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Application of ARCHIMEDES in Three Dimensions and to Solid Mechanics

A Capstone Project Submitted in Partial Fulfillment of the
Requirements of the Renée Crown University Honors Program at
Syracuse University

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and Renée Crown University Honors
May 2013

Honors Capstone Project in Aerospace Engineering

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Abstract

ARCHIMEDES is a computerized learning system that has helped Syracuse University students overcome the challenges of Engineering Statics since 2009. Its success has motivated application of ARCHIMEDES to three dimensional problems and to problems in Solid Mechanics. Other learning software was investigated before seven Solid Mechanics problems were written for ARCHIMEDES. A 3D graphical interface was developed and evaluated by a field test of student volunteers. Student preferences for various features in 3D learning software were obtained. It is clear from student responses that having a 3D scene to manipulate improves visualization of the problem, mitigating the ambiguity of a textbook problem's graphic.

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Chapter 1

ARCHIMEDES, a Computer Based Learning System

Professor John F. Dannenhoffer III developed a computer based system named ARCHIMEDES, to help students solve Statics problems. A 2009 pilot study at Syracuse University found over 65% of students believed ARCHIMEDES would build their confidence, and improve their grade [1].

Statics is one of the first core courses that engineering students take. The following is the Syracuse University course catalog description

“Fundamentals of static equilibrium. Vector algebra. Forces, moments, equivalent force systems. Free body diagrams and equilibrium problems in two and three dimensions. Analysis of structures and machines. Centroids and moments of inertia.” [3]

Many of the concepts are elementary, but a typical statics problem involves many steps. Execution of these consecutive steps proves difficult for many students, rendering attempts at a final answer unsuccessful.

ARCHIMEDES is being used to help students solve statics problems. A key element of ARCHIMEDES is its live feedback mechanism. In the paper and pencil approach to Statics problems, a student’s only feedback is the self-checking of their work, which can have its own errors. Mistakes propagate throughout each step. When solving problems in ARCHIMEDES, students cannot proceed to the next step if their work is incorrect. ARCHIMEDES notifies the student of the nature of their error, and guides the student in making the proper corrections. The

flexibility of ARCHIMEDES is powerful enough to allow any correct method chosen by the student. The student is not restricted to one specific approach.

Presently, ARCHIMEDES is used to solve two dimensional equilibrium and centroid problems. A key outcome of a statics course is the skill to successfully analyze such problems in three dimensions. Visualizing a three dimensional problem posed through a two dimensional medium is challenging for many students, let alone successfully completing the problem. Computers are a powerful aid in this respect.

A subsequent course to Statics in the engineering curriculum is Solid Mechanics. Solid Mechanics concerns the behavior of materials in response to stimuli. Problem solving in this subject relies heavily on the fundamentals of Statics, so it is a natural next step for ARCHIMEDES.

Example Problem

Figure 1 shows an example problem loaded in ARCHIMEDES. The student is presented with a problem statement and diagram. The problem is described symbolically. Numerical values are given in the final step of the solution.

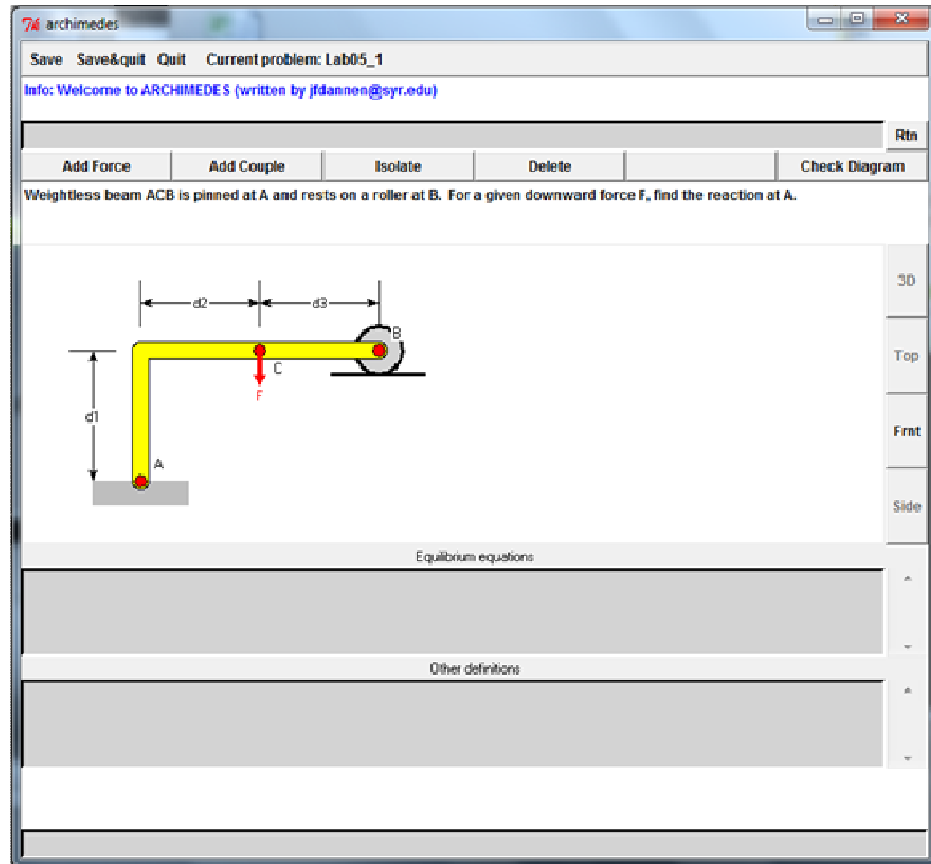


Figure 1: ARCHIMEDES when example problem is loaded.

First, the student must construct an appropriate free body diagram.

ARCHIMEDES verifies that the free body diagram is correct, and allows the student to then enter equilibrium equations. An incorrect free body diagram will elicit an appropriate error message from ARCHIMEDES, such as “The reaction(s) at Point A is/are incorrect.” Figure 2 shows a correct free body diagram with corresponding equilibrium equations.

The screenshot shows the ARCHIMEDES software window titled "76 archimedes". The menu bar includes "Save", "Save&Quit", "Quit", and "Current problem: Lab05_1". Below the menu bar, a status bar indicates "Info: Diagram is okay". A toolbar contains buttons for "Add Force", "Add Couple", "Isolate", "Delete", "Back to Diagram", and "Check Equations".

The main workspace displays a physics problem: "Weightless beam ACB is pinned at A and rests on a roller at B. For a given downward force F, find the reaction at A." The diagram shows a yellow L-shaped beam. Point A is at the bottom left corner, and point B is at the top right corner. A downward force F is applied at point C on the horizontal segment. The vertical distance from A to the horizontal segment is labeled d1. The horizontal distance from A to C is labeled d2, and the horizontal distance from C to B is labeled d3. Reaction forces are shown at A (Ax and Ay) and at B (By).

Below the diagram, the "Equilibrium equations" window is open, showing the following equations:

```

overall equilibrium
0 = Ay - F + By
0 = Ax
0 = -(F*d2) + (By*(d2 + d3))

```

Below the equations, there is a section for "Other definitions" which is currently empty.

Figure 2: Free Body Diagram and Equilibrium Equations.

In the Equilibrium equations window, the student must enter a consistent set of equations to solve for all unknowns in the free body diagram. These equations are derived from force and moment equilibrium.

Beneath the Equilibrium equations, a window is provided for other definitions. For example, the horizontal distance between points A and B could be defined here as:

$$L = d2 + d3$$

Finally, when a correct set of equations has been entered by the student, ARCHIMEDES assigns numerical values. Figure 3 shows the final solution.

76 archimedes

Save Save&quit Quit Current problem: Lab05_1

Info: Equations are okay

Add Force Add Couple Isolate Delete Back to Equations Check Answer

Weightless beam ACB is pinned at A and rests on a roller at B. For a given downward force F, find the reaction at A.

3D Top Frnt Side

Equilibrium equations

```
% overall equilibrium
0 = Ay - F + By
0 = Ax
0 = -(F*d2) + (By*(d2 + d3))
```

Other definitions

For: d1 = 0.300 m, d2 = 0.250 m, d3 = 0.250 m, F = 330 N,
specify your answer in the form: <name> = (<xvalue> , <yvalue>) <units>

A = (0 , 165.0) N

Figure 3: Solution to example problem.

