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Remote Freedom

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REMOTE FREEDOM

By

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with help from

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Project submitted in partial fulfillment
of the requirements for the degree

of

DEPARTMENT HONORS

in

Mechanical Engineering

Approved:

Project Advisor

Department Honors Advisor

Director of Honors Program

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1998

REMOTE FREEDOM:

A Remote Controlled Power Wheels™ Toy For a Child with Cerebral Palsy.

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A Remote Controlled Power Wheels™ Toy For a Child with Cerebral Palsy.

Remote Freedom Team
USU's Department of Mechanical Engineering

June 3, 1998

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ACKNOWLEDGEMENTS

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ABSTRACT

Increasing mobility is a key to ensuring that a disabled child feels accepted and as normal as possible. The object of Remote Freedom is to provide an inexpensive design that will modify a toy vehicle so that it can run remotely. The case that we designed for was a child with cerebral palsy. Originally the toy vehicle on the market needed major modifications both for the safety of the child and the addition of the remote control. The main components that were added were a safety harness, a roll bar and motors to control steering and speed.

It was discovered that to meet the space constraints in the toy, three separate servomotors had to be used to control the steering, gas petal and the gear switching mechanism. In testing the prototype, the single servomotor used to control steering became inadequate. It is recommended that two servomotor in tandem be used so that the plastic gear inside the servomotor do not fail.

The total cost of the kit developed is $346, far less than the $500 limit required. The remote control and the steering servomotors constitute the major cost. When compared with the wire-remote car out now ($6,000) this price is within the means of the families who could make use of this toy.

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INTRODUCTION

Having a disabled child feel accepted and as normal as possible can be a challenge. Certain toys like the Fisher Price® Brand Power Wheels™ toy jeep can be unsafe for parents to give to their disabled child. The Remote Freedom team proposed to modify a toy vehicle to run by remote control and to fit it for a child with cerebral palsy. The main modifications to be added to the toy are a safety harness, a roll bar and servomotors to control steering and speed. With a remote control, a guardian could operate the car for the child, yet it would allow the child to enjoy a little freedom and excitement, much like a roller coaster.

Providing enjoyment for a child is one of the fun things an adult can do. The family of Ben Cox wanted to provide for him a safe toy vehicle that he could enjoy without worrying about his safety or the cost of a commercial wire-remote car. The commercial wire-remote car on the market costs about $6000 and is out of their price range. Remote Freedom's object is to modify an existing toy car is to make it cheaper to use. It has required engineering experience each team member has gained from studies in Mechanical Engineering. The design will draw from an expertise in Engineering Statics, Structures, Controls, Electronics, Dynamics and Material Science. Communications, Marketing and Economics will also played into the final design. This is a "real life" open-ended type of design, with a lot of the common restraints that make engineering challenging. The project has definitely proven to be a very realistic engineering problem, including those annoying little problems that pop up and defeat what was thought to be the perfect design.

Some of the problems encountered were working with an existing design and using widely available parts that can be found or ordered easily. These problems would keep actual costs down compared to building a new car "from scratch". The "from scratch" model would have cost much higher than just modifying an existing design. For example, the servomotor was bought off-the-shelf because the cost of developing it outweighed the benefits we would receive in designing it from "scratch". Each of these problems was designed for in the prototype.

To accomplish the prototype design each team member was assigned responsibilities. The workload division was broken down into separate parts. Craig Peck analyzed the safety and was responsible for drawings. For example, he had the responsibility for the design of the new roll bar and seat belt. Dominic Florin analyzed the remote, controls and the connections to implement the servomotors as well as any electrical aspects of the project. This included the four bar linkages designed for steering, gas petal and gear shifting. Delmer Brower was responsible for writing the report and user's manual for the car, and helping to mount the modifications within the car. He was also responsible for testing the prototype.

Currently, the car prototype has been assembled and tested for flaws. It was discovered that the servomotor chosen had plastic gears that sheared shortly after testing the car. Replacement plastic gears were found and installed with a better mechanical advantage and a spring was added to protect the gears from shearing, in the event of a shock. It is a shock that most likely caused failure in the original motor. Another option to prevent the shearing of the gears would be to put metal gears in ($70 more) or two of the original servomotors could be used in tandem to give a better response, for almost the same price.

The car is remotely controlled by four bar linkages to change gears, steer, and switch the car on. A problem in gear shifting that has been discovered is a difficulty in keeping the car in 1st gear. This was helped by setting the trim of the servomotor, but could be improved. This is an inconvenience that can be improved on later models and is not a safety concern for the operation of this car.

To ensure proper servomotor response a large 6-Volt battery was added to the car to provide a quality power source (close to 6-volts for the entire period of operation). Hopefully this battery can be of the same brand of the original two so that it can be recharged easily and so that the batteries can be rotated to provide a long battery life.

REMOTE FREEDOM'S OBJECTIVES

Remote Freedom's plan to accomplish the building of a modified Power Wheels™ toy jeep prototype is outline in the following bullet list. The main objectives were over safety concerns, the controls over the car, and the testing of the design to verify that the design will work.

OBJECTIVES, REMOTE CONTROL:

- Choose the servomotors that will control the car
- Choose the controller
- Design the interface between the servomotors and the car
- Design an electrical system that will supply power
- Able to go forward at two different speeds
- Able to go in reverse
- Able to turn
- Simple interface between the person and the remote control device
- Easy instructions to follow for modification
- Good range of the remote controller
- Stable
- Safe

REQUIREMENTS

The most important requirement is to ensure that it is safe for the child with limited motor capabilities. Other requirements are shown in Table 1 below. The modified Power Wheels™ also must be assembled out of readily available part. This simplicity will help costs stay low for the consumer. A User's Manual will be given to aid the parents in operating the modified toy car.

Mark Horenstein, a leading design engineer, commented that "a good engineer will review a design many times, often proceeding through numerous iterations until the best configuration is found" (1998). Thus throughout the design many different solutions were considered to meet these requirements. In the Design Alternatives Considered section these alternate solutions will be discussed.

Design Parameters	Requirement
Cost of design	less than $1000.00
Cost of kit	less than $500.00
Size	fit into the toy (motors)
Weight (of kit)	less than 40 lbs.
Range of the controller	more than city block
Steering torque	300 oz.-in.
Forward / reverse	Two gears forward and one reverse
Power available	6 volt or 12 volts unmodified

Table 1. Design requirements for Remote Freedom.

PROJECT SCHEDULE

This project has required the design team to meet at least once a week to build and design the toy car. Beginning the third week in November, research was done to find a suitable remote controller to order and previous designs were evaluated. The Remote Freedom team presented two design reviews to the members of the faculty of the Mechanical Engineering at Utah State University. These reviews were on the fourth week in November 1997 and the first week in March 1998. Comments from each of the reports are included in the appendix. The final review will be June 1, 1998. In the fabrication of the toy car the design team worked on the remote controlled jeep for at least four hours a week. Upon completion of the prototype, the Remote Freedom design team tested and modified the jeep through June 1998.

The fabrication of a remote controlled jeep required space and equipment. The workspace is located at the Center for Persons with Disabilities at Utah State University. This laboratory also provided the tools necessary for fabrication. Each member of the design team has a personal computer to facilitate the writing of a User's Manual.

DESIGN CONSIDERATIONS AND RESULTS

Many considerations involved with the design of the toy car fall under the following categories: Top Five Concerns, Safety and Structure, Motor and Controls and Test and Reviewing. In the following categories each of these considerations will be followed by the results in the design of the toy car.

TOP FIVE CONCERNS

1) *What have others come up with; why did they do what they did? What should be used?*
The previous designs were not remote controlled, but were joystick based. The motors used to turn the wheels were regular DC motors with limiting brushes for control. In addition the other designs did not have to keep track of position of the wheels or have the same challenges for gear switching and had a electronic gas pedal.

2) *How will the car go forward and reverse?*
A servomotor positions the speed control lever. With the zero position being forward slow (2.5 mph) and when it turns right the car shifts up to high (5 mph), and when it turns left the car shifts into reverse.

3) *Two channels or three? What kind of servomotor(s) will be required to do this?*
One channel was used for speed and gas pedal, but there were two servomotors on the same channel. One controlled the speed and the other the gas pedal. The other channel controlled the steering.

4) *What happens if the car goes out of the controller's range?*
The range is more than a mile, so the car needs to stay within this range, but it is not foreseen as a problem to do this. Since the controller overrides the random noise that is usually present, the car stays in control. If the car goes out of range, random noises will control the car. The servomotors will stay where they are until another signal is picked up, however, if these noises are truly random and evenly distributed, the servomotors will return to their zero position and the car will then stop.

5) *How fast is the car going to stop; how is it going to do so?*
The car slows down fast enough without power that it is sufficient for breaking. The gas pedal controls whether or not the car is going, with the zero position being the "breaks".

6) *Is there going to be more than one speed and how?*
The position of the servomotor is able to control the switching between

both forward speeds, but it is a little difficult to stay in the first speed for extended periods of time.

SAFETY AND STRUCTURE

1) *What additional restraints will be required to keep the child safe?*
A roll bar and safety harness was added to keep child safe. A helmet will be required for the child to rid in car.

2) *How will the original structure be compromised by the modifications?*
Several holes were be drilled to allow the mounting of servomotor and roll bar. Material was removed to allow for the extra battery and the roll bar.

3) *What additional materials will be required?*
Extra pipe was used to allow for a secure hold of the roll bar to the frame of the car.

4) *What materials will be used in modification to ease in forming, reduce cost, and not jeopardize strength?*
Steel pipe was used in the roll bar because of its low cost and high strength. Wood was used for the mounting of servomotors.

5) *What will be the cost involved in: designing, prototyping, and building the kit?*
The cost for the kit is estimated at $346 and the cost of designing the car was $598. Two tables are shown in Tables 2 and 3.

6) *Make instructions for the modifications, which are easy to follow.*
Modifications are simple in design but does take strong mechanical inclination to adapt it to different cars.

ITEMS TO GO INTO KIT	COST
Two Futaba S3801 Servo Motors	$160
Remote Control and two small servomotors	$86
Batteries	$40
Roll Bar	$28
Seatbelt	$12
Push Rods	$10
Wood / Screws / Cotter Pins	$10
Total Cost of Kit	**$346**

Table 2. Cost of Proposed kit.

DESIGN OF CAR	COST
Materials Purchased	$296
Power Wheels (donated)	$150
Indirect Costs (donated)	$152
Grand Total	**$598**

Table 3. Cost of Design

MOTORS AND CONTROLS

1) *Find a controller with the desired range and channels.*
The controller selected has a range of more than a mile and two channels.

2) *Determine the number of degrees of freedom of the car with safety features.*
All the safety factors were implemented without changing the number of degrees of freedom. There is just two, steering and speed.

3) *How will the car turn, what kind of servomotor?*
Using a four-bar linkage for transmission and amplification of the torque from a large servomotor that can produce 194 ounce-inches of torque. (Futaba, S3801)

4) *How fast is the car going to turn and the torque required to do so?*
The servomotor has a response time of .22 seconds and can produce a torque of 194 ounce-inches. This, however, caused failure of a plastic gear and so less torque is actually used to turn it.

5) *What is the power requirements for the servomotors; how is it to be supplied?*
The power required is 6-Volts, but it needs to be high quality so a large battery, like the ones the car runs off of will be used to provide the power for all the servos.

TEST AND REVIEW

1) *Is the safety adequate?*
Yes the safety will be more than adequate. Many engineering tests were run to find the moments of inertia, energy involved in a roll over, and stresses that could be withstood by the car. In all of these tests it was found that the child and car would be safe in the event of a roll over.

2) *Are there unforeseen interactions between controls?*
There is some feedback between the servomotors, however, this noise does not effect the control of the car due to an activation requirement before the car responds.

3) *How large of a slope can the jeep run on?*
Through engineering analysis it was determined that the jeep can safely turn on a slope of 14 degrees at top speed and still not tip over.

In the following section a few of the more significant design considerations will be analyzed.

SIGNIFICANT DESIGN DECISIONS AND WHY?

In the design of the toy car there were some items that were particularly important. Controlling the steering, switching gear and starting the motors was an important part of the design. In the last part of this section the seat belt and roll bar modifications will be discussed.

CONTROL DECISIONS

STEERING

There are several choices that had to be made to decide how to control the steering of the car. In order to start the selection process for the servomotors, the amount of torque required to turn the steering wheel had to be determined.

There are several choices that had to be made to decide how to control the steering of the car. In order to start the selection process for the servomotors, the amount of torque required to turn the steering wheel had to be determined. The basic setup to measure the torque was a force-meter tied to the steering wheel. The force-meter was held perpendicular to the steering column as much as possible. The amount of force required to turn the steering wheel at a slow constant rate (to get as close to a static as possible) was recorded. The setup of this is in Figure 1. Since the amount of torque required to turn the steering wheels changes, depending on the surface and a variety of other

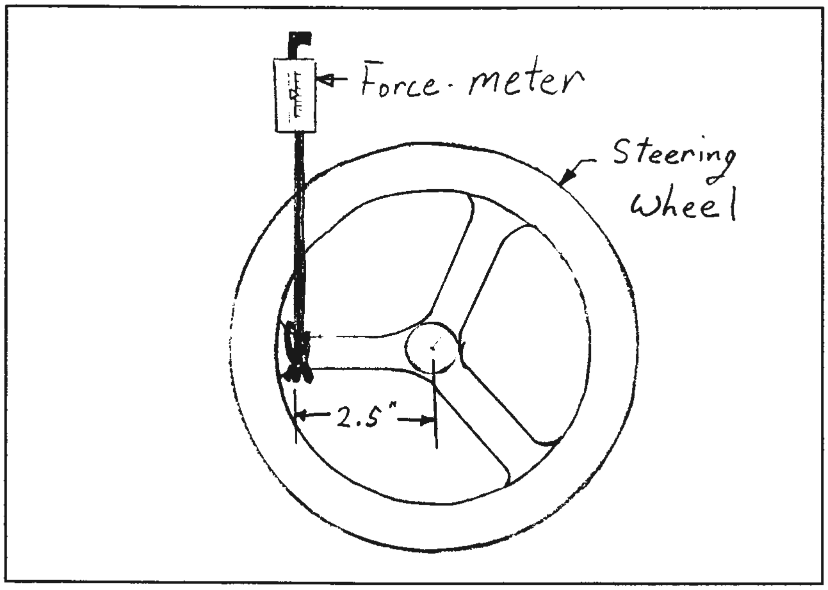

Figure 1. Torque test on steering mechanism.

environment changes, an average value was taken on each surface that was tested. These surfaces were an attempt to find the largest amount of torque that the steering would be required to operate at and is what the car would most likely be on. The highest amount of force occurred when the car was in mud or in snow at a steep angle. This force was about 7.5 pounds and that corresponds to a torque of 280 ounce-inches. The rest of the surfaces and the amount of force required to turn the steering wheel are summarized in Table 4.

SURFACE	FORCE TO TURN (LBS.)
CPD Floor	6
Asphalt	6.5
Snow at 15 Degree Angle	6.5
Dirt	7
Grass	6
Cement	5
Mud	**7.5**
Snow at 50 Degree Angle	7.5

Table 4. Various forces to turn car on different test surfaces

Next the dynamic torque was measured on the steering wheel to see what kind of an effect that could have. The test was rolling the car at top speed, about 5 mph, into a blockage of one wheel, in this case a 2 x 4. The amount of force that the force-meter went up to is what was recorded. After testing on a few surfaces, it was determined that this force was about half of the "static" test, however, it was also very sensitive to the amount of weight in the car. The more weight that the car had in it, the larger the block had to be to stop the car and not have the car jump over it, and this larger weight caused more torque at the wheel, which did become larger than the static torque. Since the car is not suppose to be running into objects, and the height of the obstruction had to be large (greater than 7 inches) it is not foreseen that the steering would have to remain controllable during such a collision. This means that the steering would move during the collision and afterward would return to where the steering wheels were set before the event.

A large servomotor, one that could produce the maximum torque of 280 ounce-inches, would have been ideal. There was no servomotor that could be ordered directly with this much torque, and a special order of a large servomotor did not appeal because of the cost. (These can get to be several hundred dollars!) Since the servomotors could turn between 60 degrees and up to almost 360 degrees, one of these servomotors could be used with a mechanical advantage. The largest servomotor that was found produced 194 ounce-inches of torque.

To connect the motor to the steering wheel required some mechanical amplification. Gears are the most common type of amplification and since we have gone through Mechanics Of Machinery we were quite comfortable with analysis of such a system. The problems of this system made the gears look less attractive; Gears are expensive to machine, and the correct amplification was impossible to find unless more than two sets of gears are used and each set of gears takes some of the power away. The softness of the plastic causes the steering column to deform as well and with the internal stresses created by gears, the teeth would skip, causing wear and an incorrect positioning of the servomotor. The gearbox would also have to be sealed to keep out the environment, which is destructive to gears. The solution was a four-bar linkage. If the steering column deformed, the wheels would turn a little, but that could be countered by the servomotor and it did not cause the servomotor to lose its zero position. The amount of amplification for a four-bar linkage is infinite, and easily changed, if desired. The efficiency of a four-bar linkage is the same as a single set of gears and the cost is lower than a set of gears. The pinned joints do not need to be protected as carefully as gears.

SWITCHING GEARS

The switching of speeds was the next challenge. A lever controlled how fast the car would go, first being about 2.5 mph, second being 5 mph, and a reverse of about 2.5 mph. Electronically changing gears would have given the ideal results, however, it would have been expensive and much more complicated than what was required. The lever controlled a set of switches that controlled the voltage to the motor. The simplest solution was to move the lever itself with a servomotor. This setup can be seen in Figure 2. The amount of force required to do so is approximately 16 ounces. The common servomotor can produce 44.5 ounce-inches of force and the lever only had to move a few inches, using less torque than the maximum torque of the common servomotor. It was planned that this servomotor could also be used to press the gas pedal, but that had to be changed.

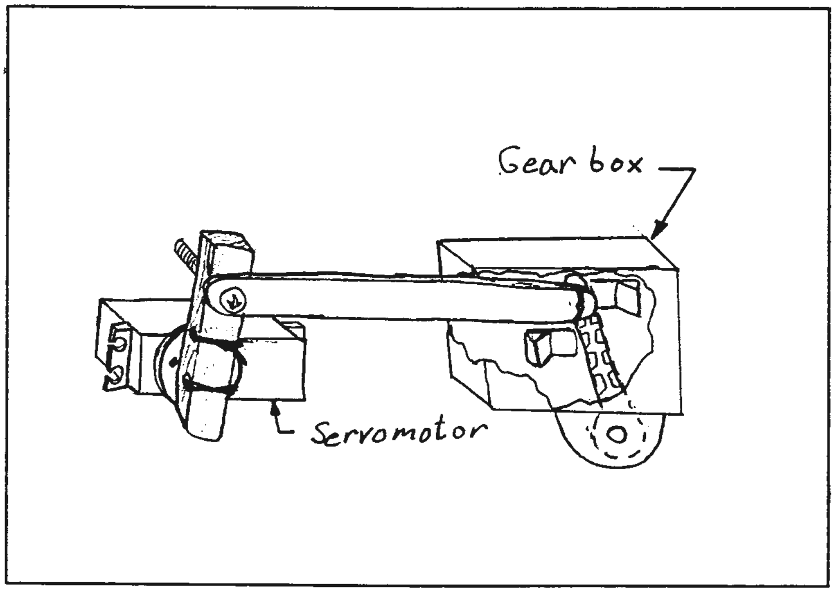

Figure 2. Gear switching mechanism

GAS PEDAL

The gas pedal was a switch that the kid would push down to go. A simple power relay that could handle the maximum current of 30 amps that occurred when the car first started out. Since the original pedal was meant to be push down by a leg it took more force than what the servomotor could produce. To complicate this the button had to be pushed whether the car was in forward or reverse. The original solution was to use a brass tube to push the button down as the servomotor turned as in Figure 3. When the servomotor turned right, it would push the button down, or left would also push the button down. Due to the large amount of friction this could not be implemented. The next solution was to put a long spring on the button such that the force from the spring, across the movement of the gas pedal remained constant. In this way only a little bit more force, from the servomotor, would be required to push the button in. See Figure 4. This took up more room than what was available in the car, so another method had to be devised. The power relay had a set of springs in it that were making it difficult to push down so the relay was taken apart and a new softer spring was put in. Now the force required to push the button in was small. Finally it was decide to use two servomotors, because of the space restraints, which would be on the same channel, meaning that both servomotors turn at the same time. This has worked very well and can be seen implemented in Figure 5.

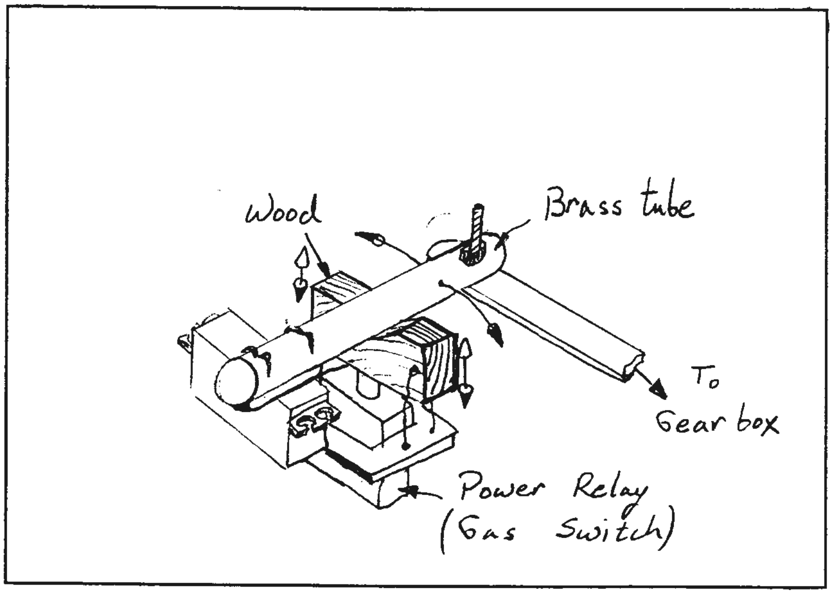

Figure 3. First design of gear switch and gas pedal with one servomotor.

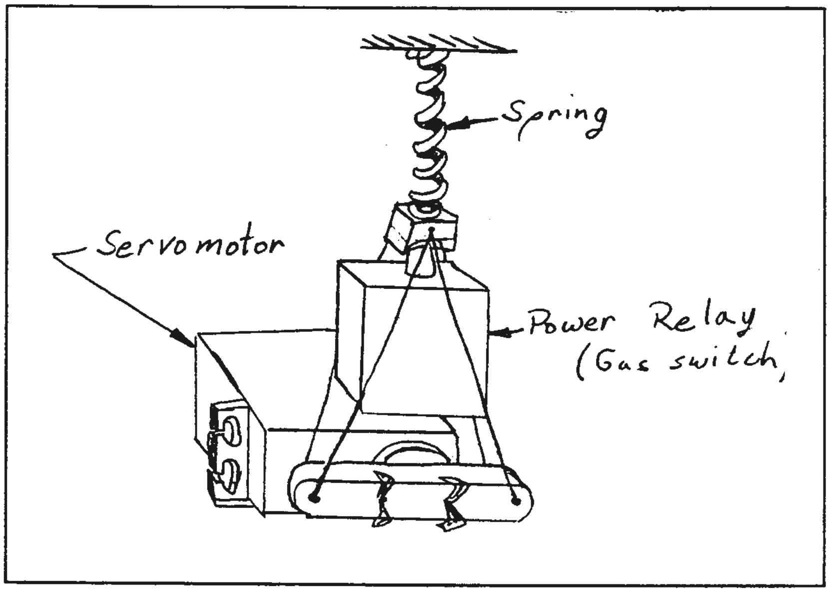

Figure 4. One of the power relay (gas switch) designs.

