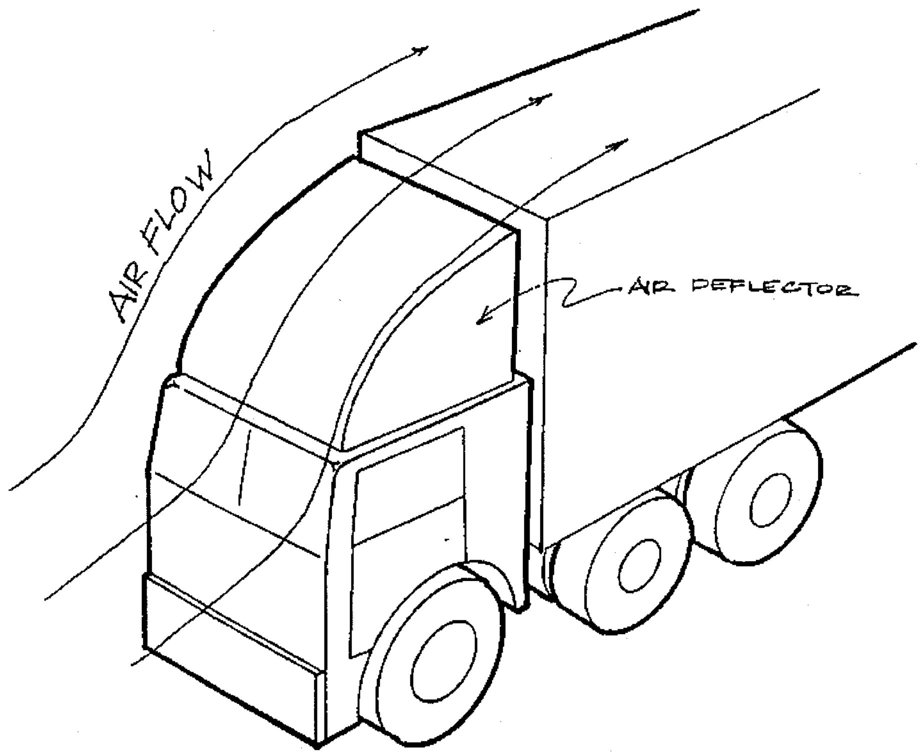


Look at things that move through the air, and notice how they are shaped:





Fast cars are shaped so that, when moving quickly, they can cut more easily through the air. As another example, you may have seen tractor-trailer trucks with big air deflectors on them. The reason for this deflector is to make the truck more aerodynamic, so the truck's engine doesn't have to work as hard and the truck driver saves money on gas.



In some situations, the force of air helps you instead of hurting you. For example, what if you want to *slow down* very fast? How about using a parachute? Now the force of the air is helping you.

Materials

So how do you reduce the force of air on your solar car? One way might be to add a body or shell to it that deflects the air around the car. Some possible materials you might use are:

- poster board
- cardboard
- foam core
- stiff insulation foam (e.g. "Foamula" - can be bought at lumber stores)
- mylar or plastic sheet

Insulation foam can be carved to shape, made smooth with sandpaper, and even painted to look nice. (Warning: some paints, like spray paint, will "melt" foam, so always try your paint on a piece of scrap foam that you don't need before using it on the real thing.)

NREL/BK-820-30830
Revised 8/23/01

Junior Solar Sprint

Classroom Investigations

This document was created by:
Andrew Heafitz

with the assistance of:
Diane Brancazio
Kevin Otto
Chris Saunders
Ginger Sturcken

Note to teachers and mentors:

This package of investigations is intended to aid the teacher or mentor in exploring the different components for a model solar car with their students. They are designed to give some background on the topic and discuss the different variables that go into each phenomena. The investigations/demonstrations illustrate the points and help the students optimize their solar cars.

We have made a conscious effort to make their activities as "real engineering world" as possible. They are intended to be fun tools to help students get a grasp of the physical property and to start building up an intuitive sense of the physical world. Even though the answers are sometimes obvious form the questions, it is still important to have the students try as many of the experiments as possible, especially the easier ones which might only take a few minutes, but will give them some hands on experience and give them real feelings for the forces involved. Sometimes the answer is a little counter-intuitive or possible more dramatic than one would think.

Also included are some commonly known examples which illustrate the principles elegantly. A fun activity is to figure out how these examples really work, or come up with others. The world and nature are full of great examples! Lastly, some of the demonstrations are not only to help design the cars, but also to test, compare and optimize the finished cars in a controlled environment in preparation for the race.

Many thanks to all the 1994 New England Jr Solar Sprint leaders, teachers and mentors whose time and effort went into preparing and testing the investigations presented here.

Transmission Investigation

What is a transmission?
The transmission in a solar car is the part that connects the motor shaft to the wheels or axle. In general, a transmission is any device which transmits mechanical power from one place to another. Power is the product of force x speed (or torque x rotational speed). Transmissions are also used to change the speed and force proportions while transmitting mechanical power.

Some transmissions are very complex, such as a transmission in a car which has several different speeds and shifts between them automatically, and some are very simple, such as the gears in a can opener. A vacuum cleaner has a belt transmission which transmits power from the motor to the beater bar which spins to brush dirt off a rug, and mechanical clock has a transmission to get power from the motor to oscillator to the second hand. Another transmission goes from the second hand to the minute hand. This transmission has a "transmission ratio" of 60 to 1. The second hand goes around 60 times to make the minute hand go around once.

What is a transmission for?
In addition to getting power from one place to another, the transmission can be used to trade speed for torque or torque speed. Hook the motor up to the solar panel or a battery if it is not sunny. The motor spins very fast, doesn't it? Try to stop the shaft with your fingers - not very difficult. If you put the car's drive wheel directly on the motor shaft, it would spin very fast (good) and when you put the car on the ground, the weight of the car would probably be enough to stop the motor (bad). If we believe this motor is powerful enough to move the car, then what's wrong. The problem is the relative proportions of torque and angular speed are not suitable for this application.

The answer to some of these problems is a transmission. The transmission can be a belt, chain, pulley, etc. drive that makes the wheels turn with higher torque (harder to stop), but at a slower speed that the motor shaft. Obviously there is a tradeoff here. High speed but not enough torque and the car won't start or accelerate quickly. Low speed and high torque and the car will accelerate quickly until it reaches its final, low speed. Then it will creep along the track at a snail's pace.

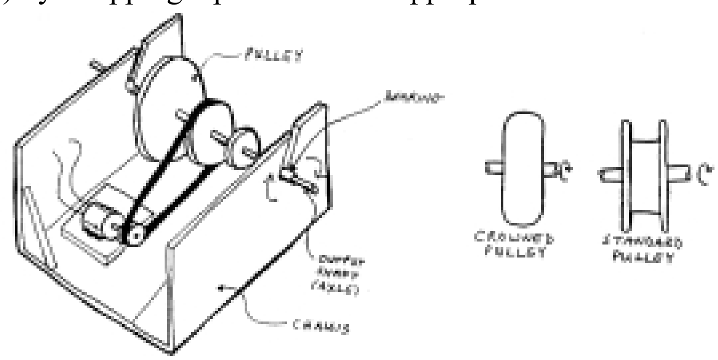
To achieve a satisfactory tradeoff, or compromise, we can build a transmission with a "transmission ratio" that gives the car a medium acceleration and medium top speed. What "medium" is will depend on the rest of the car's design. A formula 1 race car and a farm tractor both have well designed transmissions that allow them to get going and travel at the right speeds. Transmission ratios are also commonly referred at as "gear ratios". This however is misleading in that it implies that only gears are used in transmissions. Belts, chains and friction drives, etc. are all common transmissions.

Transmission Investigation #1: Effect of transmission ratio
Building a car without any knowledge of the best transmission and ratio is risky because the car will not perform to its full potential (if it moves at all). The following test setup uses a belt and pulley transmission, but the ratio of the pulley diameters applies to all of the other types of transmissions as well (gears, friction drive). Optimizing the transmission ratio in your car is critical for good performance.

Materials:

Motor and 3V power source	Cardboard, foamcore, etc. for chassis
1 small pulley for motor shaft	Rubberband or belt
3 larger pulleys for output shaft (axle)	Hot glue
Shaft bearings	2 shaft axles

Finding Materials:
Search local hardware and craft stores for objects that can serve as pulleys, bearings, axles, etc. Some of the "pulleys" we used included: drawer pulls, videocassette reels, and thread spools. Video cassettes are also great sources of small smooth cylinders that can be used as bearings. Brass tubing (craft stores) or plastic tubing (drinking straws) can also make suitable bearings. You may want to find bearings before you select an axle. Possible axles include wooden rods from hardware stores, wire hangers, and metal or plastic tubing from crafts stores. Note that shafts can be made larger (for mounting wheels, pulleys, etc.) by wrapping tape around the appropriate areas.



Build a test transmission like the one shown above. Mount the motor on a piece of stiff material (using hot glue, good tape, etc.) that is easy to grip or attach to the chassis. Use it to adjust motor location and belt tension.