Chapter 2

Literature Review

This project began with a period of research. Research efforts consisted of literature review, trying out other learning tools, and documenting what others have done. This initially covered MasteringEngineering, Stressalyzer, and MDSolids software. Fellow Syracuse University engineering student Bobby Panzcer, a student of Professor Joan Dannenhoffer, provided a report on McGraw-Hill's Connect software. In addition to software review, course textbooks for Statics and Solid Mechanics were consulted. This focused the direction of the project, extracting the pedagogical method. Literature review sought to extract what holes ARCHIMEDES can fill, what should be left to pencil and paper, and what is important for the student to get out of a specific problem.

MasteringEngineering

MasteringEngineering is an online tutorial and homework system by Pearson Education, Inc. The Mastering platform reaches over a million students across the sciences, with research showing improvement in student learning [4]. Features include self-paced tutorials, video solutions, student assessment for instructor use, math review, and access to text and notes. Pearson releases new features semiannually.

Many of these amenities do not fall within the scope of objectives for the current ARCHIMEDES. The problem solving module is of chief concern. A problem statement is provided along with a clear graphic. Numerical values and

an entry for answer submission are immediately available. Hints are accessible in the following order. First hints provide an outline of the necessary steps to solve the problem. The next tier of hints are declarative, such as “Use $F = ma$ ”. Lastly, Socratic hints are provided to assign subtasks, should a student be unable to complete a problem. Like ARCHIMEDES, MasteringEngineering provides live feedback. The exactness of the live feedback is impressive. For example, “Check your trigonometry” will be returned when entering an incorrect trigonometric function.

MasteringEngineering can handle almost any class of problem, as is evident by the use of the Mastering platform throughout various sciences. The major flaw in the software is the over-constraining on the student’s approach. Solutions can be submitted immediately, robbing students from developing a reliable problem solving method. This could be changed by withholding the numerical values and answer submission, until the approach in the first class of hints are followed through. Declarative and Socratic hints are like a “free pass” to get through a problem, sidestepping some necessary thought processes.

StressAlyzer

Dr. Paul S. Steif developed the StressAlyzer problem solving courseware for Mechanics of Materials [7]. StressAlyzer consists of six modules addressing key topics in the subject. Each module consists of a bank of problems, with randomly generated geometry and parameters. The user interface is very basic, influencing ease of use, but seems to be lacking in the clarity and usefulness of

figures. StressAlyzer seems very useful for shear and moment diagrams. Problems are posed in both directions. Students can be asked to determine the diagrams for prescribed loading or to find the loads for given diagrams. The drawback to the software is that the plotting is not interactive. Curves are automatically plotted when students input calculated stresses and moments at a given location. Being able to place points and draw the curves much like by using pencil and paper, would be a useful exercise to implement in ARCHIMEDES. StressAlyzer provides feedback on responses much like ARCHIMEDES.

MDsolids

MDsolids is educational software for Solid Mechanics, developed by Timothy Philpot [6]. At first glance, MDsolids is impressive. The volume of content is overwhelming so discussion will be focused on the indeterminate problem.

The axial structures module contains the ‘indeterminate axial’ sub-module. A drawing interface is presented for constructing the problem, with premade configurations readily available. The user assigns parameter values. MDsolids then calculates reactions, stresses, and strains, and generates a corresponding set of equations. While this is an intriguing exercise, no problem solving is involved. Further investigation shows that this is how the other modules primarily operate. Users draw systems and assign parameters for MDsolids to perform calculations.

MDsolids appears powerful for learning and understanding subject material, but not for learning how to solve problems. In spite of this, the software provides inspiration for Mohr's circle in ARCHIMEDES. There is indeed a module that operates as previously described, with circles generated for user input values. In addition to these modules, MDsolids includes animated learning tools. Exercises include interactive Mohr's circles and stress elements.

Connect

McGraw-Hill offers Connect software to link students and teachers through course content and discussion. Features such as messages, recorded lectures, and online text are included, but outside the scope of this project. Robert Panczer reported on the problem solving module in Connect, with comparisons to ARCHIMEDES.

Problem solving in Connect closely resembles the MasteringEngineering platform. Numerical values are provided immediately when the problem is posed, as are entry fields for answer submission. Correct units are automatically given next to the entry field. A "Check My Work" button returns "Please Try Again" or "Correct" when clicked, at the expense of one recorded attempt.

Other features include options for the student to view a hint or guided solution. Hints push the student in the right direction, for example, "Start with carefully listing all the given stress components, including signs." Connect Hints encourage a systematic problem solving method similar to ARCHIMEDES.

However with the numbers and answer fields readily available, Connect users can bypass the encouraged method.

Guided solutions show the necessary steps worked out for a similar problem. It is desirable that students add such step by step procedures to their toolbox through Connect, ARCHIMEDES, and other learning software.

Connect's guided solutions are extremely similar to the initial problem. Often the only change is numerical values. A "lazy" student can simply swap values in formulae given by the guided solution to move through an assignment.

Ultimately, McGraw-Hill's Connect nails down the aesthetics and adds some great features. Ambitious students can develop their problem solving skills but immediate answer submission and guided solutions provide an easy out.

Chapter 3

Solid Mechanics

Solid Mechanics follows the Statics course in the engineering curriculum at Syracuse University. Solving a Solid Mechanics problem usually involves solving a Statics problem first, so it is a natural next step for ARCHIMEDES.

Selected Topics

During the research phase, a bank of potential problems to implement in ARCHIMEDES was developed. Professor Joan Dannenhoffer co-authored the initial publication on ARCHIMEDES, and is actively using the program as a professor of ECS 325, Mechanics of Solids, at Syracuse University. Thus, it was of great interest to meet with her to discuss different avenues for improving ARCHIMEDES.

Discussion focused on which classes of problems, and specific problems, are the most challenging for students to develop the necessary problem solving skills, in a typical classroom setting. What problems would be most beneficial to implement in ARCHIMEDES? A list of such desirable problems was initiated.

1. Normal stress and strain
2. Bearing stress
3. Strain compatibility
4. Torsion
5. Shear and Bending
6. Beam Deflection
7. Buckling

The addition of normal stress and strain, bearing stress, torsion, and buckling problems to ARCHIMEDES is straightforward. Auxiliary equations with appropriate Solid Mechanics relations allow students to reach the solution. Such problems can be implemented without changing the software.

Consideration was given to single versus multi-objective problems. Should the student be asked for a single stress (strain, etc) or for that of multiple components in a system? Many Solid Mechanics problems are inherently longer as a Statics problem must be solved first. At what point is the productivity of the exercise diminished to mindless repetition? This will vary from case to case. Thought for expanding or trimming the objectives should be given to each individual problem.

Problems concerning statically indeterminate structures cannot be implemented in the current ARCHIMEDES. The recursive algorithm for evaluating input auxiliary equations will not verify an added constraint equation, or ‘equation of compatibility’ in Gere’s text. Figure 4 illustrates a statically indeterminate problem.



Figure 4: Statically Indeterminate Problem [2].

The problem requires an equation of compatibility such as $\delta_A = \delta_B$, $\epsilon_A = \epsilon_B$.

The addition of displacement vectors to ARCHIMEDES will enable the software to handle statically indeterminate problems. With this upgrade, the student can add displacement vectors (δ_A, δ_B) to the free body diagram. A valid constraint equation in the equilibrium equations window will complete a linearly independent set of equations with the force and moment balance. Then, ARCHIMEDES allows the student to proceed with numerical values.

Analysis of beams in bending, specifically shear and bending moment diagrams, introduce an interesting class of problems. Such diagrams are useful to determine values of shear and bending moment throughout a beam, and to find their maximum values. Planar beams that are simply supported, overhanging, or cantilevered, are subject to transverse loading in the form of concentrated loads, distributed loads and couples. A natural next step might include deflections of beams by integration of the bending-moment equation. These problems would cover statically indeterminate beams: continuous, fixed-simple support, and fixed-fixed.

The typical shear-bending diagram problem will simply prescribe loads, supports, and geometry for a beam, and ask the student to develop the shear and bending moment diagrams. Maximum shear, moment, or stress values might also be asked for. Solving a problem requires breaking up a beam into segments. Equilibrium equations give the shear and moment distribution for each section. Implementing this class of problems in ARCHIMEDES would include a module for defining these segments. Generating new free body diagrams for each section is desired. There is much room for discussion on the plotting interface to be

developed. Furthermore, these problems can be carried out without providing numerical values to students.

Mohr's Circle is not included in the previous list of desirable problems. Mohr's circle is a graphical representation of the transformation equations for plane stress. Construction of the circle enables the student to visualize relationships between the normal and shear stresses on elements at different orientations. The circle is also valid for other quantities including strains and moments of inertia.