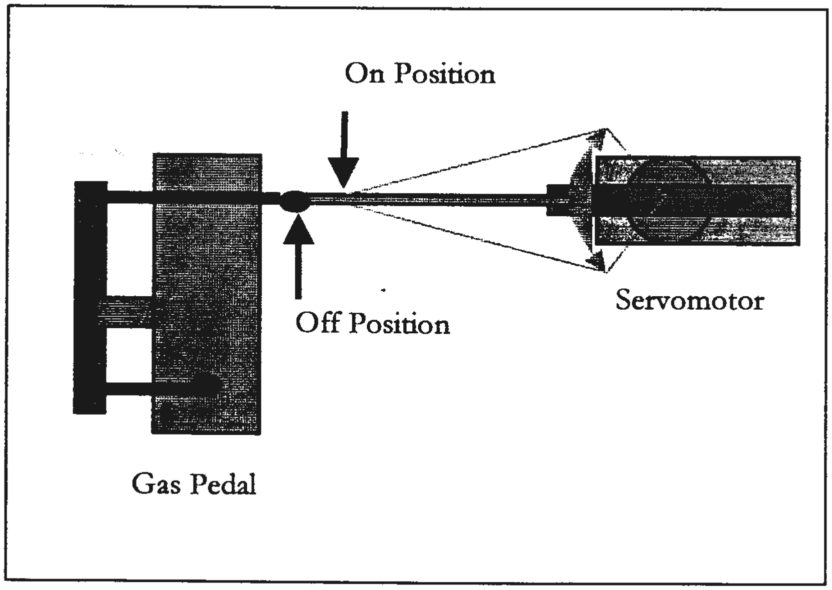

Figure 5. Final power relay design.

SAFETY DECISIONS

ROLL BAR

After meeting with Ben Cox it became apparent that the roll bar would need to be redesigned since his head was 10 inches above the original roll bar. This was also confirmed with a tensile stress analysis on the original roll bar as found in Appendix D. If the jeep were to flip over at top speed, according to this analysis, the plastic surrounding the original roll bar would fail. Thus, a new roll bar and mounting configuration were needed for the car to be safe. This new roll bar needs to within the specifications set forth by SAE standards found in Appendix D.

The easiest way to modify the roll bar would be to simply extend the bar a little further and insert bolts to hold the new bar in place. This alternative was rejected when it was determined that such a bar would fail in tension like the original roll bar failure.

A second design was to cut off the plastic sleeve that holds the roll bar and replace it with a 10-inch horizontal bar that would be welded into place. This bar would have needed to be fastened to the car by placing PVC piping as a sleeve over the metal and gluing it to the plastic in the car. A picture of this design is found in the appendix. This design hinged on the belief that the injection-molded plastic that the Fisher Price Company used was Acryno-Butadiene Styrene. By use of tetrafuron this ABS would attach to the PVC with a tensile strength of 1000 psi. This would have worked nicely had the material been ABS, but when this design was attempted with many different chemical adhesives the plastic was found to be chemically inert. As a side note it was determined from the failure of this design that the plastic on the car was actually polypropylene, and the engineering stresses were reevaluated with the properties of this plastic.

The final failed alternative design was the idea to fasten the joints connecting the roll bar by use of welds. This design failed due to the cost and danger involved in welding. Since this design should be able to be used by an average person and since most people do not have the means or experience to fasten the roll bar components by welds.

. Other design aspects of the roll bar were also evaluated, and there were many different alternatives considered. On of these was the decision on what type of material the roll bar would be made out of. The different alternatives were to make the roll bar out of PVC, aluminum or steel. The PVC would have been easily obtainable and lightweight. This would also have been easy to assemble and would have been inexpensive. Unfortunately, PVC would not have provided the strength requirements so this design material was rejected. Aluminum would have provided sufficient strength with a lightweight, but would be very expensive. Steel was the final alternative and was accepted due to its strength and since it is inexpensive. Although steel is a heavier material, it was determined that the car and motors could support the added weight.

The final design alternatives came in deciding how to create such an odd shaped roll bar. The first suggestion was to use a pipe bender to fashion the bar in the new shape. This was attempted and found to be difficult to keep the pipe from folding into an unusual shape. The next alternative was to cut the pipe into simpler sections and then weld these parts together with pipe connectors found at Anderson Lumber. This was assumed to be expensive and time consuming. Upon further analysis it was discovered that the pipe connectors were made of cast iron while the pipe was galvanized steel. These two materials are nigh impossible to weld together making this design impractical. The design agreed upon was to thread the pipe ends at the aforementioned store for a mere fifty cents per thread. This would not only create good strength, but would also enable the roll bar to be assembled and disassembled at will.

The roll bar as seen in Figure 6 is complete with ten galvanized steel pipes that are connected together with four T joints and two ninety-degree bends. These were mounted to the car and pipe insulator was taped to the bar for cushioning and appearance.

SEAT BELT

There were many different designs considered to replace the safety belt provided by the Power Wheels company. Their belt consisted of a single Velcro strap that crossed the shoulder and hooked to the another Velcro strap. This design would be entirely inadequate in the event of a roll over, and also provided little to no support for the disabled child. The new seat belt was to be designed in conjunction with the new roll bar and needed to provide safety, support and security to the users of the remote jeep. The first and most simple alternative was to replace the Velcro with a buckle and keep all of the other original components. This alternative was rejected due to the belief that in the event of a roll over, the child could easily slip around the single strap and be crushed between the car and the ground.

The second design alternative consisted of four straps. Two of these straps would be connected to the roll bar slightly above the shoulders and the other two straps would connect to the car around the child's torso. These four straps would come together at a single buckle, which would have been located at the child's chest. This design also failed after further investigation. It was noted that such a design would be very difficult to adjust to fit the measurements of different children. It was also discovered that Ben Cox is fairly bottom heavy and would need support to keep him from slipping down in the seat. It is possible that he could slip down so that the buckle, which would normally be at his chest, would be situated at his neck. If this was to occur and the car came to an abrupt stop the child would be injured.

The third design alternative consisted of the same two shoulder straps being connected together and coming down to a belt which was connected to another strap which connected to the floor of the car. Although this design provided the support for the torso, it was rejected. This rejection came from the poor positioning of the buckle and the inability to adjust the shoulder straps once the belt was in place.

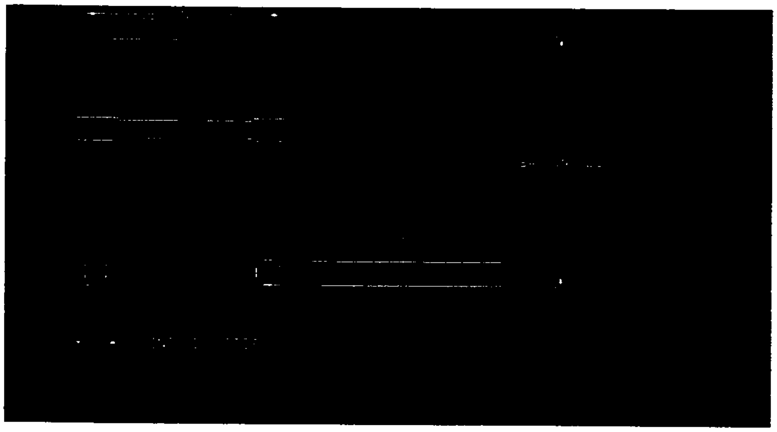

Figure 6. Roll bar design.

The fourth design consisted of the same basic design of the third, except that the two upper straps connected to the buckle and were to be adjustable. The third strap would come between the legs and position the buckle at the child's chest. This design was accepted due to its simplicity and ability to provide the necessary support. The fourth design consisted of the same basic design of the third, except that the two upper straps connected to the buckle and were to be adjustable. The third strap would come between the legs and position the buckle at the child's chest. Each of the three straps would be padded to provide support and comfort. A piece of sheet metal was designed and analyzed to fasten the lower seat belt to the base of the car. This metal was bolted in place with two grade 5 SAE standard bolts. Figures 7 and 8 show the design of the sheet metal and bolt respectively. This design was accepted due to its simplicity and ability to provide the necessary support.

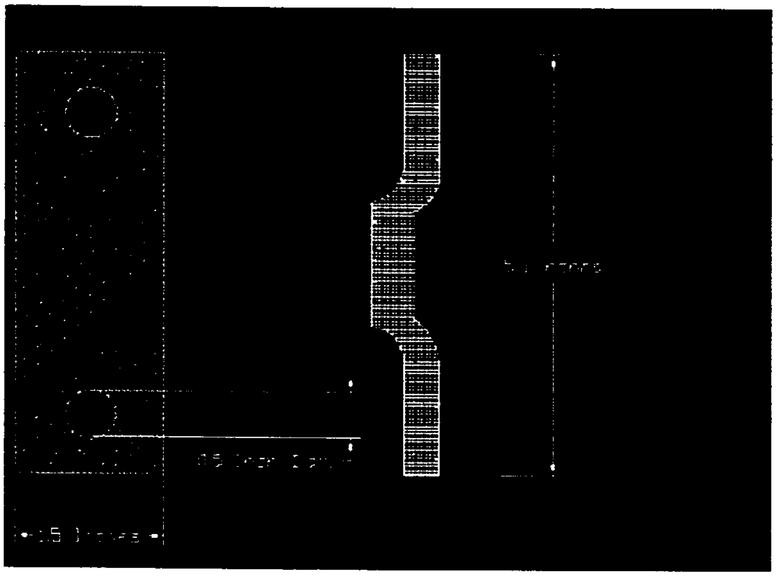

Figure 7. Sheet metal bracket for seat belt.

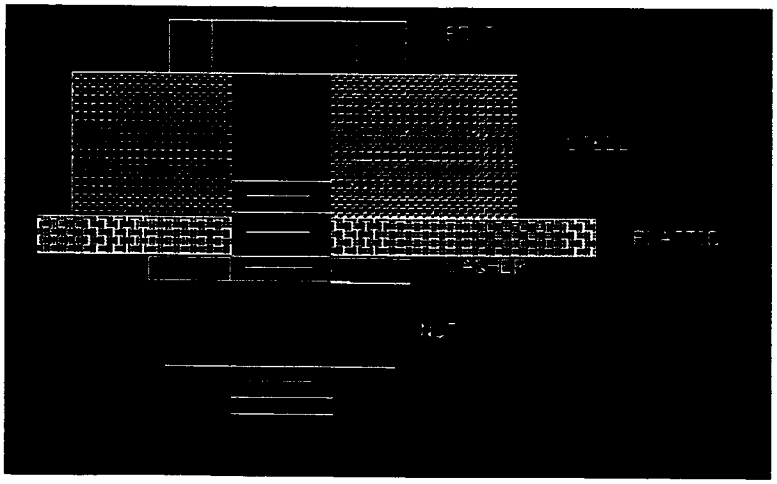

Figure 8. Bolt analysis.

FUTURE RECOMMENDATIONS

With inventing there is always room for improvement. A good design will not only complete the requirements set forth by the user, but will also include suggestions for the continual improvement of the product. In this section we set forth our recommendations for improvement on the vehicle.

The first design aspect that could be improved on the jeep is the position of the seat. After the year of improvements on the jeep, Ben Cox has grown. His growth spurt has made it difficult for him to fit comfortably in the car, especially in the position of his knees. Unfortunately, the car seat is in the largest position possible and could not be extended without cutting new seat tracks or by redesigning of the original car. This would take additional time to ensure that the car would not flip over by the change in the car's center of gravity and to measure the new torque requirements for steering.

The next suggestion would be to further improve the turning capabilities and durability of the car. Adding a second large servomotor exactly opposite the current servomotor could do this. These servomotors would need to be connected in parallel so that their torque would be complementary. This would greatly increase the ease and reliability of turning the jeep. Also the servomotor for steering currently has plastic gears. To increase the durability of the car it has been proposed that these gears replaced metal. Although these changes would greatly enhance the turning capabilities, they would be fairly expensive. The second servomotor and metal gears would enhance the response and durability of turning respectively.

The final suggestion would be to create a web page to share the specifications and instructions for modifying this car with the rest of the world. In order to make this, the Power Wheels company would need to give their consent so that all licensing and trademark laws are followed. The web page would also need to have a disclaimer to absolve USU from any liability. This would require the consent of the university. Despite the risk involved, by placing our findings on the World Wide Web, many handicapped children could have access to increased mobility and enjoyment.

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APPENDICES

Appendix A: Personal Vitae

Appendix B: Steering Mechanism

Appendix C: Gas Petal and Gear Switching Mechanism

Appendix D: Safety Calculations and Tests

Appendix E: Power Wheels Information

Appendix F: Cost Sheets and Catalog for Futaba

Appendix G: Photos of Design

APPENDIX A:

PERSONAL VITAE

540 E. 200 NORTH APT. 4
LOGAN, UT 84321
PHONE (435)-753-5385
E-MAIL SL1RN@CC.USU.EDU

Delmer T. Brower

Objective

Qualifications to work on Remote Freedom Team.

Education

1994 - 1998 Utah State University Logan, UT

BS Mechanical Engineering

- Portuguese Minor
- GPA 3.533

Computer Experience

- AutoCAD
- IDEAS modeling program
- Fortran and C Programming
- Microsoft Office (Excel, Word, and PowerPoint)
- Desktop Publishing (Quark Xpress, Photoshop, and Illustrator)

Work experience

1996 - Present Deseret Industries Logan, UT

Dock Lead

- Supervised a team of 10-15 people in Organizing and Processing donations.
- Participate in a team to evaluate plans to change the Customer Service Center.
- Put into action a plan to increase the efficiency of handling donations.

Spring 1996 Space Dynamics Lab North Logan, UT

Research Assistant

- Participated in a workshop to learn Toolbook (a multimedia training software) and how to use it to teach engineering processes to others.
- Cooperated with a Manufacturing Engineer in the design and publication of a Computer Integrated Manufacturing poster.

1994 - 1996 Publication Design and Production Logan, UT

Copy Center Worker

- Worked on a wide variety of computer projects to meet customer deadlines.
- Trained new employees on equipment and company procedures.
- Entrusted with the responsibility to supervise copy center when needed.

Interests and Awards

Interests: Racquetball, running, reading, Indian Lore.
Awards: Member of Tau Beta Pi, Golden Key National Honor Society, Alpha Lambda Delta Honor Society, Eagle Scout.

Volunteer experience

1991- 1993 Two Year Volunteer Service Fortaleza, Brazil

- Learned the value of diversity and working as a team.
- Communicated with small and large groups to enhance Public Speaking skills.

Dominic M. Florin
sl9m1@cc.usu.edu

900 West 370 South
Logan Utah, 84321
(435) 753-8971

Objective : To gain experience working in a group, using my technical knowledge and presenting technical information.

Education :

Utah State University GPA : 3.83 Fall '96 - Now
Degree : B.S of Mechanical Engineering (June '98)
Salt Lake Community College GPA : 3.91 Fall '95 - Summer '96
Granger High School GPA : 3.86 Graduated June 1995

Unique Classes :Artificial Intelligence
Drafting & Auto-CAD (3 years)
Control Theory
Robotics
Modern Compressable Flow

Computer Skills :

Programming languages : Fortran, Basic, C, and some X-Lisp
Applications : Windows 3.1, Auto-CAD , MAT-lab
Word Perfect, Quatro-Pro, Netscape

~ Willing to learn more computer skills ~

Honors & Awards :

Scholarships : * Kiwanis
* Deans Departmental (Full Tuition)
* Intermountain Electrical Association -Twice

Awards : * President's list
* President's Education Award
* Advanced Placement Scholar with Distinction
* Visual Arts Sterling Scholar

Work Experience :

8/96-Now *Salt Lake Community College / Utah State University*
Tutoring math, physics and chemistry.

5/95-8/95 *O'ccurance Inc.*
Telemarketing : Tell about products, selling products and writing up orders.

9/89-4/95 *Crestwood Apartments*
Maintenance Worker : Responsible for cleaning, fixing, showing apartment and taking applications. Work done with minimal supervision.

Community Involvement :

I am involved in both Circle - K (college) and Key Club (high school) which are service oriented clubs. This includes organizing a group to help with "Slug the Bug" immunization program and to serve food at St.Vincent De Pauls Soup kitchen.

Recommendations available upon request.

CRAIG PECK

Current Address:
494 East 765 North
Brigham City, UT 84302
801-723-6347
1-800-361-2021
FAX 801-723-7886
E-mail slf0r@cc.usu.edu

JOB OBJECTIVE

An entry-level position as a Design Engineer

EDUCATION

Four years at
Utah State University, Logan UT
GPA - 3.87

COMPUTER KNOWLEDGE

WordPerfect 6.1 C Windows95 Excel BASIC
Fortran Quatro-Pro Quicken CADAM DOS
HP48G Matlab Mathcad Fluent

EXPERIENCE

Computer Assistant, Peck Estates Realty, Brigham City, UT Jul 1994 - May 1997
- -Wrote computer software to facilitate the financial part of real estate
- -Helped Design a stronger, easier, more aerodynamic real estate sign
- -Designed Plot Maps to aide contractors in placing the foundation on a lot

Stocker/Cashier, Payless Drug, Brigham City, UT Sept. 1991 - May 1992
- -Learned Customer Relation Skills
- -Maintained and Balanced Cash Drawer

Two-Year Voluntary Service, Sao Paul, Brazil, 1992-1994
- -Developed Team Building skills by constantly working in groups
- -Communicated with both small and large groups to enhance public speaking skills
- -Learned leadership skills

PROFESSIONAL ORGANIZATIONS

A.S.M.E.
Tau Beta Phi

AWARDS

Most Outstanding Freshman in Mechanical Engineering 1992
Math Sterling Scholar 1991
Eagle Scout

APPENDIX B:

STEERING MECHANISM

Four Bar linkage for Steering (Perliminary design)

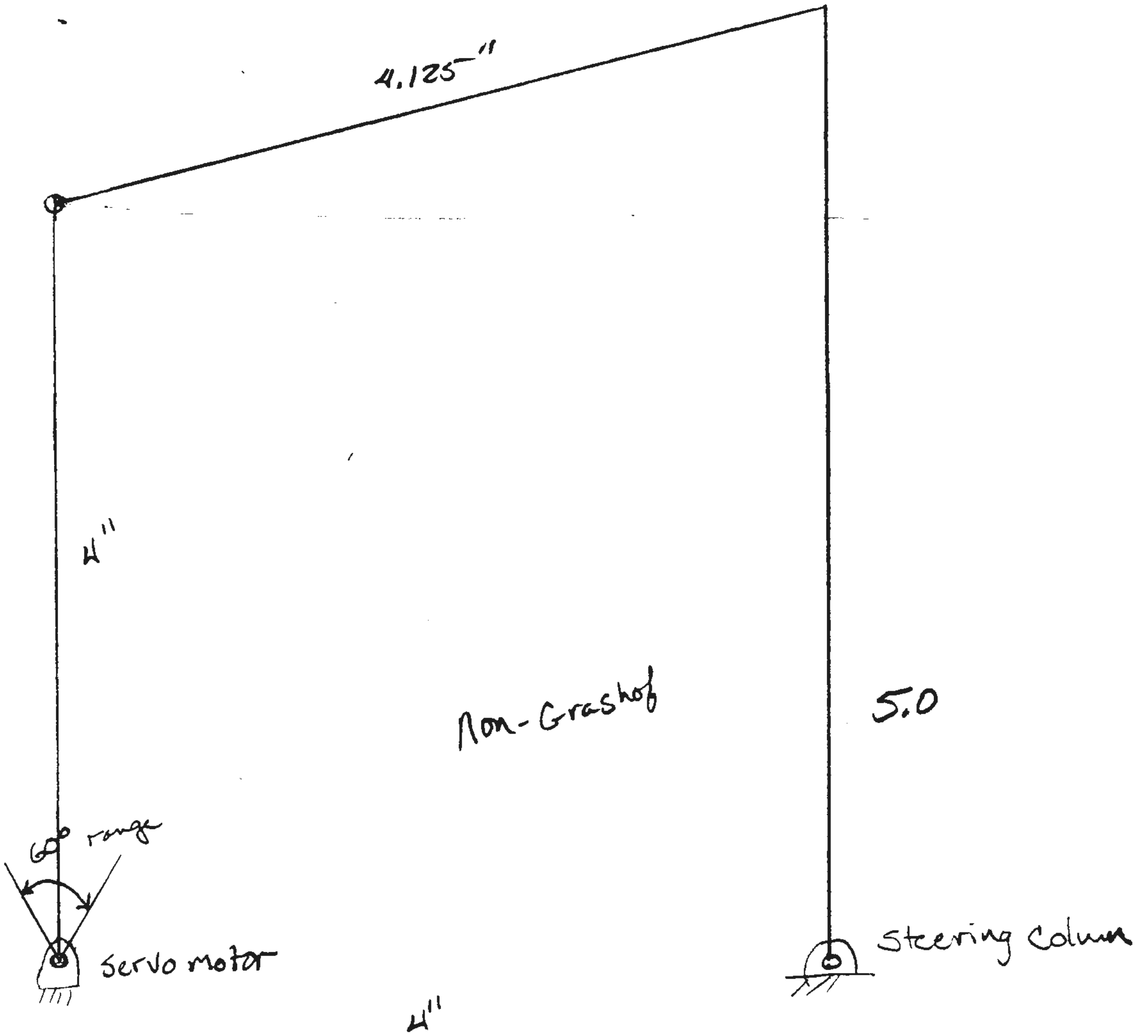
$\frac{x_2}{x_1}$ = fraction of additional torque = $\frac{240 \text{ oz-in}}{194 \text{ oz in}}$

$x_2 = \underline{\underline{4}}$ or $4.\frac{1}{8}''$

$x_2 = \underline{x_1}\ \frac{240}{194} = 4.95''$

240 oz-in

Case 1: Nuetral Position



too large

Final Four Bar Linage Design

FOURBAR 5.1 Delmer Design # 4 05-30-1998 at 10:26

Link #	Length in Inches
1	5
2	1.5
3	5.25
4	2.5

Open/Crossed = OPEN

Start Theta2 = 60 Degrees

Final Theta2 = 120 Degrees

Delta Theta2 = 5 Degrees

Mechanical Advantage - Dimensionless

Crank Angle	(T4 / T2)
60.000	1.875
65.000	1.797
70.000	1.740
75.000	1.700
80.000	1.671
85.000	1.653
90.000	1.644
95.000	1.642
100.000	1.648
105.000	1.661
110.000	1.682
115.000	1.711
120.000	1.748

Table #B1 Title __Mechanical advantage of four bar linkage

FOURBAR 5.1 Delmer Design # 4 05-30-1998 at 10:13

Angle - Degrees Of Steering

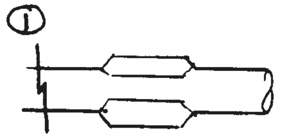
Trans. Angle	Link 2	Link 3	Link 4
57.608	60.000	11.364	**68.972**
60.561	65.000	11.137	71.698
63.549	70.000	10.979	74.527
66.553	75.000	10.883	77.437
69.560	80.000	10.845	80.405
72.554	85.000	10.861	83.415
75.522	90.000	10.927	86.450
78.452	95.000	11.043	89.494
81.328	100.000	11.207	92.535
84.140	105.000	11.418	95.558
86.872	110.000	11.678	98.551
89.513	115.000	11.987	101.500
87.953	120.000	12.346	**104.392**

Table #B2 Title _Angles made by each of steering links.