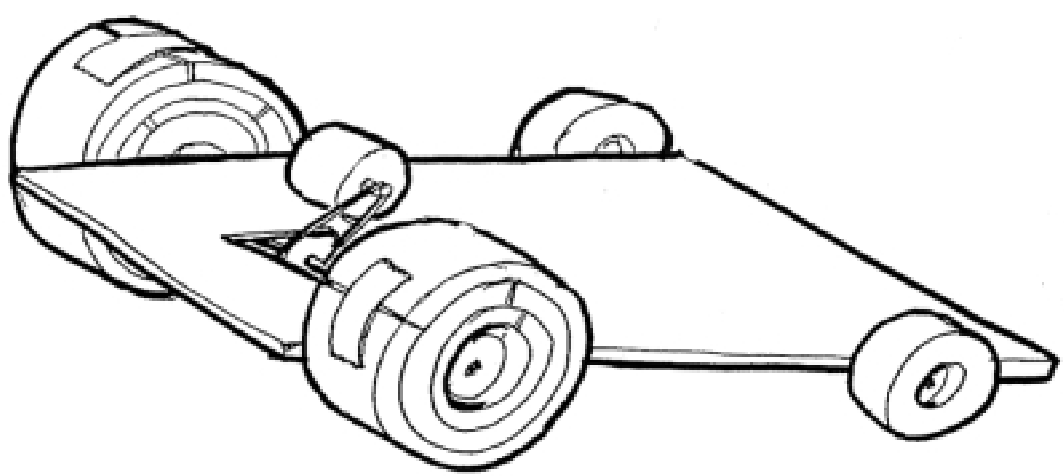
Procedure
- Move the belt to different pulleys to see the results of different ratios. See which ratios figure the highest speed, and which make the shaft easiest to stop with your fingers.
- Try different bearings between the axles and the frame.
- Try adding or removing weight from the output shaft to see the effect on acceleration.
- Notice how flat rubber bands tend to crawl up the edges of a pulley - try a "crowned" pulley (convex profile). It's counter-intuitive, but does work, and is used often in machines.

Transmission Investigation #2: Effect of wheel size
Try different wheel sizes on a sample of cars and see how the performance varies (acceleration and speed). Use a prototype car that you've built or a store-bought toy car. Wheel size is as important a factor in a car's design as the transmission ratio; in fact, they are closely related. Try to calculate what distance you car travels per one revolution of the motor. The transmission ratio will tell you how many revolutions the wheel axles will turn per wheel revolutions.

Materials:

1 toy or prototype car
Lightweight foam tape

Procedure
Experiment with this concept by varying the wheel diameter on your car. If you start with a small wheel, you can build up the diameter with various materials, for example, weather-stripping foam tape.

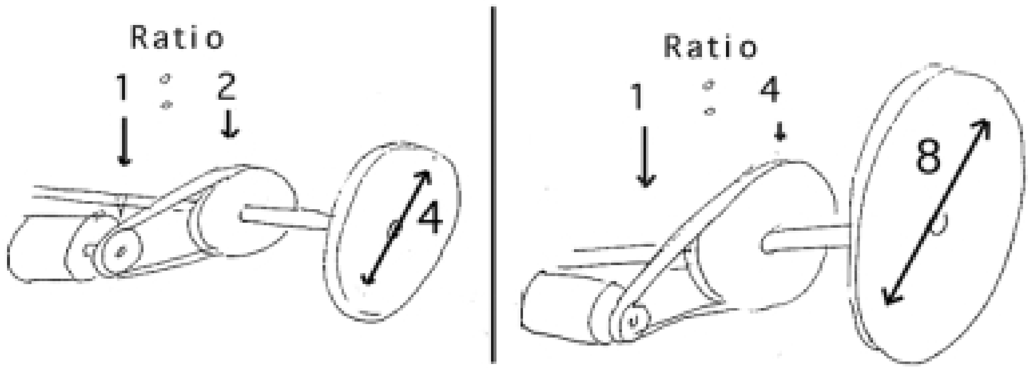


Conclusion

How much larger would the wheels need to be to make the car's top speed be twice as fast? Three times?

How can large wheels hurt the performance of your car?

The two transmission ratios and wheel size combinations shown below will produce cars with similar performance in terms of acceleration and top speed.



A last note on wheel size, the faster the axle rotates in the bearing the more friction and drag it will have. A larger wheel will allow the axle to rotate more slowly (if the car is to go at the same speed), and will waste less power in the bearings.

In nature, an analogy for wheel size would be leg length. Just as a horse and a hamster will cover different distance if each takes one step per second, cars with large and small wheels will travel different distances with each wheel rotation.

Transmission Investigation #3: Multi speed bicycle
Experiment with a transmission that you're probably already familiar with, a Multi speed bicycle.

Materials

1 Multi speed bicycle
Tape to mark a point on the wheel

Procedure:

1. Take a 10-speed bicycle and flip it upside-down so that it is resting on the seat and handlebars.
2. Hold the bicycle down and start pedaling by hand. (Watch your fingers around the moving parts!)
3. Try several different gears, both on the front gear rings and the back cluster. Each time see how fast you can go and how long it takes to get these from a complete stop.

Transmission Investigation #4: Multi speed bicycle races
A good experiment for students to do at home with their own bicycles:

Materials

2 Multi speed bicycles
2 students of similar size and physical strength

Procedure

1. Get a friend or classmate and 2 Multi speed bicycles. Put one in the highest gear (small sprocket in front, large sprocket in back) and the other in the lowest. Race to a specified point.

Conclusions
Who got there first?

Expansions
Would the winner be different if the race were longer or shorter? Try it out!

Other examples of transmissions:
A full size car has a transmission with several gears so that you can choose the right ratio for the right time. When you start off, you want a high ratio for high torque and lots of acceleration (first gear). Once you get going, you shift (or the automatic transmission shifts automatically), to a lower ratio for less torque and acceleration, but a higher speed (second, third or forth gear).

Did you know that a school bus and a sports car both have the same size engine but the transmission gives each of the vehicles its own driving characteristics?

Friction Investigation

Friction is a resisting force between two materials that are in contact and moving past each other, in other words, the sticking force between two objects being rubbed together. In a solar car, the wheels and axles have friction when they turn with respect to the chassis. Minimizing this friction will let the wheels spin more freely as well as faster, resulting in a faster car.

The interface between the axle and the chassis is called the “bearing”. A “plain bearing” can be as simple as an axle in a hole, or it could be a bushing. A bushing is a smooth sleeve in the hole that gives the axle a low friction surface to run on. A “ball bearing” is a set of balls in the hole which are arranged so that the axle rolls on the balls instead of sliding in a sleeve. Ball bearings are found in many familiar devices such as bicycles, rollerblades and skateboard wheels. Ball bearings have the least friction, but they are expensive, and more difficult to use than plain bearings and bushings. For these reasons, most Junior Solar Sprint cars use plain bearings.

Friction Investigation #1: Friction between axles and bearings of various materials
To choose the best materials for axles and bearings (e.g. metal axle in a wood bearing, etc.). find samples of the different materials and test the friction between them. This test will help determine at what angle a sample piece of material starts to slide. The steeper the hill, the more friction there is between the test piece and the material covering the slope. The more friction, the worse those materials are for bearings.

Materials

Plank that can be lifted at one end	Small objects made of various materials
Ruler	Lubricants: oil, graphite, etc.

Procedure

1. Put an object made of the first material on a sheet of the second material.
2. Then, tilt the sheet until the object starts to slide and note the angle of the sheet
3. The lower the friction, the sooner the object will start to slide and the smaller the angle will be. For example, to test metal on wood, put a piece of metal on a plank of wood and tip up the wood until the metal piece moves. Measure the height of the end of the plank so you can compare it to the next sample. One interesting feature of this test is that the weight of the object is not important. A steel paper clip will start sliding at the same angle as a heavy steel object.
4. Try different lubricants and see what happens. Soap, graphite or pencil lead and oil are good to try. Which work best on which materials? Keep in mind that it can be difficult to un-lubricate something if it doesn’t work, so test a scrap piece of material using this friction test before lubricating your car if you are not sure.

Picking two materials that “run” well together will mean that less power will be used to overcome the friction and more will go towards driving the car faster.

Friction Investigation #2: Distance of friction force from center of rotation

In addition to the materials that are rubbing together, it makes a difference where they are rubbing. Much like a lever, the farther from the center (fulcrum or pivot) a force is, the more effect it has. It is easier to stop spinning object by grabbing the outside edge than a point near the middle. Therefore, a friction force far from the center slows a spinning object (such as a wheel) more quickly than the same force close to the center.

Materials

1 large textbook
4 similar coins

Procedure

1. Put the heavy, hard cover book flat on the table. Rotate it slowly back and forth and get a feel for how hard it is to turn.
2. Now, put a stack of about 3 coins on the table under the center of the book and balance the book on the coins. Make sure that the corners of the book don't touch the table and try rotating the book slowly back and forth again.
3. Is the flat book harder to turn because of more surface area in contact with the table? Put a stack of coins under each corner and try the experiment again. Then move all the coins towards the center a little bit at a time and see if it gets easier as they come closer to the middle.