Ultimately, an ARCHIMEDES 'with all the bells and whistles' will have a bank of Mohr's circle problems. Mohr's circle is a robust calculator. Problems vary only slightly, with different prescriptions of stresses and angles. Governing equations are the same for each problem. Thus, solutions can be found bypassing Mohr's circle altogether. It is quick, and handy, but does not share the fundamental value of free body diagrams, and equilibrium equations.

Solid Mechanics in ARCHIMEDES

As a result of this research project, seven Solid Mechanics problems were written for ARCHIMEDES. The problems cover normal stress and strain, indeterminate structures, beam deflection, bearing stress, and torsion. All problems can be found in Appendix A. One problem is shown here in Figure 5.

main.tcl

Save Save&quit Quit Current problem: Aziz_3

Info: Equations are okay

Rtn

Add Force Add Couple Add Displace Isolate Delete Back to Equation Check Answer

Rigid beam AB is pinned to the wall at B and supported by cable CD. Cable CD has cross sectional area A and modulus of elasticity E. What is the deflection at point A due to force P?

3D

Top

Frnt

Side

Equilibrium equations

```
-P+CD-By=0
Bx=0
P*(d2+d3)-CD*d3=0
```

Other definitions

```
delD=-CD*d1/A/E
delA=-(d2+d3)*delD/d3
```

For: d1 = 0.400 m, d2 = 0.300 m, d3 = 0.900 m, P = 3600 N, A = 0.01000 m², E = 30000000 N/m²,
specify your answer in the form: <name> = <value> <units>

delA = 0.00853 m

Figure 5: ARCHIMEDES Problem Example

Moving forward with the Solid Mechanics branch of ARCHIMEDES will include building the bank of problems, and adding 3D Solid Mechanics problems when 3D ARCHIMEDES is complete.

Chapter 4

Three Dimensional Statics Problems

The main focus of this project was to implement three dimensional statics problems in ARCHIMEDES. This chapter discusses the approach to developing a 3D interface for ARCHIMEDES.

Motivation

Solving three dimensional Statics problems requires the same procedure as those in 2D. Force and moment equilibrium equations are used to solve for unknown reactions. In 2D, this includes forces in the x-direction, forces in the y-direction, and moments in the xy-plane (about the z-axis). 3D Statics problems, however, have six equilibrium equations. This includes force equilibrium in x, y, and z, and moment equilibrium about each axis. 3D is further complicated by the necessity of vector cross products, and of course, interpreting a 3D picture.

3D Statics problems in textbooks and the software covered in Chapter 2 are posed no differently than 2D problems. With regard to graphics, there is room for error in interpreting the problem image itself and then again in recreating the figure for a free body diagram. The idea behind a 3D ARCHIMEDES is to mitigate the graphical challenges, enabling the student to better develop a 3D problem solving method. A list of questions was developed to keep in mind during development of 3D ARCHIMEDES.

1. Are engineering views sufficient?
2. Does the user have to rotate into views?

3. Do views need to be shown simultaneously?
4. How should dimensions be provided?
5. How are forces and moments specified?
6. What combinations of vectors are sufficient?
7. How are the valid directions specified?
8. Do elements rotate independently or simultaneously?

Questions 1, 2, and 3, consider how 3D ARCHIMEDES will present an image of the problem to the student. “Engineering views” are standard top, front, and right-side views of an engineering drawing. To answer Question 2, the interface could snap directly to the standard views or rotate slowly. Then, Question 3 considers single versus multiple views of the scene.

Next, Question 4, how will the dimensions be displayed? Possibilities include dimensions on the standard 2D views, 3D dimensions in the coordinate directions only, and 3D dimensions parallel to a corresponding object.

Creating the free body diagram is addressed in Question 5, 6, and 7. As the number of equilibrium equations increases from 2D to 3D, so do the valid directions for drawing vectors. Vectors can be placed in one of six coordinate directions, one of six corresponding projections, and along or perpendicular to the free body. It is challenging to unambiguously define a vector in 3D.

Lastly, the motivation for Question 8 is how 3D ARCHIMEDES will behave with a free body on the computer screen next to the original graphic. An independent rotation would have the full graphic and free body each rotate about

their own set of local axes. On the other hand, simultaneous rotation would have the two images rotating about the same set of axes: imagine the two images side by side rotating into a position such that one is behind the other on the screen.

An interface for 3D ARCHIMEDES was developed, and a field test was conducted, in an effort to answer these questions. The interface, test, and results, are covered in Chapter 5.

THREE.JS

ARCHIMEDES is written in the Tcl/Tk programming platform. Tcl/Tk and other platforms were explored for developing an interface for 3D ARCHIMEDES. A 3D JavaScript library entitled “THREE.JS” was selected.

THREE.JS is an open source project released publicly by Ricardo Cabello on GitHub [8]. This lightweight and low complexity 3D library operates in most web browsers with the appropriate add-on.

Chapter 5

ARCHIMEDES in 3D

A 3D interface was created for ARCHIMEDES. This chapter describes the interface, a survey to evaluate the new system, and the results.

Sample program listing for 3D ARCHIMEDES is provided in Appendix C. Figure 6 introduces the program written for 3D ARCHIMEDES, using the THREE.JS JavaScript library.

Left mouse button to rotate, Mouse wheel to zoom, F5 to refresh



Q1: Develop an expression for the length of the red wire.

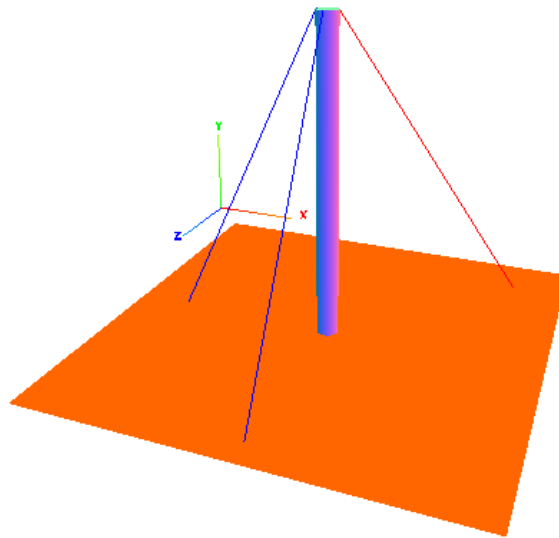


Figure 6: 3D ARCHIMEDES Question 1.

Most of the screen is occupied by an image of the current problem. The 3D tower and wire problem is popular in the Statics course. A color coordinated

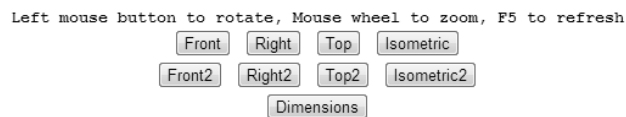
X-Y-Z coordinate system is provided. The problem statement is posed above the image.

Instructions at the top of the screen inform the student how to manipulate the scene. Holding down the left mouse button, and dragging the mouse, will rotate the scene. Scrolling the mouse wheel will zoom in and out.

Next, nine buttons allow for even more interaction. The first four, “Front”, “Right”, “Top”, and “Isometric”, snap the scene directly to the standard engineering view. The next set of four, “Front2”, “Right2”, “Top2”, and “Isometric2”, rotate smoothly from the current position to the corresponding engineering view in 2.5 seconds.

Dimensions can be triggered on or off with the “Dimensions” button.

Figure 7 shows the same problem, with dimensions activated.



Q1: Develop an expression for the length of the red wire.

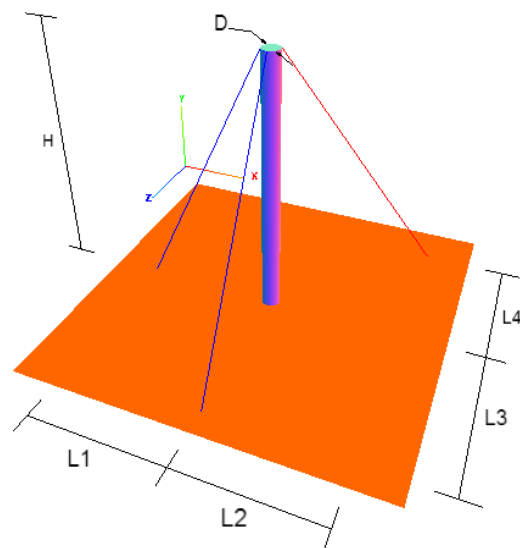


Figure 7: Question 1 with dimensions on.

As the user rotates the scene, dimension labels remain upright so that they can be easily read. Another feature hides dimensions when they are within 5% of normal to the screen. For example “L3” and “L4” will be hidden for a front view with the z-axis normal to the screen. Similarly, “L1” and “L2” will hide when the x-axis is normal to the screen, and “H” will hide when the y-axis is normal to the screen.

