Physics Curriculum Development

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1. Introduction

While sitting in on recitations and helping students review material for the introductory mechanics courses at Worcester Polytechnic Institute, often the students would comment on the course in question. Of course, there were the common complaints all students have: the course was too hard, too easy, too much homework, that the teacher was good, was bad, et cetera. However, in addition to these common complaints one will hear with any class, there was often a disturbing theme amongst the commentary; mechanics has no bearing in the student's real lives or bearing in their future careers as engineers. To use the phrasing of one student commenting on the course, "I don't get it. It's all this abstract nonsense," or in the words of another "What's the point to this? " Hearing such things from the students served as the impetus for this Interactive Qualifying Project (IQP). Talking with this project's advisor, Professor Koleci of the physics department, the possibility of introducing material into the recitation sections for her PH1111: Principles of Mechanics, a calculus based introductory mechanics course, opened. This created material was to be used in the recitation sessions and judged by two criteria: its effect on student learning and its effect on their opinions regarding physics' applicability.

2. Background

2.1 Class and Recitation Setup

The PH1111:Principles of Mechanics class typically has about 200 students. These students are distributed into recitation sessions of 20-30 students. The structure of the recitation under Professor Koleci's instruction consists of each recitation section being broken into groups of four to five students. Every group is tasked with completing a set of two to three problems relating to the topics covered in recent lectures. This approach of a cooperative learning environment, wherein students work together to solve problems, follows and has been proven a viable method through the efforts of education researchers.[i]

2.2 Student Learning

Having found an area in which to implement the IQP, we had to ask how does one measure the effect material has on student learning,

Stating that one is to measure the effect on student learning, one must be able to determine by what basis one will judge their learning.

Two methods which have been used to characterize student performance in physics courses are the force concept inventory test and measuring the transition from novice to expert problem solving methods. In its modern form, the Force Concept Inventory test is a battery of multiple-choice questions designed to test students on the basic topics of Newtonian mechanics. By issuing a pre and post class test, one may measure gains in the conceptual understanding of students. The score assigned by the test and the gains made in it has been called by some "the single most reliable index of student understanding."[ii] For this reason, the test has oft been used in recent physics education research efforts, most notably by Richard Hake who used the Force Concept Inventory as one of his metrics in a survey of six thousand students taking high school and college introductory physics classes.[iii]

Novice Classification Comments	Expert Classification Comments
• *Angular* velocity, *momentum,* circular things	• These can be solved by *Newton's Second Law*

Novice	Expert
• These deal with blocks on an *inclined plane* • Blocks on *inclined planes* with angles	• Largely use F = ma; *Newton's Second Law*. • These can be done from energy considerations. Either you should know the *Principle of Conservation of Energy.* or work is lost somewhere

Table 1: At left are novice and at right expert comments made by study participants explaining their reasoning behind physics problem classification. Note that the novices tended to classify problems based upon primarily surface details, notably here the inclined plane, whereas experts used the underlying physical principles in classifying problems.

The second metric, the transition to expert-like solving strategies, requires more direct interaction with individual students as it is not easily tested for. In a study conducted by Michelene Chi, Paul Feltovich, and Robert Glaser, all of the University of Pittsburgh, the classification schemes of physics problems between "experts", graduate students in physics, and "novices", undergraduates having taken only one semester of introductory mechanics were compared. Presented with twenty-four problems from Haliday and Resnick's Fundamentals of Physics, each participant was asked to group the problems as they saw fit. As revealed in the excerpted statements in Table 1, they showed that the "experts" in the field tended to group the problems based upon the underlying physical principles whereas the "novices" sorted problems according to surface, structural features present in the problem, such as ramps. A second trial run by the Pittsburg group wherein problems having similar surface features (ex. pulleys) but relying upon different principles to solve, force vs. energy, further demonstrated this pattern.[iv] In addition to the surface vs. conceptual approach to problem solving, it has been noted by Carl J. Wenning of Illinois State University that often the difficulty for students lies not solely, or at all, in identifying what is given and unknown in a problem, but rather in identifying how the knowns and unknowns relate to one another. He notes that in observing students trying to solve problems they oft would take a "plug and chug" approach, attempting every equation given until one worked.[v]

In order to use both metrics to analyze the effect of the implemented material a two-fold approach to the analysis was originally planned to be used. By comparing the percentage of total gainable points on the post-tests relative to the pre-tests gained for classes with the introduced material to those following the traditional format, conceptual gains in student learning would identified. One on one interviews with students which involved a problem solving or classifying session would then serve to identify expert-like problem solving approaches.

