ME 14

Transmission Contest

Objective

To design and build a single-ratio transmission that effectively couples the rotational power of an electric motor to a rotating wheel. This project serves as an opportunity to design and fabricate a device that requires preliminary calculations, detailed machining, careful alignment, and extensive testing to yield minimum frictional loses and maximum performance based on the criteria defined in a cost function.

ME14 Moodle Course Site Repository

Updates to the rules, deadlines, and important contest parameters will be maintained on the transmission contest portion of the class web site.

Overview

Each group will design, analyze, build, and test a transmission connecting the input of the transmission (electric DC motor) to the output of the system (bicycle wheel). Teams will be given a budget to order off-the-shelf transmission components from McMaster-Carr (http://www.mcmaster.com) or SDP/SI (http://www.sdp-si.com/) (or from both) to use in their transmission. Teams are free to design a transmission using gears, belts, chains, bearings, etc. Groups will also be required to machine custom components from Plexiglas to integrate the off-the-shelf components.

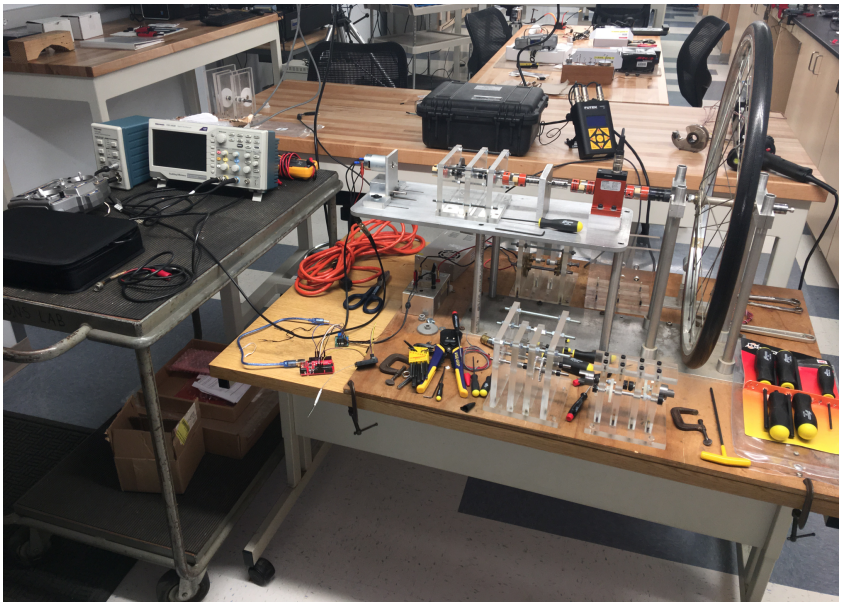


Figure 1 Transmission Contest Test Apparatus

Teams

There are 21 students enrolled in ME14 (spring 2018). Students will work in seven self-selected groups of three to design and fabricate one single-ratio transmission. Interactions

with other students in the class are highly beneficial; therefore, conversations, calculations, analyses, ideas, and tests may be shared among the students, but the transmission design and fabrication must be the effort of an individual group. In the end, the effectiveness of a design will depend on how well it is fabricated, tested, and tuned by the group.

Evaluation

The performance of each transmission will be measured once during the transmission contest. The same constant-voltage power supply and load wheel will be used for each evaluation. The load wheel will start from rest, and its speed will be measured by monitoring the DC-voltage output of an analog tachometer that is connected to the wheel shaft.

Based on the performance of each Transmission a score (S) will be computed according to the following cost function:

$$S = \frac{\dot{\theta}_{max}}{T_{250}}$$

where:

$\dot{\theta}_{max}$ = Maximum rotational speed (in rpm) of the wheel (this can be a peak speed and need not be sustained)

T_{250} = Time (seconds) required for the wheel to reach 250 rpm (or the time to reach the maximum speed if it is less than 250 rpm).

Additional parameters such as peak torque, peak power, and steady state values of each of these quantities will also be measured and used to examine the efficiency and output of transmission entry. Data will be analyzed and used to determine a contest winner.