Friction Investigation #3: Rolling resistance test

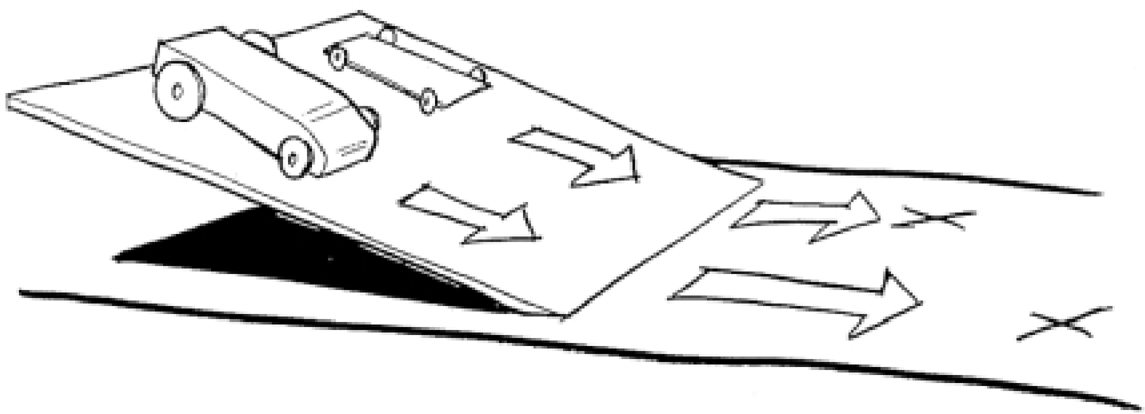
Use the roll down test described in the "aerodynamics investigation" to find the bearing and wheel combination with the lowest rolling resistance (do not change the aerodynamics of the car during this test because that will also affect the results.) Finding the best combination is an important step in building a fast car.

Materials

- Ramp
- Several prototype cars
  - without motors
  - built using various axle and bearing components
  - approximately the same weight

Procedure

1. Starting from the same point on the ramp each time, let the car roll down the hill and mark the place it rolled to. Do this 3 times for each car, or until the car repeatably rolls to the same place (to make sure you are always starting the cars the same way). Did the cars travel in straight lines? Which car went further? Try improving your car with different axles or bearing materials see how different wheels, bearings, lubricants etc. alter the final distance that the car travels.



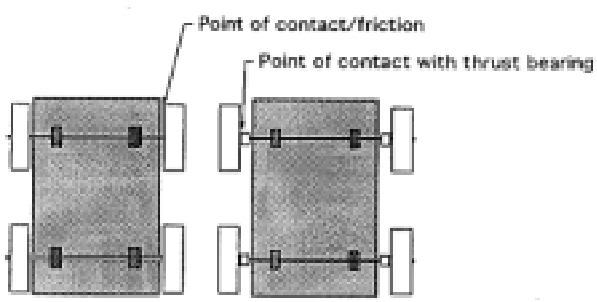
Some places to look for friction in your car design:

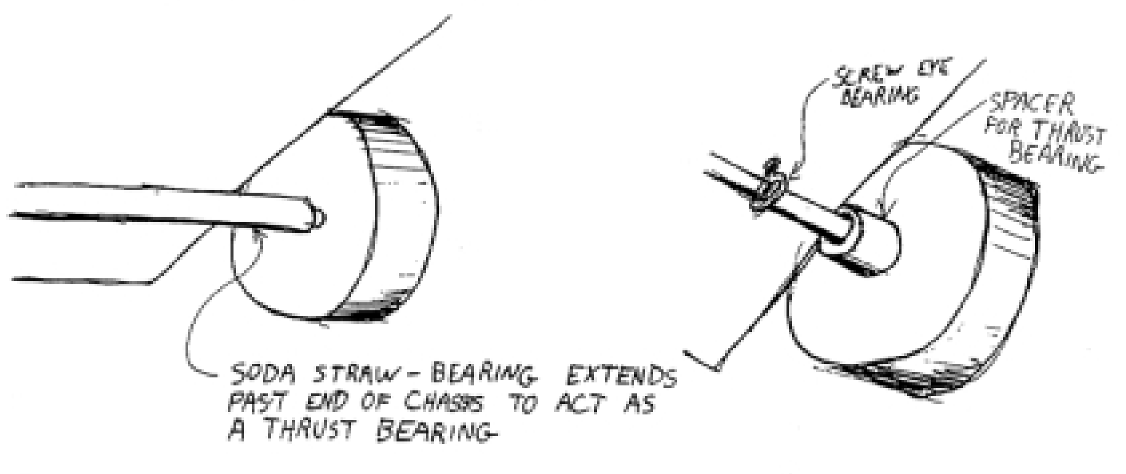
Diameter of axle - (is smaller better? Why do “Hot Wheels” toy cars have such tiny axles and go so far?) The larger the diameter of the axle the farther away from the center that contact the bearings. Like the book dragging on the table all the way out at the corners, a large axle will be harder to turn.

Wheel alignment - If the wheels are not all pointing in the same direction, the car will tend to turn. Since the guide wire keeps it going straight, some of the wheels will have to skid sideways. This takes more energy than driving straight and will slow the car down.

Axle bearings - Choose axle and bushing materials that have low friction against each other. Surface finish is critical. Make sure all of the running surfaces are as smooth as possible.

Thrust bearings - These are whatever keeps the axle from falling out the side of the car. If the edges of the wheels rub on the body, like the book, they will have a lot of drag. If there is something around the axles that let the center portion of the wheel touch first, the drag will be lower, like the book swiveling on the coins.





Aerodynamics Investigation

What is aerodynamic drag?
Aerodynamic drag or “wind resistance” is the resisting force that a moving object feels as it moves through air. You probably know that air consists of oxygen, nitrogen, carbon dioxide, and other gases, so it is clear that air does have mass and is not “nothing”. As an object moves through air it will experience a resisting force proportional to the object’s speed and geometry. Since we want our cars to go as fast as possible, let’s look into how to reduce the drag due to the physical dimensions of the car.

There are two primary physical characteristics responsible for aerodynamic drag on a moving vehicle. The first is the “frontal area” of the car, or the cross-sectional size of the car as viewed head on. The second is the shape of the car, or how “streamlined” it is.

Aerodynamics Investigation #1: Nose Cone
Aerodynamic drag can be demonstrated with an ordinary soda can. Since the soda can is lightweight and will slide easily on many hard surfaces, the friction forces on it will be low enough that we look at variations in the resistance from aerodynamic drag. If an object is relatively large and heavy, the friction forces are likely to far outweigh the aerodynamic forces unless the “wind” gets very strong. Most of us are not worried about our family’s car blowing away when sitting in the driveway, but drag is a major factor in fuel efficiency when driving at highway speeds.

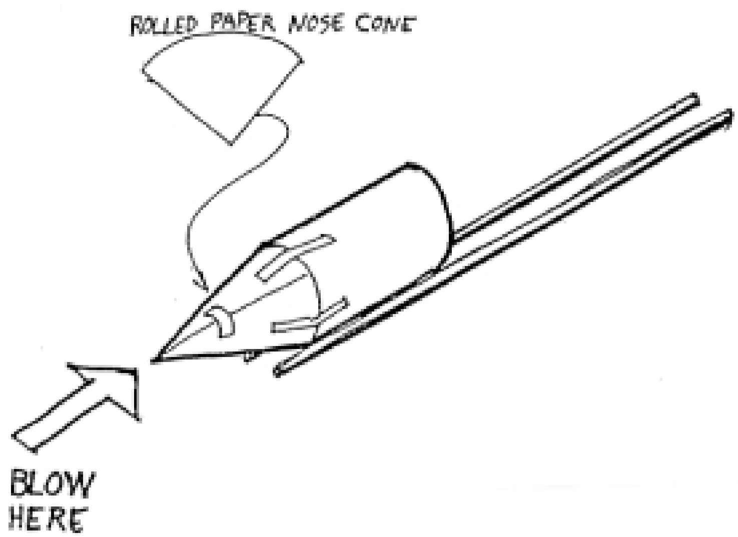
We can vary the car’s shape while maintaining it’s frontal area by using different lightweight shapes in the front of the can.

Materials

Soda can
Sheet of ordinary paper
Scotch tape
Two - ½" diameter wooden dowel rods, 3" long

Procedure

1. Set up the dowels as shown in the diagram and place the soda can on them at one end. Blow on the end of the can and see if it moves.
2. Now make a cone out of paper, and tape it to the front of the can, so it looks like a rocket with a pointed nose cone. Blow on the can with the nose cone again and see if it moves. What kind of resistance forces would this can feel if it were on a moving vehicle? As compared to the flat face can?



Aerodynamics Investigation #2: Roll down test

Roll-down tests are used by some automobile manufacturers, race car builders, and car testing organizations (among others) to test the aerodynamic drag of a car. The idea is to roll a car (with the engine turned off and out of gear) down a hill, and see how far it rolls. A car with more drag (for example, a car with a parachute behind it) will roll to a stop faster (or after a shorter distance) than a streamlined, low drag car.