2.3 Context-Rich Problems

Having identified the audience and metrics, an appropriate material type was needed. Here we noted an effort by physics education researchers into what are called context rich problems. These problems are "short, realistic scenarios giving the students a plausible motivation for solving the problem."[vi] As shown in the comparison of Figure 1, often the problems attempt to disguise what the knowns, unknowns, and objective are through use of the context, forcing students to comb for appropriate information. Perhaps partly because of this searching, a group at Iowa State University found that over the course of doing a set of context rich problems, the amount of resources accessed by students, and the pertinence of those accessed, increased, displaying a change from novice towards expert solving strategies.[vii] Another study, done at the University of Minnesota, indicated that by having students grouped together solving context rich problems, their understanding of the material, as determined by a force concept inventory, was increased.[viii] One could ask whether in the first study the context rich problems were more effective than regular problems in this regard or whether in the second it was more so the students being grouped and discussing the problems which induced the effect. However without delving into the nuances of human behavior and its observation in the educational setting, and thereby losing sight of this IQP's goals, we note that the studies suggest that the context problems have demonstrated, if not definitively, improvements over the traditional textbook problems.

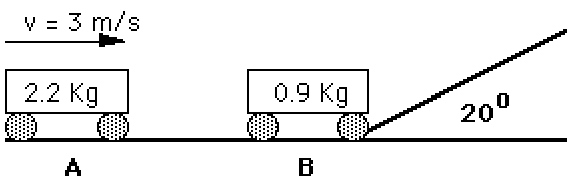
<table>
<tr><th>Traditional Problem</th><th>Context-Rich Problem</th></tr>
<tr><td>Cart A, which is moving with a constant velocity of 3 m/s, has an inelastic collision with cart B, which is initially at rest as shown in Figure 8.3. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height h of the carts before they reverse direction.

</td><td>You are helping your friend prepare for her next skate board exhibition. For her program, she plans to take a running start and then jump onto her heavy duty 15-lb stationary skateboard. She and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. She wants to reach a height of at least 10 feet above where she started before she turns to come back down the slope. She has measured her maximum running speed to safely jump on the skateboard at 7 feet/second. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned. She tells you that she weighs 100 lbs.[ix]</td></tr>
</table>

Table 2: Comparison of traditional and context-rich problems. Whereas the traditional problem spells out all details and provides a visual, the context-rich problem leaves the visual interpretation of the problem up the reader, forcing the solver to think about the problem's setup before beginning.

3. Materials Design: Application Based Problems

Although generally in favor of providing realistic contexts for students to work problems in, I found that often the term "realistic" was being used a tad loosely by groups designing context-rich problems. As an example see the following problem:

> Because parents are concerned that children are learning "wrong" science from TV, you have been asked to be a technical advisor for a science fiction cartoon show on Saturday morning. In the plot, a vicious criminal (Natasha Nogood) escapes from a space station prison. The prison is located between galaxies far away from any stars. Natasha steals a small space ship and blasts off to meet her partners somewhere in deep space. The stolen ship accelerates in a straight line at its maximum possible acceleration of 30 m/sec2. After 10 minutes all of the fuel is burned up and the ship coasts at a constant velocity. Meanwhile, the hero (Captain Starr) learns of the escape while dining in the prison with the warden's daughter (Virginia Lovely). Of course he immediately (as soon as he finishes dessert) rushes off the recapture Natasha. He gives chase in an identical ship, which has an identical maximum acceleration, going in an identical direction. Unfortunately, Natasha has a 30 minute head start. Luckily, Natasha's ship did not start with a full load of fuel. With his full load of fuel, Captain Starr can maintain maximum acceleration for 15 minutes. How long will it take Captain Starr's ship to catch up to Natasha's?[x]

