Session 3280

The “Tarzan Swing” for Learning Physics

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Introduction

Visualize a freshman physics class in which students, working in small groups, are intensely calculating and discussing the solution to a difficult problem involving geometry, trigonometry and parabolic trajectories. Finally one team is ready to check its collective solution to the problem. When their calculations prove correct, they break out in cheers and high-fives.

This actually happens.

Why does this scenario of enthusiastic learning seem to run counter to most people’s perceptions of a “normal” classroom? We certainly don’t claim to have all the answers to that question, but we do have a few ideas we’d like to share.

Background

In 1994 a proposal for “A Partnership for Excellence in Engineering Technology Education” resulted in a grant from the National Science Foundation - Advanced Technological Education program. The “Partnership” involves several Penn State campuses (with the York campus the focus), the York city high school, the York County vocational-technical school, several York area industries, and the Pennsylvania Department of Education.

The goal of this project is to improve technology education. The mechanism is to develop interesting, team-based, hands-on educational modules that can be incorporated into existing courses. The focus is on associate degree programs in Engineering Technology, but a major thrust also goes toward secondary school programs that might lead into associate degrees, and many of the modules could apply as well to four-year engineering and technology programs.

Four independent teams began late in 1994 to develop the modules that were the deliverable items for this grant. Theoretically, each team could have representation from seven different viewpoints: both faculty and students from the university, the high school and the vo-tech school, plus industry. All seven viewpoints have been involved, but no single team has included all seven. The teams developed somewhat spontaneously out of large brainstorming sessions, and each headed off independently with its own significantly different objectives, ideas and philosophies. One of those teams intended to focus on basic physics and math skills, and quickly chose the “Tarzan Swing” as the vehicle for its first module.

The Tarzan Swing

One basic scenario for a physics problem with practically unlimited variations is this: “Tarzan” needs to swing on a vine across a chasm, from one cliff into a cave on the opposite cliff. Problems can include all sorts of combinations of known and unknown parameters: cave elevation, vine pivot location, jump location and elevation of chasm bottom, for starters.

At the most elementary level, a student need know little more than the Pythagorean theorem to calculate an unknown vine length when all else is given. At the opposite extreme, to challenge the best physics students, the team considered such complicated possibilities as swinging into the open door of a moving boxcar, with obstacles requiring an initial velocity and non-planar swing.

So far this may sound like the garden-variety range of normal classroom problems. The “zinger” here is that the solutions are not to be checked against an answer sheet, but are to be tested physically! For most students, that seems to make all the difference in the world.

As the project development team began to solidify its concepts, the idea was that a framework would be built from readily-available materials (keep it cheap and simple), with multiple adjustable dimensions. Tarzan would be represented by an egg, so failures (miscalculations) would be dramatic. The now-well-known project of designing a package to protect an egg from some sort of abuse (dropped from a roof, shot out of a cannon, etc.) has similar drama, but the Tarzan Swing depends on accurate mathematical solutions rather than good intuition and creativity.

Basic Philosophies

Several basic philosophies guided the development of the Tarzan Swing. These were explicitly stated some time after the Tarzan Swing was conceived, but still very early in the process. Note that none of these philosophies is specifically y related to any particular type of physics problem. They are based on the assumption that students are doing some sort of team-based hands-on “project”.

Projects should develop basic college-entry skills in math & physics (with possible extensions to more advanced and/or more elementary skills).

Completing projects successfully ***requires*** using basic skills.

The project requires more time to design than to build. (Build and test should take (much?) less than half a day.)

The project result is: “It works” or “It doesn’t work”.

For the Tarzan Swing in particular, a few more philosophies developed along with refinement of the project. These were not necessarily put in writing, but most were spoken at various times, and were generally understood by all involved.

Problems should start very simple and increase gradually in complexity through multiple levels as new concepts are added. (Success rate initially near 100 %; always above 50%.)