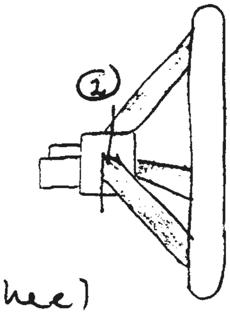
17.736

Alternatives

1)-Cutting steering column somewhere in middle
a)-support steering column by a bearing

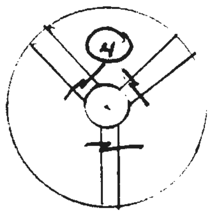


2) Cutting steering wheel away



3) Building a new steering wheel

4)



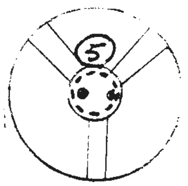
steering wheel

cut steering support as shown & support it with a larger diameter collar that would slid over the center.

Disadvantages

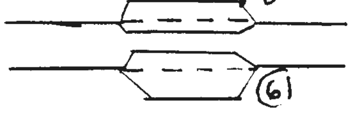
No built in support so extra support is needed.

5.) Cut out inside of steering wheel



Steering wheel

6) Remove flats off steering column



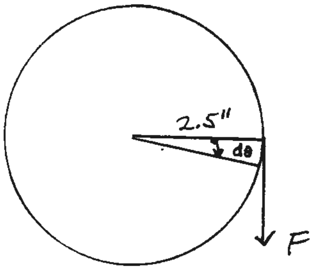
2-2-98 Remote Freedom Delmer Brown

Objective: measure spring constant of Steering mechanism:

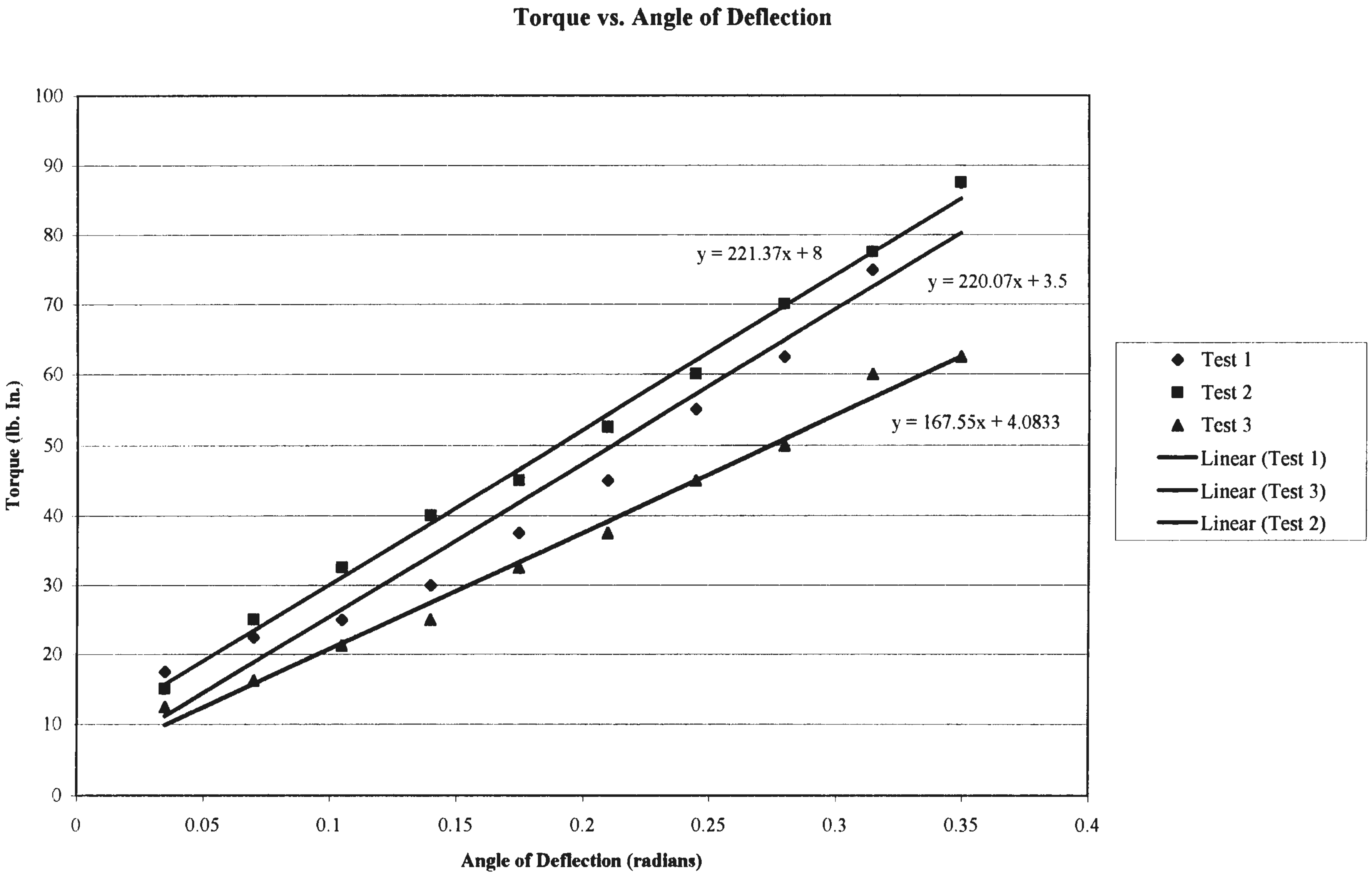
Procedure:
1- secure front wheels
2- Attach force meter 2.5" from center of Steering Wheel
3- Take readings of force for each two degree of deflection.
4- Plot curve Torque vs. θ

Angle deflection (deg)	Torque Applied (lb-in) Test #1	Test #2	Test #3
2°	17.5	15	12.5
4	22.5	25	16.25
6	25	32.5	21.25
8	30	40	25
10	37.5	45	32.5
12	45	52.5	37.5
14	55	60	45
16	62.5	70	50
18	75.0	77.5	60
20	87.5	87.5	62.5

Steering Wheel

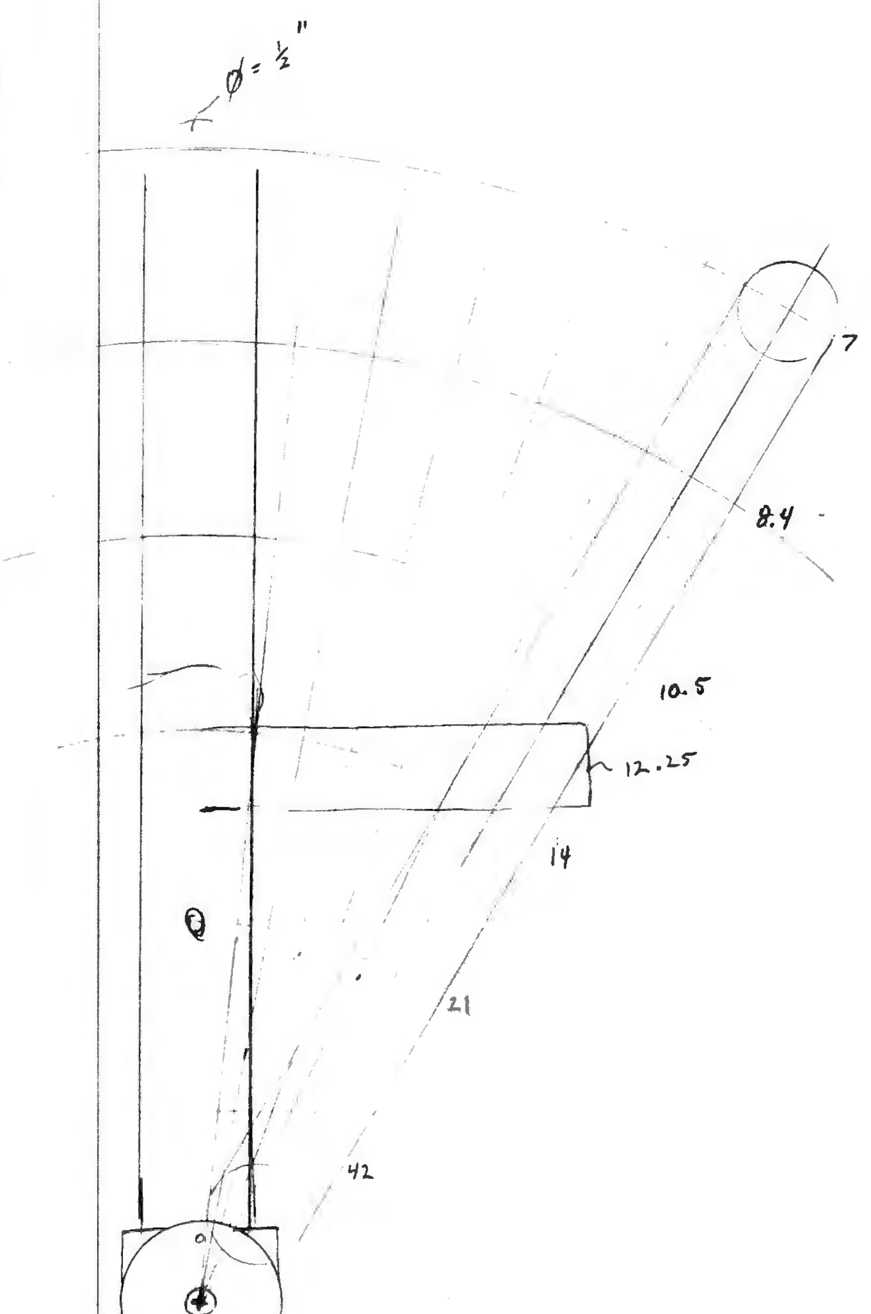


With an assumption that steering Column act like linear spring the spring constant ~~is~~ about equal to 220.5 lb-in.

Torque vs. Angle of Deflection
Torque (lb. In.)
100
90
80
70
60
50
40
30
20
10
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Angle of Deflection (radians)
y = 221.37x + 8
y = 220.07x + 3.5
y = 167.55x + 4.0833
◆ Test 1
■ Test 2
▲ Test 3
Linear (Test 1)
Linear (Test 3)
Linear (Test 2)

APPENDIX C:

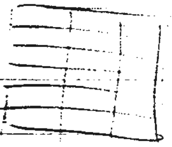
GAS PETAL AND GEAR SWITCHING MECHANISM



μ wood & brass $\approx .2$

We had several choices to control the steering of the car. ~~The no~~ A set of gears could be used to ~~[illegible]~~ turn the steering wheel. [The Servomotor did not have enough torque to turn the steering wheel directly so the servomotor will have to be geared down] [~~The steering~~ To determine the amount of Torque ~~was~~ required to turn the steering wheel several surfaces were tested. ~~The setup~~ ~~to~~ See the setup in Fig O. A Force meter

was attached to the steering wheel and pulled untill the wheel turn (almost a Static Force). The results are in Table O. The maximum ~~torque~~ ~~[illegible] and~~ Force is — and that corresponds to a Torque of —.]



(The highest torque Servomotor that we could find was 194 oz-in. Larger servomotors are available, but ~~they are~~ are much more expensive.) The problem with gears is that a solid link has to be between gears and ~~on the~~ the car is made of a soft ~~[illegible]~~ Plastic. In order to deal ~~cope~~ with a soft Steering rod a 4-bar linkage was used.

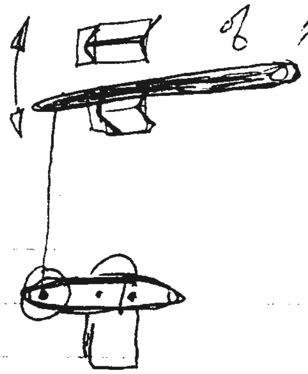
~~if the step~~ The 4-bar also allows an infinite adjustment of the Mechanical Advantage.

after [illegible]

For the gas pedal ~~Switch~~ it has to be pressed for ~~[illegible]~~ 1st 2nd and reverse gear.

* In order to switch gears properly, the original lever will be moved by a servo-motor.

~~Power is~~ The changing of speeds is done with internal switches. ~~but~~ Due to the ease of just pushing or pulling this lever

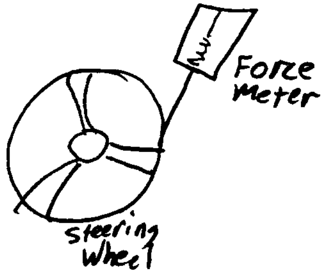


APPENDIX D:

SAFETY CALCULATIONS AND TESTS

Torque

Torque Measurement using a Chatillon 30 lb force scale



Steering wheel size 2.5" radius

Force to move the wheels

CPD Floor
1 6 lb
2 5.5 lb
3 6.5 lb

Asphat
1 6.5 lb
2 6 lb
3 6 lb

Snow 15° angle
1 5.5 lb
2 4.5 lb
3 6.5 lb

Snow 50° angle
1 7 lbs
2 7.5 lbs
3 6.5 lbs

dirt
1 7 lbs
2 6.5 lbs
3 6.5 lbs

cement
1. 4.5 lbs
2 5 lbs
3 5 lbs

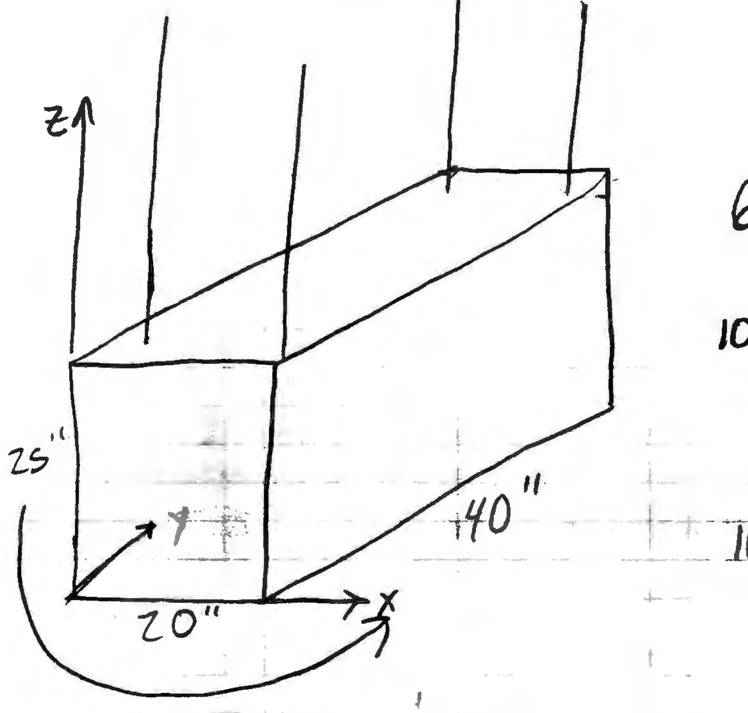
grass
1 6 lbs
2 5 lbs
3 5.5 lbs

mud 5° angle
1 7 lbs
2 7 lbs
3 7.5 lbs

Maximum Torque = (2.5")(7.5 lbs) = 18.75 lb·in

= 300 oz·in

4 Point Pendulum Test



rope length = 45"

	average period
6 oscillation	.759s
10 oscillations	.759s

rope length = 35"

	average period
10 oscillations	1.67sec

$$I = \frac{w\,d^2}{2nh(2\pi f_n)^2}$$

$f_n = \frac{1}{.759}$

$h = 45''$

$n = 4$

$W_{max} = 150\ \text{lb}$

$d = \sqrt{(20)^2 + 40^2}$

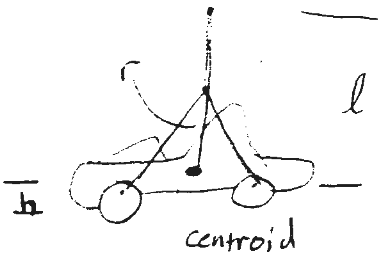
$= 44.7''$

$$I_z = \frac{150\,(44.7)^2}{2\,(4)\,45''\left(2\pi\,\frac{1}{.759}\right)^2} = \underline{\underline{12.1\ \text{lb}\cdot\text{ft}^2}}$$

$$I_y = \frac{150\,(44.7)^2}{2(4)\,35''\left(2\pi\,\frac{1}{1.67}\right)^2} = \underline{\underline{75.6\ \text{lb}\cdot\text{ft}^2}}$$

note I_y will be the maximum inertia possible since fliping around that axis is the largest inertia

Senior Design Peck, Craig



Given $l_1 = 68$ inches $W = 45$ lbf

$\tau_1 = 2.53$ sec $m = 1.4$ slugs

$l_2 = 59$ inches

$\tau_2 = 2.41$ sec

Find: h, I_{center}

---

solution:

$$r = l - h$$

$$f_n = \frac{1}{2\pi}\sqrt{\frac{mgr}{I_o}} \qquad \tau = \frac{1}{f_n}$$

$$\tau^2 = \frac{4\pi^2 I_o}{mgr}$$

$$\tau_1^2 = \frac{4\pi^2 I_1}{mg(l_1 - h)} \qquad \tau_2^2 = \frac{4\pi^2 I_2}{mg(l_2 - h)}$$

$$I_1 = I_{center} + m(l_1 - h)^2$$

$$I_2 = I_{center} + m(l_2 - h)^2$$

$$I_2 - I_1 = \frac{\tau_2^2 \cancel{m} g(l_2 - h)}{4\pi^2} - \frac{\tau_1^2 \cancel{m} g(l_1 - h)}{4\pi^2} = \cancel{m}(l_2 - h)^2 - \cancel{m}(l_1 - h)^2$$

$$4.74'(l_2 - h) - 5.22'(l_1 - h) = (l_2 - h)^2 - (l_1 - h)^2$$

$$4.74'(4.92 - h) - 5.22''(5.67 - h) = (4.92)^2 - 2(h)4.92 + \cancel{h^2} - 5.67^2 + 2h5.67 - \cancel{h^2}$$

$$23.3 - 4.74h - 29.6 + 5.22h = 24.2 - 9.84h - 32.1 + 11.3h$$

$$-6.3 + .484h = -7.94 + 1.5h$$

$$1.64 = 1.02h \qquad \underline{h = 1.6' = 19.4''}$$

$$\tau_1^2 = \frac{4\pi^2 I_1}{mg(l_1 - h)} \qquad I_1 = 41.54 \text{ lb}\cdot\text{ft}^2$$

$$I_{center} = I_1 - m(l_1 - h)^2$$

$$I_{center} = 18.6 \text{ lb}\cdot\text{ft}^2$$

Force

from the maximum inertia $= 75.6\ \text{lb}\cdot\text{ft}^2$

maximum speed $= 7.33\ \text{ft/sec}$

Momentum equation

$$\frac{1}{2} m v^2 = mgh$$

$$mgh = \frac{1}{2} I \omega^2$$

$$\frac{1}{2}\left(\frac{150}{32.2}\right)(7.333)^2 = \text{Energy} = 125.3\ \text{ft} * \text{lb}$$

$$125.3 = \frac{1}{2}\ 75.6\ \omega^2$$

$$\omega = 1.82\ \frac{\text{rad}}{\text{sec}}$$

Impulse momentum

$$\frac{M\tau}{2} = \Delta H = I\omega_1 - \cancelto{0}{I\omega_2}$$

assume $\tau = .1$ seconds

$$\frac{F(r).1}{2} = (75.6)\ 1.82$$

$R = 3.3$ feet

Radius if tiped up

$$F_{max} = \underline{\underline{825.6\ \text{lb}}}$$

From SAE 1988 Guidebook

$$F_{max} = 6\ M = 6(150)$$

$$= \underline{\underline{900\,\text{lb}}}$$

PERFORMANCE CRITERIA FOR ROLLOVER PROTECTIVE STRUCTURES (ROPS) FOR CONSTRUCTION, EARTHMOVING, FORESTRY, AND MINING MACHINES—SAE J1040 APR88

SAE Standard

Report of Construction and Industrial Machinery Technical Committee approved April 1974, and completely revised by the Off-Road Machinery Technical Committee April 1988. Rationale statement available. This SAE Standard is technically similar to ISO 3471/1-1986. (This document incorporates material formerly published as SAE J320a, J394, J395, J396, and J1011.)

1. Introduction—This SAE Standard is technically similar to ISO 3471/1-1986 with an added longitudinal load requirement, linearization of lateral force criteria for small machines, and linearization of both lateral forces and energy criteria for large machines. There is no intent to cause obsolescence of Rollover Protective Structures (ROPS) presently in use.

2. Purpose—This standard establishes a consistent, repeatable means of evaluating the load-carrying characteristics of ROPS under static loading and prescribes performance requirements of a representative specimen under such loading.

3. Scope—This standard applies to the following off-road work machines of mass greater than 700 kg that are commonly used in earthmoving, construction, logging, and mining applications as identified in SAE J1116 JUN86 and designed for an on-board, seated operator:

(a) Crawler tractors and loaders. (See SAE J1057 JUN81 Sections 3.1 and 7.1 and SAE J727 JAN86 for description and nomenclature.)
(b) Graders. (See SAE J1057 JUN81 Section 6 and SAE J870 JUL84 for description and nomenclature.)
(c) Wheel loaders, wheel tractors and their modifications used for rolling or compacting, dozer equipped wheel tractors, wheel log skidders, skid steer loaders, and backhoe loaders. (See SAE J1057 JUN81 Sections 3.2, 7.2 and 9 for description and nomenclature.)
(d) Wheel industrial tractors (See SAE J1092 JUN86 for description and nomenclature.)
(e) Tractor portion of semi-mounted scrapers, water wagons, articulated steer dumpers, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth wheel attachments. (See SAE J1057 JUN81 Sections 4.1.1.4, 4.1.2, 4.2.1.1, 4.3.1.2, 4.3.1.3, 4.3.2, and 5, and SAE J869 JUL84 and SAE J728 JUL84 for description and nomenclature.)
(f) Rollers and compactors. (See SAE J1017 JAN86 for description and nomenclature.)
(g) Rigid frame dumpers with full mounted bodies. (See SAE J1057 JUN81 Sections 4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.1.5, and 4.3.1.1 and SAE J1016 DEC84 for description and nomenclature.)