It is a context and it is, for some sense of the word, realistic. However, the students in the introductory classes are, by and large, going to be future engineers. Although the presented problem is a context, its bearing to their lives is likely limited. Therefore, following one of the goals of the IQP presented, increasing the perceived applicability of mechanics to the students, the problems to be designed had to be placed in a context engineers would relate to. Thus application based problems, drawing from the fields studied at WPI, were decided upon. To ensure that the essential physics was covered in each problem, and to ensure that the areas of applicability were actually used in practice, journals were consulted as needed. Comparing the concept-rich problems to the problems designed for the IQP, as presented in Table 3, much of the personal touch, the "I" and "you," is removed. As a consequence, the story element suffers somewhat. However, given the designed problems' relation to the engineering fields, this is viewed as a worthwhile trade off.

Existing Context Rich Problem	IQP Problem
Your friend has just been in a traffic accident and is trying to negotiate with the insurance company of the other driver to pay for fixing her car. She believes that the other car was speeding and therefore the accident was the other driver's fault. She knows that you have a knowledge of physics and hopes that you can prove her conjecture. She takes you out to the scene of the crash and describes what happened. She was traveling North when she entered the fateful intersection. There was no stop sign, so she looked in both directions and did not see another car approaching. It was a bright, sunny, clear day. When she reached the center of the intersection, her car was struck by the other car which was traveling East. The two cars remained joined together after the collision and skidded to a stop. The speed limit on both roads entering the intersection is 50 mph. From the skid marks still visible on the street, you determine that after the collision the cars skidded 56 feet at an angle of 30o north of east before stopping. She has a copy of the police report which gives the make and year of each car. At the library you determine that the weight of her car was 2600 lbs and that of the other car was 2200 lbs, where you included the driver's weight in each case. The coefficient of kinetic friction for a rubber tire skidding on dry pavement is 0.80. It is not enough to prove that the other driver was speeding to convince the insurance company. She must also show that she was under the speed limit.	It used to be thought that for a car to be safe, the entire body had to be rigid. It wasn't until the late 50s when the idea of a crumple zone, a zone typically located at the front and or rear of the vehicle which collapses upon collision, was considered. Although slow to be adapted, crumple zones are now the modern safety design paradigm. To see the difference between the two styles, consider a car colliding into a wall at 96.5km/h, 60mph. With a rigid body design, the passenger cabin will be brought to a stop in ~.1s. The crumple zone increases this stopping time by.025s. Compare the magnitude of force needed to bring the passengers to a halt for each case. Also consider the implications of each for the passengers involved.  Shown is a collision between a 1959 Bel Aire and a 2009 Malibu. They have rigid and crumple zone designs respectively. Notice that while the cabin of the Malibu remains intact, the cabin of the Bel Aire is being crushed during the collision.

Table 3: Comparison of an existing context rich problem and a problem designed as part of the IQP.

4. Implementation Problem and Solution: Problems of the Week

As the problems were being designed it was, as mentioned, intended for the problems to be implemented in the recitation sessions. Unfortunately given technical issues impeding communication and prompt delivery of the problems, this approach could not be undertaken. Talking with Professor Koleci, an alternative method of implementation was devised. The problems would serve as the Problem of the Week, a weekly bonus problem assigned with the homework. To receive credit for the problem, the groups of students seeking credit were to arrange a meeting time with me when they would work the problem. With their permission, their problem solving efforts were recorded for later analysis.

Probably due to the difficulty of matching schedules amongst group members, relatively few groups stepped forward to try for the credit. Among those that did, a common problem did occur in line with Wenning's findings; the students did not tend to realize at first the relation between the velocity of an object and its frequency while in circular motion. This observation aside, there was little deviation in their difficulty solving the IQP problems than they had previously demonstrated in the recitation sessions. The students did however express interest in the problems. Talking with some of the students afterward, a few even noted that they hadn't thought about some of the topics addressed that way or in that context before. Although the limited sample size prevented any meaningful glimpse into differences in problem solving gains, for those statements of revelation I cannot help but think that something, however small, good was accomplished with the Problem of the Week implementation.