Required equipment should be low in cost and easy to acquire.

Everything a teacher needs to know in order to run the project should be available in a clear and concise form. (It should be easy to incorporate into existing courses, with relatively little effort.)

It must be fun!

Nine Levels of Difficulty

After much discussion, a succession of nine different problems was defined, all of which could be tested using a relatively simple framework with three basic adjustments, plus a few accessories. Figure 1 provides a simple line diagram of the framework, plus a very concise description of the nine levels of difficulty. An expanded explanation follows:

Level 1:

Student Objective: To determine Tarzan's vine length (v) and the release height of Tarzan (h) such that Tarzan reaches the cave safely.

Comments: This level can be solved simply using the Pythagorean Theorem.

Level 2:

Student Objective: To determine Tarzan's vine length (v), release height (h) and the pivot point location (1) such that Tarzan reaches the cave safely. Be aware that there are a range of solutions, but not all solutions will work.

Comments: This level has many possible solutions. Students learn that real problems do not necessarily have a unique correct solution.

Level 3:

Student Objective: To determine Tarzan's vine length (v), release height (h) and pivot point location (1) such that Tarzan clears the obstacle (A) and reaches the cave safely.

Comments: This level is complicated by obstacle (A) in Tarzan's flight path. Not every solution will work here - only specific paths that avoid the obstacle. Students learn about optimization.

Level 4:

Student Objective: To determine Tarzan's vine length (v), release height (h), and pivot point location (1) such that Tarzan has enough energy to enter the cave without hitting the cave barricade.

Comments: Only solutions that allow Tarzan to enter the cave at slow enough speeds will work. Students learn Conservation of Energy.

Level 5:

Student Objective: To determine Tarzan's vine length (v), release height (h), and pivot point location (1), such that the vine is cut at point (W), and Tarzan projects through the cave safely.

Comments: Students determine solution such that string is cut at correct instant and Tarzan is projected safely into the cave. Students learn projectile motion. Also, starting with this level, students must consider string tensile strength/centripetal force.

Level 6:

Student Objective: To determine Tarzan's vine length (v), release height (h), and pivot point location (1) such that Tarzan clears the obstacle, his vine is cut, and he projects through the cave safely.

Comments: This level is the same as level five, except there is the added complication of barrier (A).

Level 7:

Student Objective: To determine Tarzan's vine length (v), release height (h), pivot point location (l), and landing spot (R), such that when the vine is cut, Tarzan projects safely through the cave and into a basket.

Comments: This level is the same as level five, except the students must now calculate the landing spot for Tarzan so that he can project safely ***through*** the cave opening into a basket at (R).

Level 8:

Student Objective: To determine Tarzan's vine length (v), release height (h), pivot point location (l), and hot wire location (W_x,W_y), such that the vine hits the string barrier (S), is then cut by the hot wire (W), and Tarzan projects through the cave safely.

Comments: This level has a string barrier (dowel rod) that provides a new "pivot point" when the string hits it. Some solutions are better than others - optimization.

Level 9:

Student Objective: To determine Tarzan's vine length (v), release height (h), pivot point location (l), hot wire location (W_x,W_y), and string barrier location (S_x,S_y), such that the vine hits the string barrier, is then cut by the hot wire (W), and Tarzan projects safely through the cave and into a basket.

Comments: This level is most difficult since the students are given two points along the trajectory. Equation of parabolic path becomes important.

Framework Implementation

In keeping with the philosophy that equipment should be inexpensive and easy to acquire, a framework for the Tarzan swing was designed and built from PVC pipes, 2x4 studs and other simple hardware. The general design features are illustrated in Figure 2. Bracing wires with turnbuckles square and stiffen the frame. U-bolts allow vertical adjustment of the cave and the release mechanism. Large "Bulldog" paper clips quickly secure the vine pivot point, once adjusted. The release mechanism to send Tarzan on his journey was created in minutes from available "junk": paper clips, a clothespin, a spoon, rubber bands, and some screws, tacks and tape to hold it together. It has worked perfectly.