Budget and Purchased Components

Each group will be given a budget of $150 to order commercial off-the-shelf transmission components to use in their design. The components can only be ordered from McMaster-Carr (http://www.mcmaster.com) or SDP/SI (http://www.sdp-si.com/). A single group order for the entire class will be placed the Friday morning after the team design reviews. Groups will not be allowed to order components outside of this single class order. Any discrete transmission component in the McMaster-Carr or SDP/SI catalog is available for groups to order. Examples of these components are spur gears, chains, belts, bearings, bushings, shafts, keys, etc. While all discrete components are viable, transmission assemblies are not allowed (e.g. planetary gearbox assemblies) since this violates the spirit of the competition. If there is any question about whether a component is allowed or not, get clarification from a professor or TA. Only parts confirmed to be in stock will be ordered so be sure to check on availability of parts in advance. You can call or email either vendor to obtain this information.

Note: Each group must submit their bill of materials (BOM) using a specifically formatted Excel form which will be posted to Moodle. The total cost of the components cannot exceed $150 not including tax and shipping. It is imperative that you submit your bill of materials (BOM) using this form and that you carefully and accurately complete each field as instructed.

Drawing Approval

You are required to make a detailed engineering drawing of each part you plan to fabricate in the machine shop. Students will be required to get their part drawings "approved" BEFORE they start setting up on a machine (lathe or mill). This simply means you need have a drawing (can be done by hand or in Solidworks) of each part on a separate piece of paper to show to John, Bruce or one of the TA's. You should be prepared to discuss your planned set-up and fabrication procedure (better yet, consider outlining it for easy review). Once you get the seal (date & initials of John or TA) of approval on your printed drawing, you can machine your part. You will be required to turn in your signed shop drawings for grading after the competition.

Important Dates

THURSDAY May 10 – PRELIMINARY DESIGN REVIEW (PDR) during scheduled class time

Each team will have a 12-minute time slot assigned to them during the normally scheduled class time for their design review. For this design review, you will need your transmission analysis, clearly stating your assumptions and gear ratio, as well as a discussion of the different trades you made in the design and a rationale for choosing your group's design approach (e.g. spur gears vs. belts, bushings vs. bearings). You will need your complete order from McMaster-Carr and SDP/SI for approval; this can be modified after the review, but this component list should reflect your initial design and be within budget. Finally, you will need a Solidworks assembly of your transmission, integrated with the model of the transmission contest test apparatus. You must bring hard copies of all these documents to the design review for approval and upload your PDR material to the Moodle course site PDR submission portal by 2 pm on the day of your PDR presentation. This is a group assignment, and only one packet needs to be turned in for each group.

Note: Groups will sign up for design review time slots before the scheduled date of the PDR. **Also, be sure to list all the names of your team members on the front page of your presentation along with your team name (if you have one).**

FRIDAY May 11 – 9am – Final Component list due, one per group

You must select your transmission components for this contest from McMaster-Carr and http://www.sdp-si.com/. Each team must submit its bill of materials (BOM) to Pr. Mello by 9 am on Friday, May 11. This deadline attempts to account for the 3-hour time zone difference to the east coast such that that the SDP-SI order will be placed early enough in the day to assure expedited delivery by Monday of the following week. Your BOM must be submitted using a specified Excel template which will be uploaded to Moodle. Your team's BOM should be emailed to Pr. Mello (mello.caltech.edu). The McMaster-Carr components should arrive in the ME shop by Monday, May 14. The SDP-SI order will arrive by Tuesday, May 15 (at the latest).

SATURDAY May 12 (due 6 pm) – Detailed Summary of Design, Fabrication, and Test Plan, one per group.

Submit a detailed summary of your final design concept and fabrication/test plan to the same Moodle PDR submission site. This plan should include a discussion of your design, a summary of your design analysis, a copy of the component list that you submitted to John on Thursday, pictures of your SolidWorks assembly, and drawings for each component that you plan to manufacture.

Also, provide a fabrication and test plan with a detailed schedule showing key milestones and outlining who is responsible for all the various aspects of the project (i.e. who is fabricating what parts, who is doing what testing, and when these activities will take place). Discuss what testing your group plans to do to validate your analysis assumptions and your design.

Upload this package to the Moodle submission site by 6 pm Saturday, May 12. You do not need to include any raw Solidworks files in this package. Include pictures of your assembly and/or pdf files of your drawings. This is a group assignment, and only one packet needs to be turned in for each group.