5. Surveys

Having worked in small groups of students with limited results attained, a larger base of information was sought. A short survey, shown in Table 4, was written and sent to WPI's student body in order to determine opinions of the population at large.

1. What year are you in at WPI?
2. What is your major?
3. Which mechanics class did you take? o PH1110: General Physics: Mechanics o PH1111: Principles of Physics: Mechanics
4. On a scale of one to five, how much do the topics of the introductory mechanics (forces, momentum, rotational motion, angular momentum, etc.) apply in your field? 1. No connections to field 2. Not applicable 3. Neutral 4. Applicable 5. Very applicable
5. If you answered 3 or more to question three above, where do the introductory physics topics apply in your major? If you answered below 3, are there any topics which could be included in the introductory course relevant to your major?
6. Are there any comments, critiques, observations, suggestions, etc. for the introductory course you took?

Table 4: Survey questions sent to the student body.

There was no statistically significant trend in the student's perceptions from question 4. Responses varied greatly, even between people in the same major. In response to question 5, those answering 3 or more answered, in some way, design and among those answering less than 3, it was often brought up that students wished that they had had an introduction to stress analysis. Furthermore, in question 6, the surveyed students, despite their varied opinions on most topics, as a whole approved and liked the use of projects at the end of PH1111.

6. Interviews

As the survey revealed little about student opinions, direct interviews with students were conducted. The students were asked the questions from the internet survey with the modification of question 4 to be from 1 to 10. In addition they were presented with 4 sets of problems one after the other. Each set had one of the designed, application based, problems from the IQP work and a textbook problem taken from University Physics by Ronald Reese which required use of the same topics to solve. After each set was shown the interviewees were asked the following:

- Which problem, if either, would you prefer to solve and why?
- Which problem, if either, do you find to be more interesting and why?
- Which problem, if either, do you believe students would learn more from by doing?

After the problem set questions were answered, a final series of questions was asked:

- Describe your general opinion of each type of problem, traditional textbook problem and application based.
- If you had had more problems like the application ones shown do you believe that your personal interest in physics would be any different than it is now? If so how?
- Do you believe that student interest in the topics of the physics mechanics would change and if so how?
- Do you feel that the application based problems would help or hinder students to learn the material and prepare them for the engineering contexts they later see the mechanics concepts placed in?

The interviewees spanned many of the majors offered at WPI with interviewees from biochemistry and chemistry, biomedical engineering, civil engineering, electrical and computer engineering, interactive media and game design (IMGD), and mechanical engineering. Although varied in the particular chosen value, those in the engineering fields consistently chose 8 or higher, averaging approximately 8.8. However among the two students interviewed studying chemistry, the only science field present, discrepancies were shown, one saying it only applied slightly, rating it "a 4 or a 5", and another saying it was related in many ways, rating applicability at 8.5.

In answering how the questions relating to the traditional versus applied problems, invariably the interviewees found the applied problems more interesting. Many interviewees stated that they liked the background that came with the problems as it made the physics concepts have bearing to their everyday lives and that the context and problem structure forced them to think about the problem conceptually. In responding as towards which question they preferred the interviewees tended to fall into two camps. One group, finding the application based problem more interesting, consistently chose the application based problems. The second group tended to factor in, to varying degrees, how difficult they perceived each problem to be. This led them to fluctuate between the traditional and the applied problems with slight leanings towards the application problems given interest level. Similarly, in answering which they believed students would learn more from doing, the interviewees responses largely fell into two camps. The first, noting both the background knowledge instilled by the problems and contexts or wordings similar to those encountered in their engineering classes, chose the application problems. The second switched between the traditional and application problems. Interviewees here tended to note the walking through the problem solving process through multiple parts in the textbook problems whereas the application based problems tended to assume that you knew how to use them and seemed to be geared towards now showing you how to use them. One interesting response was presented by an IMGD student who stated that “They’re both pretty interesting one of them involves more thinking outside the box and one is simply solving a problem…They’re both teaching different things really; one teaches you problem solving, one teaches you how to regurgitate…” As context, he later described how the textbook problems required you to follow a solution “recipe,” a pre-memorized series of steps, to arrive at the solution.