Materials

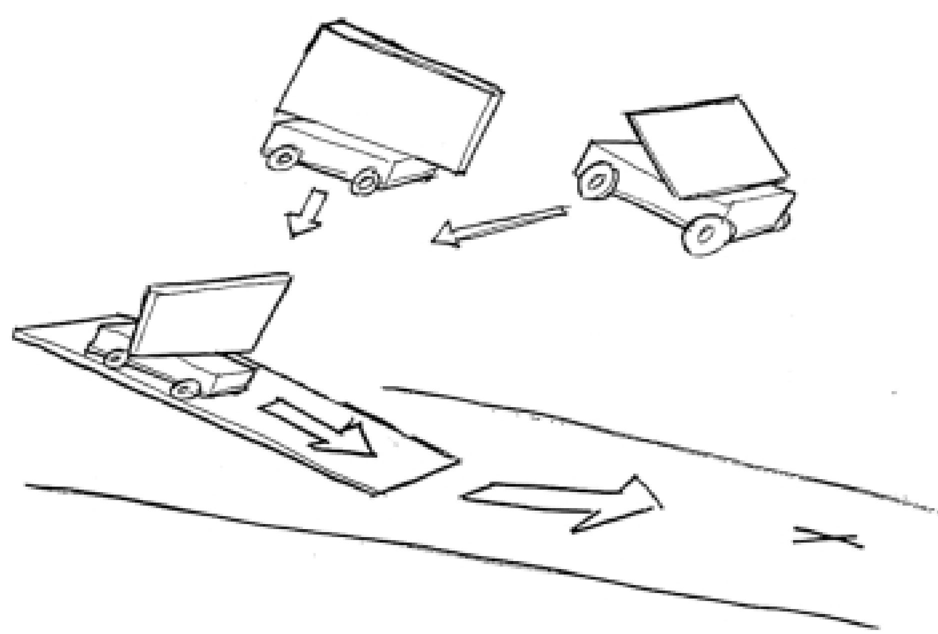
Ramp
One miniature car (a small toy car and track may also work)
Different car profile shapes to put on the car (blocks, streamlined shapes of paper, sheets of foamcore, etc.)

Procedure

1. Set up the ramp and release the car from the top until it repeatably rolls to the same place.
2. Repeat with different frontal areas, keeping the car weight constant. Use one which has a very large frontal area.
3. Try out different streamlined shapes as you did with the nose cone on the soda can. Be careful to keep the other variables constant.

Expansion

Why is it invalid to use different test cars? What other physical properties can affect the amount of distance traveled?



How can you reduce aerodynamic drag in your car?

1. What effect would a streamlined body or nose cone have on the car's top speed and its acceleration? How can you build an aerodynamic shape?
2. The roll-down test is a good tool that can be used to fine-tune the aerodynamics of the final solar car design. Leave enough time to work on the aerodynamics.

Everyday examples of aerodynamic drag:

Aerodynamic drag is considered in many facets of modern life where high speeds are demanded relative to the power source provided.

Semi tractor-trailer trucks now have a "fairing" above the cab to streamline the trailer. Truckers find that the added cost of the fairing is easily offset by the savings in fuel.

When coasting down hill on a bicycle, crouching down reduces the frontal area, and prevents the rider's body from acting like a sail (or parachute).

Birds and fish have streamlined bodies to slip through air or water with minimal effort. Water drag is very similar to aerodynamic drag; the same rules apply, but the effects are seen much sooner in water. (Is it easier to swim through the water headfirst presenting a small frontal area or to walk in chest deep with a large frontal area?)

Airplane and ship profiles are designed to minimize drag as much as is reasonably possible, to increase fuel economy.

Ships have barnacles (clam-like crustaceans which attach themselves to anything solid in the water, including whales and ships) periodically removed from the bottom surface to make them smoother and reduce their drag when moving through the water.

Structure Investigation

A key component of a car is the underlying structure, or the "chassis". The chassis is a mechanical component that must provide structural support for the motor, wheels, axles, solar panels, etc. When designing a chassis to perform these functions, you may also find you want to make the structure as lightweight as possible (why?). How do we make a chassis that is strong and light? Some materials have a higher "strength to weight ratio:" than others. For example, similar weight sheets of paper and plastic will probably not support the same amount of weight. In addition to the inherent strength of a material, its stiffness also plays a major role in the forces that the structure can withstand. We will see in these investigations what the relative strengths of some materials are and how the shape of a material can impact its stiffness.

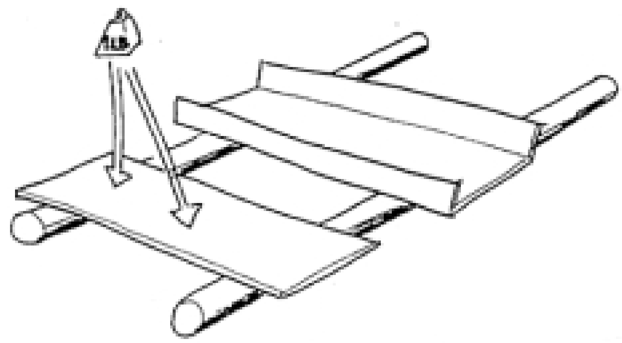
Structures Investigation #1
The difference in the loads that a miniature car frame can carry with materials of different strength and shape can be demonstrated effectively without building an entire chassis. Here dowel rods are used to simulate axles and wheels, that is, they allow the material to flex and bend much as real wheels and axles would.

Materials

- Two - 1" diameter round dowels. 2' long
- Various size sheet of:
  - Ordinary cardboard 1/16" thick (such as the back of a pad of paper)
  - Corrugated cardboard
  - Foamcore board
  - Balsa sheet, 1/8", 1/16" thick
  - Plastic sheets
  - Small weights (up to 1 lb.)

Procedure

1. Lay various materials across the dowels and place weights at various positions. Compare how well the materials support the weights. At what position do the weights have the least effect on the shape of the chassis materials?
2. Try two thicknesses of the same materials. Is the extra strength worth the added weight to you? Can you combine materials to achieve satisfactory performance?
3. Vary the shapes of the materials and see how much weight they can support (keep the size and weight of the material constant). What effect does folding have? Does direction matter?
4. Try corrugated cardboard with ribs running the long and short way. Why is corrugated cardboard used more frequently than the same thickness of simple cardboard.



Chassis for model solar cars:

1. What materials (or combinations of materials) would you like to use in a model solar car? Are there any other materials you would consider but didn't have today?
2. Composite structures, made from multiple materials, can be designed to have high stiffness to weight ratios that are much higher than those of the component materials themselves. "Foamcore" (foam sandwiched between heavy paper) is one example. Can you think of others?

Everyday Examples

Structural design is a very important part of engineering every commercial product, from machines to clothes. Consider the following examples:

A rubber band is stronger but less stiff that a circular strip of paper of equal width. (Prove it with an experiment).

Bridges and buildings use different shapes to increase the ability to withstand loads from different directions, including weight and wind.

Bridge beams are shaped in cross-section (such as an "I-beam", "channel", or a "box-section") to maximize the stiffness and strength to forecasted loads (such as vertical load against gravity) for a given amount of material. Other cross-sectional shapes are used for different forecasted loading.

Cars and planes use different structural shapes to withstand loads, provide stiffness, and to connect, support and protect different systems (driver, engine, wheels, etc.) into a whole product.

Photovoltaic (Solar Panel) Investigation

The solar panel is the power source for the car. Sunlight strikes the solar cells and the light is converted to electricity on an atomic level. How much electricity is produced is related to the amount of light that the panel collects and how efficiently is can convert the light into electricity.

Your car will have a solar panel mounted somewhere on it. You want the panel to collect as much light as possible, and to convert it as efficiently as possible. The first task is to figure out where to position the panel on the car. The top side is probably best, and nothing should cast a shadow across it.

Trade-off: Tilting panel vs. Fixed panel

The angle of the panel to the sun also makes a difference. Look at the shadow cast by the panel when it is rotated to different angles. The larger the shadow the more light it is catching. However, you may not be able to aim the solar panel directly at the sun with your car design. The position of the sun during the race is unknown (time of day, time of year and racetrack orientation play a role in the sun's position compared to your car). A tiltable solar panel will allow you to adjust you car the day of the race, but at what cost? A tiltable solar panel is harder to build than a fixed panel, it may weight more and cause more aerodynamic drag. These last two will slow your car down. Is a tiltable panel worth all the drawbacks? To answer that question you need to know how much difference the angle of the panel to the sun makes. If you get a lot more power, maybe it is worth the extra effort. If it doesn't seem to make a big difference, spend your time making the car better and faster in other ways.

Panel efficiency

Once the sunlight has hit the panel, the panel converts the energy of the sun to electricity. Does all of the solar energy get converted or does some get reflected and some get turned into heat and lost? A lot of the efficiency of the solar cells has to do with how well they were designed and built. Unfortunately good solar cells are expensive. The solar racing car built by Honda that won the 1993 race across Australia had some of the best cells ever made. A 5 inch x 12 inch panel (like the one in the kit) made of these cells would cost about $9,000! 200 panels this size allowed the car to average over 50 mph across the entire continent on solar power alone! These cells were almost 25% efficient. That means that 25%, or one quarter, of the sunlight hitting the panels was turned into electricity. Your solar panel is not as good, probably around 10% efficient. However, there are some ways to make your panel as efficient as possible. Keep it clean (dirt and dust will block sunlight like a dirty window). Keep it cool. Solar cells work better when they are not hot. Teams racing full size solar cars will often spray water over the race car's solar panels to keep them cool and running more efficiently when the car is parked and charging its batteries from the sun.