Tuesday May 23 – Transmission Contest during scheduled class time

The transmission competition will be held during the normal class time. There will not be any time available in class to work on your project, so make sure it is complete before the start of class. Groups will go in random order and will only have time for one run during class.

Wednesday May 23, – Final Design debriefing (due by 4 pm)

Each group should clean their workbench and prepare their device for grading in the ME shop. Each group should leave a brief (1-2 page) group summary describing the innovative features of your transmission and evaluating the successes and failures of your design. Did aspects of your design perform better than you had anticipated? Did things go wrong that you didn't expect? What would you have done differently were you given more time? What was the score you expected to receive based upon your analysis and what score did your team receive? Discuss what you view as the key contributions to why you may not have received your predicted score. You only need to turn in a single summary for your entire group.

Additionally:
1. The group should leave all manufacturing drawings (with initialed approvals from John, Bruce or any of the TA's) for all manufactured parts in your assembly on the workbench.
2. Each student should also leave his or her design notebook in the ME shop with the group's device for grading. Ensure that your name is in your notebook and the TAs will attempt to return them to you Saturday afternoon.
3. Each student should submit, via email, a brief statement of work that outlines their contribution to the project and a summary of their opinion stating how well the group worked together. Each email will be considered confidential and will not be shared. Email this to Professor Mello at mello@caltech.edu by 11:59 pm on Friday, May 23.

CONTEST DETAILS

Safety

A transmission that is judged to be a potential safety risk to any participant or spectator will be disqualified. It is mandatory that safety glasses be worn always while fabricating and testing. It is, of course, also mandatory that safety glasses be worn always while in the M.E. Shop.

Energy Sources

The power used by the transmission to spin the load wheel is limited to the power supplied by the electric motor. This must be true on an instant-by-instant basis, which means that no appreciable energy from the motor can be stored in the transmission.

Transmission Project Materials

Your transmission will be constructed using from materials supplied by the M.E. Shop in addition to your single order(s) to McMaster-Carr and/or SDP/SI for this project.

The ME Shop will provide each team with the following items:

- 6" x 24" x ~1/2" thick acrylic sheet (or other dimensions depending upon availability at the time our order is placed)
- 1.5-in diameter x 6" length aluminum round stock
- 5/16" diameter x 24" length aluminum shaft (optional you may purchase your own)
- 5/16" diameter x 24" length steel keyed shaft (optional you may purchase your own)
- 3/8" diameter x 24" steel keyed shaft (optional you may purchase your own)
- Two 5/16" bore Flexible shaft coupling hubs, for attaching to the transmission setup (http://www.mcmaster.com/#6408k11)

Additionally, the following items will be available for all teams to use:

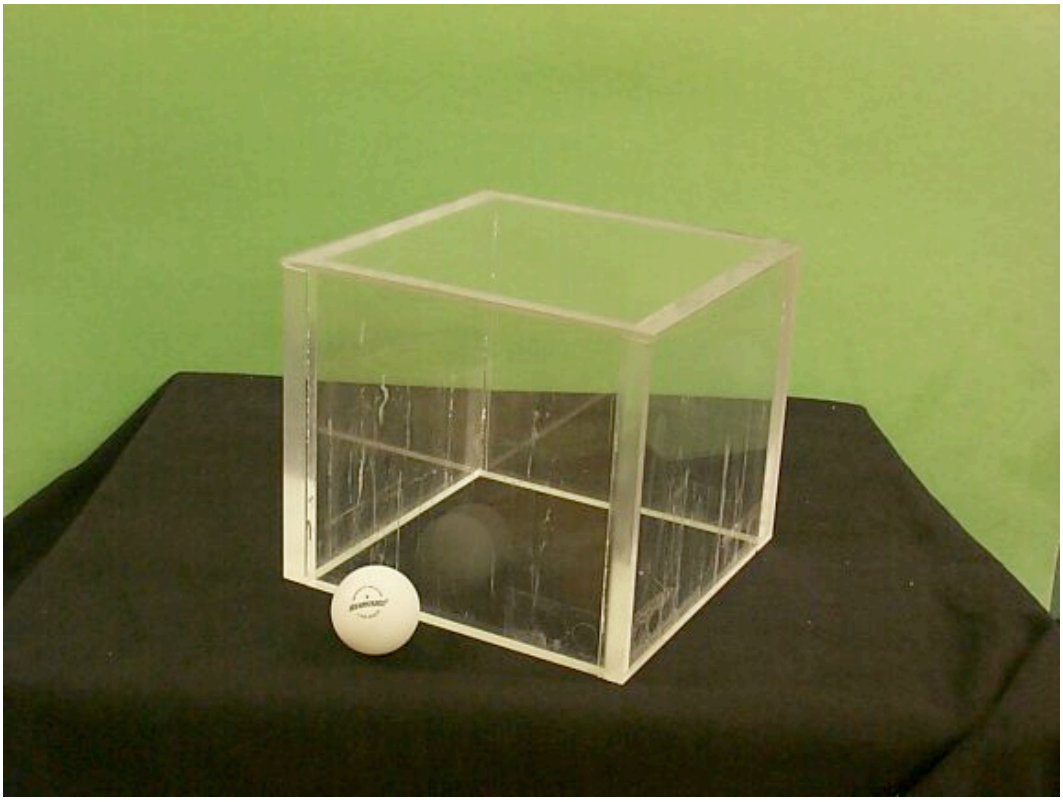
- 10-32 socket head cap screws, various lengths
- 1/4" and 5/16" retaining rings
- Additional supplies, subject to John's approval