Free-standing accessories include an adjustable-height barrier, a "catch-basket" and a "vine-cutter". The device for cutting the vine took quite a bit of development. We wanted to be able to construct problems in which tarzan "let go" of the vine and completed his trip in a parabolic trajectory.

The first idea that seemed practical was to have a torch that burned through the thread at the right point in its swing. To make it even more dramatic, we planned to use magician's "flash string", that ignites very easily and burns with a flame that is bright orange but not very hot. Among our first tests was a surprise. The string swung through the flame so quickly that it did not burn! Subsequent tries revealed that slow swings (low elevation starts) produced the desired dramatic flame, but not instantaneously. The actual release point was some distance past the flame location, so trajectories could not be calculated reliably. On one test Tarzan and his vine swung forward through the flame unscathed, but the return swing ignited, sending a ball of orange flame at the feet of the person who had operated the release mechanism! The "flash string" was abandoned.

What did work for cutting the thread was a nichrome wire heated yellow-hot. This was sized to work at 12 volts, so that a readily-available car battery could be substituted for our high-current power supply. As an interesting side-light, it was discovered that modern polyester thread does not separate quite as quickly at cotton. The difference is slight, but we made a point to get all-cotton thread for this apparatus.

The Real World

What works so beautifully in idealized physics problems sometimes proves annoyingly different in the real world. Some combination of air resistance, stretching and flexing can absorb enough energy to make real trajectories noticeably different from idealized ones. It was necessary to create a "fudge factor" graph for students to use when energy levels were important in their calculations.

When we finally tried using an egg instead of a golf ball or other weight to represent Tarzan in our experiments, we discovered that eggs are not that easy to break. A light tap (or even a relatively substantial one) might crack the egg without releasing the contents. Using water balloons for Tarzan and placing pins, thumbtacks or staples wherever an errant Tarzan was likely to hit produced a much more satisfying (and easier to clean) result.

Testing of the levels that involved wrapping the vine around an obstruction (changing the pivot point) revealed that this relatively high-energy situation did not match calculations at all. Apparently there is so much hidden energy transfer in this situation (stretching thread and balloons, bending frames and obstacles, etc.) that deviation from theory is too great for simple fudge factors. It might be possible to stiffen everything enough to make it work, but upon reconsideration of these levels it was decided to try for something different that would introduce new physical principles. (Changing the pivot point complicates the math without changing the physics.)

As of this writing, the new upper-level problems probably will involve a very elastic vine that is stretched to “launch” Tarzan into the cave. This situation, with its changing forces and angles, probably is best solved by writing a computer program to do stepwise calculations and iterate to a solution. Such problems would be used only in classes where some basic level of programming skill (or a high level of mathematical skill) is assumed.

In order to keep student groups independent in their projects, instructors need to be able to provide different fixed dimensions to each group. To be sure that each problem situation really is solvable, a computer program was written to simulate all possible configurations. A teacher can play with any or all of the parameters, change dimensions to match a different framework, switch between American and metric units, and test any desired setup very quickly on the screen. It also offers the option of doing a form of sensitivity analysis. It is possible to see the range of solutions obtained when random errors are added to critical dimensions.

A visiting professor, who had brought his class to try these exercises, suggested initially that the whole situation be simulated on computer to avoid using the bulky, messy, slow physical framework. (He did not know, at the time, that we already had a simulator program.) Before the exercise was over, that professor realized that there simply is no substitute for the appeal of testing theories in the real world. Computer simulations are not the same.

Two significant surprises occurred during that particular exercise: (1) One balloon had a hole poked only in its unstretched tip; instead of bursting, it sprayed water all over as it swung back and forth. (2) One group’s balloon swung right into the cave initially, but took a slightly different path on the second swing, and burst then. Such delightful unexpected developments are very unlikely to appear in any computer simulation, and seem very artificial if they do.