Despite different views on which questions they preferred, in the post problem questioning, the interviewees all had an overall positive review of the application problems. In giving their general opinions, each interviewee advocated a balance between the traditional and application problems, typically suggesting that the traditional problems first be used to get used to the problem solving methods before following up with applications. Here, a civil engineering student interviewed replied stating “I think a lot of people would be more interested. I know that a lot of people go into the intro physics courses thinking that ‘I have to take this as a requirement to just get through the course’…Maybe they get something out of it maybe they don’t but they never do actually come up with idea of using it in application. So they’d definitely get more out of it especially if one of the problems is in their field. Like the one with architecture that one I like perked up, ‘oh this is interesting I might have to work with architects one day…’” Similarly when asked how they believed application based problems would alter their personal interest and students’ interest as a whole, the interviewees responded favorably. One interviewee, an electrical and computer engineering student, pointed out that, being a visual learner, he liked having things he saw everyday and could picture easily put into problems. Similarly a biomedical engineer responded by noting how the questions were similar in nature to problems he had encountered in his biomedical engineering classes in that at times the path to finding what was asked for was not laid out explicitly as in many traditional physics problems. Unsurprisingly given responses to the first two of the three post-problem questions, the interviewees unanimously stated that they believed the application based problems would help students learn and better prepare them for the engineering contexts they are likely to face in later courses.

7. Conclusion

The project began wishing to determine quantitatively the effect of application based learning implemented in a recitation setting and to determine students’ opinions regarding physics’ applicability. In the sense of this original purpose, little was found. A quantitative description of the effect of application based curriculum was not able to be made. The school-wide student survey revealed no trends. This may be a true representation of the student body however the sample size was not large enough to state this with any certainty.

If not quantitatively as originally intended, qualitative descriptions have been made. Watching the students solve the application problems as the problem of the week, interest in the problems was observed. This interest was later echoed in student interviews with the interviewees stating that they would have liked to see a balance between the traditional textbook problems and the developed application based problems in their course.

Further work is left to be done in the future in the development of the more application based problems and in the implementation of the problems themselves so that quantitative data may be attained. Metrics already selected and the groundwork laid, this is a viable route one could take future project work. Anyone seeking to undertake the task and desiring original results in full is encouraged to contact the author.

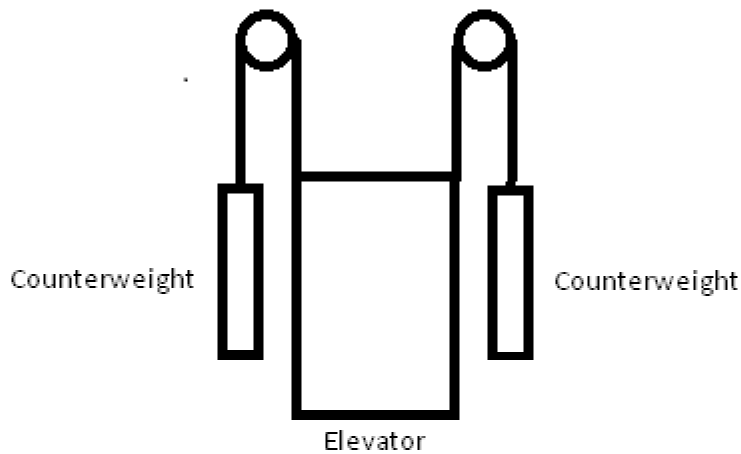
8. Acknowledgements

I would like to thank all the students who provided their time, whether through interview or survey completion, in completing the project. I would also like to thank Professor Carolann Koleci for the opportunity to conduct this project and for her patient guidance along the way.

Appendix A: Problems

Elevator counterweights

In a typical cable elevator, counterweights are used as a safety precaution. By counteracting the force of gravity acting on the elevator with these weights, it is hoped that should the brakes, or another mechanism holding the elevator in place or in motion, fail that the passengers will remain unharmed. Your goal in this problem is to show how the counterweights accomplish this task.