Note—Additional machine types listed in SAE J1116 JUN86 may utilize these ROPS performance criteria if so directed by other SAE reports such as SAE J1042 FEB86. SAE J1194 JUL83 and SAE J2194 DEC87 cover agricultural tractors (defined in SAE J1150).

Exclusions—Machines whose use is predominantly, or entirely, in manufacturing plants and/or warehouses are specifically excluded. Rough terrain forklifts, 360 deg rotation excavators and excavator based machines are also excluded along with rollover protection for the operator of an attachment with an alternate seat position from that used for mobile operation (for example, an attachment backhoe).

4. Definitions

4.1 Bedplate—A substantially rigid part of the testing fixture to which the machine frame is attached for the purpose of the test.

4.2 DLV—Deflection Limiting Volume, defined in SAE J397 APR88.

4.3 FOPS—A Falling Object Protective Structure complying with SAE J231 JAN81 or SAE J1043 APR85, as appropriate.

4.4 Machine Frame—Main chassis or main load bearing member(s) of the machine which extend(s) over a major portion of the machine and upon which the ROPS is directly mounted.

4.5 Maximum Recommended Mass, M—The manufacturer's maximum recommended mass including attachments in operating condition with all reservoirs full to capacity, tools and ROPS; exclusive of towed equipment such as rollers, compactors, and drawn scrapers.

For the tractor portion of semi-mounted scrapers, water wagons, articulated steer dumpers, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth wheel attachments, M is the manufacturer's maximum recommended mass of the tractor portion (prime mover) only. Kingpins, hitches and articulated steering components that attach to hitches or towed units are excluded from the mass of these machines.

For rigid frame dumpers, M excludes the mass of the dump body and the payload when the "ROPS only" criteria are selected. When the "body only" criteria are selected, M includes the mass of the dump body but excludes the mass of the payload.

Soil, mud, rocks, branches, debris, etc., that commonly adhere to or lie on machines in use are not considered as part of the mass of any machine. Material dug, carried, or handled in any manner is not to be considered part of the machine mass in determining test requirements.

4.6 Representative Specimen—A ROPS, mounting hardware and machine frame (complete or partial) for testing purposes, that is within the manufacturer's specifications.

4.7 Rollbar ROPS—A one- or two-post ROPS without a FOPS or any cantilevered load-carrying structural members.

4.8 Rollover Protective Structure (ROPS)—A system of structural members whose primary purpose is to reduce the possibility of a seat-belted operator being crushed should the machine roll over. Structural members include any subframe, bracket, mounting, socket, bolt, pin, suspension or flexible shock absorber used to secure the system to the machine frame, but excludes mounting provisions that are integral with the machine frame.

4.9 Simulated Ground Plane (SGP)—The flat surface on which a machine, after rolling over, is assumed to come to rest.

4.9.1 LATERAL SIMULATED GROUND PLANE (LSGP)—For a machine coming to rest on its side, the plane is determined as follows (see Fig. 1):

(a) Upper ROPS member to which the lateral load is applied.
(b) Outermost point in the end view of the above member.
(c) Vertical line through the above point.
(d) Vertical plane parallel to machine longitudinal centerline through the above line.
(e) Rotate plane described in (d), 15 deg away from the DLV about the horizontal axis within the plane established in (d) passing through the point described in (b). This establishes the LSGP. LSGP is established on an unloaded ROPS and shall move with the member to which load is applied while maintaining its 15 deg angle with respect to the vertical.

4.9.2 VERTICAL SIMULATED GROUND PLANE (VSGP)—The VSGP applies only to Rollbar ROPS. For a machine coming to rest in an upside-down attitude, the plane is defined by the top crossmember of the ROPS and that front (rear) part of the machine likely to come in contact with flat ground at the same time as the ROPS and capable of supporting the upside-down machine. The VSGP shall move with the deformed ROPS. See Fig. 2.

5. Methods and Facilities

5.1 General—The following points are explicitly stated to aid in understanding underlying principles, intention, and application: the requirements are force resistance in the lateral, vertical, and longitudinal directions and energy absorption in the lateral direction. There are limitations on deflections under the lateral, vertical, and longitudinal loading. The energy requirement and limitations on deflection (DLV) under lateral loading are intended to assure that the ROPS will deflect when it impacts a surface which will not significantly deform (frozen ground, concrete, rock) while retaining significant capability to withstand subsequent impacts in an overturn.

This evaluation procedure will not necessarily duplicate structural deformations due to a given actual roll. However, specific requirements are derived from investigations on ROPS that have performed the intended function in a variety of actual rollovers, as well as analytical considerations based upon the compatibility of ROPS and the machine frame to which it attaches. Therefore, it is expected that crush protection for a seat-belted operator will be assured under at least the following conditions: An initial forward velocity of 0-16 km/h on a hard clay surface of 30 deg maximum slope, 360 deg of roll about the machine longitudinal axis without losing contact with the slope.

5.2 Instrumentation—Systems used to measure mass, force and deflection shall have the capabilities shown in Table 1.

TABLE 1—INSTRUMENTATION CAPABILITIES

Means to Measure	Accuracy
Machine Mass	±5% of max mass
Deflections of ROPS	±5% of max deflection
Force on ROPS	±5% of max force

The above percentages are nominal ratings of the accuracy of the instrumentation and should not be taken to indicate that compensating overtest is required.

5.3 Test Facilities—Fixtures must be adequate to secure the ROPS/machine frame assembly to a bedplate and to apply the required lateral, vertical and longitudinal loads as determined by the formulas of Table 3. Typical installations are shown in Figs. 3 - 9.

5.4 ROPS/Machine Frame Assembly and Attachment to Bedplate

5.4.1 The ROPS shall be attached to the machine frame as it would be on an operating machine. A complete machine is not required for the evaluation; however, the machine frame and mounted ROPS test specimen must represent the structural configuration of an operating installation. All normally detachable windows, panels, doors, and other non-structural elements shall be removed so that they do not contribute to or detract from the structural evaluation.

5.4.2 The ROPS/machine frame assembly shall be secured to the bedplate so that the members connecting the assembly and bedplate experience minimal deflection during testing. The ROPS/machine frame assembly shall not receive any support from the bedplate, other than that due to the initial attachment.

5.4.3 The test shall be conducted with any machine/ground suspension elements blocked externally so that they may not contribute to the load/deflection behavior of the test specimen. Suspension elements used to attach the ROPS to the machine frame and acting as a load path shall be in place and functioning at the start of the test.

5.4.4 For non-articulated machines and articulated machines using both frames, connections to the bedplate shall be directly from the machine frame at or near the front and rear axle supports, or equivalent. For articulated machines, the hinge shall be locked if both frames are used in the evaluation; if only that frame to which the ROPS is mounted is used, the connections shall be at or near the articulation joint and axle support (or alternatively at the extreme end of the frame). For single axle prime movers, the support shall be at the drive axle (see Fig. 7). Crawler tractors and crawler loads shall be connected to the bedplate through the main housing and/or track frames. See Figs. 3 and 13.

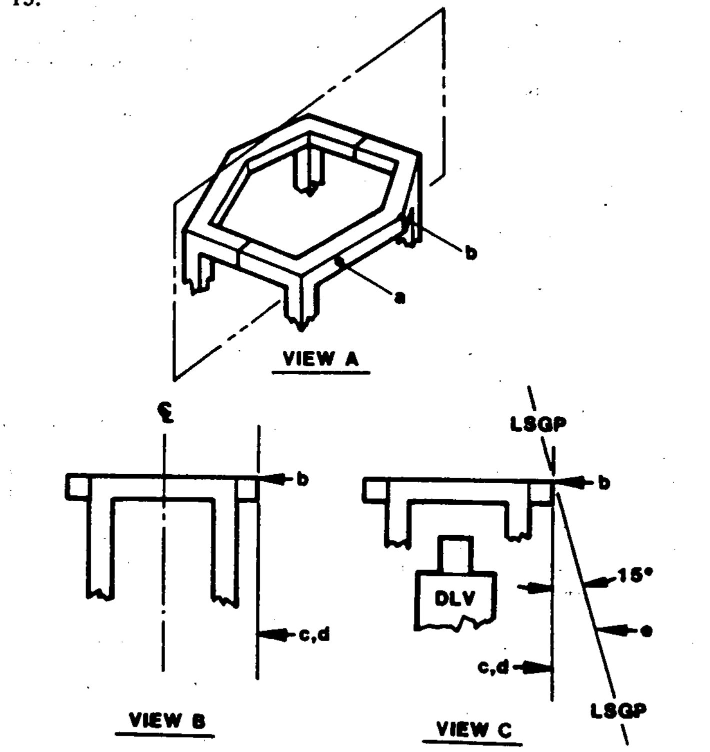


FIG. 1—DETERMINATION OF LATERAL SIMULATED GROUND PLANE (LSGP) (Refer to section 4.9.1 for description of a, b, c, d, e.)

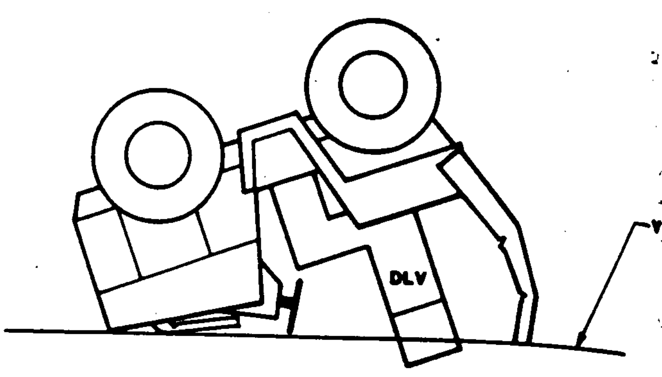


FIG. 2—INTRUSION OF VERTICAL SIMULATED GROUND PLANE (VSGP) INTO THE DLV

6. Loading Procedure

6.1 General

(a) All load application points must be identified and marked on the structure before any loading is applied.

(b) The loading sequence shall be lateral, vertical, then longitudinal (exception: wheel industrial tractors shall be lateral, longitudinal, then vertical).

(c) No straightening or repair is permitted during or between loading phases.

(d) A load distribution device may be used to prevent localized penetration. It must not impede rotation of the ROPS.

6.2 Lateral Loading

6.2.1 Load distribution devices may not distribute the load over a distance greater than 80% of the length L, defined as follows: for a one- or two-post ROPS with an FOPS and/or cantilevered load-carrying structural members, the length L is that portion of the cantilevered load-carrying members which predominantly covers the operator. It is measured from the extreme face of the ROPS post(s) to the far end of the cantilevered load-carrying members (Fig. 10). For all other ROPS, the length L is the total longitudinal distance between the outsides of the front and rear posts (Fig. 11).

6.2.2 For a Rollbar ROPS, the load application point shall be in line with the upper lateral crossmember.

6.2.3 For all other one- or two-post ROPS, initial loading shall be dictated by the length L and vertical projections of the front and rear planes of the DLV. The load application point shall not be within L/3 from the one- or two-post structure. Should the L/3 point be between the vertical projection of the DLV and the one- or two-post structure, the load application point shall move away from the structure until it enters the vertical projection of the DLV (Fig. 10).

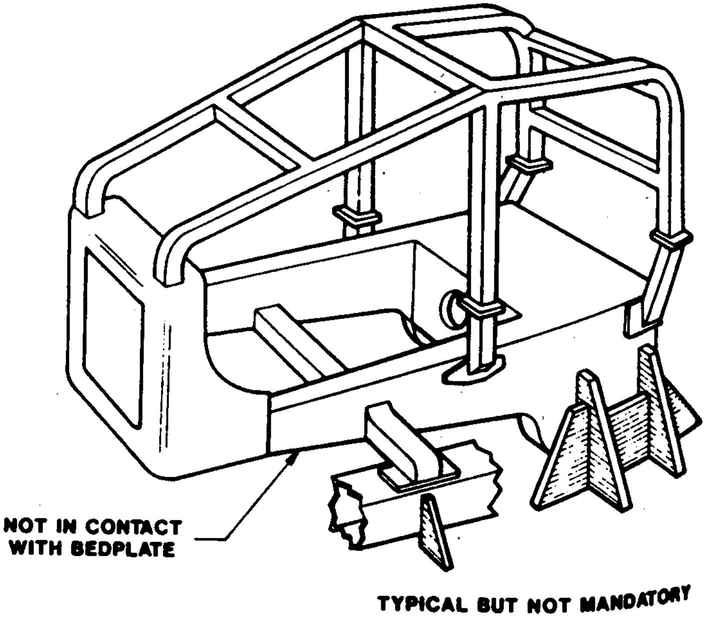


FIG. 3—TEST BED ANCHORAGE OF TRACK-TYPE TRACTOR

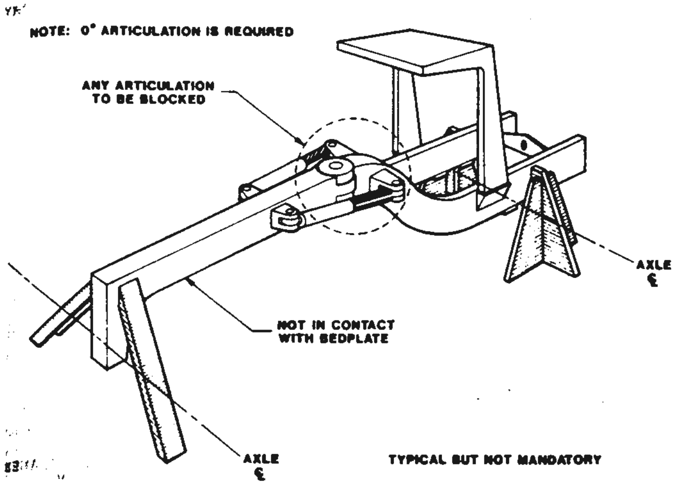


FIG. 4—ANCHORAGE OF ARTICULATED MOTOR GRADER (COMPLETE FRAME)

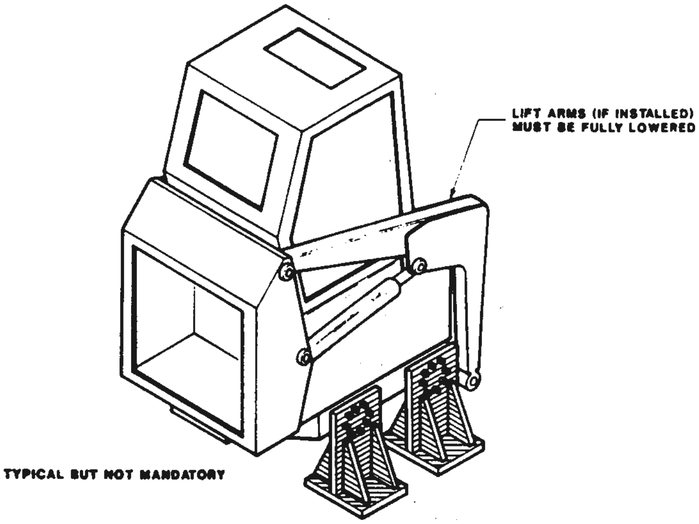


FIG. 6—ANCHORAGE OF SKID STEER LOADER

6.2.4 For ROPS of more than two posts, the load application point shall be located between vertical projections of planes 80 mm outside of the front and rear boundary planes of the DLV (Fig. 11).

6.2.5 Should the operator's seat be off the machine longitudinal centerline, the loading shall be against the outermost side nearest the seat. For on-centerline seat, if mounting of the ROPS is such that different force-deflection relations are likely by loading from left or right sides, the side loaded shall be that which will place the most severe loading requirements on the ROPS/machine frame assembly.

6.2.6 The initial direction of the loading shall be horizontal and perpendicular to a vertical plane through the machine longitudinal centerline. As loading continues, ROPS/machine frame deformations may cause the direction of loading to change; this is permissible.

6.2.7 The rate of deflection shall be such that the loading can be considered static. At deflection increments no greater than 15 mm (at the point of application of the resultant load), the values of force and deflection are to be recorded. This loading is to continue until the ROPS has achieved both the force and energy requirements. See Fig. 12 for method of calculating energy. The deflection used in calculating energy is to be that of the ROPS along the line of action of the force. Any deflection of members used to support load application devices shall not be included in the total deflection.

6.3 Vertical Loading—After removal of the lateral load, a vertical load shall be applied to the top of the ROPS (exception: wheel industrial tractors shall have longitudinal load applied prior to vertical loading, refer to paragraph 6.4).

6.3.1 For a Rollbar ROPS, the vertical load shall be applied in the same plane on the undeformed structure as the lateral load of paragraph 6.2.2. For all other one- or two-post structures, the center of the vertical load shall not be applied any nearer to the posts than was the lateral load of paragraph 6.2.3.

6.3.2 In no instance is there any further limitation on the manner of distributing this load on the ROPS. Fig. 13 shows a typical vertical loading.

6.3.3 The rate of deflection shall be such that the loading can be considered static. Loading is to continue until the ROPS has achieved the force requirement. The structure shall support this load for a period of 5 min or until any deformation has ceased, whichever is shorter.

6.4 Longitudinal Loading—After removal of the vertical load, a longitudinal load shall be applied to the ROPS (exception: wheel industrial tractors, see paragraph 6.4.3(d) for test sequence).

6.4.1 The longitudinal load must be applied at the deformed location of the originally established point, since the lateral (and vertical) loading of the ROPS likely results in permanent deformation of the structure. The load distribution device may span the width in cases where no rear (front) crossmember exists. In all other cases, the device may not distribute the load over a length greater than 80% of the width W of the ROPS. See Fig. 14.

6.4.2 The longitudinal load shall be applied to the upper structural members of the ROPS along the longitudinal centerline of the ROPS, except for wheel industrial tractors. This machine classification shall have longitudinal (rear) load applied one-quarter of the width W of the ROPS from either rear post.

6.4.3 The direction of loading (fore or aft) must be selected to place the most severe requirements on the ROPS/machine frame assembly. The initial direction of loading shall be horizontal and parallel to the original longitudinal centerline of the machine. Some additional factors to consider in arriving at the direction to apply the longitudinal load are:

(a) Location of ROPS relative to DLV and the effect that longitudinal deflection of the ROPS would have on providing crush protection for the operator.

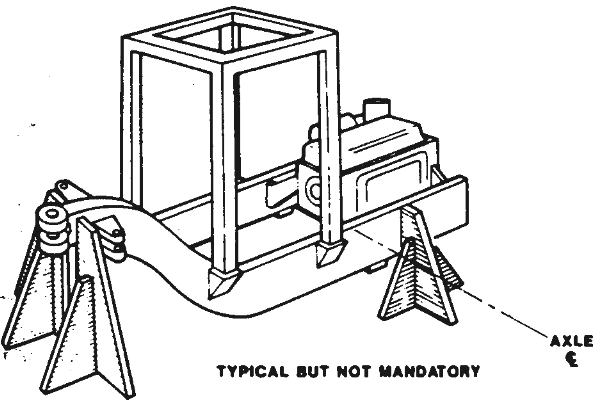


FIG. 5—TEST BED ANCHORAGE OF HALF AN ARTICULATED FRAME

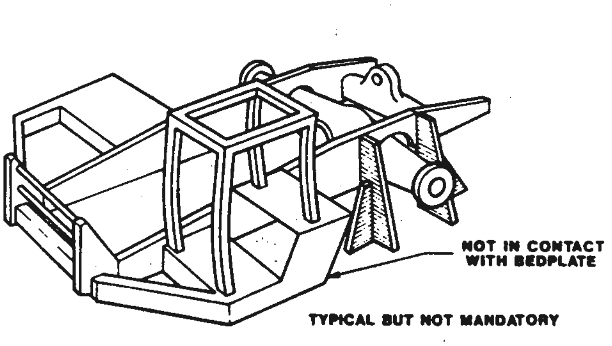


FIG. 7—TEST BED ANCHORAGE OF TRACTOR PORTION (PRIME MOVER)

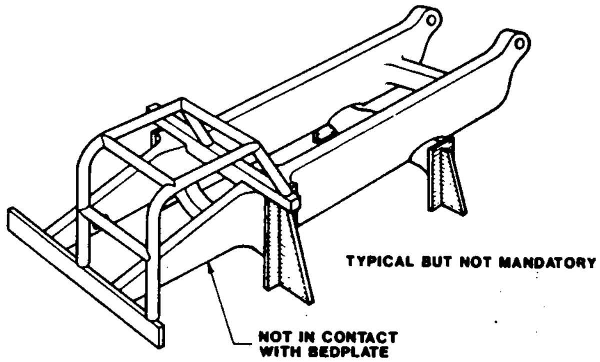


FIG. 8—ANCHORAGE OF DUMPER FRAME—ROPS ONLY OPTION

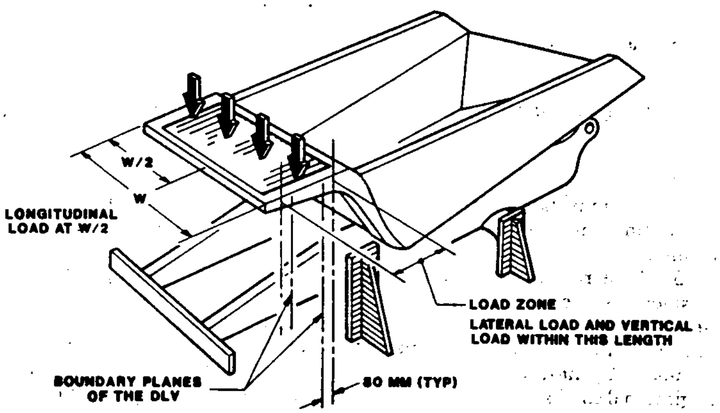
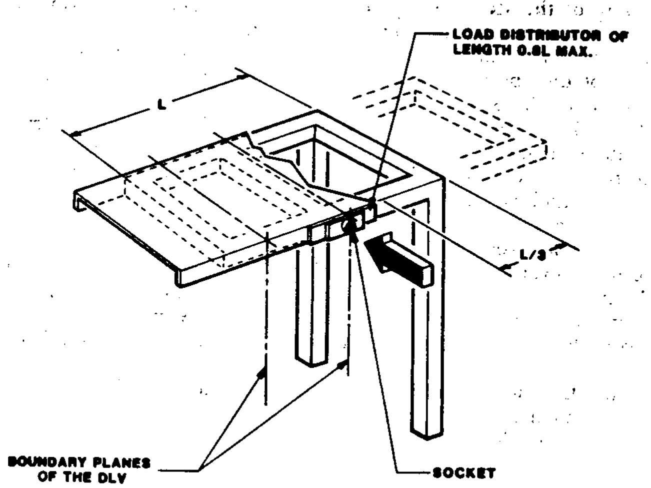


FIG. 9—LOADING OF DUMPER BODY ONLY OPTION



LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE

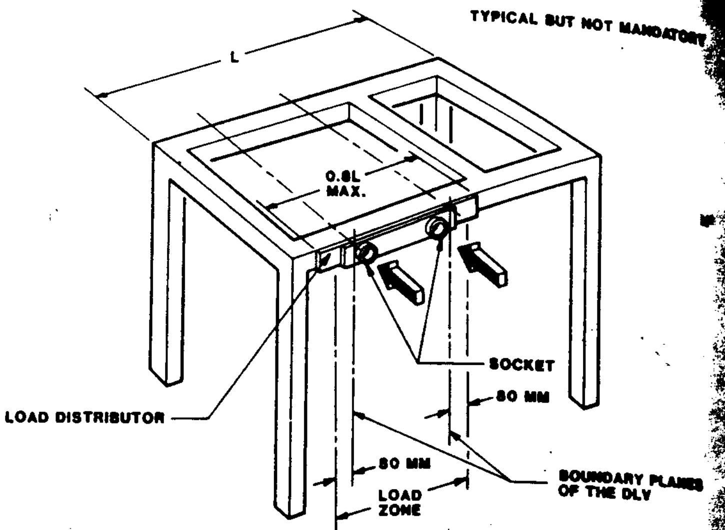
FIG. 10—TWO-POST ROPS WITH FOPS LATERAL LOAD APPLICATION POINT

(b) Machine characteristics that can limit direction of the longitudinal component of loading on the ROPS.