Another type of real-world problem developed when the Tarzan Swing framework was transported to Penn State’s University Park campus for a demonstration. The bonded plastic-pipe end sections will not fit into an ordinary car; they require a truck, van or large station wagon. A new design has been constructed with the intent of providing exactly the same critical dimensions (mainly “to avoid recalculating graphs and tables made for the Instructor’s Manual) while making the framework easier to store, transport, assemble and adjust. This new design also is less expensive, and more rigid at the critical vine support point. Figure 3 provides a simple illustration highlighting the modified feature. During transport, all six pieces of metal conduit can be packed inside the single plactic pipe for easy carrying.

Team Development

Our NSF-ATE project proposal included funding for graduate-level courses for team members. It was assumed that collaborative learning, assessment, evaluation, team-building and similar “educational” subjects would be of interest to participants. Perhaps if younger public-school teachers had been involved, they would have jumped at the chance to take prepaid graduate courses that would help toward a master’s degree or improved standing on the salary scale. Instead, the teachers who became involved already had the degree, the salary scale and lots of experience. They didn’t want to waste the time required by a threecredit course to go over things they had been exposed to already a number of times over the years. Thus, instead of full courses, we concentrated on four-to-seven-hour workshops that could be attended by many more people.

The first such workshop was on team-building. People got to know each other a bit. Some of the barriers between students and teachers were at least lowered, if not broken. The value of everyone's contributions was emphasized. Some of the obstacles to effective teamwork were overturned. And, of course, every team selected a name. The team developing the Tarzan Swing, adopting the suggestion of its only woman number, called itself "PMS" -- for Physics and Math Skills, naturally.

A second workshop concentrated on Assessment and Evaluation -- techniques and tools for determining whether the educational modules being developed by the various teams were truly effective.

A third workshop grew out of the observation by an industrial participant that his team seemed to be floundering. He had experienced some training in Project Management on the job, and recognized that such skills were precisely what his team needed. He helped arrange a Project Management workshop for members of all the teams to attend. Some follow-up undoubtedly is needed, but attendees universally recognized the value of the techniques and procedures explained there. A revelation for most of the attendees was the value of stating explicit "close-outs", meaning the conditions that define the end of the project.

Experience with the Tarzan Swing

From near the beginning there was an intuitive conviction among the team members that the Tarzan Swing would be interesting, educational and valuable. Experience with two different physics classes actually has surpassed expectations.

The first such experience was with a physics class from Penn State's Harrisburg campus that was brought to York for most of a day to work with the Tarzan Swing. The room had a constant buzz as student groups worked out their solutions, attached water balloons to carefully measured lengths of thread, and adjusted the framework to match their given or calculated dimensions. That buzz was punctuated by cheers and occasional groans as groups saw successful tests or looked for a mop. One student who has been involved in the development team from its origin commented that he was amazed by the "level of energy" in the room.

During the 1995 fall semester, the Tarzan Swing exercises were used as part of a regular freshman physics class, virtually replacing the normal lectures on projectile motion. A test designed to measure both qualitative and quantitative understanding of velocity, acceleration, projectile motion and energy was administered to students before and after doing the exercises. Before the Tarzan Swing exercise, students averaged 23.8 % on the test; after the exercise, the average rose to 51.3%. There are far too many caveats for the results of this single measurement to be taken too seriously; however, compared to the 14% gains reported by Halloun and Hestenes [1], it is very encouraging.

A few anecdotes illustrate the appeal and effectiveness of this approach to learning physics. One group virtually refused to leave the lab until they had solved their problem correctly. It was an evening lab, supposed to end at 9:50 pm, but the instructor did not want to force the students to quit, in spite of the fact that he had to get up before 5:00 a.m. the next day to take the system to University Park for a demo.