- The shop has tools for making retaining ring grooves and a broach set for cutting keyways.
- Replacement supplies and materials are available on a limited basis. When in doubt, check with the shop.
- Glues and epoxies may be used only for bonding.
- These materials may be mechanically modified in any way (disassembled, cut, machined, ground, etc.).
- The project materials may not be altered chemically (except locally by glues for bonding).
- Welding is not permitted.
- Light machine oil, mineral oil, or vegetable oil can be used SPARINGLY to lubricate. Do not contaminate the evaluation apparatus. For many traction materials, including belts and pulleys, once they are contaminated with oil it is nearly impossible to effectively clean them.
- It is permissible to build tools, jigs, and fixtures to help fabricate your transmission, and also to help prepare it for evaluation. For example, you might want to build a template or other device to help ensure that your transmission is set up "perfectly" before each evaluation. This may help provide consistent performance.
- You are not allowed to use the laser cutter, water jet, 3D printer, or CNC machine for any components in your transmission contest.

Transmission Specifications

Size:

When each evaluation begins, your transmission must fit into a 7" tall x 6" wide x 8" long (inside dimensions) Plexiglas box with the width dimension being the dimension from the input shaft to the output shaft. This rule requires your entire transmission to fit inside the box at t=0, when electrical power is applied, at the start of the evaluation. A Plexiglas testing box is available in the M.E. Shop to check the size of your transmission. You must mount one of the provided shaft coupling hubs to both your input and output shaft. You should use the transmission setup in the ME Shop to determine the lengths of your input and output shafts, and as well as the required positions of the shaft coupling hubs.



Transmission Ratio:

Teams must design around a targeted a gear ratio in the range $5.0 < N < 7.0$.

Mass:

There is no limit on the transmission's mass; however, you must be able to install/de-install it within the allocated time.

Physical Interaction:

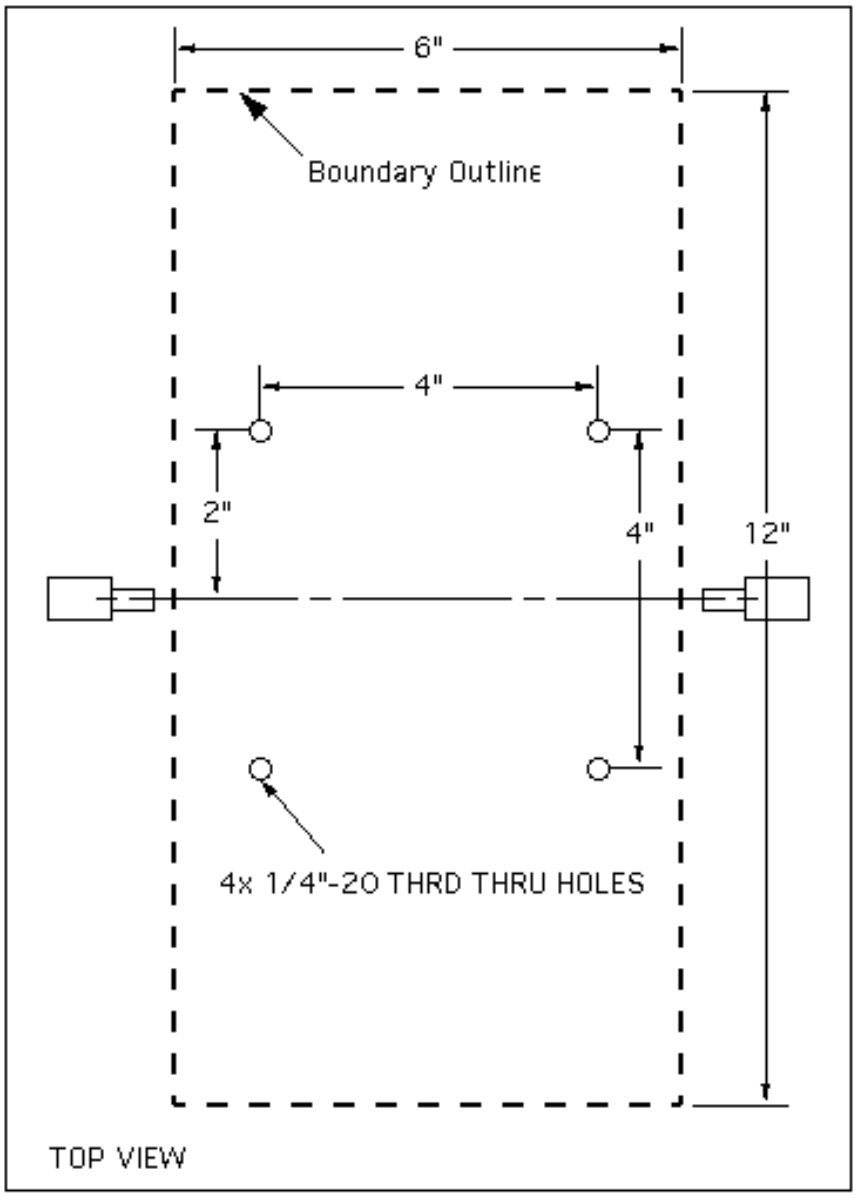
No manipulation of, or interactions with, a transmission is allowed during evaluation.

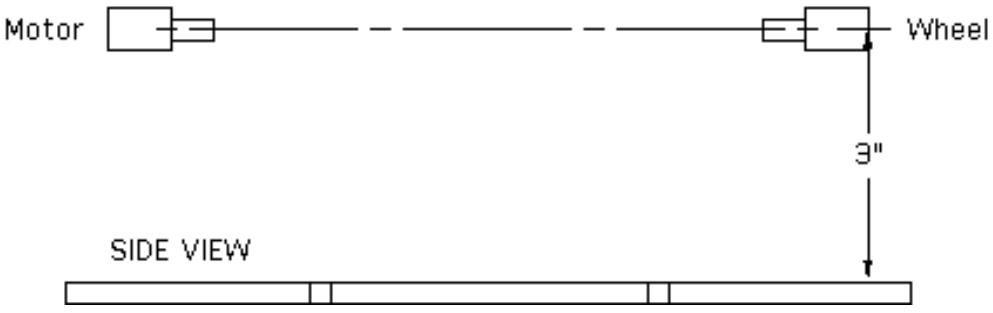
Installation:

Four threaded mounting holes are provided to simplify the installation of your transmission. It is recommended that you use at least two of these to fasten your transmission to the mounting platform shown in the figure below. Note that the transmission may be placed anywhere within the 6 x 12-inch outline on the mounting platform at the start.

Both the motor and wheel have flexible 1/4-inch shaft couplings to connect for misalignment, as well as flexible spider shaft couplings that connect to your transmission. Examine the transmission setup in the ME Shop early in your design process, and be sure to test your transmission on the setup before the contest day.