The following series of figures are screenshots of 3D ARCHIMEDES, edited for viewing in this report. A force, labeled “P”, is added to the scene in Figure 8.

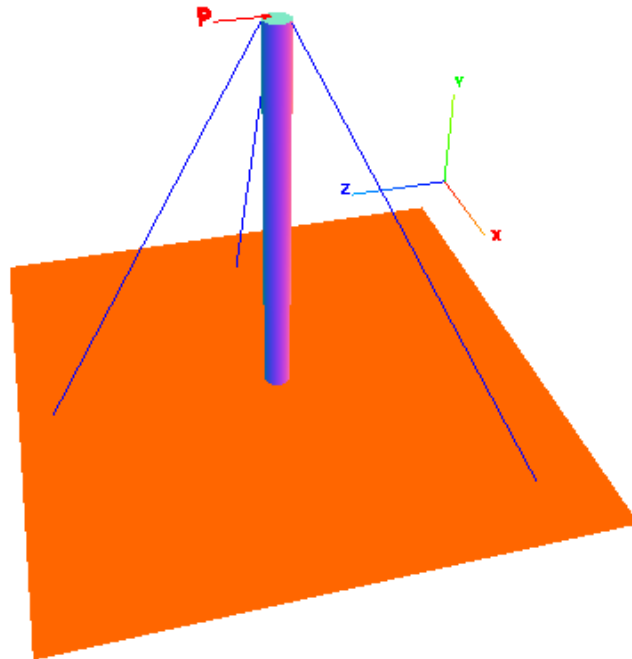


Figure 8: Applied Force P.

A new problem is drawn in Figure 9, with multiple views of a beam leaning on a wall. “Top”, “Front”, and “Right” engineering drawing views are shown fixed. The user can manipulate the scene (rotate, zoom, trigger dimensions) that appears on the upper right hand side of the screen.

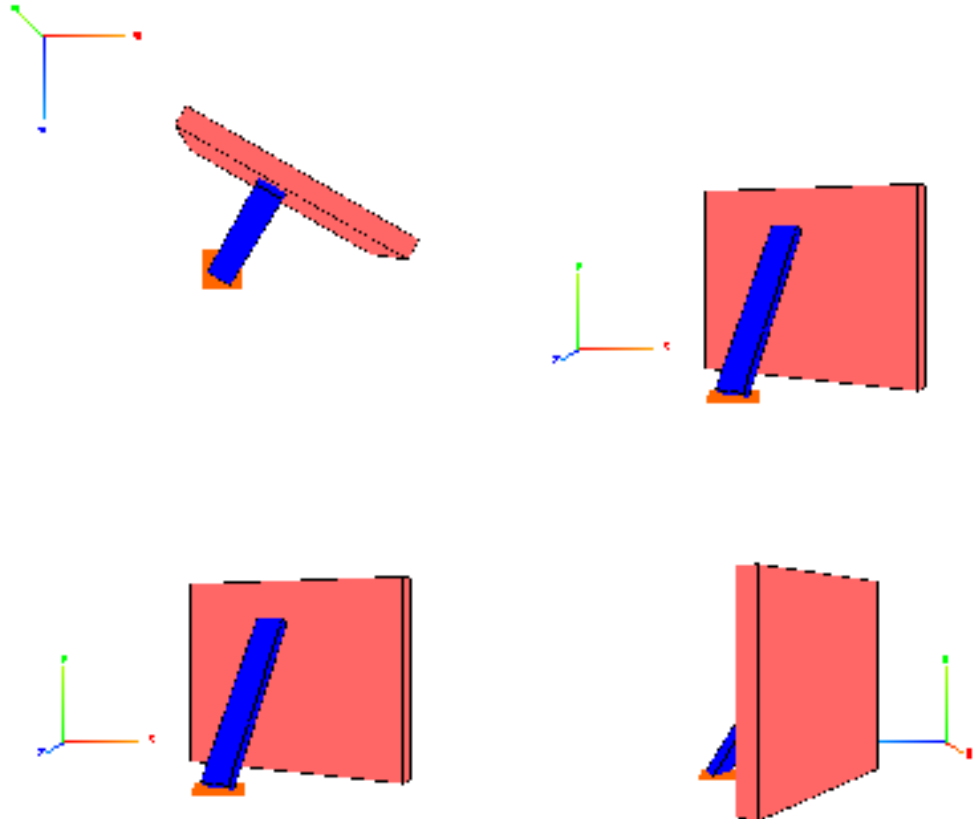


Figure 9: Engineering Views.

Returning to the wire problem, Figure 10 illustrates vector selection. Pressing the “tab” key rotates through preset vector combinations.

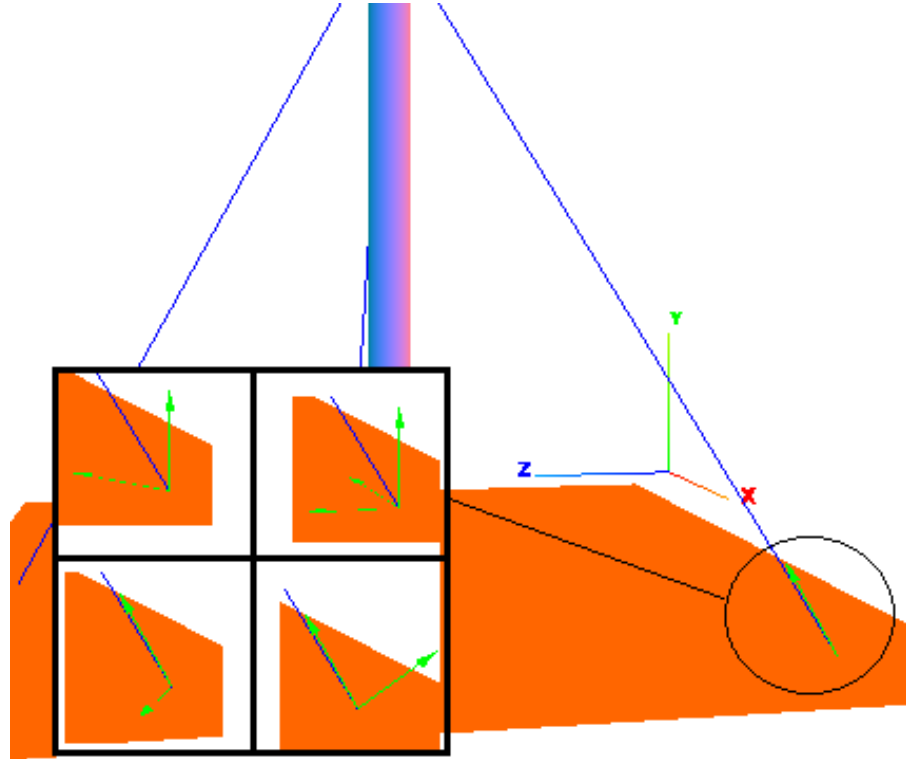


Figure 10: Vector Selection.

Lastly, Figure 11 shows an isolated, free body diagram of the beam problem. Force due to gravity is added automatically. The “tab” key is used to select the appropriate ground reactions, while the spacebar is used to select the reaction at the frictionless wall. This scene is later used to test independent versus simultaneous rotation.

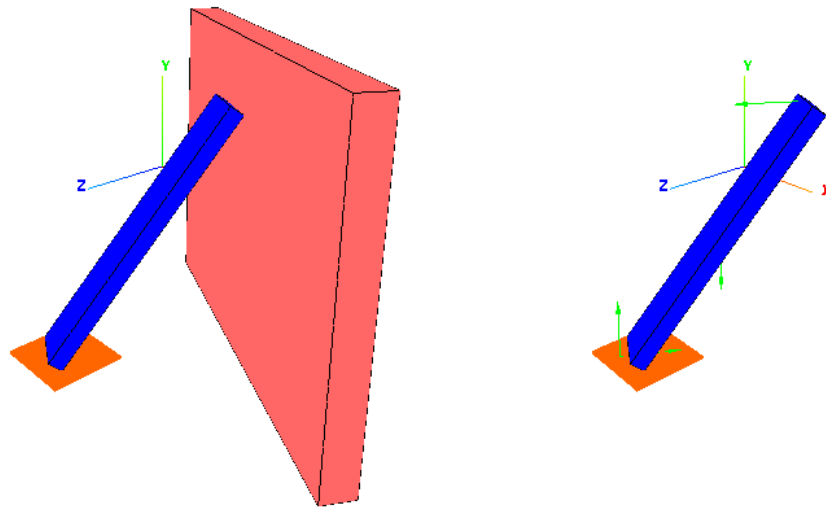


Figure 11: Free Body Diagram.