The students finally were successful, and left the lab about 10:45. In another case, one group's test failed, but rechecking their calculations showed no error. The instructor encouraged them to believe the math. They carefully reset all their adjustments on the framework, had a successful test, and gained a new appreciation for the way mathematics models the real world.

Summary and Conclusions

Preliminary testing of the Tarzan Swing with two classes of physics students seems to support the original philosophies and expectations. Students really enjoy the exercises, and seem to be learning from them at least as well as from traditional lectures. The approach of intense calculation followed by a quick and dramatic physical test seems to be very effective. It seems likely that additional experiments in the same vein also could enhance the teaching of physics.

Additional secondary and post-secondary teachers have expressed interest in the Tarzan Swing. Significant testing and evaluation is planned for at least the 96-97 school year, and possibly beyond. Feedback from such testing is expected to result in refinement of equipment, procedures and written material, with national dissemination as an eventual goal.

Acknowledgement

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Bibliography

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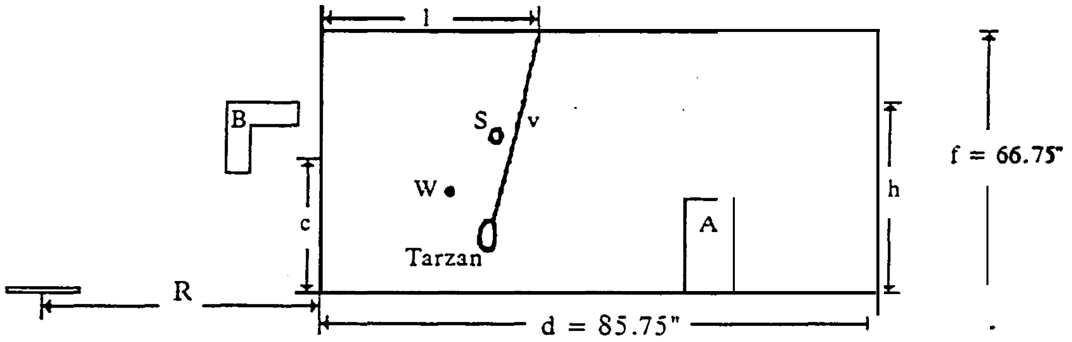
Biography

CHARLES A. GASTON is a technical generalist, with degrees in Engineering Science from Penn State, Stanford and Purdue. During 28 years with IBM, his projects ranged from seismology to cosmology, with meteorology, respiratory physiology and a few other -ologies in between. After two years of teaching Mechanical Engineering Technology courses, now he directs the NSF-ATE grant that supports this work.

KARL P. TROUT received his M.S. in physics from Penn State in 1990. Since then, he has been teaching introductory physics at Penn State's York Campus, where he received the teaching award in 1993. He has attended two NSF workshops on physics teaching as well as several other teaching classes. His present research interests include physics education, relativistic thermal physics, and ice spikes.

SIDE VIEW OF TARZAN SWING APPARATUS



SUMMARY OF LEVELS

Level	Given	Find	Comments
1	c, d, l, f	v, h	One solution
2	c, d, f	l, v, h	Range of solutions
3	c, d, f, obstacle A	l, v, h	Range of solutions complicated by obstacle
4	c, d, f, barrier B	l, v, h	Conservation of Energy
5	c, d, f, hot wire W	l, v, h	Projectile motion
6	c, d, f, hot wire W, obstacle A	l, v, h	Projectile motion with obstacle A
7	c, d, f, hot wire W	l, v, h, R	Catch Tarzan
8	c, d, f, string barrier S	l, v, h, hot wire W	Projectile motion with barrier S
9	c, d, f, R	l, v, h, hot wire W, string barrier S (if necessary)	Project Tarzan to given landing site