(c) Experience which may indicate the possibility of longitudinal tipping or the tendency of a particular classification of machine to skew as it rotates about a longitudinal axis during an actual rollover as described in paragraph 5.1.

(d) Wheel industrial tractors shall have longitudinal load applied from the rear to cover the possibility of a rear upset. For this machine classification only, the test order shall be lateral, longitudinal (rear), then vertical loading. A longitudinal energy requirement also applies (refer to paragraph 6.2.7 for guidance and Section 8 for acceptance criteria).

6.4.4 The rate of deflection shall be such that the loading can be considered static. This loading is to continue until the ROPS has achieved the longitudinal requirement(s).



LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE

FIG. 11—FOUR-POST ROPS LATERAL LOAD APPLICATION POINT

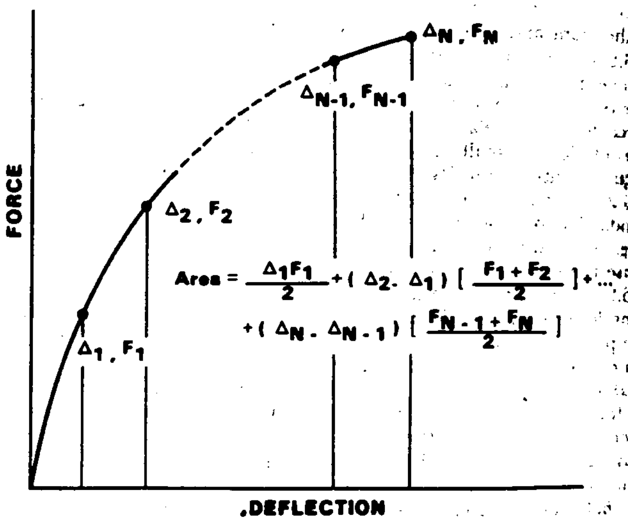


FIG. 12—ENERGY EQUATION

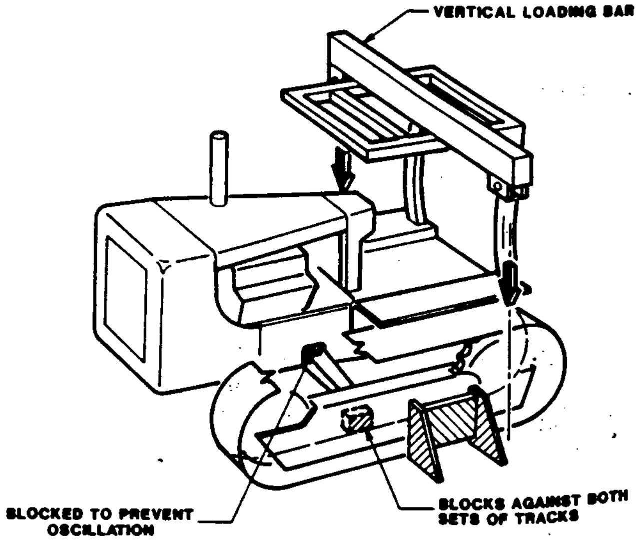


FIG. 13—VERTICAL LOADING EXAMPLE

7. Temperature-Material Requirement—In addition to the loading requirements, there is a Temperature-Material requirement to assure that the ROPS will have meaningful resistance to brittle fracture. This requirement may be met by applying the static loadings with all structural members at, or below, −18°C if materials specifications and procurement assure that materials in ROPS subsequently manufactured will have toughness characteristics similar to those in the tested representative specimen. Alternatively, the requirement may be met by applying the loadings at higher temperature if all ROPS structural members are fabricated from materials that meet the following mechanical requirements. (See SAE J1119 APR80 for additional information.)

7.1 Bolts and nuts used structurally shall be SAE Grade 5, 7, or 8 (SAE J429 AUG83 and SAE J995 JUN79) or metric property class 8.8, 9.8, or 10.9 bolts (SAE J1199 SEP83 and ISO 898/1) and property class 8, or 10 nuts (ISO 898/2).

7.2 Structural members of the ROPS and the mounts which attach it to the machine frame shall be made of steels that meet or exceed one of the Charpy V-notch (CVN) impact strengths at −30°C shown in Table 2. (The Charpy V-notch evaluation is primarily a quality control check and the indicated temperature does not directly relate to operating conditions.) Specimens are to be "longitudinal" and taken from flat stock, tubular, or structural sections before forming or welding for use in the ROPS. Specimens from tubular or structural sections are to be taken from the middle of the side of greatest dimension, not to include welds.

7.3 Steel less than 2.5 mm in thickness with a maximum carbon content of 0.20% shall be considered to meet the Charpy requirement.

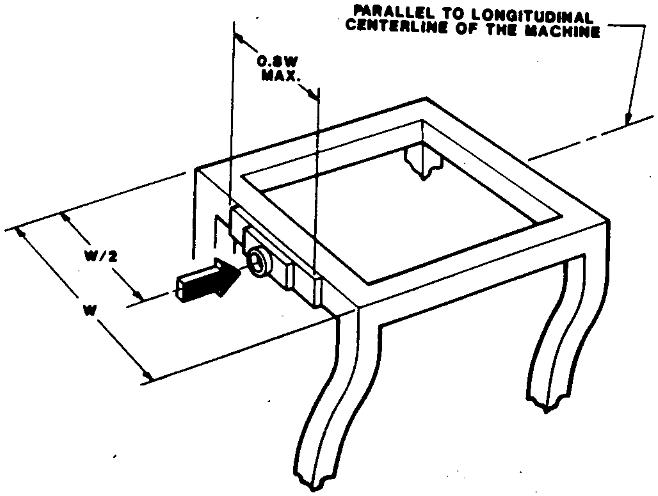
8. Acceptance Criteria

8.1 The specific lateral force and energy, vertical load carrying capacity, and the longitudinal requirement(s) are to be met or exceeded in the testing of a single representative specimen. The equations for the various machine classifications are given in Table 3.

8.2 The force and energy requirements under lateral loading do not need to be attainable simultaneously; accordingly, one may be significantly exceeded before the other is attained. If the force is attained before the energy, the force may decrease but must again attain the required level when the lateral energy requirement is met or exceeded. (Longitudinal loading of wheel industrial tractors shall also meet the requirements of this section.)

8.3 The limitations on the deflections are absolute; no part of the ROPS shall enter the DLV at any time during the lateral, vertical, or longitudinal loading phases of the test.

8.4 The lateral simulated ground plane (LSGP) shall not enter the DLV (upright mode) at any time during lateral loading phase of the test (except as noted in paragraph 8.6). See Fig. 1.



TYPICAL BUT NOT MANDATORY

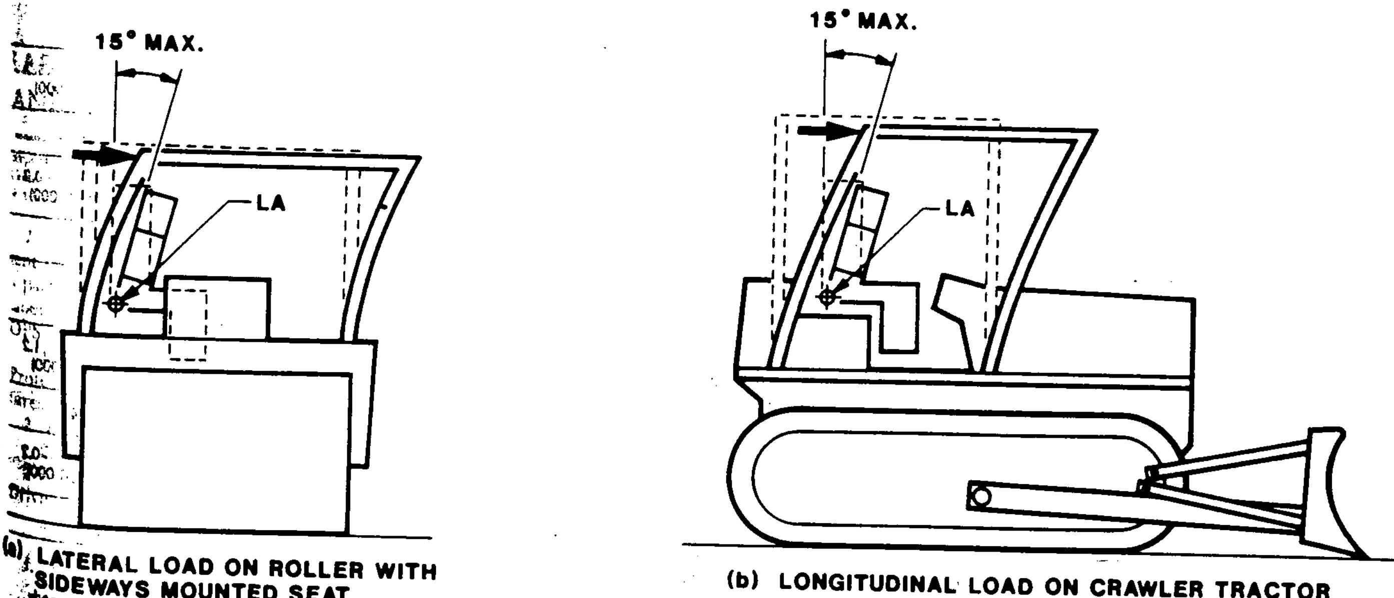
LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE

FIG. 14—FOUR-POST ROPS LONGITUDINAL LOAD APPLICATION POINT

TABLE 2—MINIMUM CHARPY V-NOTCH IMPACT STRENGTHS

Specimen Size, mm	Energy, J
10 × 10[a]	11.0
10 × 9	10.0
10 × 8	9.5
10 × 7.5[a]	9.5
10 × 7	9.0
10 × 6.7	8.5
10 × 6	8.0
10 × 5[a]	7.5
10 × 4	7.0
10 × 3.3	6.0
10 × 3	6.0
10 × 2.5[a]	5.5

[a] Indicates preferred size. Specimen size shall be no less than the largest preferred size that the material will permit. (Reference: ASTM A 370, Standard Methods and Definitions for Mechanical Testing of Steel Products.) More data on specifics of CVN specimen size/test temperature interaction that meet the intent of the basic requirements of Table 2 can be found in SAE J1119 APR80.



(a) LATERAL LOAD ON ROLLER WITH SIDEWAYS MOUNTED SEAT

(b) LONGITUDINAL LOAD ON CRAWLER TRACTOR

FIG. 15—ALLOWABLE ROTATION OF UPPER DLV ABOUT THE LOCATING AXIS

TABLE 3—FORCE AND ENERGY EQUATIONS

Machine Classification	Machine Mass (Kilograms)	Lateral Load Force (Newtons)	Lateral Load Energy (Joules)	Vertical Load Force (Newtons)	Longitudinal Load Force (Newtons)
Crawler tractors and loaders	700 to 4 630	6 M	$13\,000(M/10\,000)^{1.25}$	19.61 M	4.8 M
See Section 3(a)	4 630 to 59 500	$70\,000(M/10\,000)^{1.2}$	$13\,000(M/10\,000)^{1.25}$	19.61 M	$56\,000(M/10\,000)^{1.2}$
	>59 500	10 M	2.03 M	19.61 M	8 M
Graders	700 to 2 140	6 M	$15\,000(M/10\,000)^{1.25}$	19.61 M	4.8 M
See Section 3(b)	2 140 to 38 010	$70\,000(M/10\,000)^{1.1}$	$15\,000(M/10\,000)^{1.25}$	19.61 M	$56\,000(M/10\,000)^{1.1}$
	>38 010	8 M	2.09 M	19.61 M	6.4 M
Wheel loaders, wheel tractors and their modifications used for rolling or compacting, dozer equipped wheel tractors, wheel log skidders, skid steer loaders, and backhoe loaders	700 to 10 000	6 M	$12\,500(M/10\,000)^{1.25}$	19.61 M	4.8 M
	10 000 to 128 600	$60\,000(M/10\,000)^{1.2}$	$12\,500(M/10\,000)^{1.25}$	19.61 M	$48\,000(M/10\,000)^{1.2}$
See Section 3(c)	>128 600	10 M	2.37 M	19.61 M	8 M
Wheel industrial tractors See Section 3(d)	700 to 10 000	6 M	$12\,500(M/10\,000)^{1.25}$	19.61 M	4.8 M*
	10 000 to 128 600	$60\,000(M/10\,000)^{1.2}$	$12\,500(M/10\,000)^{1.25}$	19.61 M	$48\,000(M/10\,000)^{1.2}$
	>128 600	10 M	2.37 M	19.61 M	8 M*
	*Energy absorption must exceed 1.4 M Joules for longitudinal load				
Tractor portion of semi-mounted mounted scrapers, water wagons, articulated steer dumpers, bottom dump wagons, side dump wagons rear dump wagons and towed fifth wheel attachments	700 to 1 010	6 M	$20\,000(M/10\,000)^{1.25}$	19.61 M	4.8 M
	1 010 to 32 160	$95\,000(M/10\,000)^{1.2}$	$20\,000(M/10\,000)^{1.25}$	19.61 M	$76\,000(M/10\,000)^{1.2}$
See Section 3(e)	>32 160	12 M	2.68 M	19.61 M	9.6 M
Rollers and compactors	700 to 10 000	5 M	$9\,500(M/10\,000)^{1.25}$	19.61 M	4 M
See Section 3(f)	10 000 to 53 780	$50\,000(M/10\,000)^{1.2}$	$9\,500(M/10\,000)^{1.25}$	19.61 M	$40\,000(M/10\,000)^{1.2}$
	>53 780	7 M	1.45 M	19.61 M	5.6 M
Rigid frame dumpers	700 to 1 750	6 M	$15\,000(M/10\,000)^{1.25}$	19.61 M	4.8 M
ROPS only option	1 750 to 22 540	$85\,000(M/10\,000)^{1.2}$	$15\,000(M/10\,000)^{1.25}$	19.61 M	$68\,000(M/10\,000)^{1.2}$
See Section 3(g)	22 540 to 58 960	10 M	1.84 M	19.61 M	8 M
	58 960 to 111 660	$413\,500(M/10\,000)^{0.2}$	$61\,450(M/10\,000)^{0.32}$	19.61 M	$330\,800(M/10\,000)^{0.2}$
	>111 660	6 M	1.19 M	19.61 M	4.8 M
Rigid frame dumpers	700 to 10 000	6 M	$6\,000(M/10\,000)^{1.25}$	19.61 M	4.8 M
Body only option	10 000 to 21 610	$60\,000(M/10\,000)^{1.2}$	$6\,000(M/10\,000)$	19.61 M	$48\,000(M/10\,000)^{1.2}$
See Section 3(g)	21610 to 93 900	7 M	0.73 M	19.61 M	5.6 M
	93 900 to 113 860	$420\,000(M/10\,000)^{0.2}$	$16\,720(M/10\,000)^{0.63}$	19.61 M	$336\,000(M/10\,000)^{0.2}$
	>113 860	6 M	0.68 M	19.61 M	4.8 M
Rigid frame dumpers Combination of ROPS and Body Option See Section 3(g)	When both ROPS and body are used, the lateral loading force and energy requirements and the longitudinal loading force for each shall be 60 percent of those indicated by the equations for the ROPS only or body only option respectively. The vertical loading requirements for both ROPS and body shall be 19.61 M. Lateral, longitudinal or vertical loading of the ROPS and/or body need not be applied simultaneously to both members of a combination. The only limitation on the order of the six loadings is that the vertical loading of members shall be applied after the lateral loading and the longitudinal loading of members shall be applied after the vertical loading. See Figure 9 for further guidance.				

M = Maximum recommended mass (kg) as defined in Section 4.5

8.5 For a Rollbar ROPS only, the vertical simulated ground plane (VSGP) shall not enter the DLV at any time during vertical loading phase of the test. See Fig. 2.

8.6 During lateral loading with a side-mounted operator or for longitudinal loading with the operator facing the direction that the ROPS will deflect under load application, it is permissible for the upper portion of the DLV to be rotated "forward" up to 15 deg about its locating axis (LA) to prevent intrusion of ROPS members (or the LSGP in lateral loading only). Forward rotation of the DLV shall be limited to less than 15 deg if interference with any machine component or controls occurs at a lesser angle. See Fig. 15.

8.7 If longitudinal load is applied in the direction opposite to that indicated in paragraph 8.6 (that is, with operator facing direction opposite that ROPS will deflect under load application), no rotation of the DLV is allowed, and the force requirement shall be attained within the same deflection as required to achieve the lateral energy requirement.

8.8 The ROPS shall not break away from the machine frame due to failure of the machine frame or mounting thereto.

9. Labeling of the ROPS—ROPS meeting the requirements of this report shall be labeled according to SAE J1164 MAY83.

10. Reported Results—A sample format is given in Table 4.

APPENDIX—HISTORICAL RATIONALE

ROPS criteria for various types of off-road work machines were originally presented in reports beginning with SAE J320, J394, J395, J396 and J1011 plus the companion report, J397. Later, it became apparent that efficiency could be obtained if the machine specific documents were combined into one report, SAE J1040.

J1040 has been revised as new information has been accumulated with regard to the criteria, or the need to cover more machines has been identified. Basic concepts of this report have not changed over the years. The essential requirements of ROPS are to exhibit a force resistant and energy absorption capacity. Criteria values were determined through a process in the 1960's where ROPS designs were subjected to laboratory tests as well as rollovers on slopes. Judgmental factors were applied by knowledgeable personnel to establish basic pass/fail standards for ROPS on various types of machines. Formulas established in the original reports were based on this best judgment of which ROPS designs provided crush protection for an operator during the rollover scenario described below, taking into account rollovers are rarely repeatable. The formulas were construed to at least provide crush protection for a seat-belted operator in a rollover of 360 deg about the machine longitudinal axis during which the machine does not lose contact with a hard clay surface of 30 deg maximum slope and has an initial forward speed of no more than 16 km/h.

TABLE 4—REPORTED RESULTS

1. Identification
    - 1.1 Machine(s)
        - 1.1.1 Type:
        - 1.1.2 Manufacturer:
        - 1.1.3 Mode:
        - 1.1.4 Serial Number (if any):
        - 1.1.5 Machine frame part number(s):
    - 1.2 ROPS
        - 1.2.1 Manufacturer:
        - 1.2.2 Model:
        - 1.2.3 Serial Number (if any):
        - 1.2.4 ROPS part number:
    - 1.3 DLV Location
2. Criteria
    - 2.1 Maximum recommended mass (kg):
    - 2.2 Lateral force requirement (N):
    - 2.3 Lateral energy requirement (J):
    - 2.4 Vertical force requirement (N):
    - 2.5 Longitudinal force requirement (N):
    - 2.6 [For wheel industrial tractors only] Longitudinal energy requirement (J):
3. Test Results

    The following force and energy levels were achieved or exceeded with no penetration by a ROPS structural member or the simulated ground plans (where applicable) into the DLV. (Refer to section 8 of SAE J1040 APR88 for acceptance criteria)

    - 3.1 Lateral Loading
        - 3.1.1 The maximum force attained after the energy requirement was achieved or exceeded (N):
        - 3.1.2 The absorbed energy attained (J):
    - 3.2 Vertical Loading

        The maximum force attained (N):
    - 3.3 Longitudinal Loading
        - 3.3.1 [For all machines except wheel industrial tractors]

            The maximum force attained (N):
        - 3.3.2 [For wheel industrial tractors only]
            - 3.3.2.1 The maximum force attained after the energy requirement was achieved or exceeded (N):
            - 3.3.2.2 The absorbed energy attained (J):
4. Conclusion
    - 4.1 The performance requirements of SAE J1040 APR88 were met in this test for a maximum machine mass (kg):
    - 4.2 Date of Test:
    - 4.3 Name and address of test facility:
    - 4.4 Tested by (signature):
    - 4.5 Date of test report:

LABELING OF ROPS AND FOPS AND OPS—SAE J1164 JAN91

SAE Standard

Report of the Construction and Industrial Machinery Technical Committee, approved April 1977, revised by the Off-Road Machinery Technical Committee May 1983. Rationale statement available. Completely revised by the Off-Road Machinery Technical Committee January 1991. Rationale statement available.

1. Scope—This SAE Standard establishes the specifications and content for labeling of ROPS, FOPS, and OPS, which may commonly be a part of construction, forestry, mining, and industrial machines. The label content herein shall be applied to a ROPS and/or FOPS and/or OPS on any of these machines.

1.1 Purpose—To provide a uniform content of labels on Rollover Protective Structures (ROPS) and/or Falling Object Protective Structures (FOPS) and/or Operator Protective Structures (OPS).

2. References

2.1 Applicable Documents

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1116 JUN86—Categories of Off-Road Self-Propelled Work Machines, Sections 1, 2, 4, and 5

3. Label Specifications

3.1 The label shall be a permanent type and permanently attached to the structure.

3.2 The label and its content shall be of a size that is legible.

3.3 The label shall be located on the structure where it can be read and is protected from environmental defacing.

4. Label Content

4.1 The name and address of the manufacturer or fabricator with certification control of the ROPS and/or FOPS and/or OPS.

4.2 ROPS and/or FOPS and/or OPS model number, if any.

4.3 Machine make, model(s), or series number(s) the structure is designed to fit.

4.4 Maximum mass (weight) of machine for which the structure is certified.

4.5 List by number and date or subscript the specific SAE performance criteria met (for example, SAE J1040 APR88, SAE J231 JAN81, SAE J1042 FEB86, SAE J1084 APR80).

4.6 A list of other performance criteria met may be included (such as ISO).

4.7 The manufacturer may include such other information as deemed appropriate, such as regulatory requirements, installation, repair or replacement information.