Solar Panel Investigation #1: Power generation

Materials

Solar panel
Motor
Voltage and/or current meter
Sunlight
Lamps

Procedure

1. Hook up the leads of the solar panel to a volt meter (or a motor). Try the following tests to get a feel for how sensitive the solar panel is to different conditions.
2. Vary light level on the solar panel (indoor light, incandescent light bulbs, fluorescent lights, direct sunlight, open shade).
3. Vary angle of panel to sun (watch the size of the panel's shadow change and see how the volt meter changes).
4. Investigate effects of shadows on part or all of panels. What happens if you cover only 1 cell?
5. Investigate how much difference temperature makes. Take a cool panel and quickly place it in the sun. Let the panel warm up in the sun and see if you can detect the difference on the volt meter.
6. Does it matter which way the motor (or volt meter) is hooked up to the solar panel?
7. Put a current meter (ammeter) in series with the motor and solar panel. How does the light level affect the current

NREL/BK-820-30826
Revised 8/23/01

Junior Solar Sprint

So...
You Want To Build
A Model Solar Car

TABLE OF CONTENTS

TOPIC	PAGE
SOLAR ENERGY	4
Teacher Background	4
Activity One	5
Activity Two	6
Activity Three	7
Activity Four	8
Activity Five	9
Activity Six	10
So You're Building A Model Solar Car...	11
Bibliography	12
Helpful Hints for Transmission Design	13
Theoretical Calculations for a Solar Car	14
Design Considerations for a Solar Car	17
Here's To Helios (Part One)	18

Building a solar powered model car is similar to building a real car. Young engineers must consider the effects of the following forces when they design their vehicles and select the materials to use for the chassis and wheels.

Friction	Inertia	Speed
Momentum	Gravity	Drag

Engineers must consider aerodynamics - the motion of air and the forces that act on a body in motion - when they design the vehicles.

In addition, the builders of solar cars must know how a solar cell works and how to transfer the sun's energy to the wheels of the vehicles. This packet includes information and activities that will demonstrate solar cells and gears.

SOLAR ENERGY

Teacher Background

Why do we experiment with and research alternative energy sources such as solar energy? Solar vehicles convert the sun's energy directly into electricity. Electric vehicles have their energy stored in a battery. Since electric and solar vehicles do not directly burn fuel, there are few harmful emissions produced. Replacing gasoline fueled vehicles with electric and solar cars would reduce CO^2 emissions by 43% to 54% per vehicle.

The basic building block of a solar-electric system is the Photovoltaic Cell. The amount of electrical power delivered by the cell depends on its size and efficiency. These cells are thin silicon wafers with a positively charged impurity, such as Boron deposited on the surface. The parent silicon wafer is negatively charged. This "sandwich" forms a "p-n" junction where the "p" layer accepts electrons and the "n" layer gives them up to create a flow of current.

When exposed to light, a Photovoltaic panel experiences a flow of electrons from one layer to another; these electrons are driven by photons in the light striking them. By attaching conducting wires to the "p" and "n" layers, a source of power is formed that will power a radio, drive a motor, or charge a storage battery.

The electrical output of a photovoltaic panel or cell may be measured directly by using a voltmeter or millimeter. Voltage represents the potential or pressure of electricity being produced while Amperes are a rate of flow for the electrical current.

Power or wattage can be determined from a combination of volts and Amps. A small multi meter works best for these experiments and can be connected directly to the positive and negative terminals of the solar cell.

The activities that follow give students an opportunity to explore the power generated by solar cells or panels. By trial and error, students can determine conditions that provide for optimal performance of a model using this system.

Activity One

Topic: During what part of the day is the most power produced by the sun?

Materials Needed:
Solar cell
Motor with propeller or spinner
Sunshine

Procedure:
1. Connect the solar cell to the motor.
2. Take the cell and motor outside. Notice how fast it runs.
3. Count how many times per minute the fan turns.
4. Do this at different times of the day - 9 a.m., 12 noon, and 3 p.m.
5. Note the weather conditions at each trial.
6. Repeat above steps for several days.

RECORD THE NUMBER OF TURNS OBSERVED AT DIFFERENT TIMES OF DAY:

DATE	9 a.m.	12 noon	3 p.m.	WEATHER CONDITIONS
AVERAGE				

Conclusions:

At what time of the day is more power produced?

What weather conditions are most advantageous to the production of power?

What weather conditions are the least advantageous?

Expansion:

Why are storage batteries used in the system?

Activity Two

Topic: At what angle of inclination does the sun produce the most power?

Materials Needed:
Average Turns Data from Activity One
Straw
Protractor
Sunshine

Procedure:
1. Hold a straw so that it is parallel to the sun's rays and casts no shadow. (Other than a ring)
2. Measure the angle using a protractor.
3. Do this at the times of day used in Activity One.

RECORD THE ANGLE OF THE SUN AT DIFFERENT TIME OF DAY

	9 a.m.	12 noon	3 p.m.
ANGLE OF THE SUN			
AVERAGE # TURNS			

Conclusion:

What effect could the altitude of the sun have for the use of solar power?

What modifications must be made in the solar panel's placement in order to maximize the power at any time during the day?

Expansion:

Graph the angle of inclination and the number of turns observed in Activity One.

Activity Three

Topic: Which delivers more power, 2 solar cells in a series or parallel?

Materials Needed:
2 photocells about 5V
1 small motor (1.5V)
1 millimeter
1 voltammeter
Soldering iron
Black and red wire

Procedure:
1. Prepare the cells (if not already) by soldering the red wire to the backside or positive poles. Solder the black wire to the front or negative pole.
2. Wire the solar cell into a series. (See the diagram)
3. Place in full sun and measure the milliamps and volts.
4. Wire the solar cells into a parallel circuit. (See the diagram)
5. Place in full sun and measure the milliamps and volts.
6. Compute the Power in watts that was generated.

Volts X <u>milliamps</u> = Watts
1000

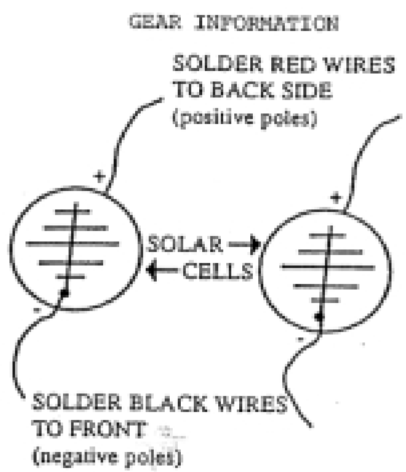
	Milliamps	Volts	Power in watts
Series			
Parallel			

Conclusion:

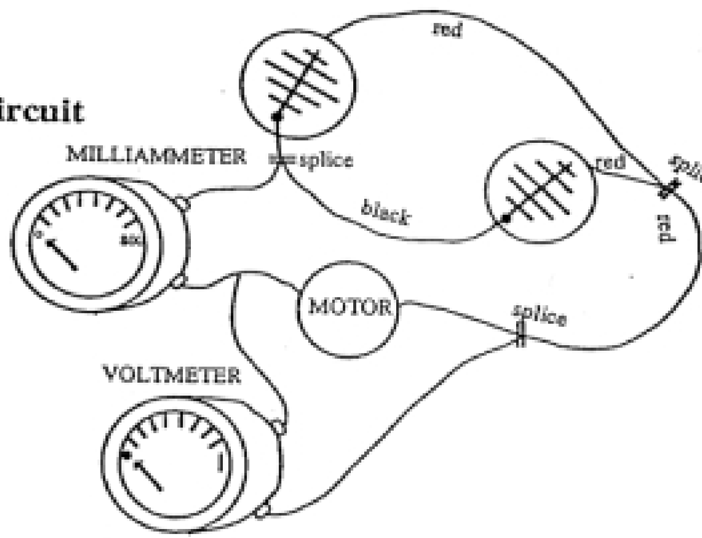
Which circuit produced a higher voltage?

Which circuit produced the greatest power in watts?

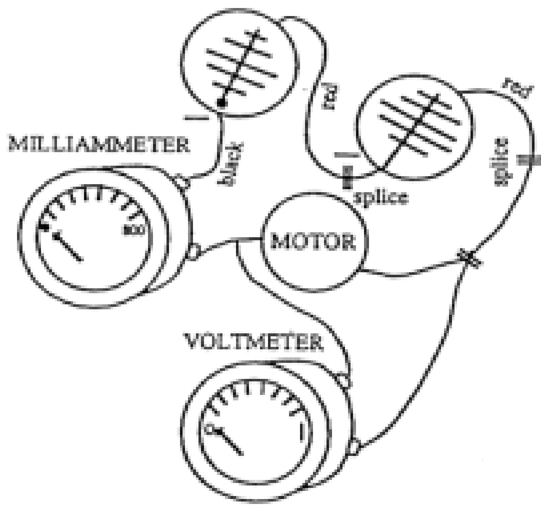
Teacher Note: Cells wired in series produce a higher voltage (charge). Cells wired in parallel produced a stronger current. No more energy is produced in either wiring method. Just different voltage and current conditions occur.



