Project 3: The Rescue Ranger Winch

24-370 Engineering Design I, Spring 2011
Assigned 13 April, Design and report due 5 May

Overview:

In this individual project, you will design a helicopter-mounted winch for use in search and rescue operations. The winch will be comprised of an electric motor and gearbox, a battery, custom capstan and support components, and various catalog components including wire rope, a shaft, bearings, and fasteners. The winch must lift a distressed individual and rescuer of a given average mass over a predetermined height within an allotted time. Design for low mass will be important, because the assembly will be carried by a fuel-intensive helicopter. Ethical considerations will also be important for this life-critical task. Cost and environmental considerations are also important to your customer.

You will not build a prototype winch, due to time and budgetary constraints, but instead must issue a report that convincingly predicts its success. This report will have a similar structure to the reports from projects 1 and 2. Simple models and analyses will be a key to making a convincing case for your design, including simple analyses of dynamics and stress. Adept use of SolidWorks static stress analyses of parts and assemblies will also, separately, be needed. All designs will be run through the ED1 neural simulator, so be sure to take into account all course lessons. Your final report must be submitted electronically by midnight on the date above.

There will be no true competition for lowest mass or cost designs, as no truly objective test of functionality can be applied. However, you must consider and balance the potentially-competing factors of mass, cost, environmental impact, and ethical considerations such as factor of safety. Exceptional designs will be awarded a bonus of up to 10% based on a subjective, holistic evaluation, and may even be fabricated.

Please read this project description in full, and use the course email address, TA office hours, and/or Q&A sessions at the beginning of class if you have any questions about the project.

Specifications and constraints:

You will find detailed project requirements below, which constrain the design space available to you. This will keep the project manageably simple, while requiring use of many of the skills you have learned during this course. In particular, you will need to perform an analysis of the mechanical task, use specified components in your design, and provide a detailed final report.

Mechanical task and analysis requirements:

You will design a winch for use in rescue operations, in which distressed individuals will be quickly lifted into a helicopter. The individuals and helicopter, however, are smaller than you might have anticipated. FEMA has been successfully trained chipmunks to explore rubble in cases where openings are too small or dangerous for human workers. The chipmunks must be delivered to or picked up from specific locations on a rubble pile, and are transported using a miniature autonomous helicopter. In a typical run, a squad of trained chipmunks with rescue electronics, having a total mass of approximately 750 grams, must be lifted a height of 2 meters. FEMA expects that the winch will be used about 1000 times per year, and expects the device to last for at least two years. Each lift must last less than 5 seconds, due to physiological stresses on the trained chipmunks and expectations of positional stability for the helicopter. Training chipmunks is expensive and time-consuming, and trapped humans may be counting on them to save their lives. Plus, chipmunks are really, really cute. Dropping the team, due to either mechanical failure or inadequate performance, would be catastrophic.

You must perform a simple analysis of this mechanical task that determines the minimum torque, speed, and power requirements of your motor. Use symbolic representations of the gear ratio $\boldsymbol{R}$, drum radius $\boldsymbol{r}$, gearbox efficiency $\boldsymbol{\eta}$, coefficient of friction $\boldsymbol{\mu}$, and factor of safety on performance $\boldsymbol{FOS_p}$. For this analysis, assume that acceleration periods at the beginning and end of the lift contribute negligibly to total lift time.

You must also perform a numerical simulation of the final system performing the worst-case lifting task. Assume that all system elements are initially at rest, then a constant (nominal) voltage is applied to the motor. Do not consider problems related to control, such as deceleration of the motor once the payload reaches the helicopter. You will provide a plot of rescuer height vs. time, and include your Matlab code.

Overall layout and required components:

The winch will be comprised of several pre-determined components laid out in a predetermined order. This is to reduce the design space explored during concept design, allowing more time to be spent on detailed design and on cost and environmental analyses. By contrast, no drawing of this layout is provided so as to allow creativity within these constraints. The winch components will be connected in the following manner: (i) custom mounting component(s) will attach to the helicopter base, bearing(s), and the gearmotor, (ii) a catalog electric motor and gearbox will connect to the mounting component(s) and a shaft coupler, (iii) a catalog shaft will connect to the gearbox output shaft by means of the catalog shaft coupler, (iv) catalog bearing(s) set in the mounting component(s) will support the shaft, (v) a custom capstan will connect to the drive shaft and wire rope, (vi) the catalog wire rope will connect to the capstan on one end and payload on the other, and (vii) assorted catalog or custom components will be intermingled as fasteners, spacers, thrust washers, etcetera.

Custom Base: A custom mounting component or set of components will support the bearing or bearings, provide support and reaction points for the motor, and provide attachment points for the entire assembly to the base of the helicopter. This component will need to withstand the loads imposed by the payload and the motor. You will need to choose an appropriate material and manufacturing method for this component, which will involve an analysis of the cost of production and environmental impact.

Motor Selection: The winch will be driven by an electric motor. You must select a commercially-available motor and gearbox for your design. In order to perform the mechanical analysis above, you will need to obtain detailed motor specifications.