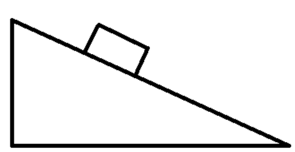
1. Draw a free body diagram of the elevator setup shown above. You may assume that the mass of each counterweight is the same.

2. Find the equation of motion for the elevator/counterweight system.

3. Based on your equation, estimate what the mass of each counterweight should be in order to keep elevator secure?

4. If a full elevator with some counterweights suffers a failure causing it to fall, how much slower will it be upon hitting the bottom of the shaft compared to an elevator setup without the counterweights?

Ramps



1a. Draw a free body diagram for the mass in ramp system shown.

1b. Find the equation of motion of the system.

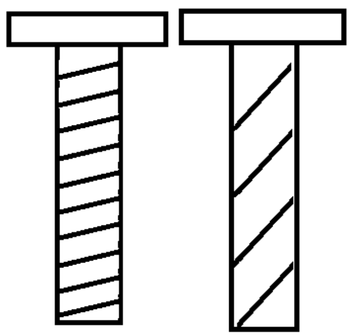
1c. Explain qualitatively what the equation found in 1b means.

1d. In the case where there is no hanging mass, what does the equation you found in 1b simplify to?

Fig. 1:

2. Suppose you have a drill which can exert minimal torque upon a screw. Of the threadings presented in Fig. 2, which should you choose and why?

Fig. 2:



Hint: Look at the equation derived in part 1c.

Limon Dam

A mountain range separates eastern and western Peru. The mountain range prevents precipitation from reaching the western half of the country. To enable water access, a 40m tall dam, the Limon Dam, is being constructed which will supply water from eastern Peru for irrigation in western Peru. To waterproof the dam, cement is being used on one side. It is poured out on the 120m long incline. A cart with a level is then dragged up the slope by two steel cables to create a smooth surface. Care must be taken however, given the drag as the level is pulled through the cement, to prevent the cables from snapping. The carts weigh approximately 3000kg and a steel cable can maintain a tension of 50000N before snapping. How quickly can the cart safely be pulled up the slope?

Hints:

- What is the angle of the incline?
- The drag is proportional to velocity (i.e. the velocity times a constant).

Figure 1: Shown is the dam under construction. Note the smooth surface of the dam created by the cart dragging process.

Gun Barrel

When designing a gun, the manufacturer must decide upon various factors. One such factor is the barrel length. The average gun will have .45cm of packing which will produce _____ of pressure behind the bullet. Accounting for atmospheric pressure and friction from the barrel, what should the length of a cylindrical barrel be in order to maximize the bullet's exit velocity?

Hint: You will have to use $P_1V_1 = P_2V_2$

What assumptions have been made in modeling this system?

What could be included to give a refined model?

Asteroid Collision

The asteroid belt is a collection of asteroids approximately ~2.7AU, 403 914 600 km, from the sun, 254 316 600km further away from it than the Earth. Often you will hear in the news of a meteor from the belt headed towards Earth and how scientists are concerned of a collision. But why should one be concerned? If the mass of a meteor is m, how much energy will have upon impact? (You may ignore effects due to the Earth's orbit.) In terms of megatons of TNT, how much energy would a 9Mg asteroid have upon collision?

Voyager Flight

The force of gravity, as will be discussed later in class, is equal to $G\frac{m_1 m_2}{r^2}$ where G is a constant, m1 and m2 are two masses, and r^2 is the separation between them.

The Voyager 1 space probe was designed to examine the outer gas giants of our solar system. Launched in 1977 it has since traveled 16.976 billion km, a distance taking it beyond the edge of our solar system. Other such probes are also being designed. Wanting to minimize the weight due to excess components, something that must be considered is the escape velocity, the minimum velocity needed to escape the

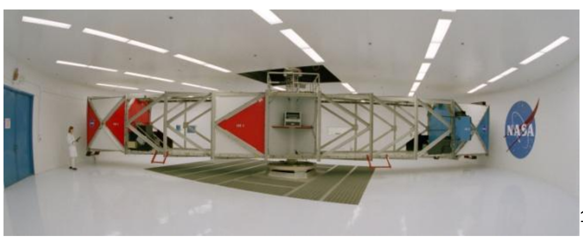
Earth's gravitational pull. By looking at the change in energy from when the rocket is at the Earth to when it is far away, determine what this velocity is.