Evaluating the System

A field test was conducted with ten student volunteers to evaluate 3D ARCHIMEDES. The survey given to the students is in Appendix B. This section of the report extracts the questions asked of the students, and provides comments.

Before seeing the software for the first time, student volunteers were asked six preliminary questions.

1. *How comfortable do you feel in solving statics problems in general?*
2. *How comfortable do you feel in solving 3D statics problems?*
3. *Did you find ARCHIMEDES to be useful to you in the Statics course?*
4. *What do you find challenging about a 3D statics force-moment equilibrium problem?*
5. *What steps do you take to mitigate these difficulties when solving problems on paper?*
6. *What do you expect to see in a 3D version of ARCHIMEDES?*

After a demonstration of the software, students then completed nine tasks that required interacting with the software. The purpose of this evaluation was to test 3D ARCHIMEDES, not the students' knowledge of statics. Hints regarding subject matter were provided when asked for.

1. *Develop an expression for the length of the red wire.*

This task tests interpretation of dimensions on the screen, and is solved with the distance formula.

2. *Fill in the matrix for the moment about the base of the cylinder due to force P only.*

Here students must set up a vector cross product, requiring proper interpretation of a force vector and problem dimensions.

3. *Rotate to a left hand view of the scene. Top, Front, and Right views are shown fixed.*

This task corresponds to the engineering views of Figure 9.

4. *Decompose the tension in the wire into a y force and projection in the xz plane.*

The student must scroll through combinations of vectors using the tab key.

5. *On the isolated beam, draw an appropriate free body diagram to solve for the friction coefficient for impending motion.*

On this task, the student gets to evaluate independent rotation, where the scene and free body each rotate about their own set of axes.

6. *Develop an expression for the angle between the beam and the ground.*

Simultaneous rotation is enabled for this task.

7. *Describe the given vectors by answering the following:*

Are the given vectors correctly drawn to represent wire tensions on a free body diagram of the cylinder?

Yes / No

Vector/Wire A: Is the x component positive / negative / zero?

Is the y component positive / negative / zero?

Is the z component positive / negative / zero?

These questions are repeated for the other wires.

8. *On which faces of the stress element are positive stresses drawn correctly/incorrectly?*

Like task 7, task 8 tests the students' understanding of vector representations and scene geometry.

9. *How will the cube rotate about each axis due to force P?*

Again, the student needs to correctly understand a vector, and visualize how the body will react in three dimensions.

Next, students are asked their preference on a variety of features.

1. *Do you prefer view buttons that rotate or snap to standard views?*
2. *Do you prefer single or multiple views?*
3. *Do you prefer that elements rotate independently or simultaneously?*
4. *Do you prefer to draw vectors, or select preset ones?*
5. *Do you prefer dimensions to be permanent or triggered by a button?*

Lastly, the students answer a series of follow up questions.

1. *How does this 3D version of ARCHIMEDES make the challenges and difficulties mentioned in your earlier responses better or worse?*
2. *How does 3D ARCHIMEDES help or hinder your problem solving method?*
3. *What do you think is missing from this 3D ARCHIMEDES?"*

Results

Ten engineering students at Syracuse University volunteered to evaluate 3D ARCHIMEDES. Time taken to complete the evaluation ranged from 30 to 50 minutes. The average comfort level for Statics in general was 4 out of 5, while this number dropped to 3.5 for 3D Statics only. Five of the ten students indicated that ARCHIMEDES was useful to them in the Statics course. Ten students is a small sample size and not representative of a normal distribution. Future efforts should strive for a larger sample. It is additionally worthwhile to survey students who find themselves less comfortable with Statics.

When asked what is challenging about a 3D Statics problem, “visualization” was a recurring response. Of course this is as expected, hence the motivation for this project. One student did answer, however, “I don’t find them [3D Statics problems] to be challenging”.

A popular student response for how to mitigate this visualization challenge was to “stay organized”. Said in different terms, students draw carefully, check their work, write clearly and leave plenty of space, write out clear directions, and take their time. These responses are working components in a successful problem solving method, but do not address the issue of “visualization”. 3D ARCHIMEDES can fill this niche.

Student volunteers were previously familiar with ARCHIMEDES. So, when asked of their expectations, they appropriately mentioned “Problems with guidelines for how to progress step by step to get to the solution, like in 2D ARCHIMEDES” and “Assisted steps”. It is ultimately an objective for 3D

ARCHIMEDES to systematically approach problems as in the 2D version, but that is beyond the present state of 3D ARCHIMEDES. Other appropriate expectations included multiple views, a rotatable 3D image, and taking vector cross products.

Only one student answered all parts of task completion correctly, while the average was 7 of the 9 tasks completed correctly. This report is not about student performance, though it is reassuring that results indicate an average difficulty of the evaluation. Tasks were assigned to immerse the students in the 3D ARCHIMEDES software. Table 1 summarizes the students' preferences after using 3D ARCHIMEDES.

| | | | |
|--------------------------|----|-------------------|---|
| <u>Rotation Buttons</u> | | <u>Vectors</u> | |
| Snap | 6 | Preset | 8 |
| Rotate | 3 | Draw | 2 |
| <u>Views</u> | | <u>Dimensions</u> | |
| Single | 4 | Permanent | 6 |
| Multiple | 4 | Triggered | 4 |
| <u>Rotating Elements</u> | | | |
| Independently | 10 | | |
| Simultaneously | 0 | | |

Table 1: 3D ARCHIMEDES student preference poll.

Underlined headers refer to the subjects of the five preference questions introduced in the last section, also available in Appendix B Section III. Note that the counts for Rotation Buttons and Views do not add up to a total of 10, as students abstained from answering.

View buttons that snap to a standard engineering view took a slight majority over the slow rotation buttons. While observing students complete the

evaluation, it was noted that the slow rotation buttons were seldom used.

Comments indicate that students prefer to interact with the scene by clicking and dragging the mouse to rotate.

There is no consensus on whether or not a single view or multiple views of the scene is preferred. Perhaps the best option is to have both modes made available to the student. It is clear from the comments that efforts should be made to make the multiple views larger and clearer.

Responses are unanimous that independently rotating elements are preferred over a simultaneous rotation. Recall from Figure 11 that this means students prefer a scene and corresponding free body diagram to each rotate about their own set of axes, rather than simultaneously about a central axis.

From a programming standpoint, it is desirable to be able to easily draw any 3D vector. In 2D ARCHIMEDES, students draw vectors on the free body, but they can only draw in a series of prescribed directions. Work on 3D ARCHIMEDES did not progress this far, and students chose from preset vectors in the evaluation. This was voted as the preference though students did not actually get to experience drawing vectors.

Again, from a programming standpoint, it was desirable to have dimensions triggered on or off. Student opinion indicates however that perhaps this is an unnecessary complexity, and dimensions should just be left on. During the evaluation, questions were posed both with dimensions off at the start, and on at the start. Some students stalled before triggering the dimension on, taking a while to realize they were necessary to see the geometry parameters. As there is

still significant desire for triggered dimension buttons, they should be on when the problem is loaded, with a button still available to trigger them on or off.

Students' responses to follow up questions highlighted how 3D ARCHIMEDES mitigated the challenges of 3D Statics problems, noted faults and areas for improvement in the program and provided some interesting suggestions that had not yet been considered.

First, the positive feedback:

"It was much easier to conceptualize how everything fit together"

"Definitely helped me visualize the problem much better. I always want to be able to look at the problem from multiple angles and cant with textbook problems"

"Makes 3D visualization much easier!"

Clearly this beta version of 3D ARCHIMEDES is tackling the graphical challenges of 3D Statics problems.

Where 3D ARCHIMEDES struggles, is the presentation of 3D vectors. It was noted that they are still difficult to understand; not enough is done to erase the ambiguity of a given vector. Graphically, it was suggested that vectors are drawn with longer and thicker arrows. Further notes for improvement included:

"Some dimensions are difficult to understand"

"Polish and refinement are all that is missing."

Dimensioning the scene in a clear manner follows the same challenges as unambiguously drawing a vector. Reference lines can be drawn closer to the

appropriate geometry, and a descriptive statement could be provided to mitigate this issue.

3D ARCHIMEDES is robust in its present state. In addition to polishing and refining, there are several important steps ahead that are covered in the following section. Before proceeding, some additional suggestions should be addressed. One student was not fond of the color scheme, and suggested a black background be implemented. Challenges for colorblind students should be kept in mind, as should other conditions in general. Being able to pan the camera was also suggested. Camera panning was present initially but removed due to a programming conflict with how the view buttons operated. The ability to pan the camera is still an objective.