Poly Propelene Properties

Tensile strength = 5 ksi

Modulus of Elastisity = 2×10^5 psi

impact strength = $10 \frac{ft-lb}{in}$

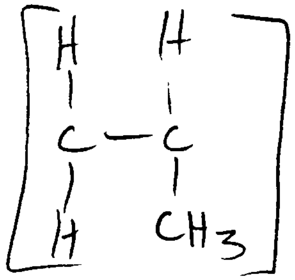
Maximum continuous use temperature = 200°F

specific gravity = .92

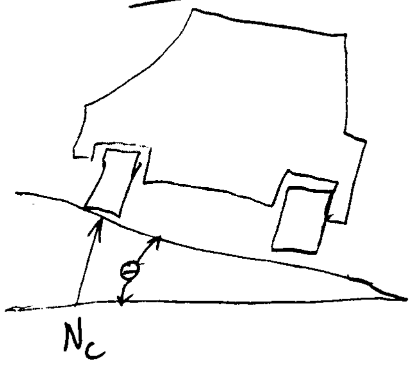
fatigue Stress = 2000 psi

Coeficient of Thermal Expansion = $90 \times 10^{-6}\,°F^{-1}$

Molecular Structure



Maximum angle



$$F = \mu N$$

$$N_c \cos\theta - mg = 0$$

$$N_c \sin\theta = \frac{mv^2}{\rho}$$

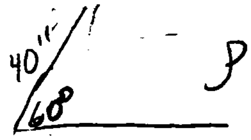
$$\tan\theta = \frac{v^2}{g\rho}$$

ρ = radius of curvature

v = maximum velocity = 7.33 ft/se

ρ

maximum turning angle ≅ 30°
car length = 40''



$\rho \Rightarrow \rho \sin 30° = 40''$

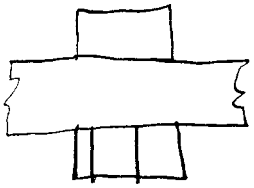
$\rho = 80'' = \underline{6.67 \text{ feet}}$

$$\tan\theta = \frac{(7.33)^2}{(32.2)(6.67)} = \underline{\underline{14°}}$$

but this is slightly larger since we are above sea level and have less gravity

BOLTS

seat belt bolts

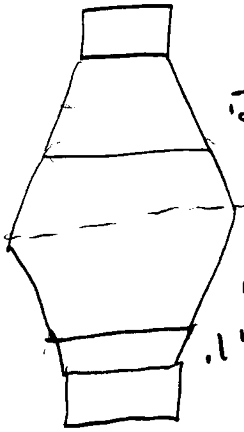


Use $\frac{1}{2}''$ Grade 5 bolts

$S_p = 85$ ksi

$E_{steel} = 30$ Msi

$E_{PP} := .2$ Msi



$$k = \frac{.577 \pi E d}{\ln \frac{(1.15t + D - d)(D+d)}{(1.15t + D + d)(D-d)}}$$

pg 340 Design of Machine Elements

$K_1 = 32 \times 10^6$ lb/in

$K_2 = 28 \times 10^5$ lb/in

$K_3 = 3.5 \times 10^5$ lb/in

$K_4 = 11 \times 10^6$ lb/in

$$\frac{1}{K_m} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4}$$

$K_{material} = \underline{152 \times 10^3 \text{ lb/in}}$

from pg 341 of aforementioned book

$A_t = .1419$ $\quad l_d = 1.75$

$A_d = .196$ $\quad l_t = 0$

$$\frac{1}{K_{bolt}} = \frac{1}{\frac{.1419\ 30 \times 10^6}{.25}} + \frac{1}{\frac{.19635 \times 30 \times 10^6}{.25}}$$

$$\underline{\underline{K_{bolt} = 9.88 \text{ Mlb/in}}}$$

BOLTS

Seat belt bolts continued

$$C = \frac{k_b}{k_b + k_m} = .985$$

so the bolt will recieve most of the load

$$\text{Pressure} = \frac{\sigma_{al}\,A_t}{2\,C} = \frac{(85\,\text{ksi})(.1419)}{2\ \ .985}$$

$$P = 6.1\ \text{ksi} \text{ or } \underline{6100\ \tfrac{\text{lb}}{\text{in}^2}}$$

since $\underset{\text{maximum}}{\text{Force}} \approx 900\,\text{lb}$

Assuming the seat belt recieves all of this load

$$\sigma_{max} = \frac{900\,\text{lb}}{(.1419)+(.1419)} = \underline{3170\ \tfrac{\text{lb}}{\text{in}^2}}$$

so this seat belt will work for a force of up to

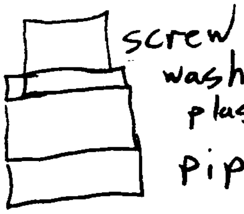
$$6100\ \tfrac{\text{lb}}{\text{in}^2}\ (.1419)(2) = \underline{\underline{1731.\ \text{lb}}}$$

a factor of safety of 2

SCREWS

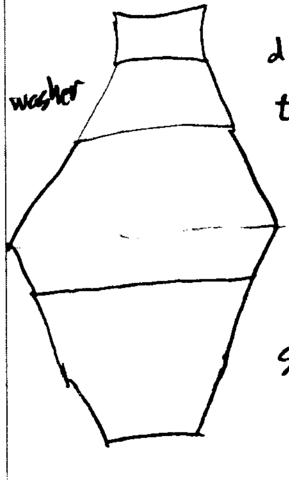
For the roll bar

$\frac{1}{8}$" Grade 5 Coarse screws



washer .1" 1
plastic .2" 2
pipe .2" 3

$$K = \frac{.577\pi E d}{\ln \frac{(1.15t + D - d)(D + d)}{(1.15t + D + d)(D - d)}}$$



$d_1 = .125$ $D_1 = .240$
$t_1 = .1$
$d_2 = .240$ $D_2 = .53$
plastic $t_2 = .15$
$d_3 = .356$ $D_3 = .587$
plastic $t_3 = .05$

steel $d_4 = .125$ $D_4 = .356$
$t_4 = .2$

$K_1 = 16 \times 10^6$ lb/in

$K_2 = 327 \times 10^3$ lb/in

$K_3 = 791 \times 10^3$ lb/in

$K_4 = 22.6 \times 10^6$ lb/in

$$\frac{1}{K_m} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4}$$

$$\underline{\underline{K_m = 226 \times 10^3 \text{ lb/in}}}$$

from pg 341 of Design of Machine Elements

$A_d = \frac{\pi}{4}(.125)^2 = 1.23 \times 10^{-2}$ in^2

$A_t = .0318$ in^2 $\ell_t = .5$"

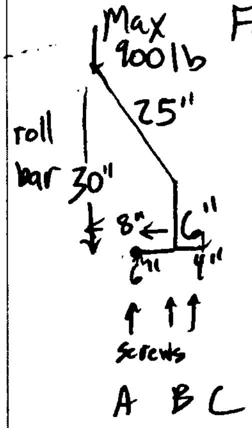
$$\frac{1}{K_{bolt}} = \frac{1}{\frac{(.0318)(30 \times 10^6)}{.5}} \Rightarrow K_b = \underline{\underline{1.9 \times 10^6 \text{ lb/in}}}$$

SCREWS (cont.)

$$C = \frac{K_b}{K_b + K_m} = .894$$

$$P = \frac{\sigma_{al} A_t}{2C} = \frac{(85\,\text{ksi})(.0318)}{2(.894)}$$

$$\underline{\underline{= 1.5\ \text{ksi}}}$$



Force on screw worst case

$$\Sigma M_B \quad (900\,\text{lb})\, 8'' = (x)\, 6'' + (y)\, 4''$$

$$x + y = 900\,\text{lb}$$

$$x = 1800\,\text{lb} \uparrow$$

$$y = 900\,\text{lb} \downarrow$$

so the screws in the back are in tension while those in the front are in compression

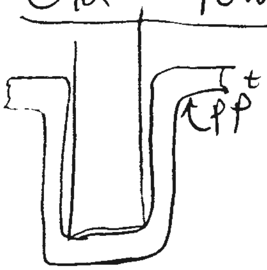
Since $A_t \cong 2\,\text{in}^2$, the most dangerous is the screws in tension

$$\sigma = \frac{Mc}{J} + \frac{F}{A} \cong \frac{7200(1)''}{\frac{1}{2}1(4)^3} + \frac{1800}{2\,\text{in}^2}$$

$$\underline{\underline{\sigma = 1.125\ \text{ksi}}}$$

Even though this is really close $n = 1.3$ assumptions were made which increase this further

Old Powerwheel's roll bar



$t = .118$ inches

$U = 125.3$ ft * lb Max Energy cakulated earlier

$\sigma_t = 5$ Ksi

$A = (1.118)^2 \frac{\pi}{4} - 1^2 \frac{\pi}{4} = .196 \text{ in}^2$

$E_{pp} = .2 \times 10^6$ psi

Strain energy tension

$$U = \frac{F^2 L}{2AE} \Longrightarrow 125.3 = \frac{F^2 \, 1''}{2(.196)(.2) \times 10^6 \frac{\text{lb}}{\text{in}^2}}$$

$$F = 3134.2 \text{ lb}$$

$$\sigma = \frac{F}{A} = \underline{\underline{16.0 \text{ ksi}}}$$

this shows that if the old roll bar were to flip over at maximum speed the plastic would fail.

Rivots For the seat belt.

Seat belt is a nylon mesh thickness ≅ .1"
width = 1"

Tensile Strength = 13.7 ksi

Energy = $\frac{1}{2}mv^2$ $m_{child} = 60\,lb$
$V_{max} = 7.33\,ft/sec$

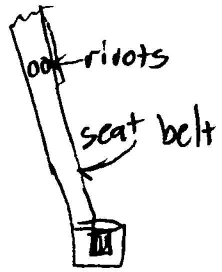
Conservation of Energy $U = E_{max} = 50.1\,ft \cdot lb$

tension & compression

strain energy $U = \frac{F^2 l}{2AE}$ $E_{nylon} = .3 \times 10^6\,psi$

pg. 119 of Design of Mashinery

area of washer $= (.2)^2 \frac{\pi}{4} = .0314\,in^2$



there are 6 washrs to hold the load

$$F^2 = \frac{(50.1\,ft \cdot lb)(2)\left(.3 \times 10^6 \frac{lb}{in^2}\right)(.0314\,in^2)}{(.2\,inches)}$$

$$\underline{F = 2173\,lb}$$

$$\sigma = \frac{F}{A} = \frac{2173}{(6)(.0314)} = \underline{11.5\,ksi}$$

$$\text{Safety Factor} = \frac{13.7}{11.5} = \underline{1.2}$$

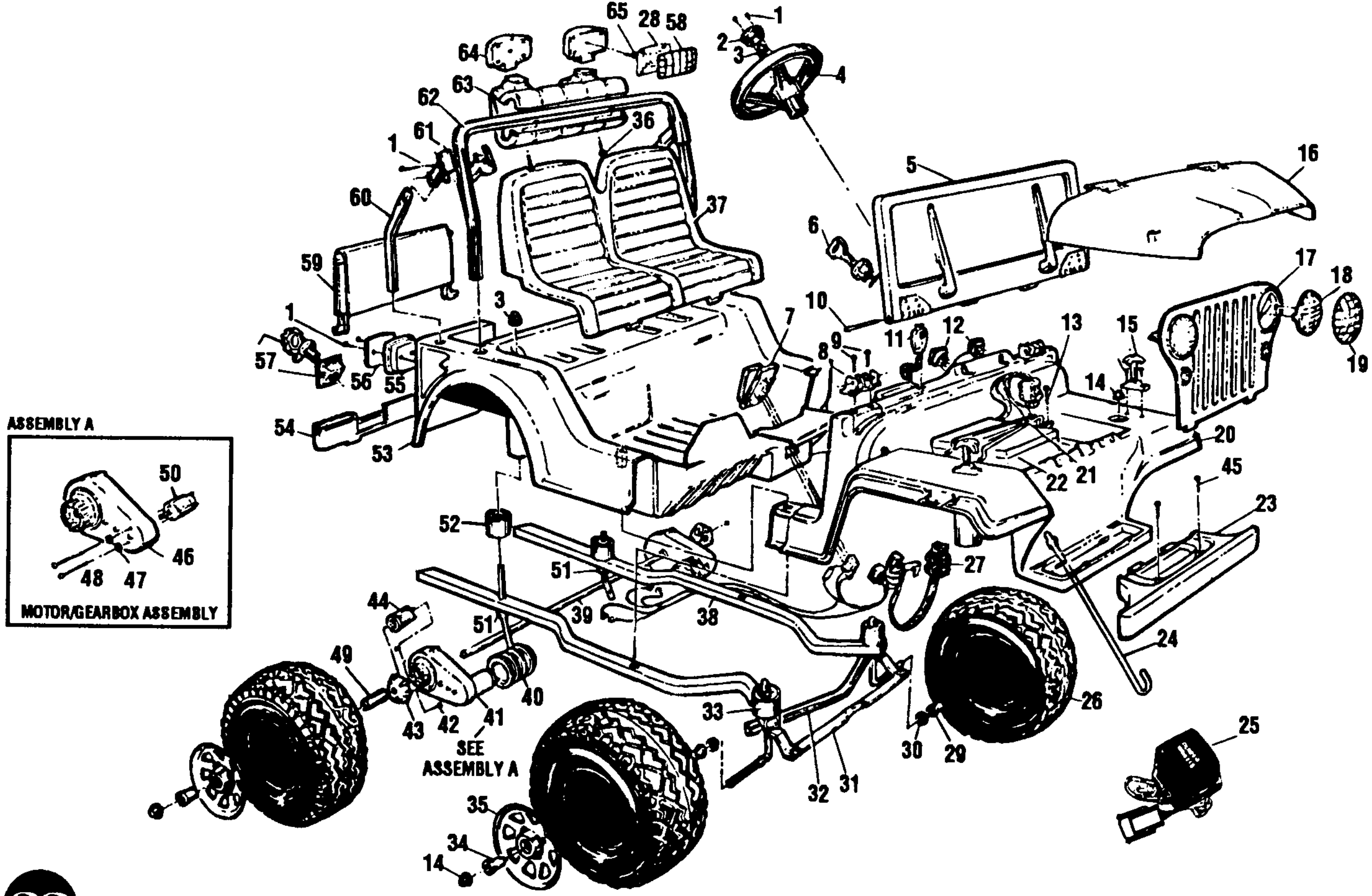
but this is instant stopping at the maximum speed and assuming the rivots dissipate all of the energy

APPENDIX E:

POWER WHEELS INFORMATION

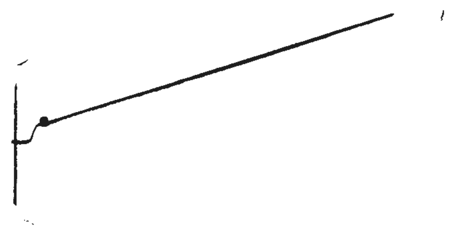
PARTS DIAGRAM

JEEP®
MODEL NO. 86225
12 VOLT



6-2-98 | Remote Freedom | Brower, Delmer

Instructions on disassembling Car



Gear

Removing steering column

1- remove (2) screws in center of steering wheel
2- with regular pliers work clamp off steering column
3- remove clamp at bottom end of steering column.
4- Grind Flat off

Removing seat

1- remove roll Bar by pulling straight up
2- remove 4 screws holding seat down
3- pull seat forward until stops & pull seat directly up

6-2-98 | Remote Freedom | Delmu Brown

- removing body to adapt electrical

1.) unscrew (10) screw, (4) up front six in back

2.) Disconnect battry connector & remover battery ensamble

3.) with flat screwdriver unclamp clasps on sides of car.

APPENDIX F:

COST SHEETS AND CATALOG FOR FUTABA

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TOWER HOBBIES

This page also available in Portugues

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7303

- Dial **800-637-4989** toll-free if you know what you want and have all of the stock numbers ready (U.S. and Canada).
- Dial **800-637-6050** toll-free for questions or assistance with your order (U.S. and Canada).
- Dial **217-398-3636** if you live outside the U.S. or Canada.

Our telephone sales hours are Monday-Thursday 8am-10pm, Friday 8am-7pm, Saturday 9am-5pm and Sunday 10am-7pm (US central time, GMT -6 hours).

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- Send e-mail orders to orders@towerhobbies.com.

In your e-mail order message, please indicate the quantity, stock number and a brief description of each item you wish to order, your Tower customer number (if known) your shipping AND mailing address (if different) and payment information (Discover, Visa, MasterCard or COD). If paying by credit card please include the card number, expiration date, bank name if known, your billing address and a daytime phone ordering from. If for some reason you send us your order twice, please indicate this by including the phrase "DO NOT DUPLICATE" somewhere on your order.

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- Dial 800-637-7303 toll-free in the U.S. and Canada.
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Note that we cannot always respond via FAX. Please include the same information in your FAX as with e-mail ordering, above.

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- **Credit Cards:** We accept Discover, Visa or MasterCard. There is no surcharge added for credit card orders. We reserve the right to verify credit card orders for your protection. For fastest processing, please always include a daytime phone number.
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1800 637 7303

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	LA4959**	Futaba 4VF 4Ch FM 4 S3003 Servos	154.99	IN STOCK
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	LA4968**	Futaba 6VH Skysport Heli 6 Channel/4 S148 Servos	219.99	IN STOCK
	LA4969**	Futaba 6VH Skysport 6 Channel/4 S3101 Servos/MC114H	339.99	IN STOCK
	LA4970**	Futaba 6VA 6Ch,4 S3003 Servos	179.99	IN STOCK
	LA4971**	Futaba 6VA Skyport 6 Channel 2 S3003 & 3 S3302 Servo	339.99	IN STOCK
	LA4972**	Futaba 6XA 6 Channel/4 S3003	209.99	IN STOCK
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	LA4983**	Futaba R122JE 2 Channel Receiver	44.99	IN STOCK
	LA4984**	Futaba R112JE 2 Channel BEC Receiver	49.99	IN STOCK
	LA4985**	Futaba R113iP 3 Channel PCM Receiver	99.99	IN STOCK
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	LA4987**	Futaba R127DF 7 Channel FM Receiver	64.99	IN STOCK
	LA4988**	Futaba R128DF 8 Channel FM Receiver	99.99	IN STOCK
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LA4929	Airtronics 94501Z Microlite Servo w/Z	69.99	IN STOCK
LA4930	Airtronics 94581Z Sailwinch Servo w/Z	54.99	IN STOCK
LA4931	Airtronics 94732Z Contest Air BB Servo w/Z	79.99	IN STOCK
LA4932	Airtronics 94735Z Contest Heli BB Servo w/Z	79.99	IN STOCK
LA4933	Airtronics 94737Z Contest HS BB Servo w/Z	79.99	IN STOCK
LA4934	Airtronics 94738Z Contest HT BB Servo w/Z	79.99	IN STOCK
LA4935	Airtronics 94921Z Low Profile BB Servo w/Z	89.99	IN STOCK
LA4936	Airtronics 94924Z Low Profile BB Retract w/Z	74.99	IN STOCK
LA4937	Aristocraft Seeker Receiver 72 MHz	94.99	IN STOCK
LA4938	Astro Flight Zero Loss Connector (2)	7.99	IN STOCK
LA4939	DuraTrax Futaba Antenna-5 Replacement Antenna	4.99	IN STOCK
LA4940	FUTABA ANT13 REPL ANTENNA	4.99	LATE JAN
LA4941	Ernst Charge Receptacle-Futaba FM	2.39	IN STOCK
LA4942**	Futaba 2PC 2 Channel/2 S3003 Servos	59.99	IN STOCK
LA4943**	Futaba 2PCKA 2 Channel/2 S3003 Servos	84.99	IN STOCK
LA4944**	Futaba 2PC 2 Channel/1 3003 Servo/MC210CB	94.99	IN STOCK
LA4945**	Futaba 2PCKA 2 Channel/1 3003 Servo/MC210CB	119.99	IN STOCK
LA4946**	Futaba 2PC 2Ch/1-S3003 Servo	53.99	IN STOCK
LA4947**	Futaba 3UCP PCM 3Ch/2 S9301 Servos/2 Stick	379.99	IN STOCK
LA4948**	Futaba 2PCKA 2 Channel/1 S3003 Servo	74.99	IN STOCK
LA4949**	Futaba 3PJF FM 3 Channel	274.99	IN STOCK
LA4950**	Futaba 3PJ 3 Channel 9101I PCM 1 S9101	369.99	IN STOCK
LA4951**	Futaba 3PDF FM/2 S3003 Servos	179.99	IN STOCK
LA4952**	Futaba 4NBF Conquest 4-Ch FM/2 S3101 Servos	189.99	IN STOCK
LA4953**	Futaba 2PC 2 Channel/1 S3003 Servo/Explorer ESC	99.99	IN STOCK
LA4954**	Futaba 2PC 2 Channel/1 S3003 Servo/1 S3304 Servo	114.99	IN STOCK
LA4955**	Futaba 2PC 2 Channel/1 S3003 Servo/Spike ESC	89.99	IN STOCK
LA4956**	Futaba 2DR 2 Channel 2 3003 Servos	48.99	IN STOCK

9120 W. 2700 South
Copper Belt Hobbies $ ~~[illegible]~~

3 channel RC ~~$479~~ (379)
Van Gard 219
~~4 channel RC~~
Air Tronics
~~Van Gar~~ $ 229
4 channel
Hatoba $300
J.R. $519 to 600

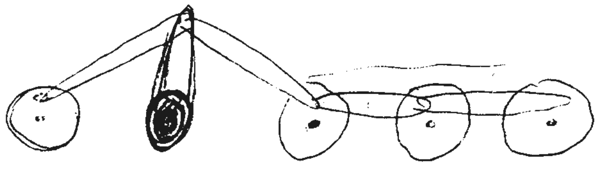
2 Base $1,00

3 chanel 324 -> 595

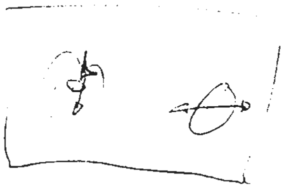
Am $109 -> 220 2 chanel ~~[illegible]~~ "J.R."
Reciver $50.00 Micro-Pro✚ (2-chanel)

M.R.S Hobby Shop 2445 South 600 East

3 P- Magnum ~~[illegible]~~
Futaba FM 249 399 PCM
4



2 Stick



Attack

59.9

FM for Futaba

209.99 - no Servos

389.99 - for PCM.

