ME 777/877 – Computer Aided Engineering
Project #2 – parts to print due Wed., 10/28 and report due Sun., Nov. 8th

Problem Statement: For this project, a functioning, pneumatically-actuated crane will be analyzed, designed, fabricated, and tested. The teams will be three students and can have a mixture of undergraduate and graduate students. (That is, graduate students will NOT have to complete this project individually.) A schematic of the crane is shown in Figure 1. The task of the crane is to successfully lift a weight of 1.5 kg and hold it suspended at the maximum height for 1 minute.

The goal is to create a kinematic linkage with the minimum weight and material usage. The designs must avoid fracture and buckling. All components will be fabricated out of P430 ABS plastic, which is the material used in the Stratasys rapid prototyping machine in Kings. S221. More information on the material is available on myCourses.

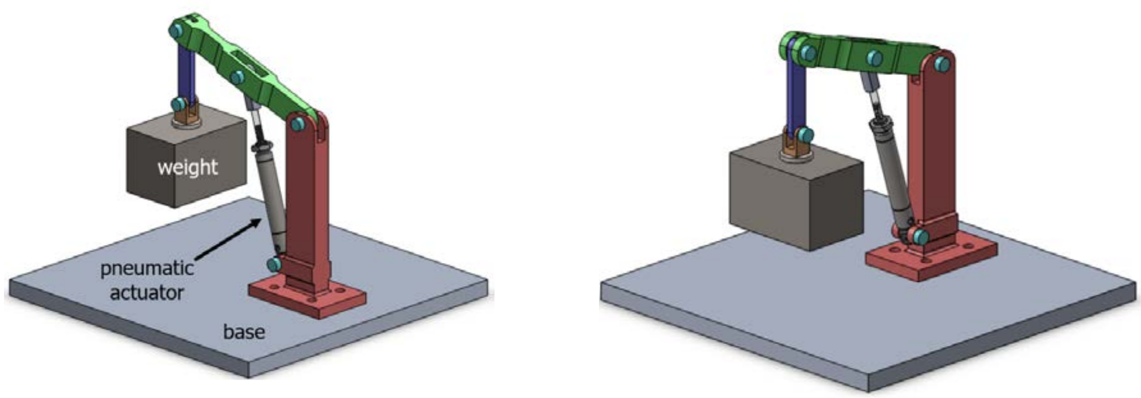

Figure 1: Isometric views of the pneumatically-actuated crane with weight lifted

The project will consist of the following steps:

Step 1. Create a SW model of the overall geometry

You are provided with the overall dimensions of the crane. You are also provided with SolidWorks (SW) parts of the base plate, pneumatic cylinder (actuator), rod end, magnet, magnet mount, and weight. Use the coordinate system provided in the base part for all of your work, graphs, etc.

Step 2. Perform a kinematic analysis in SolidWorks

Design some rudimentary members OAB, BCD and DE, and add them to a SW assembly. Use mates to enforce the same function between two parts as a pin would physically achieve. For this step do not model actual pins and include them in the assembly, as you will then have to define contact and the model will be very slow and/or crash. Input a linear motor (i.e., actuator with a defined displacement distance) into the assembly with the full extension of 25.4 mm (1 inch) being achieved in 5 seconds. Perform a motion analysis study to determine and graph the following:

- Graph 1: Trajectories (paths) of points C, D and E. You can achieve this by plotting the z- vs. y-positions for each of these points. Plot all points on the same graph.
- Graph 2: Positions in z- and y-directions of pins C, D and E.
- Graph 3: Velocities in z- and y-directions of pins C, D and E.
- Graph 4: Accelerations in z- and y-directions of pins C, D and E
- Graph 5: Reaction (resultant) forces on pins A1, B, C, D and E.

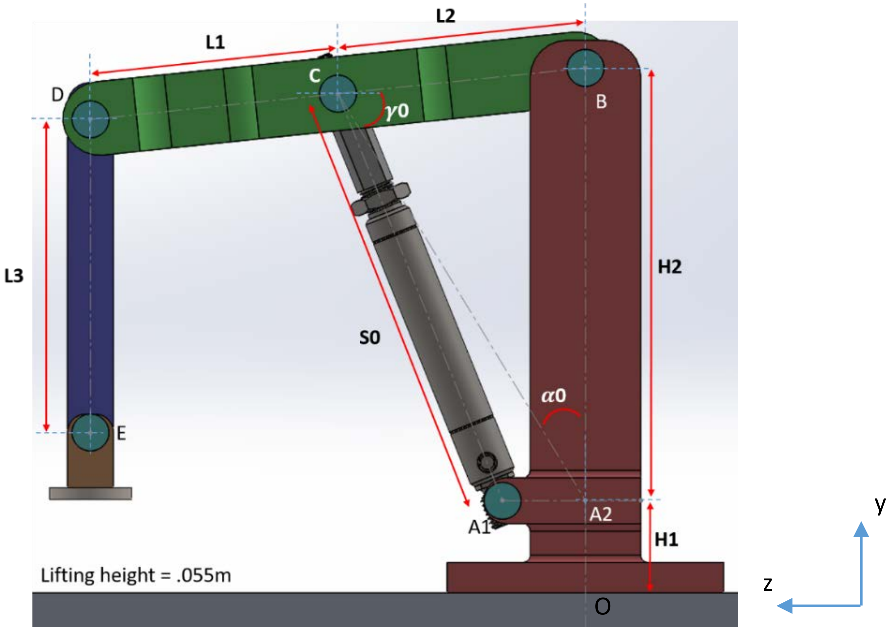

Figure 2: Side view of crane mechanism and definition of variables and points

For Graphs 2-5, plot the outputs vs. linear displacement of the cylinder. Each plot should start from 0 and go to 25.4 mm (1 inch). Make the plots (i.e., position, velocity, etc.) by exporting data to Matlab or Excel (i.e., right click on the SW plot and select export as .csv). Be sure to comment on all the graphs.