Space Shuttle Columbia

In 2003 the Space Shuttle Columbia burned up upon entry. After examination, it was determined that a piece of insulatory foam which had fallen off of the shuttle during its launch damaged the thermal protection. On previous shuttle launches foam had fallen off without repercussions so it was never thought to be a problem. However when looking at the energy that the foam had, one realizes how grave a mistake this was. The shuttle was moving at about ~800m/s and the piece which fell was ~2kg. How much kinetic energy did it have when it struck the shuttle? To put this in perspective, how high would a 907kg, or 1 ton, boulder need to be lifted to have that much potential energy?

Black Out

When turning in a jet fighter, the centripetal acceleration causes blood to be forced towards the lower parts of the pilot's body. This decreases blood flow to the brain. Should the acceleration be too great, this will result in a G-force induced loss of consciousness, or G-LOC for short. An average person will pass out at around 5g. Through practice with devices such as the one shown below, trained pilots may maintain consciousness at upwards of ~9g. Given this, if a jet flies with some given speed, v, what is approximately the minimum turn radius a trained pilot can execute without passing out? How does this compare to how tightly someone without the appropriate training could turn?



[1]

Centrifugal Casting

When manufacturing piping, a process known as centrifugal casting is used to attain consistent, high quality results. In this process, hot metal is poured into a cylindrical mold, as shown below. The mold is rotated between 300-3000rpm. This forces the metal against the walls of the mold. Care must be taken in selecting the rotation rate of the mold. If it is too fast, then the mold is liable to be damaged, too slow and the metal will not stick to the walls, instead being pulled away from them by gravity. To make a cylindrical pipe of some radius, r, what is the minimum rotation rate which must be used such that the metal remains on the wall so it may be cast effectively?

[1] http://www.nasa.gov/centers/ames/multimedia/images/2006/20gcentrifuge.html

 [2]

Crumple Zone

It used to be thought that for a car to be safe, the entire body had to be rigid. It wasn't until the late 50s when the idea of a crumple zone, a zone typically located at the front and or rear of the vehicle which collapses upon collision, was considered. Although slow to be adapted, crumple zones are now the modern safety design paradigm. To see the difference between the two styles, consider a car colliding into a wall at 96.5km/h, 60mph. With a rigid body design, the passenger cabin will be brought to a stop in ~_____s. The crumple zone increases this stopping time by ______s. Compare the magnitude of force needed to bring the passengers to a halt for each case.

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2 http://www.google.com/imgres?imgurl=http://www.bharatroll.com/images/product16.jpg&imgrefurl=http://www.bharatroll.com/doublepoured-alloy-chill.html&usg=__tL9jdjTNACoxdhYx3pjPQ_wF2Sg=&h=246&w=246&sz=19&hl=en&start=17&zoom=1&tbnid=-FHOgaNggoIWMM:&tbnh=162&tbnw=183&prev=/images%3Fq%3Dcentrifugal%2Bcasting%26um%3D1%26hl%3Den%26sa%3DN%26rls%3Dcom.microsoft:en-us:IESearchBox%26biw%3D987%26bih%3D498%26tbs%3Disch:10%2C811&um=1&itbs=1&iact=hc&vpx=580&vpy=224&dur=1197&hovh=196&hovw=196&tx=81&ty=149&ei=G5uPTLbYMoG88gaq_oyZDg&oei=EZuPTL2_LI-isAP1n5iyDg&esq=5&page=3&ndsp=8&ved=1t:429,r:6,s:17&biw=987&bih=498

Shown is a collision between a 1959 Bel Aire and a 2009 Malibu. They have rigid and crumple zone designs respectively. Notice that while the cabin of the Malibu remains intact, the cabin of the Bel Aire is being crushed during the collision.

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