2 chanel ≈ 79.99 w

Futaba Rec

Pistol style

forward/Reverse

JR. - Fi

JR 605 Servo

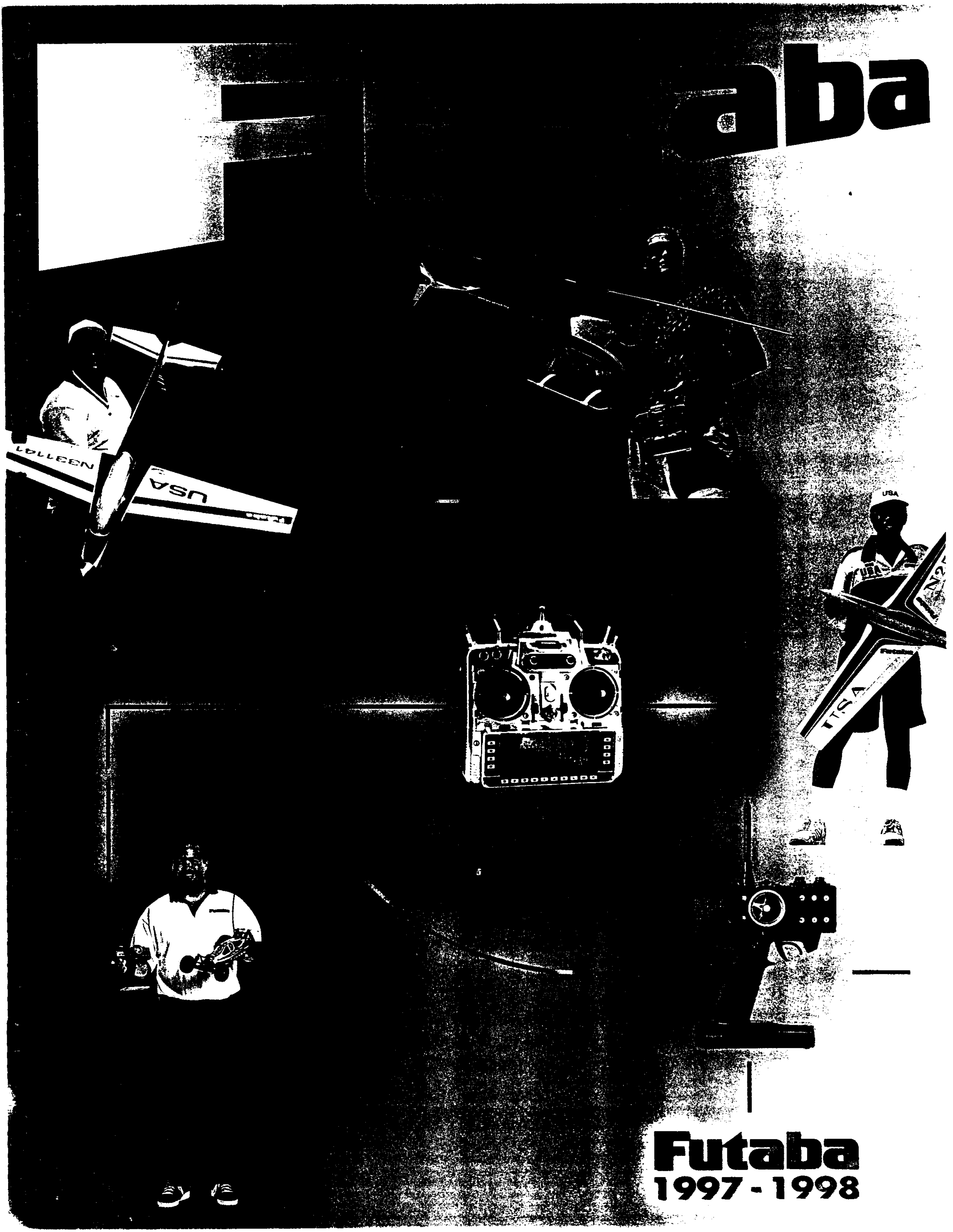
1/4 Scale ... 139.95

Same ~~spec~~ except for

Brand.

Air tronics 9~~4~~158 Same Stuff

$159.95



Futaba
1997 - 1998

GENUINE FUTABA ACCESSORIES

CHARGERS

DUAL

FBC-6B (4) Dual charger for 7UHF/7UHP 9.6v/50mAH and 4.8v/100mAH
$ 36.95

FBC-8B (4) Dual charger for J-series FM/2NL/2PBKA/2PB/2PD/3PB/4NBF/9V 4.8v/45mA and 9.6v/45mA
$ 19.95

FBC-19B (4) Dual charger for Z-series 4.8v/100mA and 9.6v/70mA
$ 36.95

NICD POWER PACKS

TRANSMITTER NICD POWER PACKS

NT-8A Z-series Quick charge
9.6v/700mAH
$ 99.95

NT-8C FN-series, 2E (27MHz)/2F and 3EGX 9.6v/500mAH
$ 36.95

NT-8H PCM, J and G series
9.6v/500mAH
$ 36.95

NT-8F 4NBL/4NBF/4NBP/4VF/3PJ 3PDF/2PC/2PCKA/6X
9.6v/1000mAH
$ 69.95

NT-8LP 2PKA/2PD/3PB 5UA/F/P/ 6NHP/7UAF/P(S) and 7UHF/P(S)
9.6v/500mAH
$ 36.95

NT-8JY 4NBL/4NBF/4NBP/4VF/3PJ 3PDF/2PC/2PCKA/6X
9.6v/500mAH
$ 44.95

NT-8B 9VA/9VH/6NPK/7NFK
9.6v/500mAH
$ 44.95

NT-8R 2PBKA and 2PB
9.6v/500mAH
$ 49.95

2-500RS 2L and 4L NiCd sticks (requires 4) 2-AA NiCds/2.4v/500mAH
$ 9.95

RECEIVER NICD POWER PACKS

NR-4G(3-pin connector)
NR-4K(J-connector)
Lightweight NiCd 4.8v/250mAH
2.0oz./2.18" x 1.18" x 0.56"
$19.95

NR-4RB(J-connector)
Fast charge/high power NiCd
4.8v1000mAH/3.9oz.
2.62" x 1.75" x 0.68"
$44.95

NR-4M(3-pin connector)
NR-4J(J-connector)
Flat pack NiCd 4.8v/500mAH
3.3oz./2.25" x 1.97" x 0.56"
$19.95

NR-4QM(3-pin conn.)
NR-4QB(J-connector)
Square pack NiCd 4.8v/500mAH
3.3oz./2.00" x 1.12" x 1.12"
$19.95

NR-5F
Flat Pack NiCd 6.0v/600mAH
3.31" x 1.45" x 0.67"/3.5oz.
$ 29.95

NR-6PB(J-connector)
Flat pack/high voltage NiCd
6.0v/450mAH/3.1oz.
3.35" x 1.26" x 0.69"
$29.95

NR-5RB(J-connector)
Fast charge/high voltage NiCd
6.0v/1000mAH/4.8oz.
1.75" x 2.00" x 1.25"
$64.95

NR-5T Hump Pack NiCd
6.0v/600mAH/3.5oz.
1.99" x 1.20" x 1.24"
$ 29.95

DRY CELL BOX

FBB-1
Battery box for 4-AA batteries (not included) with BEC plug
$ 5.95

SERVO HORNS

Description	*Part No.*	*Price*
Splined Horn A X-shaped	FSH-6X	2.95
Splined Horn B star	FSH-6S	2.95
Splined Horn C disc	FSH-6R	2.95
Splined Horn D wheel	FSH-6W	2.95
Splined Horn E arm	FSH-6E	2.95
Splined Horn F small X	FSH-6F	2.95
Splined Horn G large wheel	FSH-6G	2.95
Winch drum	FSH-5801	8.00

GEAR SETS

S25/125	FGS-25	4.50
S28/128	FGS-28	5.95
S30/130/5101	FGS-30	4.50
S3002	FGS-3002	69.95
S3003	FGS-3003	4.95
S31S/131S/9201 9202/9301/9304	FGS-31S	5.95
S31SH/131SH/9401 9403	FGS-31SH	5.95
S3101	FGS-3101	5.95
S132	FGS-32	5.95
S132H	FGS-32H	5.95
S133	FGS-33	5.95
S3302/S3801	FGS-3302	24.95
S3303	FGS-3303	39.95
S134	FGS-34	5.95
S134G	FGS-34G	5.95
S135S/9601	FGS-35S	6.95
S136G	FGS-36G	14.95
S38/138	FGS-38	4.50
S48/148/3001/9001	FGS-48	4.50
S5102	FGS-5102	44.95
S5801	FGS-5801	34.95
S9101	FGS-9101	5.95
S9102	FGS-9102	9.95
S9203	FGS-9203	64.95
S9204	FGS-9204	59.95
S9302/9303	FGS-9302	69.95
S9402	FGS-9402	70.00

CASE SETS

S30/130/5101/9101	FCS-30	5.95
S3001	FCS-3001	5.95
S3002	FCS-3002	5.95
S3003	FCS-3003	5.95
S31S/131S/9201/9301 9401/9403/9304	FCS-31S	5.95
S3101/3102	FCS-3101	5.95
S32/32H	FCS-32	5.95
S133/5102	FCS-33	5.95
S134/134G/3302 3801	FCS-34	6.95
S35/135/9601	FCS-35S	5.95
S36/136G	FCS-36G	5.95
S38/138	FCS-38	4.50
S48/148	FCS-48	5.95
S5801	FCS-5801	8.95
S9001	FCS-9001	5.95
S9102	FCS-9102	5.95
S9202	FCS-9202	5.00
S9203/9402	FCS-9203	7.95
S9302/9303	FCS-9302	5.95

HARDWARE

Servo grommets (20)	FSH-10	4.95
Servo horn screws & washers (10)	FSH-11	4.95
Square grommets (20)	FSH-20	5.95
Servo eyelets (20)	FSH-21	4.95
Servo mounting screws & washers (10)	FSH-32	4.95
Accessory pkg. S125	FSH-33	5.00
Servo arm S3801	FSH-38	5.95
Servo grommets rectangle (20) S28/29/30/31/32	FSH-40	4.95
Servo horn screws (10) S28/29/30/31/32	FSH-41	3.75
Servo Accessory pkg. S28/30/31/32/48 148/9301	FSH-42	6.95
S33/133 horn screw	FSH-44	3.75
Servo grommet S134/3302	FSH-46	10.50
Servo eyelet S134/3302	FSH-47	9.00
Grommets (Split/20)	FSH-48	5.95

SERVO TRAYS

Description	*Part No.*	*Price*
2+1/S48,148,3003	FST-28T	7.50
Single/Vertical S28 through S148	FST-28V	5.95

MINI CONNECTORS

Description	*Part No.*	*Price*
Servo/NiCd Connector Set	FPC-3MF	7.50
J-Type NiCd Conn.	FPC-8F	5.95
J-Type Female	FPC-8J	6.95
J-Type Servo Conn.	FPC-8M	3.95
J-Type Connectors (NiCd/Servo)	FPC-8MF	8.95

ANTENNAS

2NCS/2NBR/2PB 2PBKA/2PD/2V/3PB 4NBL/4NBF/4NBP 4V/6X	ANT-5	8.00
3EGX/4L/5LK/5NHL 6NFK/6V/7NFK	ANT-6	9.95
G-Series	ANT-8	8.00
T3PG (long)27/75	ANT-11	9.95
9Z/8U/7U/5U/3UCP	ANT-12	10.95
2CR/2DR/2PC/2PCKA	ANT-13	8.00
3PJ (black/fits 3PDF)	ANT-14	20.00
3PDF	ANT-15	8.00

ACCESSORIES

Clip-on Screwdriver	FTA-6	3.50
9VA/9VH/9Z Strap	FTA-8	15.95
Futaba Alloy Case	9Ch.case	84.95
AM Trainer Cord	M-TC-AM	20.95
G-series/FM Trainer Cord	M-TC-FM	20.95
CAMpac Memory Module for 9Z Up to 8 models	CAM-pac	129.95
CAMpac Memory Module for 8UA/H Up to 5 models	CAM-pac8	99.95
3PJ/3PDF Small Grip and Steering Wheel (Red/Blue/Green)	FTA-9R/B/G	19.95
3PJ/3PDF Large Grip and Steering Wheel (Red/Blue/Green)	FTA-10R/B/G	19.95
8Ch. Transmitter Carrying Case	FTA-11	19.95
Fail Safe Unit	FS-1	79.95

CORDS / ADAPTERS

Aileron extension cord	AEC-1	8.95
Dual servo extension	AEC-2	8.50
J-Type aileron extension	AEC-3	5.95
Servo adaptor J-Type to standard	AEC-9	7.95
Servo adaptor standard to J-Type	AEC-10	7.95
J-Extension 16" cord	AEC-11	6.95
J-Extension 1M cord	AEC-12	7.95
J-Type dual servo extension(replaces AEC-4)	AEC-13	9.95
Transmitter charge cord	NCC-1	8.95
Receiver charge cord	NCC-2	8.95
J-Type transmitter charge cord	NCC-3	9.95
J-Type receiver charge cord	NCC-4	11.50
8SG DSC charge adaptor	NCC-8	11.50
9V/9Z DSC charge adaptor	NCC-9	11.50
3PB/3PJ DSC cord	NCC-10	7.50
3UCP DSC cord	NCC-11	7.50
J-Connector mini switch harness	SWH-7	11.00
Mini switch harness w/charge cord	SWH-8	12.50
Mini switch w/BEC connector	SWH-10	11.00
J-Mini switch w/2-pin connector	SWH-12	8.95
J-Mini switch harness w/charge cord	SWH-13	10.95

Please respect FCC regulations regarding band use. Surface models are only to be operated on approved 27 and 75MHz frequencies; Aircraft only on 50, 53 and 72MHz.

MATCHED TRANSMITTER/RECEIVER CRYSTALS

Frequency	*AM $20.00*	*FM $35.00*	*FM Dual Con. $ 40.00*
50.940/Ch.07	FMC-111	FMC-411	FMC-811
72.030/Ch.12	FMC-112	FMC-412	FMC-812
72.050/Ch.13	FMC-113	FMC-413	FMC-813
72.070/Ch.14	FMC-114	FMC-414	FMC-814
72.090/Ch.15	FMC-115	FMC-415	FMC-815
72.110/Ch.16	FMC-116	FMC-416	FMC-816
72.130/Ch.17	FMC-117	FMC-417	FMC-817
72.150/Ch.18	FMC-118	FMC-418	FMC-818
72.170/Ch.19	FMC-119	FMC-419	FMC-819
72.190/Ch.20	FMC-120	FMC-420	FMC-820
72.210/Ch.21	FMC-121	FMC-421	FMC-821
72.230/Ch.22	FMC-122	FMC-422	FMC-822
72.250/Ch.23	FMC-123	FMC-423	FMC-823
72.270/Ch.24	FMC-124	FMC-424	FMC-824
72.290/Ch.25	FMC-125	FMC-425	FMC-825
72.310/Ch.26	FMC-126	FMC-426	FMC-826
72.330/Ch.27	FMC-127	FMC-427	FMC-827
72.350/Ch.28	FMC-128	FMC-428	FMC-828
72.370/Ch.29	FMC-129	FMC-429	FMC-829
72.390/Ch.30	FMC-130	FMC-430	FMC-830
72.410/Ch.31	FMC-131	FMC-431	FMC-831
72.430/Ch.32	FMC-132	FMC-432	FMC-832
72.450/Ch.33	FMC-133	FMC-433	FMC-833
72.470/Ch.34	FMC-134	FMC-434	FMC-834
72.490/Ch.35	FMC-135	FMC-435	FMC-835
72.510/Ch.36	FMC-136	FMC-436	FMC-836
72.530/Ch.37	FMC-137	FMC-437	FMC-837
72.550/Ch.38	FMC-138	FMC-438	FMC-838
72.570/Ch.39	FMC-139	FMC-439	FMC-839
72.590/Ch.40	FMC-140	FMC-440	FMC-840
72.610/Ch.41	FMC-141	FMC-441	FMC-841
72.630/Ch.42	FMC-142	FMC-442	FMC-842
72.650/Ch.43	FMC-143	FMC-443	FMC-843
72.670/Ch.44	FMC-144	FMC-444	FMC-844
72.690/Ch.45	FMC-145	FMC-445	FMC-845
72.710/Ch.46	FMC-146	FMC-446	FMC-846
72.730/Ch.47	FMC-147	FMC-447	FMC-847
72.750/Ch.48	FMC-148	FMC-448	FMC-848
72.770/Ch.49	FMC-149	FMC-449	FMC-849
72.790/Ch.50	FMC-150	FMC-450	FMC-850
72.810/Ch.51	FMC-151	FMC-451	FMC-851
72.830/Ch.52	FMC-152	FMC-452	FMC-852
72.850/Ch.53	FMC-153	FMC-453	FMC-853
72.870/Ch.54	FMC-154	FMC-454	FMC-854
72.890/Ch.55	FMC-155	FMC-455	FMC-855
72.910/Ch.56	FMC-156	FMC-456	FMC-856
72.930/Ch.57	FMC-157	FMC-457	FMC-857
72.950/Ch.58	FMC-158	FMC-458	FMC-858
72.970/Ch.59	FMC-159	FMC-459	FMC-859
72.990/Ch.60	FMC-160	FMC-460	FMC-860
75.410/Ch.61	FMC-161	FMC-461	FMC-861
75.430/Ch.62	FMC-162	FMC-462	FMC-862
75.450/Ch.63	FMC-163	FMC-463	FMC-863
75.470/Ch.64	FMC-164	FMC-464	FMC-864
75.490/Ch.65	FMC-165	FMC-465	FMC-865
75.510/Ch.66	FMC-166	FMC-466	FMC-866
75.530/Ch.67	FMC-167	FMC-467	FMC-867
75.550/Ch.68	FMC-168	FMC-468	FMC-868
75.570/Ch.69	FMC-169	FMC-469	FMC-869
75.590/Ch.70	FMC-170	FMC-470	FMC-870
75.610/Ch.71	FMC-171	FMC-471	FMC-871
75.630/Ch.72	FMC-172	FMC-472	FMC-872
75.650/Ch.73	FMC-173	FMC-473	FMC-873
75.670/Ch.74	FMC-174	FMC-474	FMC-874
75.690/Ch.75	FMC-175	FMC-475	FMC-875
75.710/Ch.76	FMC-176	FMC-476	FMC-876
75.730/Ch.77	FMC-177	FMC-477	FMC-877
75.750/Ch.78	FMC-178	FMC-478	FMC-878
75.770/Ch.79	FMC-179	FMC-479	FMC-879
75.790/Ch.80	FMC-180	FMC-480	FMC-880
75.810/Ch.81	FMC-181	FMC-481	FMC-881
75.830/Ch.82	FMC-182	FMC-482	FMC-882
75.850/Ch.83	FMC-183	FMC-483	FMC-883
75.870/Ch.84	FMC-164	FMC-464	FMC-884
75.890/Ch.85	FMC-185	FMC-485	FMC-865
75.910/Ch.86	FMC-186	FMC-486	FMC-886
75.930/Ch.87	FMC-187	FMC-487	FMC-887
75.950/Ch.88	FMC-188	FMC-488	FMC-888
75.970/Ch.89	FMC-189	FMC-489	FMC-889
75.990/Ch.90	FMC-190	FMC-490	FMC-890

AM	*$15.00*
26.996/Brown	FMC-21
27.045/Red	FMC-22
27.095/Orange	FMC-23
27.145/Yellow	FMS-24
27.195/Green	FMC-25
27.255/Blue	FMC-26

FM	*$ 20.00*
26.995/Brown	FMC-321
27.045/Red	FMC-322
27.095/Orange	FMC-323
27.145/Yellow	FMS-324
27.195/Green	FMC-325
27.255/Blue	FMC-326

FM	*$ 35.00*
50.800/Ch.00	FMC-400
50.820/Ch.01	FMC-401
50.840/Ch.02	FMC-402
50.860/Ch.03	FMC-403
50.880/Ch.04	FMC-404
50.900/Ch.05	FMC-405
50.920/Ch.06	FMC-406
50.940/Ch.07	FMC-407
50.960/Ch.08	FMC-408
50.980/Ch.09	FMC-409

FM dual conversion	*$ 40.00*
50.800/Ch.00	FMC-800
50.820/Ch.01	FMC-801
50.840/Ch.02	FMC-802
50.860/Ch.03	FMC-803
50.880/Ch.04	FMC-804
50.900/Ch.05	FMC-805
50.920/Ch.06	FMC-806
50.940/Ch.07	FMC-807
50.960/Ch.08	FMC-808
50.980/Ch.09	FMC-809

MODULES

TJ-27FM
3PJ27MHz FM
$ 69.95

TJ-75FM
3PJ 75MHz FM
$ 69.95

TK-50PCM
9VA/9ZA/9VH/9ZH 50MHz FM
$ 74.95

TK-72PCM
9VA/9ZA /9VH/9ZH 72MHz FM
$ 74.95

TL-27FM
3PB Magnum 27MHz FM
$ 74.95

TL-75FM
3PB Magnum 75MHz FM
$ 74.95

TP-72AM
5UA 72MHz AM
$ 49.95

TP-27FM
3UCP 27MHz FM
$ 69.95

TP-50FM
5UAF/5UAP/7UAFS/7UAPS 7UHFS/7UHPS/8UAP/8UAF/ 8UHP/8UHF/ 50MHz FM
$ 69.95

TP-72FM 5UAF/5UAP 7UAFS/7UAPS/7UHFS/ 7UHPS8UAP/8UAF/8UHP/8UHF 72MHz FM
$ 69.95

TP-75FM
3UCP 75MHZ FM
$ 69.95

TK-FSS72FM
Synthesizer 9ZAPS/9ZHPS
72MHz FM
$199.95

ONE YEAR LIMITED WARRANTY

Futaba digital proportional RC systems are warranted to the original purchaser for one full year from the date of purchase against defects in material and workmanship. During this period Futaba will repair or replace, at our discretion, the defective component.

This warranty does not apply to improperly installed, handled, abused, damaged in crash, nor to any unit which has been repaired or altered by unauthorized agencies. Under no circumstances will the buyer be entitled to consequential of incidental damages. This limited warranty gives you specific legal rights; you may have other rights which vary from state to state. Batteries and plastic housings are not covered by warranty.

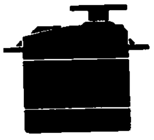
This warranty applies to Futaba products purchased and used in the continental United States, Hawaii and Alaska.

GENUINE FUTABA SERVOS

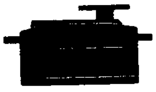
Genuine Futaba servos are the easiest and most efficient way to upgrade your Futaba system. No other system provides you access to as many different sizes, shapes and functions as Futaba. Currently, there are 23 Futaba servos available ranging from the micro, 0.60 ounce S3101 to the mighty 195 ounce/inches of torque of the S3801. The performance and reliability of our servos have made them the favorite choice of professionals including top RC competition specialists and motion picture special effect artists.

New model Futaba servos, like the 9001, take advantage in the latest developments in coreless motor design. Others feature ball bearings and precision ground metal gears for smooth action and durability. And all Futaba servos use space efficient, reliable SMT assembly.

Get the most from your RC system with the finest servos available, genuine Futaba.