Shaft, Bearing and Coupler Selection: A catalog shaft will be used to bear the load of the lifted parties. This is a separate shaft from the gearbox output shaft, which may not be used directly due to excessive radial forces and bending loads. The shaft size must be selected based on analysis of the stresses induced by the payload and the motor torque. An appropriate catalog bearing or set of bearings must be selected to support the shaft, and an appropriate shaft coupler must be selected to connect the motor output shaft to the drive shaft.

Custom Capstan: A custom-designed capstan (or drum, spool, or windlass) will wind up the wire rope. The capstan will need features for wire rope termination as well as attachment to the driving shaft. This component will need to withstand the loads imposed by the wire rope and shaft. You will need to choose an appropriate material and manufacturing method for this component, which will involve an analysis of the cost of production and environmental impact.

Wire Rope Selection: A wire rope will connect the capstan to the rescue apparatus. You must select an appropriate, commercially-available wire rope for this application. Consider factor of safety, minimum bending radius, flexibility of the rope construction, and corrosion resistance, among other important properties.

Other Catalog Components: Additional catalog components must be selected and used, for example, to fasten the base to the helicopter, fasten the gearbox to the base, and fasten the capstan to the shaft.

Final Report

You will submit a final report presenting your design, divided into the following sections:

1. Cover page: Please include the following on one side of one page:
    a. Your name, the project name, and the date
    b. A color isometric screen shot of your assembly at the top of the page
    c. A brief description of the design and rationale, in 200 words or less.
    d. Estimated peak mechanical power requirement, $\boldsymbol{P_m}$
    e. Estimated overall factor of safety with respect to the mechanical task, $\boldsymbol{FOS_{lift}}$
    f. Estimated overall factor of safety with respect to part strength, $\boldsymbol{FOS_{strength}}$
    g. Your guess at the weakest link, i.e. the place your design would fail if it did.
    h. For each of items d-g, provide the page number where its calculation is be found
2. Conceptual Design Sketches and Simple Modeling and Analysis
    a. Please include all your notes and sketches from your idea generation sessions. These will be evaluated on the basis of apparent quality of design ideas. A typical set of sketches and notes might occupy 2 pages for each component in your assembly.
    b. Your notes must include free-body diagrams, using force and moment balance to obtain reaction forces, with symbolic parameters. This will allow you to understand the implications of different design choices on the function of your components and assembly.
    c. Include hand-drawn sketches and analyses you performed by hand. For example, you might model one aspect of the part as a beam in bending, and then relate peak stress, beam height, and part mass in a single function. You will probably need more than one simple model to analyze different aspects of each component.
3. Detailed Model and Analysis of Final Design
    a. Provide an exploded view of the full assembly, in which each component is visible and the relationships between components are clear
    b. Include a description of each custom-designed component. On a single page for each custom part, please include the following elements:
        i. A color isometric screen shot of the component , with each feature identified (either by a number or a line) and its function described in about 5 words.

        ii. A color screen shot of an appropriate static stress analysis for the component, with visible units in psi. Be sure to apply meaningful fixtures and constraints.
        iii. The material used and the yield strength of the material
        iv. The manufacturing process that would be used for mass production
        v. The mass of the component
    c. Include an appropriately dimensioned engineering drawing for each custom component, including tolerances where necessary. For components that will be manufactured based on a provided CAD model, a sparse dimensioning regime may be used, as discussed in class. Overall dimensions, hole locations, and hole dimensions must be included. Holes with tight tolerances, such as those for bearings, must include these tolerances.

4. Materials, Manufacturing, Cost , and Environmental Impact
    a. For each custom component, provide the following on a single page
        i. Estimated cost of production, and the basis of this estimate
        ii. An environmental Life Cycle Analysis of the component, and its basis
        iii. A brief discussion of these interrelated factors, in 200 words or less, including:
            1. Design changes for compliance with manufacturing plans
            2. How manufacturing plans affected material selection
            3. How material selection affected cost and environmental impact
            4. Whether mechanical considerations conflict with cost or environment
    b. Include a table or spreadsheet itemizing the costs associated with each component, both custom and catalog, used in the design and the total estimated cost of parts.
5. Component Selection and Analysis
    a. Motor selection and analysis
        i. You must provide two mechanical analyses of motor performance
            1. A simple analytical calculation of the mechanical requirements of the task, following the description above.
            2. A detailed numerical estimate of the mechanical performance of the motor you selected, using Matlab, in the manner described above. Provide a figure, with labeled axes, and your Matlab code.
        ii. Also provide a verbal explanation of your reasons for selecting this motor and gearbox. Please address issues of power, torque, efficiency, mass, and cost.
        iii. Finally, calculate the battery requirements for a single lift.
    b. For each required catalog component, i.e. drive shaft, bearing(s), and shaft coupler, provide a detailed justification of its use, including:
        i. A strength analysis (you may reference a page from sections 2 or 3).
        ii. A short description of factors that influenced its selection, including mechanical considerations, cost and environmental impact (≤50 words)
    c. Also provide a rationale for each additional catalog component. In one page or less, briefly explain what factors influenced your decision (50 words or less).
6. Ethical Considerations
    a. On one page of your report, explain how ethical considerations have influenced your design decisions. Pertinent to this discussion are, the societal benefits of the design and application, mechanical performance and factor of safety, cost and manufacturing considerations, and expected environmental impact.