Parallel Circuit



Series Circuit



6

Activity Four

Topic Generalization: Drive belts are a form of pulley system that can be used to turn wheels and gears.

Materials Needed:
Hammer, nails, board
Rubber band
Large spool and small spool

Procedure:
1. Hammer two nails into a board far enough apart to lightly stretch the rubber band between them.
2. Place the small wooden spool over one nail and the larger spool over the other nail. The spools should turn freely.
3. Slip the rubber around both spools so when one spool is turned the other moves.
4. Place a mark on the top edge of each spool.
5. Beginning to the mark, turn the large spool through one complete turn.

Conclusions:

How many times did the small spool turn?

In which direction did the spools turn?

Expansion:

Does the length of the drivebelt make a difference?

Activity Five

Topic Generalization: Gears can be used to transfer forces from one part of a machine to another part. With gears, the direction or speed of rotation of other objects can be changed.

Materials Needed:
Board and spools from Activity Four
Hammer and nails
Rubberband

Procedure:
1. Drive another nail farther away from the large spool and move the small spool onto it.
2. The rubberband will now stretch tighter around both spools.
3. Turn the large spool around once again to see if the smaller spool turns the same distance as before.
4. Twist the rubberband so that it forms a cross between the spools.
5. Turn the larger spool again.

Conclusions:

How many times did the smaller spool turn?

In what direction did it turn?

Activity Six

Topic Generalization: The mechanical advantage in gears is determined by the ratio of the number of teeth on the gears.

Materials Needed:
Pieces of heavy cardboard
Compass, pencil, scissors
Board, nails, hammer

Procedure:
1. Cut a 3" gear with 8 teeth and a 6" gear with 16 teeth from heavy cardboard.
2. Mount the gears on the board with the nails so the teeth mesh and they turn freely.
3. Mark one tooth on each gear.
4. Turn the small gear to the right. On the chart, record how far the large gear turns.
5. Turn the large gear. Note how the small gear turns.
6. Now cut a 12" gear with 32 teeth and test it as you did the other two gears.

RECORD NUMBER OF TURNS OBSERVED

3" Gear	1	2	_	1	2	_
6" Gear				XXX	XXX	XXX
12" Gear	XXX	XXX	XXX			

RECORD NUMBER OF TURNS OBSERVED

3" Gear				XXX	XXX	XXX
6" Gear	1	2	_	1	2	_
12" Gear	XXX	XXX	XXX			

RECORD NUMBER OF TURNS OBSERVED

3" Gear				XXX	XXX	XXX
6" Gear	XXX	XXX	XXX			
12" Gear	1	2	_	1	2	_

Conclusions:

What is the ratio of the small gear to the middle-sized gear?

What is the ratio of the middle-sized gear to the largest gear?

So You're Building A Model Solar Car...

Here are some tips on the construction process from teachers and engineers.

Materials and Design
Weight is crucial. Solar cells do not provide much power to move heavy vehicles. Choose materials that are light as well as easily formed. Examples: Balsa wood, construction insulation foam, and cellophane on a frame.

Aerodynamics is also important. Drag and crosswinds should be considered. The chassis should provide for stability and allow for the placement of the components (e.g., motor, solar panel, and eyelet).

The choice of materials for the wheels and the wheel alignment can make a big difference on the amount of friction. There should be minimal rolling resistance.

Mechanization
The drive train, tire, and gear assembly can be collected from old toys or snap together car kits. On four-wheel-drive kit vehicles it is best to disconnect the front wheel drive as it increases the amount of friction to be overcome.

A gear is a wheel with teeth on the outer edge. By itself a gear does not do much of anything. Gears must be teamed up with other gears in order to provide torque. Gears can change speed of rotation and direction.

In a car, the crankshaft revolves in line with the car's direction of travel. So the work done by the engine has to change direction in order to turn the driving wheels. The direction is changed by having two gears that are set at right angles. A good demonstration of this would be seen in a rotary egg whisk. The handle turned is connected to a gear on the spindle of a whisk. This changes vertical movements to horizontal movements for the whisk to beat an egg.

Imagine you have two gears that mesh together - one with ten teeth and the other with twenty teeth. If you turn the smaller gear, the driven gear, it will go around once with the twenty-toothed gear has made only half a revolution. With an arrangement like this you would be able to lift a heavy weight with a small amount of effort. Exactly one-half the force has been expended over twice the time. But if you turn the larger gear, it will go around once while the ten toothed gear has done two revolutions. You would use this arrangement for speed. See Fig. 1

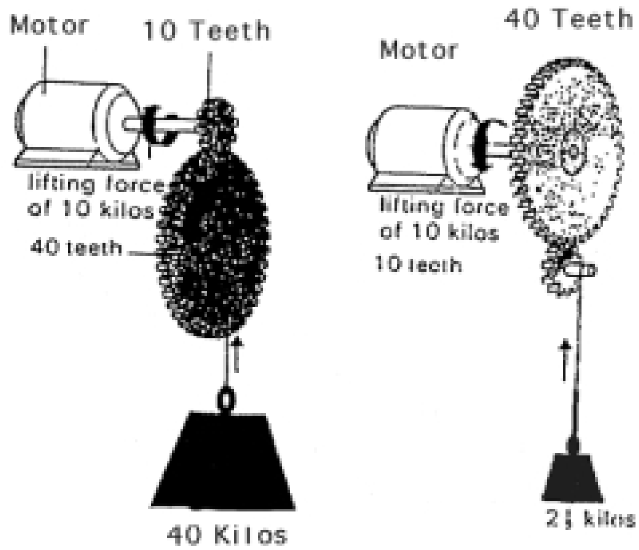


Figure one

In this machine, the smaller wheel - the pinion - has only a quarter as many teeth as the larger, so it will turn four times as fast. The left-hand machine will lift the heavier weight. When the positions are reversed, only a smaller weight can be lifted, but a greater speed.

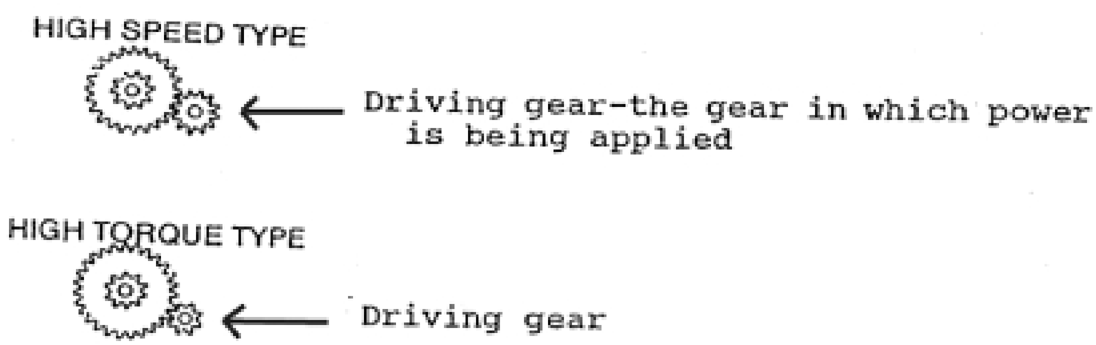


Figure 2

Biography

Bright Ideas published by the Arizona Energy Office, 3800 North Central Ave., Suite 1200, Phoenix, AZ 85012.

Lowery, Thomas. The Everyday Science Book, Palo Alto, CA: Seymour Publications, 1985.

American Tour de Sol pamphlet published by the Northeast Sustainable Energy Association, 23 Ames Street, Greenfield, MA 01301.

Pollard, Michael. How Things Work, New York, NY: Larousse & Co., 1978.

Helpful Hints for Transmission Design

1. **How should I design the transmission?**

   Be creative. There is no one solution to the problem.

2. **How should I get power from the motor to the wheels?**

   Experiment with several different ways such as gears, pulleys, or some other method of drive, to get power to the wheels. Don't be discouraged --- your first try may not work.

3. **What should I know about gears?**
   The pitch of a gear describes the number of teeth that can be put on a 1 inch diameter gear. Gears with different pitches will not fit together well, so the same pitch must be used throughout the transmission. Gears in 48 and 64 pitch are the ones most often used in slot cars. You can buy gears for the 1/24 scale slot cars at several slot car tracks in the Denver area or possibly through your local hobby shop.

4. **Where can I find parts?**

   Cheap, motorized toys, old cassette/8 track tape players, old motorized can openers, recycled materials and small gear reduction boxes will have gears and pulleys that may work in your transmission. Look for them in second hand stores, discount stores like Target and Wal-mart, or your brother's toy box.

5. **What else should I think about as I design the car?**

   Think about the friction of the following components:
   - Gears moving against each other
   - The stretching or slipping of a belt
   - The tires on the track
   - All the other moving parts of the car

Theoretical Calculations for a Solar Car

en• er• gy\'en-ə r-jē\ *n, pl*-**gies**[LL *energia,* fr. Gk *energeia* activity, fr. *Energos* active, fr. *en* in + *ergon* work - more at work] **1 :** the capacity of acting or being active <intellectual~> **2 :** natural power vigorously exerted <work with ~> **3** : the capacity for doing work.