S125


S3401


S136G


S148


S3001


S3002


S3003


S3101


S3302
S3801


S9101


S9001
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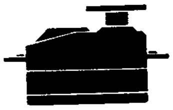
S9204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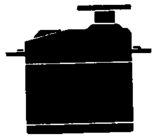

S9202
S9404
S9304


S9303
S9402


S9602

Part No.	Description	Dimensions (Inches)	Weight/Torque (Ounce/oz./in.)	Transit (sec/60°)	Bearing	Gear	Price	Aircraft	Helicopter	Sailplane	Big Bird	Gas Car/Boat	Offroad car	Onroad car	Sailboat
S125	Arm Type Sail	1.79 x 0.91 x 1.66	2.3oz./129.15	0.62	1 BB	Nylon	$74.95								■
S136G	Compact Retract	1.78 x 0.89 x 1.00	1.48oz./76.4	0.50	2 BB	Metal	84.95	■			■				
S148	Standard	1.59 x 0.78 x 1.42	1.5oz./41.7	0.22	1 Oilite	Nylon	39.95	■	■	■	■	■	■	■	
S3001	Standard	1.59 x 0.78 x 1.42	1.59oz./41.7	0.22	Oilite/BB	Nylon	44.95	■	■	■	■	■	■	■	
S3002	High Torque Mini	1.22 x 0.63 x 1.19	1.23oz./45.8	0.16	2 BB	Metal	109.95	■		■				■	
S3003	Standard	1.59 x 0.78 x 1.42	1.3oz./44.4	0.22	1 Oilite	Nylon	29.95	■		■	■	■	■	■	
S3101	Micro	1.10 x 0.51 x 1.17	0.60oz/34.7	0.22	1 Oilite	Nylon	69.95			■					
S3102	Micro	1.10 x 0.51 x 1.09	0.74oz./51.40	0.25	1 Oilite	Metal	109.95			■					
S3302	Metal gear 1/4 Scale	2.33 x 1.13 x 1.96	3.6oz./111	0.19	2 BB	Metal	109.95				■	■	■		
S3401	High Speed.	1.54 x 0.79 x 1.47	1.66oz/44.4	0.15	2 BB	Nylon	89.95					■	■		
S3801	Arm Type Sail	2.33 x 1.13 x 1.96	3.77oz./194.0.	0.22	2 BB	Metal	109.95								■
S5801	Sail Winch	1.81 x 0.98 x 1.73	2.93oz./136.1	0.5	2 BB	Metal	224.95								■
S9001	CL/BB	1.59 x 0.78 x 1.42	1.69z./54.2	0.22	Oilite/BB	Nylon	79.95	■	■	■	■	■	■	■	
S9101	High Speed Std.	1.52 x 0.77 x 1.36	1.59oz/43.1	0.16	2 BB	Nylon	109.95	■	■	■				■	
S9102	Wing Mount /CL	1.76 x 0.87 x 1.02	1.62oz./50	0.13	2 BB	Nylon	134.95	■	■	■	■	■	■	■	
S9202	Helicopter/CL	1.59 x 0.79 x 1.40	1.76oz./69.4	0.22	2 BB	Nylon	109.95	■	■			■			
S9203	Helicopter/CL	1.59 x 0.79 x 1.48	1.87oz./76.4	0.11	2 BB	Metal	159.95	■	■				■	■	
S9204	High Torque	1.59 x 0.79 x 1.48	1.887z./131.9	0.19	2 BB	Metal	159.95	■	■						
S9303	High Torque	1.59 x 0.79 x 1.56	2.28oz./100	0.19	2 BB	Metal	124.95	■	■		■	■	■	■	
S9304	High Torque/CL	1.59 x 0.79 x 1.40	1.76oz./69.4	0.22	2 BB	Nylon	109.95	■	■	■	■	■	■	■	
S9402	High Torque/CL	1.59 x 0.79 x 1.48	1.94oz/111.1	0.09	2 BB	Metal	159.95	■	■	■	■	■	■	■	
S9404	High Torque/CL	1.54 x 0.79 x 1.47	1.94oz./79.2	0.11	2 BB	Metal	124.95					■	■	■	
S9602	High Speed/CL	1.41 x 0.59 x 1.47	1.09oz./37.5	0.09	2 BB	Nylon	124.95	■		■				■	

Abbreviations: CL-Coreless Motor BB-ball bearing(s)

NARROW BAND RECEIVERS

R112JE 2 Channel/BEC
1.84" x 1.24" x 0.62"
0.72oz./27, 72 & 75MHz AM
$59.95

R122JE 2 Channel/BEC
1.82" x 1.31" x 0.67"
0.62 oz./27, 72 & 75MHz AM
$59.95

R113F 3 Channel/FM
1.13" x 1.69" x 0.63"
0.72oz./27 & 75MHz FM
$109.95

R113IP 3 Channel PCM1024
1.13" x 1.69" x 0.63"
0.72oz./27 & 75MHz FM
$199.95

R114H 4 Channel
1.31" x 1.87" x 0.81"
0.95oz./72 & 75MHz AM
$89.95

R127DF 7 Channel FM
1.39" x 2.52" x 0.82"
1.5oz./50, 72 & 75MHz FM
$139.95

R128DF 8 Channel FM
1.39" x 2.51" x 0.82"
1.3oz./50 & 72MHz FM
$179.95

R128DP 8 Channel PCM Dual Conversion
1.48" x 2.48" x 0.97"
1.5oz./50 & 72MHz FM
$249.95

R129DP 9 Channel PCM1024 Dual Conversion
1.48" x 2.48" x 0.97"
1.5oz./50 & 72MHz FM
$259.95

R148DF 8 Channel FM Slim Line Dual Conversion
1.00" x 2.20" x 0.90"
1.1oz./50 & 72MHz FM
$199.95

R148DP 8 Channel PCM1024 Dual Conversion
1.00" x 2.20" x 0.90"
1.1oz./50 & 72MHz FM
$279.95

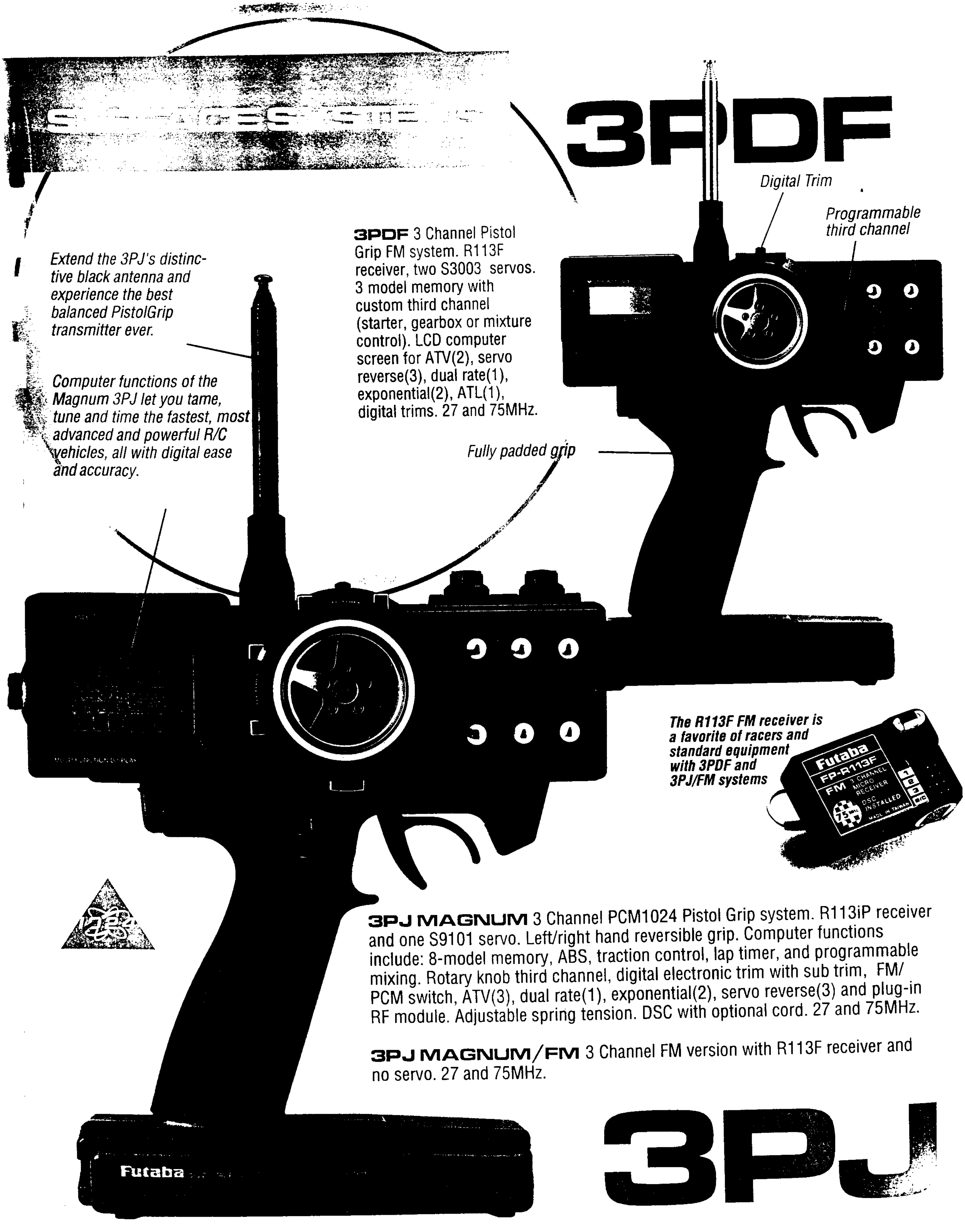
R309DPS 9 Channel PCM1024 w/Synthesizer Dual Conversion
1.43" x 2.53" x 0.94"
72MHz only.
$629.95

ESC'S

MC210CB
MOSFET Electronic Speed Control with reverse. *Capacity: 7.2v* (6-cell) to 8.4v (7-cell)/ 142A (continuous), 586A (surge). Braking and one-speed reverse. *Includes:* LED check circuits, motor connectors. 30A fuse protection. *VDR:* 0.0062ohm
1.79" x 1.63" x 1.02"/2.55oz
$89.95

MC114H Electric power helicopter/airplane electronic speed control. *Capacity:* 8.4v (7-cell) to 9.6v (8-cell)/0.0044 ohm FET resistance. *Includes:* LEO check circuits, auto cut function, start switch.
1.21" x 1.45" x 0.60"/1.66oz.
$89.95

3PDF



3PDF 3 Channel Pistol Grip FM system. R113F receiver, two S3003 servos. 3 model memory with custom third channel (starter, gearbox or mixture control). LCD computer screen for ATV(2), servo reverse(3), dual rate(1), exponential(2), ATL(1), digital trims. 27 and 75MHz.

Extend the 3PJ's distinctive black antenna and experience the best balanced PistolGrip transmitter ever.

Computer functions of the Magnum 3PJ let you tame, tune and time the fastest, most advanced and powerful R/C vehicles, all with digital ease and accuracy.

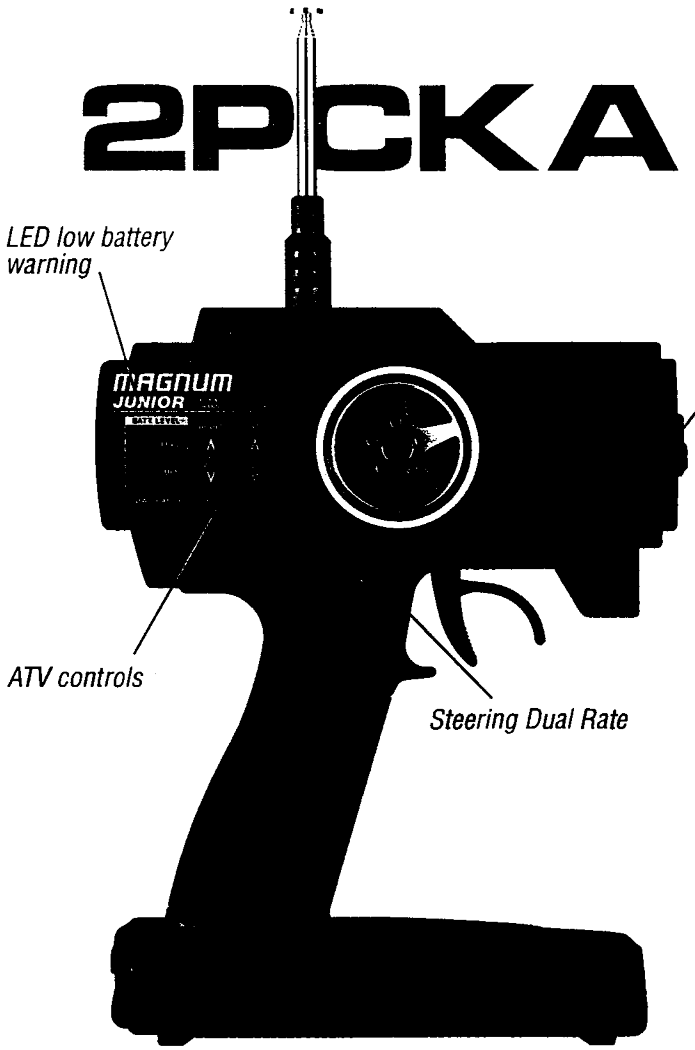
The R113F FM receiver is a favorite of racers and standard equipment with 3PDF and 3PJ/FM systems

3PJ MAGNUM 3 Channel PCM1024 Pistol Grip system. R113iP receiver and one S9101 servo. Left/right hand reversible grip. Computer functions include: 8-model memory, ABS, traction control, lap timer, and programmable mixing. Rotary knob third channel, digital electronic trim with sub trim, FM/PCM switch, ATV(3), dual rate(1), exponential(2), servo reverse(3) and plug-in RF module. Adjustable spring tension. DSC with optional cord. 27 and 75MHz.

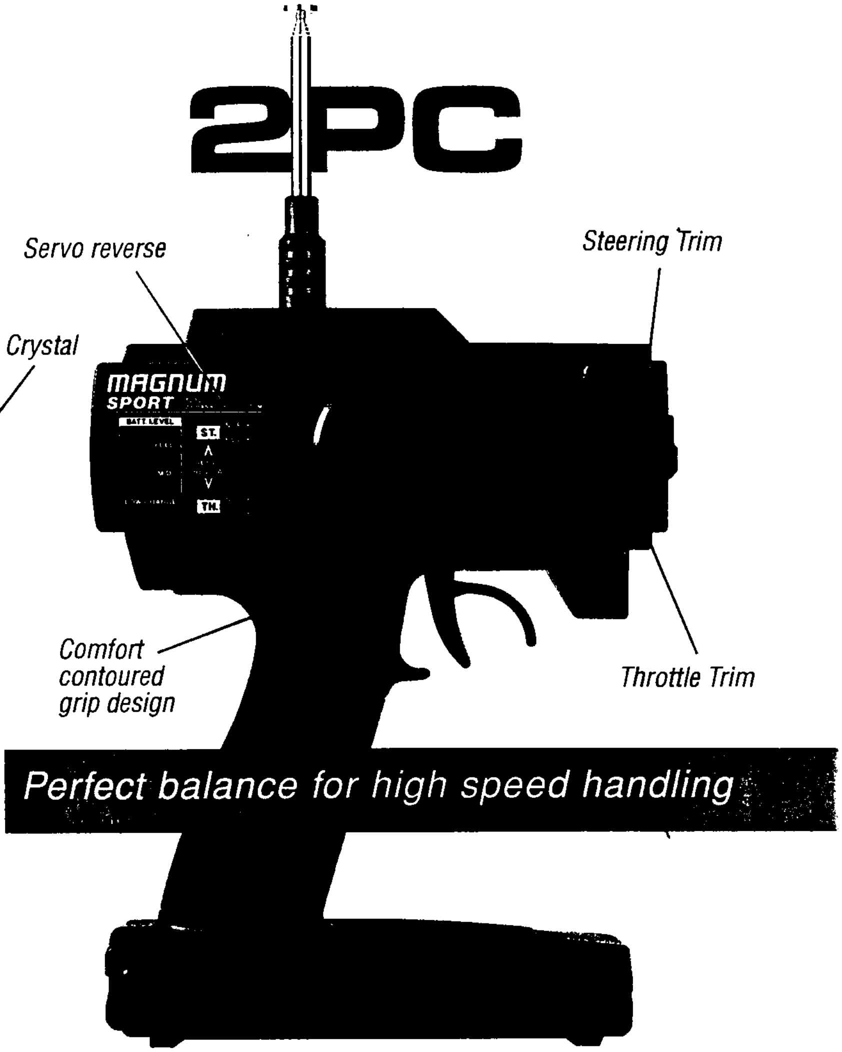
3PJ MAGNUM/FM 3 Channel FM version with R113F receiver and no servo. 27 and 75MHz.

3PJ

2PCKA



2PC



Perfect balance for high speed handling

2PCKA MAGNUM JUNIOR
2 Channel Pistol Grip system. R122JE 2 Channel BEC receiver, two S3003 servos, steering dual rate, throttle ATV, fine trim, servo reverse. Requires AA size alkaline batteries(not included). 27 and 75MHz.

2PCKA MAGNUM JUNIOR/E
Same as above with one S3003 servo and MC210CB electronic speed control with reverse. 27 and 75MHz.

2PC MAGNUM SPORT
2 Channel Pistol Grip system. R122JE receiver, two S3003 servos. Trim adjust. Servo reverse (2). Requires AA size alkaline batteries(not included). 27and75MHz.

2PC MAGNUM SPORT/E
Same as above with one S3003 servo and one MC210CB speed control.
27 and 75MHz.

2VR ATTACK SR
(not shown) 2 Channel dual stick system. R122JE/BEC narrow band receiver, 2-S3003 servos. Dual audible/LED low battery alarm, servo reverse and fine trim adjust. Available 72 or 75MHz.

<

2DR 2 Channel dual stick system. R122JE/BEC narrow band receiver, 2-S3003 servos. Servo reverse, built-in handle and ergonomic case design. Available on 72 or 75MHz.

APPENDIX G:

PHOTOS OF DESIGN

Photo1: Ben Cox with his brother on a test drive.

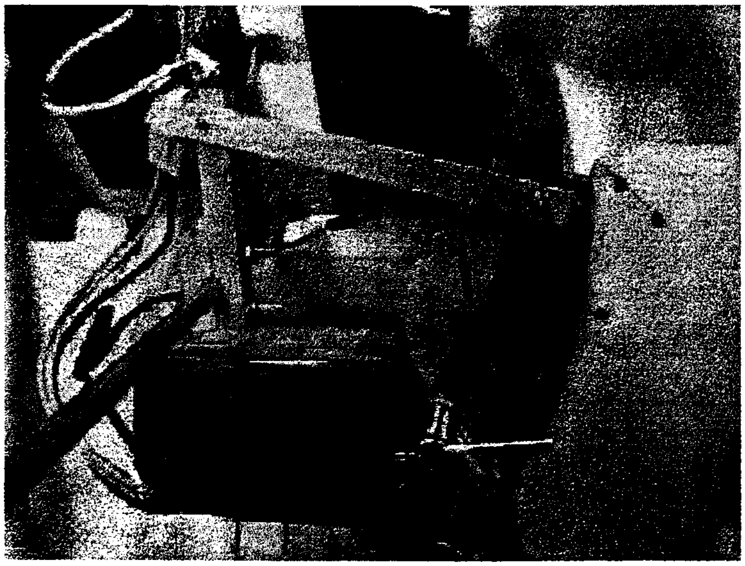


Photo 2: Four bar linkage used for steering.

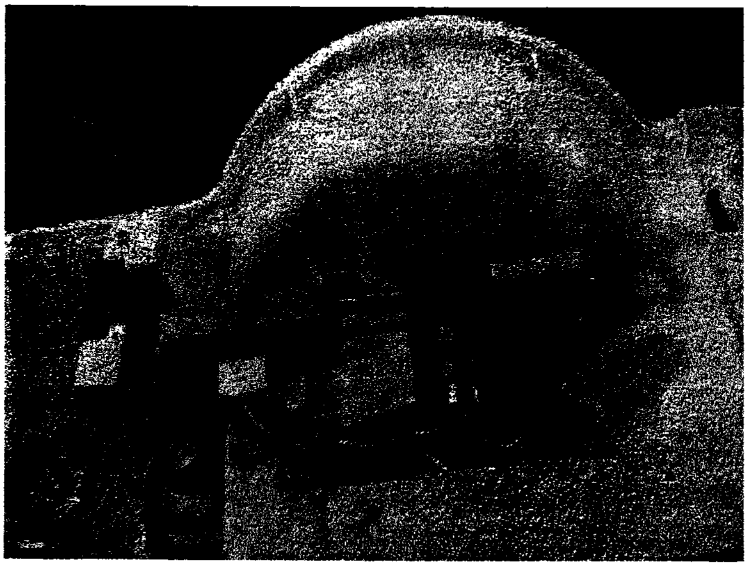


Photo 3. Four bar linkage for gear box switching.

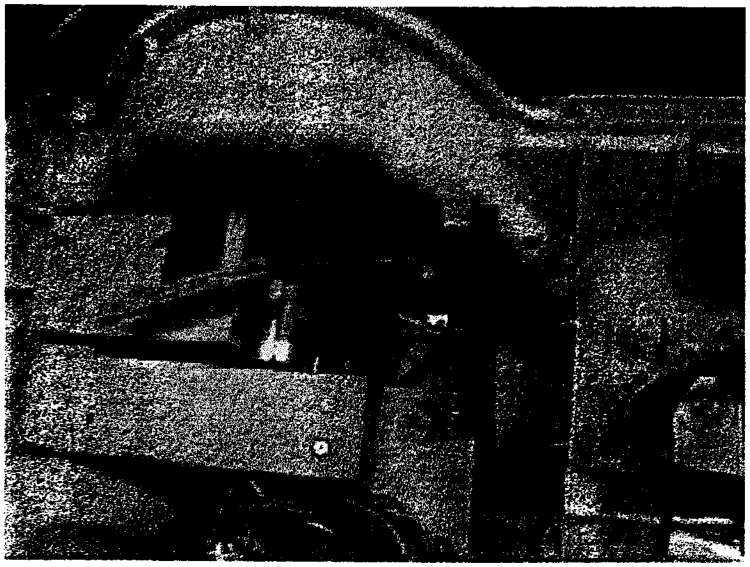


Photo 4. Mechanism for gas pedal.

Photo 5. Failed Roll bar fixturing.

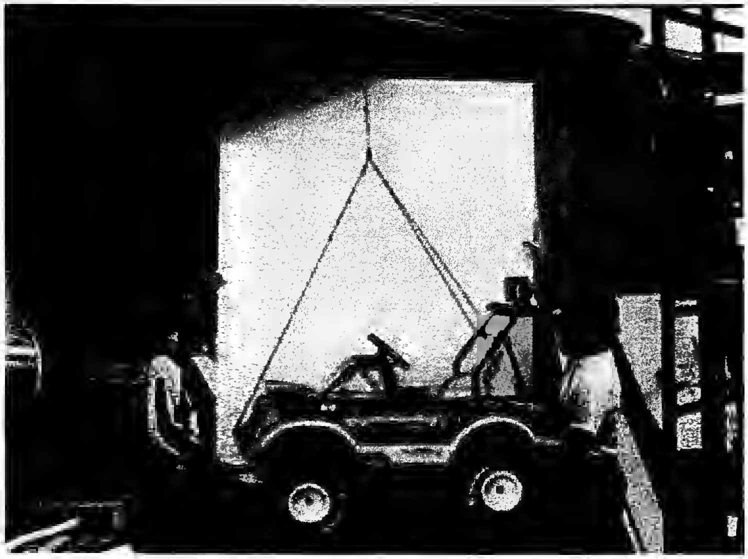


Photo 6. Quadfilar pendulum test for moment of inertia.