Step 3. Analyze the two pins

Perform <u>hand calculations</u> to design the pins B and D to withstand the peak force exerted on the structure in plots from Graph 5. (Note that pins at A1, C, and E will be provided as these are part of the mechanism given for the project.) Consider shearing of the pins and tear out of the surrounding material. Make sure that you have included a free body diagram (or other appropriate schematic) for each calculation. These will be checked as part of the project grading. Comment on your design and resulting safety factor.

Step 4. Conduct a kinematic analysis by hand

For pin C only, perform trigonometric hand calculations to determine the position, velocity, and acceleration of pin C with respect to linear displacement of the cylinder. Plot your theoretical calculations on top of the results from SW.

Step 5. "Optimize" the three members of the structure

See Simulation_Example.docx on myCourses for how to setup a motion analysis FEA simulation. Use a similar procedure to determine the orientation where the highest stress occurs on members OAB, BCD, and DE. Next, perform a redesign of the member to raise or lower its safety factor. <u>Select the Safety Factor based on your judgment</u>. Write up and show at least one iteration of this process in your report for each member (e.g., figures of before and after the redesign). Continue this analysis until you are satisfied that the lowest mass has been achieved. Be sure to comment on how the design changes affected the simulation results.

<u>Health warning</u>: trying to use SW to truly "optimize" the mechanism might be from impractical to utterly frustrating. Instead, use your engineering sense to arrive at a good design using the stress analysis capabilities of SW as a tool. Design part-by-part, not all members at the same time.

Step 6. Manufacture, assemble, and test mechanism

With your design completed, you will submit your components to be printed on the Stratasys rapid prototyping machine in Kings. S221. These will then be assembled together and tested with the provided base, cylinder, weight, etc. More information on the testing will be announced via myCourses and email. <u>Your SW parts for 3D printing are due Wed., 10/29, at 9 am.</u>

Step 7. Write report

Write a formal engineering report summarizing the process and your findings. Include information from each step of the analysis process including the theoretical equations used and appropriate plots and graphs. (See the grading sheet for more details.) I will leave it up to you to determine the exact information you want to include, but your report should contain an introduction and conclusion/recommendation section. Be sure to be concise but complete. You will be graded on providing enough information for us to understand what you did and why, without unnecessary figures and plots. Also, you will be graded on the professional formatting of your report (e.g. Table of Contents, page numbers, List of Figures, correctly referencing figures in your report, overall appearance and professionalism, etc.). ***Please include the Project #2 grading sheet as the first page of your report.***

Given:

- Performance features: cylinder stroke = 25.4 mm (1 inch), maximum inlet air pressure = 4.14 bar (60 psi), and mass of weight = 1.5 kg (3.3 lbs.)
- Distances and lengths: $L_1 = L_2 = 67.5$ mm, $H_1 = 25$ mm, $H_2 = 117.5$ mm, $S_0 = 119.2$ mm, and L_3 based on the weight resting on the base for your linkage design
- Pin diameters (critical so structure can assemble together easily): Pin C, ∅4.7625 mm (0.1875”); Pin A1, ∅4.064 mm (0.16”); and Pin E, ∅.4.572 mm (0.18”).
- To assure that the pins will assemble into holes at B and D without any requirements for a press fit, undersize the pins (which will be printed as part of your design) by 0.06 mm (0.0024”).
- Specifications of the pneumatic actuator and the magnet are given in myCourses.
- The weight must be resting on the base when the actuator is fully retracted (i.e., not hanging in the air).
- The maximum weight of the parts you design should be under 100 g.
- Material properties of the ABS polymer used by the Stratasys rapid prototyping machine are given in myCourses. You will have to create a custom material in SW using these properties.
- Solid models of the parts are provided on myCourses, including base plate, magnet, magnet mount, pneumatic cylinder, and rod end.
- The base plate has 8 tapped holes (#8 – 32) for attaching the crane. You can use as many or as few of these as you desired. Have the clearance holes on your crane be ∅4.5 mm (∅0.177”) to assure the bolts easily pass through the holes.

Some further comments:

- Again, the components that your team will need to provide designs for printing are:
    - Members: OAB, BCD, and DE
    - Pins: B and D
- All calculations should be in SI units.
- Include in your report the results of a mesh convergence study.
- Be sure to comment on your constraints and loading conditions in your final report as well as the element type and size used (see “mesh convergence” above).
- Recall that the goal is a lightweight design. So try to optimize the design, without of course compromising the functionality and safety of operation.
- Everyone must work in teams of 3 on this project unless approved beforehand. No teams of 1, 2, 4, etc. people are allowed.