A solar car takes electromagnetic radiation (light) from the sun and converts it into *electrical energy* with its solar panel. It then converts that electrical energy into *mechanical energy* using a motor. Finally, the motor converts mechanical energy into *kinetic energy* and the car moves forward. Energy can easily be converted from one form to another although there is usually a loss of energy with each conversion. For instance, if you connect your motor to a AA battery, it will run and slowly begin to heat up. This heat is lost energy! If the motor were converting the electrical energy into mechanical energy without any losses, the motor would not heat up at all. There are so many possible sources of lost energy in a real-world situation that we often simplify the problem by assuming that there are no losses at all.

Problem:
If we assume that there are no loses in the conversion of energy from the solar panel to the forward motion of the car, how long will it take our car to travel the 20 meter length of track?

What additional information do we need to make our calculations? Clearly if the car weighs more, we would expect it to travel slower. Therefore we would expect that the velocity of our car will depend upon its ***mass,*** *m.* We can measure the mass of our car by weighing it on a scale.

In addition, we need to be familiar with the concept of ***power.*** Power takes into account how quickly a given amount of energy is released. We could find a candle and a firecracker that has the same energy content, but the way in which that energy is released is quite different. In this case, the firecracker has considerably more power than the candle.

For the solar cell array, we can calculate the power output, *P.*

The panel is rated at 3Volts, 1.5Amps. How does this correspond to Power? *Electrical power* is the product of voltage and current:

$$P(\text{watts}) = I(\text{amps}) \cdot V(\text{volts}) = \frac{\text{kilogram}\cdot\text{meter}^2}{\text{Second}^3} = \frac{\text{kg}\cdot\text{m}^2}{\text{s}^3}$$

Electrical power is usually expressed in units of ***watts.*** A watt is 1volt x 1amp. Therefore our solar panel produces:
1.5 amps • 3volts = 4.5 watts
Compare this to a 60 or 100 watt light bulb. Our solar panel produces very little power!

The amount of energy contained in sunlight is approximately $1000 W/m^2$. That means that in a

square area of land 1meter on each side, the available power is 1000 watts. The single crystal silicon solar cells in your solar panel are approximately 15% efficient. Therefore if we had a $1m^2$ silicon cell, it would produce approximately 15% of 1000W=150Watts/m^2. Your solar panel has 6 individual cells connected to one another in series. Their combined area is about 6 cells x 2in x 4in = $48in^2$ = $0.03m^2$. If we multiply this area by 150W/m^2 we get:
150W/m^2 x $0.03m^2$ =4.5W. This is precisely what we calculated above!

Using some basic equations of motion from physics, we can now calculate the time, *t*, it will take our car to travel the 20m of track.

Equation 1, one of the most fundamental equations in physics, is that a force acting on an object is a function of the mass, *m*, of the object and the acceleration, *a,* that the object is experiencing.

$$F = m \bullet a \qquad \textbf{(1)}$$

Acceleration is simply the rate at which the velocity changes. For example, when a car accelerates, its velocity starts at 0mph and it ends up at 55mph. If it reaches 55mph in 8 seconds, the average acceleration is:

$$\bar{a} = \frac{v}{t}$$

$$\frac{55mph}{8s} = \frac{55miles}{hour} \bullet \frac{1}{8s} \bullet \frac{1h}{3600s} = \frac{0.0019miles}{s^2} = \frac{3.074meter}{s^2} \qquad \textbf{(2a)}$$

The line over the *a* in Eq. 2 means average. In order to keep the units consistent I have used some conversion factors. I have also expressed the answer in English and metric units. The calculations you will make below will use metric units. We can rewrite our expression (2a) for acceleration and solve for the velocity, *v*.

$$v = \bar{a} \bullet t \qquad \textbf{(2b)}$$

The third equation is an expression relating distance traveled, *d*, to acceleration and time.

$$d = \tfrac{1}{2} a \bullet t^2 \qquad a = \frac{2d}{t^2} \qquad \textbf{(3)}$$

Which can be rewritten in terms of the acceleration.

The only other equation we need is an expression that relates power and acceleration. Remember that power takes into account the speed with which energy is released. As you can see, the Eq. 4 has the velocity term in it for this reason.

$$P = F \bullet v \qquad \textbf{(4)}$$

Now, we want to make substitutions in this final equation until we are left with variables we know and can solve for the time, *t*. We know *P*=4.5watts, *d*=20meters, and we'll speculate that our example car weights *m*=0.5kilograms (about 1.1pounds). Pay close attention to the units we've used here because the equations assume that you are using these units. In the following section we will substitute Equations 1-3 into Equation 4.

$$
\begin{aligned}
P &= F \bullet v = (ma) \bullet (at) \\
&= ma^2 t \\
&= m\frac{\{2d\}^2 t}{\{t^2\}} = \frac{m4d^2 t}{t^4} = \frac{m4d^2}{t^3}
\end{aligned}
$$

We've done it! We have successfully eliminated the force, acceleration and velocity from our equations and have arrived at an equation with only one unknown quantity, *t*. We can rewrite our result and solve for *t* as follows:

$$t = \sqrt[3]{\frac{4(0.5kg)(20m)^2}{(4.5W)}} \qquad \textbf{(5)}$$

Using a calculator we can solve the problem.

$$t = \sqrt[3]{\frac{4(0.5kg)(20m)^2}{(4.5W)}} = \sqrt[3]{177.78} = 5.62\sec onds$$

So, if our car weighs 0.5kg, and there are no losses in the transmission of power, it will make the 20m trip in less than six seconds!! Using the mass of your own car and Eq. 5 above, you can determine how quickly your car should run the track. On race day you will undoubtedly find that the actual time is much more than this. If you time your car on the 20m track and compare that time to your theoretical time in order to estimate the efficiency of your car. If your car takes twice as long as you thought it would, it is 50% efficient. Good luck and enjoy yourselves!

Design Considerations for a Solar Car

Howard Wilson, Program Manager, GM Sunraycer Project

A solar car, whether full sized or a smaller model, must perform with very little energy available from the solar panel. Since the energy is limited, the designer must do everything possible to make the car efficient so that the maximum amount of energy is used to make the car go. In a car like Sunraycer, we had to consider many things. With the solar panel area limited, we wanted to have the most efficient solar cells possible. The electrical load on the solar panel had to be continuously adjusted by electronic controls to maximize the power under any condition of sunlight. The motor for driving the wheels had to be very efficient, too.

Aerodynamic Drag is very non-linear with speed. At very low speeds, below 10 mph, it doesn't have to much effect, but as speed increases to more than 30 mph, aero drag gets important. The magnitude of drag depends on the frontal area of the car, i.e., maximum cross section looking at the car from the front, multiplied by the coefficient of aero drag, which depends on the car's shape, multiplied again by the velocity squared. It is this velocity squared term that makes the drag increase quickly with velocity or speed. So the designer should make the frontal area of the car as small as possible and make the body as streamlined as he or she can. A poorly designed shape might have a coefficient of 0.5, and a very good shape might be as low as .012. So you can see that the drag could range over four to one. Make a smooth teardrop shape as well as you can considering that the solar panel has to be included. Use the wheels with the disc structure, not spokes. If spokes are used, they should be covered on both sides. Be sure the underbody is smooth, too, not open like a regular car. Make the openings for the wheels (if the body covers the wheels) as small as possible. If the wheels are not enclosed in the body, consider wheel pants.

Rolling Resistance is another energy waster. It is the energy lost in the wheel bearings and in the tire deformation. The tires on the Junior car are probably solid rubber so tire pressure is not a factor, but the rubber should not be very soft and the tires should be smooth (no tread) and very narrow. The bearings should be given careful attention. The shafts should be straight and the bearings (if they are sleeve bearings) should be made from a low friction material like Teflon or oilite (bronze). The lubrication should be very light - no grease.

The Drive Train can waste energy, too. Gears can be particularly wasteful if they aren't precision made. Some form of belt drive may be best, but be sure the belt doesn't slip, and that it is not overly tight. The drive ratio is important. You will want to experiment to see which drive ratio gives the best results with your car. It may be that different ratios are best for different sun conditions. You may want to be able to quickly change ratios to do best on a cloudy day from that ratio that is best on a sunny day.

The Weight of the Junior car is a very important design consideration. Since the car is probably accelerating most of the run, the weight is more important that if the car was traveling at a constant speed. Also the weight is a direct multiplier on rolling resistance. Twice the weight means twice the rolling resistance for the same wheels, tires and bearings. So use light-weight materials, built-up construction, or other lightening techniques. Remember though, that there must be enough weight on the drive wheels so that they don't spin.

NREL/BK-820-30827
Revised 8/23/01

Junior Solar Sprint

Inside Tips on Parts and Construction

Written by:
Robert Haehnel

Parts is Parts:

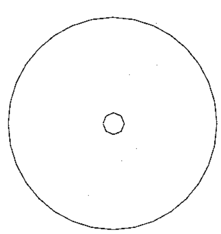
So you are ready to build the ultimate JSS car. You have the perfect design, and the ultimate gear ratio and tire size combination. But you just visited every hobby store in the Upper Valley and could not find a single gear or pulley that would fit your motor. Now what do you do? It is time to cannibalize!