The most intriguing suggestion is to enable the student to move the coordinate axes around the scene. Additionally, actual scene coordinates could be provided as the student moved the cursor about the screen. These features present themselves as part of a solution to vector ambiguity.

Moving Forward

To take 3D ARCHIMEDES to the next level, a “short list” of updates, and the ultimate goal should be kept in mind. The ultimate goal follows the title of this project, that is, to apply ARCHIMEDES to 3D and Solid Mechanics.

Polishing, refinements, and quick fixes comprise the short list that give ARCHIMEDES 3D a functional, purposeful use. Force couples are important in Statics, and are present in 2D ARCHIMEDES but have not been tried in 3D

ARCHIMEDES. 3D moment reactions have not been implemented either. The short list continues with camera panning, the ability to isolate a body, and trials of the suggestions in the previous section.

It is clear from student responses that just having a 3D scene to manipulate improves visualization of the problem. Quick implementation of ARCHIMEDES 3D is achievable by duplicating textbook problems. Finally, again with the ultimate goal in mind, this project is to improve ARCHIMEDES, not just develop a stand alone 3D interface. The interface developed here should mesh with 2D ARCHIMEDES and its live feedback, systematic procedures.

Conclusion

The primary objective of this Capstone Project resulted in a 3D interface for ARCHIMEDES learning software that helps engineering students solve Statics problems. A secondary result includes the addition of Solid Mechanics problems for the present version of ARCHIMEDES. Student volunteers evaluated the 3D interface.

Student opinion indicates that a 3D interface is favorable to a typical textbook problem. Having a scene to manipulate on the computer screen mitigates the difficulties found in 3D Statics. Preferences of various features in 3D ARCHIMEDES were also extracted from the student evaluations. Only ten student volunteers participated, and they indicated they are comfortable solving Statics problems. Future efforts should include an increased sample size, and target students who are less comfortable with Statics.

Future improvements to 3D ARCHIMEDES include adding force couples and moments that are currently present in the 2D version. Student volunteers suggested several ideas that are worth implementing and testing. Finally, 3D ARCHIMEDES will be integrated with 2D ARCHIMEDES for student use.

Works Cited

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Appendix A: Solid Mechanics Problems in ARCHIMEDES

Seven Solid Mechanics Problems written for ARCHIMEDES are shown here. Problems titled Aziz_1 and Aziz_2 require further development so solutions are not given.

The screenshot shows the ARCHIMEDES software window with the following details:

- Title Bar:** archimedes
- Menu Bar:** Save, Save&quit, Quit, Current problem: Aziz_1
- Info:** Welcome to ARCHIMEDES (written by jfdannen@syr.edu)
- Toolbar:** Add Force, Add Couple, Isolate, Delete, Check Diagram, Rtn
- Problem Text:** Beams AB, CD, and DE, of cross sectional area A, are pinned to the wall and rigid beam BDF. Beams AB and EF are steel (use E_{steel}) while beam CD is aluminum (E_{alum}). What is the stress in beam CD due to force P at point D?
- Diagram:** A 3D view of a mechanical system. Three horizontal beams (AB, CD, DE) are pinned to a vertical wall at points A, C, and E. A rigid vertical beam BDF connects the right ends of these beams. A force P is applied at point D. Dimensions L and H are indicated.
- Input Fields:** Equilibrium equations, Other definitions
- View Controls:** 3D, Top, Frnt, Side

Figure 12: ARCHIMEDES Problem Aziz_1

archimedes

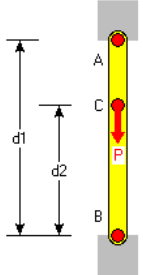
Save Save&quit Quit Current problem: Aziz_2

Info: Welcome to ARCHIMEDES (written by jfdannen@syr.edu)

Rtn

Add Force Add Couple Isolate Delete Check Diagram

Beam AB of cross sectional area A and modulus of elasticity E is fixed at its endpoints. What is the stress in section AC due to force P at point C?



3D

Top

Frnt

Side

Equilibrium equations

Other definitions

Figure 13: ARCHIMEDES Problem Aziz_2

main.tcl

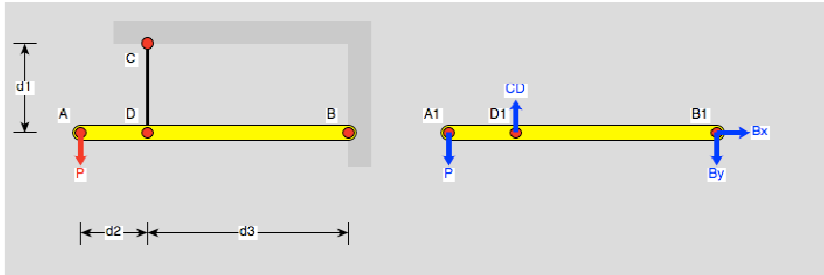
Save Save&quit Quit Current problem: Aziz_3

Info: Equations are okay

Rtn

Add Force Add Couple Add Displace Isolate Delete Back to Equation Check Answer

Rigid beam AB is pinned to the wall at B and supported by cable CD. Cable CD has cross sectional area A and modulus of elasticity E. What is the deflection at point A due to force P?



Equilibrium equations

$$\begin{aligned} -P + CD - B_y &= 0 \\ B_x &= 0 \\ P * (d_2 + d_3) - CD * d_3 &= 0 \end{aligned}$$

Other definitions

$$\begin{aligned} \delta_{e1D} &= -CD * d_1 / A / E \\ \delta_{e1A} &= -(d_2 + d_3) * \delta_{e1D} / d_3 \end{aligned}$$

For: $d_1 = 0.400$ m, $d_2 = 0.300$ m, $d_3 = 0.900$ m, $P = 3600$ N, $A = 0.01000$ m², $E = 30000000$ N/m², specify your answer in the form: <name> = <value> <units>

$\delta_{e1A} = 0.00953$ m

Figure 14: ARCHIMEDES Problem Aziz_3

main.tcl

Save Save&quit Quit Current problem: Aziz_4

Info: Equations are okay

Rtn

Add Force Add Couple Add Displace Isolate Delete Back to Equation Check Answer

Beams A and C are pinned to the wall, and joined to Beam B by a bolt of radius r . Beam B is subject to force P as shown. All beams have square cross sections with thickness t . What is the average bearing stress in the section of the bolt through beam C?

3D Top Frnt Side

Equilibrium equations

```
A + C = P
A = C
```

Other definitions

```
area = 2 * r * t
stress = C / area
```

For: $t = 0.480$ ft, $r = 0.0360$ ft, $P = 3600$ lb,
specify your answer in the form: <name> = <value> <units>

stress = 52100 lb/ft²

Figure 15: ARCHIMEDES Problem Aziz_4

main.tcl

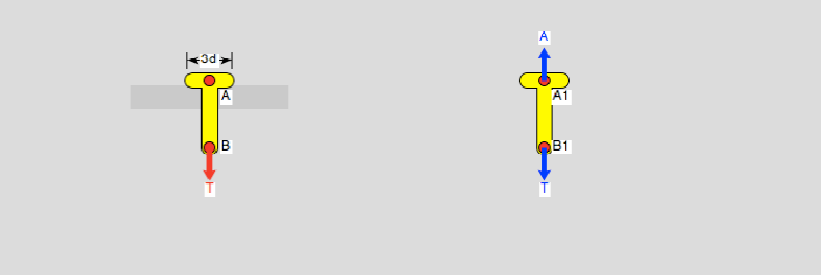
Save Save&quit Quit Current problem: Aziz_5

Info: Equations are okay

Rtn

Add Force Add Couple Add Displace Isolate Delete Back to Equation Check Answer

A bolt through a steel plate has a diameter d , and is subject to force T . What is the average bearing stress in the circular head of the bolt with diameter $3*d$?



3D
Top
Frnt
Side

Equilibrium equations

$A = T$

Other definitions

```
area0 = pi * (3*d/2)^2
area1 = pi * ( d/2)^2
area = area0 - area1
stress = A / area
```

For: $T = 1800 \text{ N}$, $d = 0.00500 \text{ m}$,
specify your answer in the form: <name> = <value> <units>

stress = 11500000 N/m2

Figure 16: ARCHIMEDES Problem Aziz_5

main.tcl

Save Save&quit Quit Current problem: Aziz_6

Info: Equations are okay

Rtn

Add Force Add Couple Add Displace Isolate Delete Back to Equation Check Answer

Beams A and C are pinned to the wall, and joined to Beam B by a bolt of radius r . Beam B is subject to force P as shown. All beams have square cross sections with thickness t . What is the maximum average shear stress in the bolt?