Transmission Mounting Plate





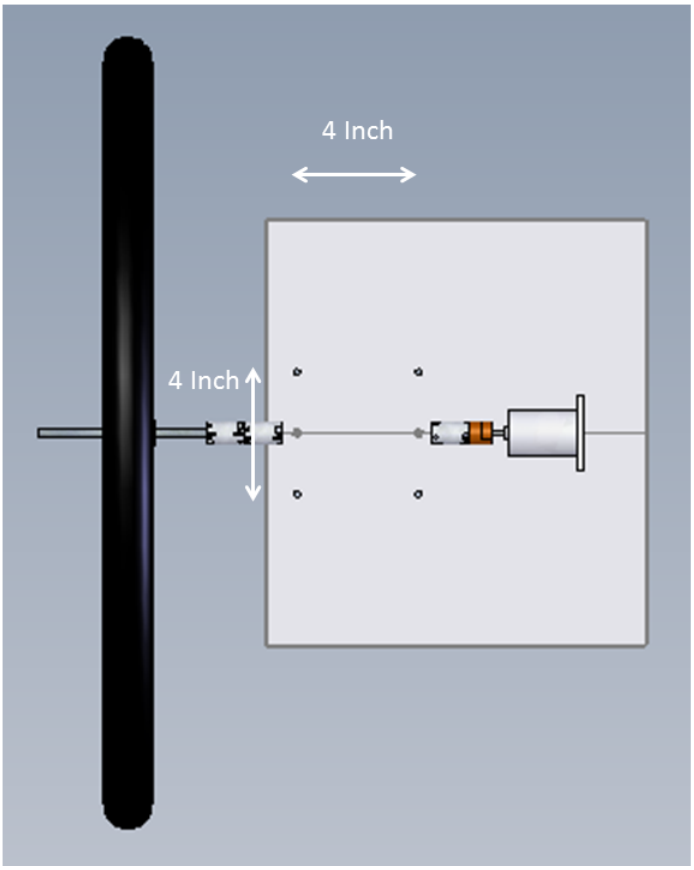
Additional Rules

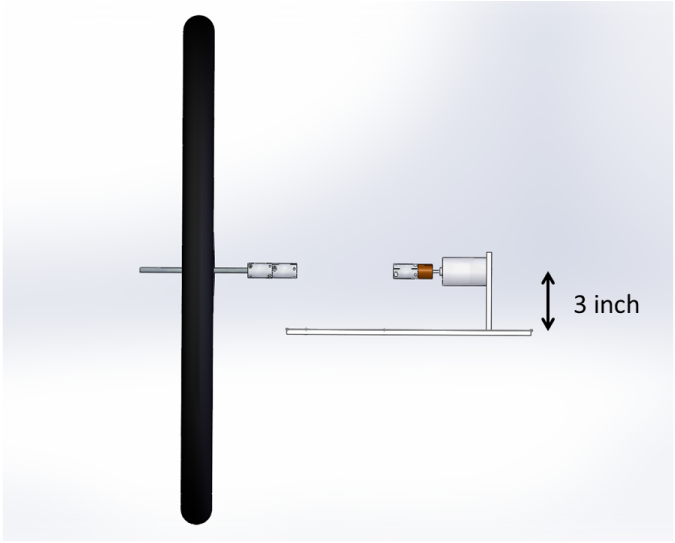
Each transmission must have a fixed gear ratio. No variable transmission designs will be permitted.

Each transmission must be designed to functionally interact with nothing other than the mounting platform, the motor shaft, and the wheel shaft.

Evaluation Apparatus

- Flexible couplings with 1/4-inch ID split clamps are provided on both the motor and wheel shafts. These flexible couplings can accommodate 0.020-inch of radial misalignment, and 5° of angular misalignment.
- The motor and wheel shafts will additionally have spider shaft couplings, which allow for an easy connection to your transmission.
- **The rotational inertia of the load wheel is approximately: I = 0.167 [kg-m^2]**
- **The rotational inertia of the motor is approximately: I = 6.5 x 10^-6 kg-m^2**
- The motor performance at its normal operating voltage of 12V is characterized by the following (approximate) specifications:
    - **Stall Torque (Ts) = 0.133 N-m**
    - **No-Load Speed (ω_0) = 5500 rpm**
- Intentional damage to the evaluation apparatus will result in disqualification.
- The evaluation apparatus will be available in the ME Shop for transmission testing for the duration of the project.