Figure 1

THE TARZAN SWING

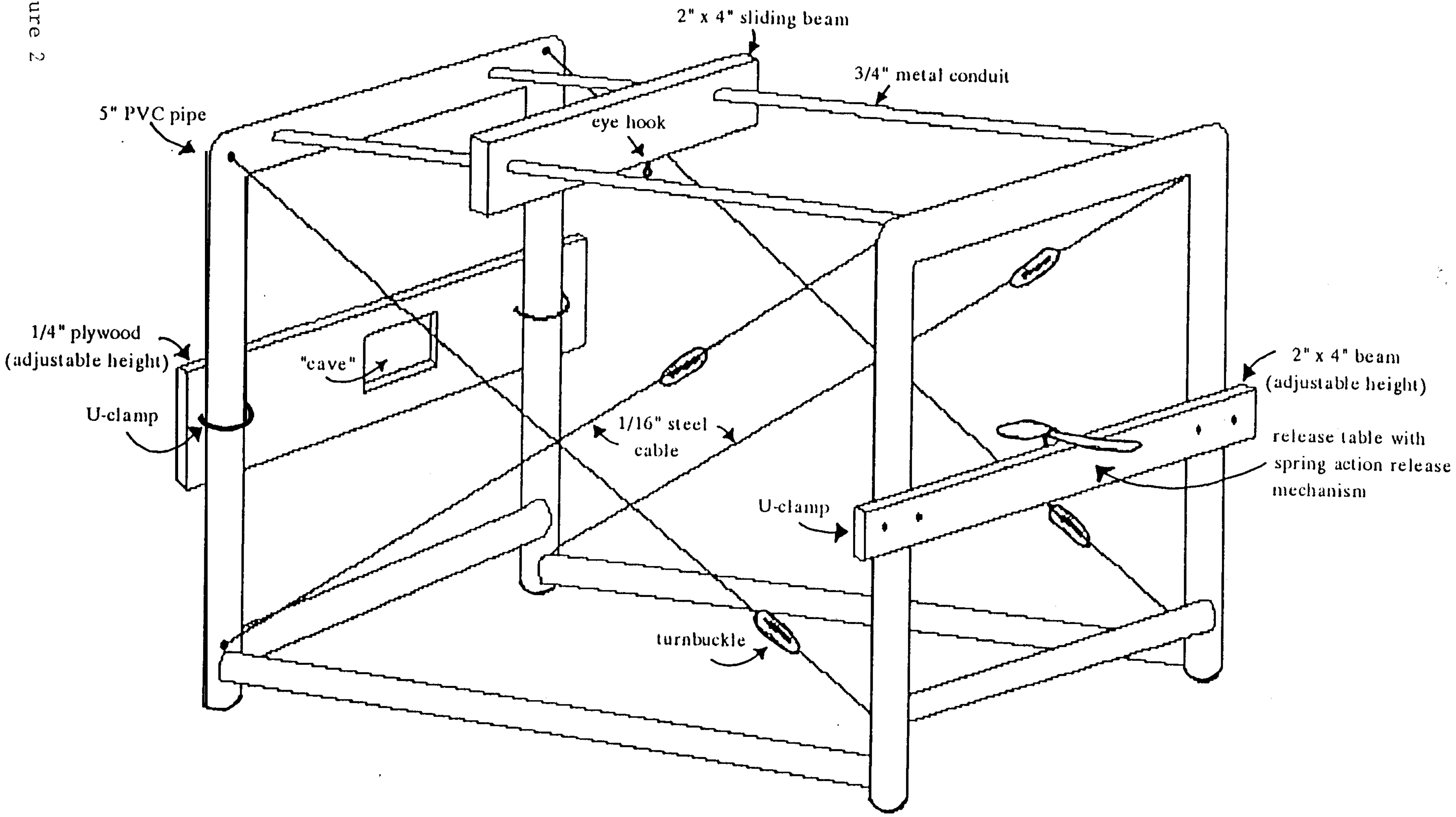


Figure 2

THE TARZAN SWING (Version 2)