3D Top Frnt Side

Equilibrium equations

```

AB + BC = P
AB = BC

```

Other definitions

```

area = pi * r^2
shear = AB / area

```

For: $t = 0.480$ ft, $r = 0.0360$ ft, $P = 3600$ lb,
specify your answer in the form: <name> = <value> <units>

shear = 442000 lb/ft²

Figure 17: ARCHIMEDES Problem Aziz_6

main.tcl

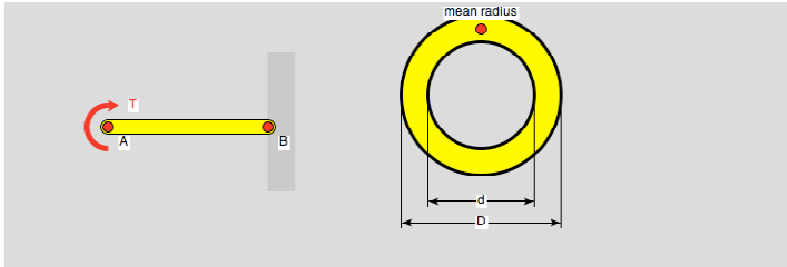
Save Save&quit Quit Current problem: Aziz_7

Info: CONGRATULATIONS! You have successfully finished Aziz_7.
Info: Please save your work before quitting to return to the problem list.

Rtn

Add Force Add Couple Add Displace Isolate Delete Back to Equation Check Answer

A circular tube with outer diameter D , and inner diameter d , is fixed to the wall at B. Torque T is applied at point A. What is the shear stress at the mean radius of the tube?



Equilibrium equations

Other definitions

```

Jout = pi/2 * (D/2)^4
Jin  = pi/2 * (d/2)^4
J    = Jout - Jin
c    = (D/2 + d/2) / 2
shear = T * c / J

```

For: $T = 300 \text{ Nm}$, $D = 0.0500 \text{ m}$, $d = 0.0400 \text{ m}$,
specify your answer in the form: <name> = <value> <units>

shear = 18630000 N/m2

Figure 18: ARCHIMEDES Problem Aziz_7

Appendix B: ARCHIMEDES 3D EVALUATION

ARCHIMEDES 3D

Date: _____

Time: _____

SECTION I: PRELIMINARY QUESTIONS

Please answer by circling a number indicating your level of comfort.
Use the scale: 1 = not at all, 3 = neutral, 5 = I expect to arrive at the correct answer.

7. How comfortable do you feel in solving statics problems in general?

1 2 3 4 5

8. How comfortable do you feel in solving 3D statics problems?

1 2 3 4 5

9. Did you find ARCHIMEDES to be useful to you in the Statics course?

YES / NO

10. What do you find challenging about a 3D statics force-moment equilibrium problem?

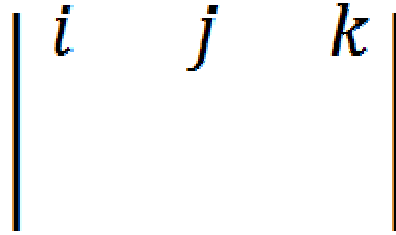
11. What steps do you take to mitigate these difficulties when solving problems on paper?

12. What do you expect to see in a 3D version of ARCHIMEDES?

SECTION II: TASK COMPLETION

10. Develop an expression for the length of the red wire.

11. Fill in the matrix for the moment about the base of the cylinder due to force P only.



12. Rotate to a left hand view of the scene. Top, Front, and Right views are shown fixed.
(Proctor will review your answer on the screen).
13. Decompose the tension in the wire into a y force and projection in the xz plane.
(Tab key through choices of vectors)
14. On the isolated beam, draw an appropriate free body diagram to solve for the friction coefficient for impending motion. Assume a frictionless wall.
(Tab for bottom of beam, spacebar for top) Force due to gravity is drawn for you.
15. Develop an expression for the angle between the beam and the ground.
16. Describe the given vectors by answering the following:
Are the given vectors correctly drawn to represent wire tensions on a free body diagram of the cylinder?
Yes / No
- Vector/Wire A: Is the x component positive / negative / zero?
Is the y component positive / negative / zero?
Is the z component positive / negative / zero?
- Vector/Wire B: Is the x component positive / negative / zero?
Is the y component positive / negative / zero?
Is the z component positive / negative / zero?
- Vector/Wire C: Is the x component positive / negative / zero?
Is the y component positive / negative / zero?
Is the z component positive / negative / zero?

17. On which faces of the stress element are positive stresses drawn correctly/incorrectly?

Convention: Positive normal and shear stresses on positive faces are drawn in positive directions. Positive normal and shear stresses on negative faces are drawn in negative directions.

| | | | |
|-----|---------|---|-----------|
| + x | correct | / | incorrect |
| - x | correct | / | incorrect |
| + y | correct | / | incorrect |
| - y | correct | / | incorrect |
| + z | correct | / | incorrect |
| - z | correct | / | incorrect |

18. The cube shown is fixed to rotate around its center and cannot translate. How will the cube rotate about each axis due to force P?

Rotation about x: positive / negative

Rotation about y: positive / negative

Rotation about z: positive / negative

SECTION III: PREFERENCES

6. Do you prefer view buttons that rotate or snap to standard views?
7. Do you prefer single or multiple views?
8. Do you prefer that elements rotate independently or simultaneously?
9. Do you prefer to draw vectors, or select preset ones?
10. Do you prefer dimensions to be permanent or triggered by a button?

SECTION IV: FOLLOW-UP QUESTIONS

4. How does this 3D version of ARCHIMEDES make the challenges and difficulties mentioned in your earlier responses better or worse?

5. How does 3D ARCHIMEDES help or hinder your problem solving method?

6. What do you think is missing from this 3D ARCHIMEDES?

Other comments:

Appendix C: 3D ARCHIMEDES Program Listing

Main Script:

```

<script>
if ( ! Detector.webgl ) Detector.addGetWebGLMessage();
//Create variables for scene
var container, camera, controls, scene, renderer;
// set the initial vectors
var vectorcase = 1;
// set the initial view
var viewcase = 1;
init();
animate();
function init() {
// create and control the camera
camera = new THREE.PerspectiveCamera( 60, window.innerWidth /
window.innerHeight, 1, 3000 );
camera.position.z = 750;
controls = new THREE.OrbitControls( camera )
controls.addEventListener( 'change', render );
//load scene geometry
scene = new THREE.Scene();
geometries()
//external script
// renderer
renderer = new THREE.WebGLRenderer( { antialias: false } );

renderer.setSize( window.innerWidth, window.innerHeight );
container = document.getElementById( 'container' );
container.appendChild( renderer.domElement );
window.addEventListener( 'resize', onWindowResize, false );
}
function onWindowResize() {
camera.aspect = window.innerWidth / window.innerHeight;
camera.updateProjectionMatrix();
renderer.setSize( window.innerWidth, window.innerHeight );
render();
}
function animate() {
requestAnimationFrame( animate );
controls.update();
}
function render() {
if (test == 0){
//dimensions face the camera
scene.getChildByName('H').rotation = camera.rotation
//dimensions to hide when they align with camera
var x = new THREE.Vector3(1,0,0);
var y = new THREE.Vector3(0,1,0);
var z = new THREE.Vector3(0,0,1);
var dotx = x.dot(camera.position) / x.length() /
camera.position.length();
var doty = y.dot(camera.position) / y.length() /
camera.position.length();
}
}

```

```

var dotz = z.dot(camera.position) / z.length() /
camera.position.length();
if (Math.abs(dotx) > .95) {
scene.getChildByName('dimx').visible= false}

else {
scene.getChildByName('dimx').visible= true}

if (Math.abs(doty) > .95) {
scene.getChildByName('dimy').visible= false}

else {
scene.getChildByName('dimy').visible= true}
if (Math.abs(dotz) > .95) {
scene.getChildByName('dimz').visible= false}

else {
scene.getChildByName('dimz').visible= true}
}
}
renderer.render( scene, camera );
}
</script>

```

View Buttons:

```

// functions for view buttons
function angleBetweenQuats(qBefore,qAfter) {
  q1 = new THREE.Quaternion();
  q1.copy(qBefore);
  q1.inverse();
  q1.multiplySelf(qAfter);
  var halfTheta = Math.acos( q1.w );
  return 2*halfTheta;
}
function lookTowards(fromObject,toPosition, dTheta) {
  var quat0 = new THREE.Quaternion();
  quat0.setFromRotationMatrix( fromObject.matrix );
  var eye = fromObject.position;
  var center = toPosition;
  var up = new THREE.Vector3(0,1,0);
  var mat = new THREE.Matrix4();
  mat.lookAt(center,eye,up);
  var quat1 = new THREE.Quaternion();
  quat1.setFromRotationMatrix( mat );
  var deltaTheta = angleBetweenQuats(quat0,quat1);
  var frac = dTheta/deltaTheta;
  if (frac>1) frac=1;
  THREE.Quaternion.slerp(quat0,quat1,fromObject.quaternion,frac);
}
function frontview(){

camera.position.x=0;
camera.position.y=0;
camera.position.z=750;