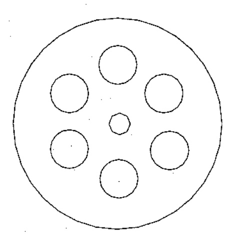
The best place to find gears and pulleys of all different sizes is in old tape recorders and VCRs. The very kind that you may find in Thrift stores all over the Upper Valley. While you're pawing through the tape recorded stock at the local thrift store also consider electric mixers, and remote control cars as other possible donors to your JSS cause.

As you start taking apart these relics save any belts, shafts, or screws that you come across. They may prove to be useful! The large pulley in a VCR makes a good, light weight, wheel. You will find in the tape recorders flywheels also. The flywheel shaft may run in a bronze (gold colored) bearing, that could be used as a low friction axle and bearing for the next JSS champion. Getting these parts off without damaging them is a little tricky. Use a vise to support the outer part and tap lightly with a hammer and punch on the inner part to drive the shaft or bearing out.

Also keep your eyes peeled for old "Spirograph" kits. These have a range of gears that could be used. A word of caution in using Spirograph gears. The holes in those gears don't go through the center. Consequently, you will need to locate the center of the gear, and drill a hole there for mounting these gears to your motor or axle.

Getting wheels that are the right size is not easy either. I have found that you can make wheels out of wood or Plexiglas with hole saws. If there is a carpenter, or wood worker in your midst you may be able to coerce them into making some wheels of various sizes for your students. Usually hole saw kits can make wheels in sizes ranging from ½" in diameter to over 3". A wheel made from a hole saw may look like the one on the left below. You can make the wheel lighter by drilling it out to look like the one on the right.





You may be able to find wheels on old toys that can work too. Many times those wheels are mounted on solid steel axles that are more useful than the wheels are. Be careful not to bend the axle while you are removing the wheels.

Does your wheel need a little more traction? Put a rubber band, or an o-ring around the circumference to keep it from spinning on hard surfaces. You might want to glue it on so that it doesn't spin off the wheel during the race.

Those that are planning on using pulleys for their drive train may want to manufacture their own. This can be done using the hole saws mentioned above (cut a groove in the circumference of the wheel for the belt to ride in) or using various diameter dowels from the hardware store. With the dowels you must carefully drill a hole at the center of the dowel for the motor shaft or axle. You can make a very smooth running bearing/axle combination from brass tubing and shafts that are available in many hobby shops all over the Upper Valley. To further reduce the friction use some graphite lubricant in your bearing assembly.

For the students that want to have *the* part for their JSS car be prepared to pay the ultimate price. There are precision gears, bearings and pulleys out there, but they are not cheap ($5 + ea.), and you will need to order them. Plan on a month delivery time. Just locating a manufacturer may take at least that long.

The Chassis:

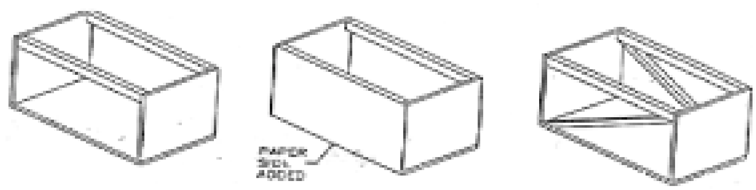
Now you need something on which to mount your solar panel, motor, gears, wheels and egg beater to. This main support structure is called the chassis. A few pointers on your chassis design. First, plastic soda bottles make good car bodies, but make a lousy chassis. It is too darn difficult to attach things to it. Better materials for the chassis are:

Foam Core (available at most graphic arts places)
Blue board installation (see lumber yards and hardware stores)
Wood (Balsa and pine are good choices)
Corrugated cardboard

This list isn't all inclusive, but gets you started. A note about Balsa, it is light, but splinters easily when it is drilled. Pine is a little heavier, but is stiffer, and is more "machinable". You may find that you will want to use a combination of the above materials in your car. Although "Legos" seem to offer an advantage in being versatile, you will pay a big penalty in weight. Nevertheless, you may find gears and axles from Lego sets that are useful.

A word about stiffness. The two beams below are the same size, but the orientation on the right is 19 times stiffer that the one on the left. Take home message: to make your chassis stiff and light, choose thin materials, and orient the long dimension vertically.

You can make a chassis stiffer just by skinning it with paper. The chassis on the left below would be very floppy. Adding paper to the outside of the frame (center figure) stiffens the chassis significantly. Another way to stiffen the chassis is to cross brace it as shown on the right.



What about putting it all together. Hot glue is great in the speed of assembly department, but you may find that wood glue is stronger and lighter. Screwing the chassis together works well too, but you'll pay a weight penalty there as well. If you do use screws put a little glue on the threads before screwing them in and they will hold better.

A Word about the Panel:

A trouble free way to attach your solar panel is using "velcro". It will make it easy to remove and re-attach your panel to your chassis. Alligator clips on your power leads from your panel to your motor allow you to quickly detach the entire panel from your car, and are a convenient on/off switch.

JSS Drive Train Design Tips

Robert Haehnel

So you want to build a JSS car, but have no idea what you should choose for the wheel size or gear ratio. Here are a few tips on how to get started. First off we need to start with what we know.

Known:

Motor Speed, ω — *8300 revolutions per minute (rpm) under load (0.278 in.-oz. torque at the speed)*

Vehicle Speed, V: — *The finishing times for the 1994-95 Upper Valley Race were around 6.5 seconds*

Track Distance = 20 m (65.6 ft)

$$V = \frac{20m}{6.5s} \approx 3m/s = 300cm/s$$

Gear Ratio Known:

If we have a set of pulleys or a couple of mating gears then we already have the gear ratio. Now we just need to find out what size drive wheel(s) we need to be competitive. The below figure shows how a pulley or gear system might look.

The variable **D** is the diameter of the pulley, variable **N** is the number of teeth on the gear, subscript **d** refers to the gear attached to the drive axle, and subscript **m** is the gear attached to the motor.

$$D_m = 1/4cm \qquad D_d = 1-1/4cm$$
$$N_m = 8 \qquad N_d = 40$$

Step 1: Determine the gear ratio.
For a pulley system the gear ratio is:

$$R = \frac{D_d}{D_m} = \frac{1.25cm}{0.25cm} = 5$$

And for a gear system

$$R = \frac{N_d}{N_m} = \frac{40}{8} = 5$$

Step 2: Find out the speed of the wheel.
If the motor spins at 8300 rpm then the wheel will spin at:

$$\omega_d = \omega_m = \frac{8300rpm}{5} = 1660rpm$$

But we need the wheel speed in revolutions per second (rps)

$$\omega_d = 1660rev/\min = 27.6r/s$$

Step 3: Calculate the wheel circumference.

To determine the wheel diameter we first need to know the circumference of the wheel (the distance the JSS car will travel each time the wheel turns one full revolution). This is simply:

$$C = \frac{V}{\omega_d} = \frac{300cm/s}{27.6r/s} = 11cm$$

Step 4: Determine the wheel diameter.
Now we can find out what diameter wheel, D_w, we need. The wheel diameter is determined from the calculated circumference:

$$D_w = \frac{C}{\Pi} = \frac{11cm}{3.14} = 3.5cm(1.4inches)$$

Step 5: Check calculation.
Now check to make sure the diameter of your wheel is bigger than the diameter of the drive gear. If it is, you're up and running. If it is not, you need to choose smaller pulleys or gears.

Wheel Size Known:
In this example we already have a tire size we want to use. We just need to find a suitable gear ration. Our wheel diameter, D_w, is 8cm (3.1inches).

Step 1: Calculate circumference.

$$C = \Pi D = 3.14(8cm) \approx 25cm$$

Step 2: Find the wheel speed.

$$\omega_d = \frac{V}{C} = \frac{300cm/s}{25cm} = 12rps$$

Now we'll convert that into rpm

$$\omega_d = 60\,\text{sec}/\min(12\,rev/\text{sec}) = 720\,rpm$$

Step 3: Determine the gear ratio.

$$R = \frac{\omega_m}{\omega_d} = \frac{8300\,rpm}{720\,rpm} = 11.5$$

Step 4: Design transmission.

Since the drive pulley/gear Robe be no larger than the drive wheel, we need to select a pulley/gear accordingly. For a pulley system we will make the drive pulley 10 cm in diameter. The diameter of the motor pulley then is:

$$D_m = \frac{D_d}{R} = \frac{10cm}{11.5} = 0.9cm$$

Notes: In these calculations friction and wind drag were not considered. In rt HaJSS car friction and drag will affect performance. To compensate we need to make the wheel diameter smaller, or the gear ratio bigger if we are going to get the best performance. This fine tuning of the cars performance will need to come from experience gained by testing the car, but these calculations will give you an idea of where to start.

Notice that we came up with two different combinations of gearing and wheel size. There is a host of different combinations that will work well. What you come up with for your car depends on what you have available to you for constructing your car.