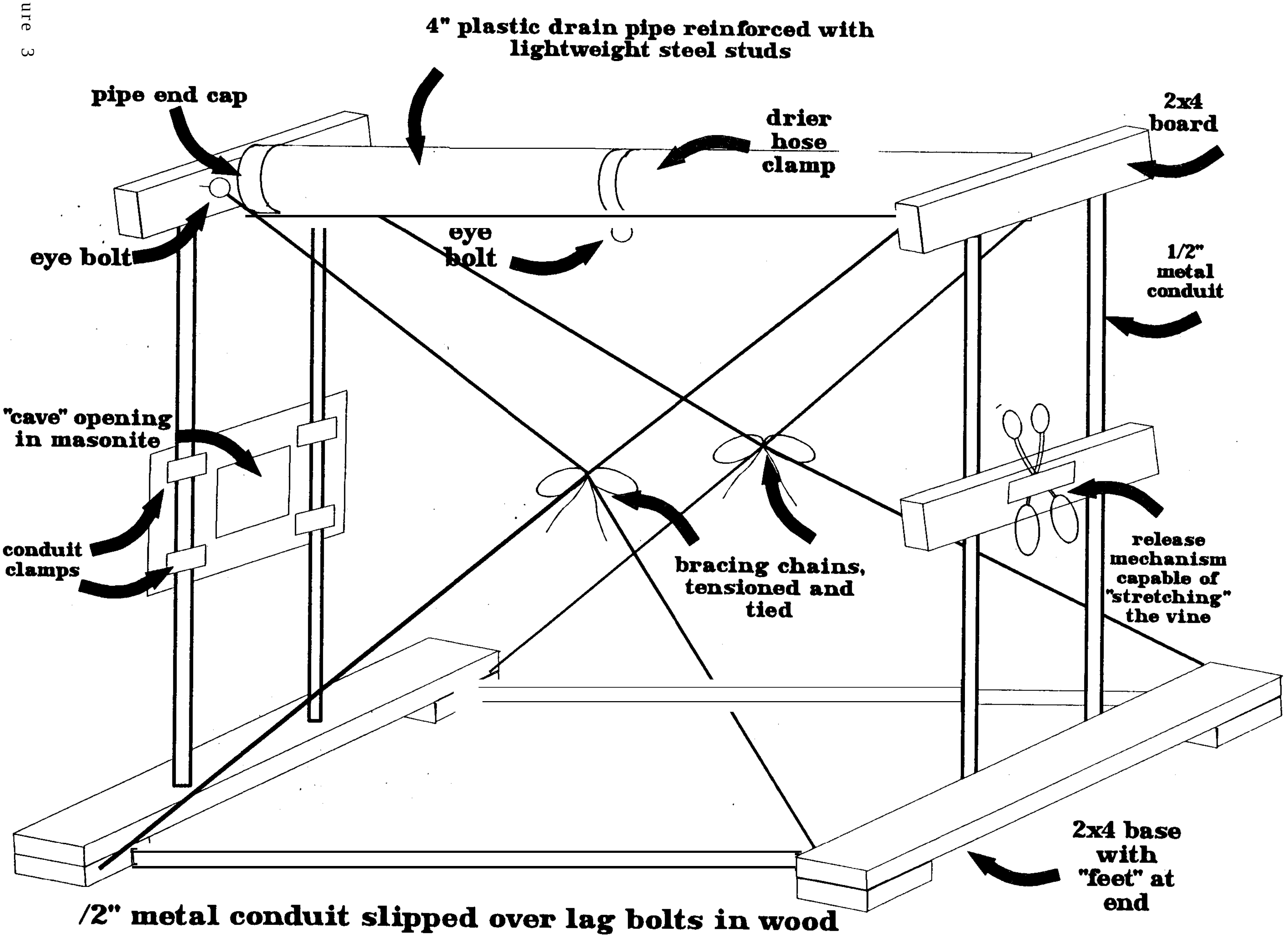


Figure 3