```

```

render()
}
function frontview2(){
//start
var r = Math.sqrt( camera.position.x * camera.position.x +
camera.position.y * camera.position.y + camera.position.z *
camera.position.z );
var theta = Math.acos( camera.position.z / r ) ;
var phi = Math.atan(camera.position.y / camera.position.x);
//steps
var dtheta = (0 - theta )/50;
var dphi = (Math.PI/2 - phi)/50;
//move
var i = 0;
movestep = 50
move();
function move(){
camera.position.x = r * Math.sin(theta + i * dtheta) *
Math.cos(phi + i * dphi)
camera.position.y = r * Math.sin(theta + i * dtheta) *
Math.sin(phi + i * dphi)
camera.position.z = r * Math.cos(theta + i * dtheta)
render()
if (i < movestep) {
setTimeout(move, 50)
i = i + 1;
}
}
}
}

```

Sample Geometry:

```

function geometries(){
axis = new THREE.AxisHelper( 100 );
axis.position.set( -240, -150, -240 );
axis.matrixAutoUpdate = false;
axis.updateMatrix();
scene.add( axis );
var cylinder = new THREE.Mesh( new THREE.CylinderGeometry( 10,
10, 300, 500, 1), new THREE.MeshNormalMaterial() );
//(r1,r2,length,segments,)
cylinder.position.set( 0, 0, 0);
cylinder.matrixAutoUpdate = false;
cylinder.updateMatrix();
scene.add( cylinder );
var ground = new THREE.Mesh( new THREE.CubeGeometry( 400, 400, 0,
1,1,1), new THREE.LineBasicMaterial({color: 0xff6600}) );
//0height-plane
ground.position.set( 0, -150, 0);
ground.rotation.set( 90*Math.PI/180, 0, 0);
ground.matrixAutoUpdate = false;
ground.updateMatrix();
scene.add( ground );
//labels
var xlabel = new THREE.Mesh( new THREE.TextGeometry( "X", { size:
10, height: 5, curveSegments: 6, font: "helvetiker", weight:

```

```

"bold", style: "normal" }), new
THREE.MeshBasicMaterial({color:0xff0000}));
xlabel.position.set(-130,-150,-242)
xlabel.name = 'xlabel'
scene.add(xlabel)
var material2 = new THREE.LineBasicMaterial({
color: 0xFF0000
});
var geometry = new THREE.Geometry();
geometry.vertices.push(new THREE.Vertex(new
THREE.Vector3(7.071,150,-7.071)));
geometry.vertices.push(new THREE.Vertex(new THREE.Vector3(150,-
150,-150)));
var wire1 = new THREE.Line(geometry, material2);
wire1.matrixAutoUpdate = false;
wire1.updateMatrix();
scene.add( wire1 );
}

```

Selecting Vectors:

```

function vectors () {
// along the wire
var vec1 = new THREE.ArrowHelper( new THREE.Vector3( -1.28787, 3,
1.28787 ), new THREE.Vector3( 0, 0, 0 ), 35, 0x00ff00 );
vec1.position.set( 150, -150, -150 );
vec1.name = 'vec1'

// up and projection of wire
var vec2 = new THREE.ArrowHelper( new THREE.Vector3( -1.28787, 0,
1.28787 ), new THREE.Vector3( 0, 0, 0 ), 35, 0x00ff00 );
vec2.position.set( 150, -150, -150 );
vec2.name = 'vec2'

var vec3 = new THREE.ArrowHelper( new THREE.Vector3( 0, 1, 0 ),
new THREE.Vector3( 0, 0, 0 ), 35, 0x00ff00 );
vec3.position.set( 150, -150, -150 );
vec3.name = 'vec3'

if (vectorcase ==1) {
scene.remove(scene.getChildByName('vec1'));
scene.remove(scene.getChildByName('vec2'));
scene.remove(scene.getChildByName('vec3'));
scene.add(vec1)
}else if(vectorcase ==2){
scene.remove(scene.getChildByName('vec1'));
scene.remove(scene.getChildByName('vec2'));
scene.remove(scene.getChildByName('vec3'))
scene.add(vec2);
scene.add(vec3);}
}
function keydown( event ){
event.preventDefault();
var keyCode = event.keyCode;
if (keyCode == 9){
if(vectorcase == 1) {

```

```
vectorcase = 2;  
} else if(vectorcase ==2){  
vectorcase = 1;  
}  
vectors()}  
render()  
}
```


Summary of Capstone Project

A proposal for this Honors Capstone Project was approved in November 2011. The objective was to further develop ARCHIMEDES to handle three dimensional Statics problems as well as Solid Mechanics problems in both two and three dimensions. ARCHIMEDES is a computer based learning system developed by Dr. John Dannenhoffer, Associate Professor of Aerospace and Mechanical Engineering, here at Syracuse University. Dr. Dannenhoffer has agreed to serve as Capstone Advisor.

ARCHIMEDES is currently being used to help students solve Statics problems. A key element of ARCHIMEDES is its live feedback mechanism. In the paper and pencil approach to Statics problems, a student's only feedback is the self-checking of their work, which can have its own errors. Mistakes propagate throughout each step. When solving problems in ARCHIMEDES, students cannot proceed to the next step if their work is incorrect. ARCHIMEDES notifies the student of the nature of their error, and guides the student in making the proper corrections. The flexibility of ARCHIMEDES is powerful enough to allow any correct method chosen by the student. The student is not restricted to one specific approach.

Presently, ARCHIMEDES is used to solve two dimensional equilibrium and centroid problems. A key outcome of a statics course is the skill to successfully analyze such problems in three dimensions. Visualizing a three dimensional problem posed through a two dimensional medium is challenging for many students, let alone successfully completing the problem. Computers are a

powerful aid in this respect. The primary objective of this Capstone Project is to upgrade ARCHIMEDES to function with three dimensional problems. Success of this project will increase the applicability of ARCHIMEDES and benefit all students who use it.

A secondary objective of this Capstone Project is to apply ARCHIMEDES to Solid Mechanics problems. Solid Mechanics concerns the behavior of materials in response to stimuli. Problem solving in this subject relies heavily on the fundamentals of statics, so it is a natural next step for ARCHIMEDES. Indeed, expanding ARCHIMEDES to include solid mechanics problems includes the three dimensional component.

With these objectives in mind, literature review began in the Spring of 2012. Alternative learning software was evaluated at this time, and course textbooks for Statics and Solid Mechanics were consulted to extract the pedagogical method. A list of desirable Solid Mechanics topics and problems was developed in addition to a list of the necessary features for a 3D learning system.

Development of Solid Mechanics problems in ARCHIMEDES began in the Fall of 2012. Professor Joan V. Dannenhoffer, who coauthored the initial paper on ARCHIMEDES, was instructing ECS 325: Mechanics of Solids at the time. She agreed to be the Honors Reader for the project, and assisted in outlining the desired Solid Mechanics problems to be implemented.

The 3D interface for ARCHIMEDES was also being developed at this time. As a result of the literature review, the JavaScript library entitled THREE.JS was selected for creating the software. A Statics problem was illustrated in the

new “3D ARCHIMEDES”. The primary feature of the software is manipulation of the scene with the mouse and a set of view buttons. Other features change how the scene is displayed, and how it behaves due to user input.

Finally, a field test was developed to evaluate 3D ARCHIMEDES in the Spring of 2013. After approval from Syracuse University’s Office of Research Integrity and Protections, student volunteers completed the evaluation that ranged from 30-50 minutes of required time. The evaluation included preliminary questions that asked about the students’ previous experience with Statics, and what they expected to see in 3D ARCHIMEDES. After a demonstration of the software, the students were asked to complete 9 tasks using the software. Then, students were asked what they preferred about the various features, and a series of follow up questions.

This Capstone Project culminates with this report, and a presentation at the end of the Spring 2013 semester. Efforts toward improving ARCHIMEDES are already significant with the implementation of Solid Mechanics problems. 3D ARCHIMEDES evaluation results highlight the next steps before the interface is added to the current software. For a stand alone 3D interface, it is clear from student responses that having a 3D scene to manipulate improves visualization of the problem, mitigating the ambiguity of a textbook problem’s graphic.