- The load wheel has the following experimentally measured performance properties: (note that these are approximate, limited by our measuring capabilities).
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Speed (rpm)	76.2	156.6	232.8	301.2	337.5
Drag Torque (N-m)	0.00905	0.02450	0.04880	0.07790	0.09840

- **Wheel Model:** A curve fit to the measured drag torques has the following form (w is the wheel speed in radians/second):

- Drag Torque [N-m] = $7.29390 \times 10^{-7}\ w^3 + 2.91430 \times 10^{-5}\ w^2 + 8.37900 \times 10^{-4}\ w$

- ***NOTE: These parameters may be subject to change. Please check the web site for updates.***

Time

The timing of the evaluation procedure is:

- 90 seconds to set-up your transmission, starting from when your group is called to start.
- 300 seconds maximum duration of each evaluation starting with the application of power. That is, if your device does not reach its top speed by 250 seconds, then we will evaluate your performance based on the data obtained at the end of this period. No action of the transmission is permitted prior to the application of electrical power to the motor.
- 90 seconds to remove your transmission after the evaluation.

Grading

Remember winning isn't everything. Having the transmission with the highest "score" is not the goal of this class. The primary goal is to learn something about engineering design and to apply the engineering material that you have learned in your other classes to a design problem. Your term grade will be only very slightly influenced by your transmission's "score." Instead, your grade will depend much more heavily on what you have learned about solving engineering design problems.

So that we can better understand your design solving process, you will be expected to document your work in a design notebook and turn it in with your design debrief.

The transmission contest is worth 100 points. Grading will be based as follows:

- Contest Score (**20 points**)
  The team with the top score will receive a full 20 points. Other teams will receive the contest score portion of their grade based upon the following formula

$$\text{contest score} = \frac{\text{your team's score x } 20}{\text{top team score}}$$

- Preliminary Design Review (**15 points**)
  You will be graded on the design review package sent via email prior to the actual design review. Your entire group will receive the same score. You will be graded on the design, fabrication and test plan you turn in via email. Your entire group will receive the same score.

- Design Summary (**5 points**)
  You will be graded on the design summary your team turns in after the competition. Your entire group will receive the same score.

- Device (**30 points**)
  You will be graded on the implementation of your design and the quality of your transmission. Factors include smoothness of operation, quality of machining, robustness of the design. This is independent of your score in the competition. Your entire group will receive the same score.

- Individual Contribution (**20 points**)
  You will be given a score for your individual contribution to your team project based on your participation in the design, build, and test process as well as your statement of work. This is an individual score.

- Design Notebook (**10 points**)
  You will be given a score for your design notebook. You will be graded on the thoroughness of your notebook for the design, build, and test phase of the project. This is an individual score.

Project Testing

The transmission apparatus will be available (in the shop) for testing approximately 1 week prior to the contest. Angular speed and torque measurement diagnostics will be disabled but teams will still be able to test fit their transmission and run it. Be sure to keep a record of your testing activities in your design notebooks.

NOTE: These rules are subject to change. As the rules evolve, any updated versions will be posted on the course web page

Appendix: Motor Specifications for DC Motor

REF: URL==>> https://www.usbid.com/parts/RS555PH3255

Stall Torque: 1360.3 g-cm (0.133 Nm)

No load speed: 5050 +/- 650 rpm (nominal value stated at 5500 rpm)

Mabuchi DC Motor RS-555PH-3255

Originally designed to be installed in portable drills and printers. This model features improved design to reduce external noise levels. Has "wrap around" magnetic shield. High torque 380.3 gm-cm with a stall-torque figure of 1360 gm-cm. An excellent find for the small or medium sized OEM who requires modest quantities of this quality product but cannot satisfy the manufacturer's demand for large quantity purchases. Hundreds of application in Robotics, the RC field etc. (shaft is 1/4 flat - stainless steel 1/8" dia). No load speed is 5500P.PM - excellent for "gearing down" to provide ultra high torque for larger projects. 1-7/16" dia x 2-5/8" long. Flatted shaft is 1/2" long. 3/16" push on terminals. This unit features 5 pole construction for higher torque and power efficiency, anisotropic magnets, and coil specs of 55 turns of 32mm wire.