Concordia University
Engineering and Computer Science

MECH 211 – Mechanical Engineering Drawing

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Credits: 3.5

Lecture 12
Case Study

Université Concordia University

Design a Catapult

- You are an engineer (that is good to know and even better to start imagining being one)
- Your kid sibling is asking you to make a catapult for them for playing during the winter season
- What are the things that you should know to design and manufacture this catapult

Needs or Functionality

- What you are going to launch with it?
- How fast do you want projectile to go?
- How far will your catapult launch the projectile?
- Which mechanism will be used in the catapult?
- How will you to design it?
- Once it is designed, how will you produce it?

Preliminary Design Constraints

- The projectile: "assume an eraser, used in the drawing class".
- The eraser must be launched to a minimum distance of 10 meters.
- Since you are designing this for your kid sibling, you cannot use unsafe elements, such as:
  - Mechanisms which produce a lot of energy or sound, such as explosive materials, etc.
  - Gasoline or heat to power the device.

Design Requirement

Since the catapult should be easily built, you must consider the following:

- Using a minimum number of parts in the assembly (<=15).
- Using power sources like springs, air cylinders, rubber bands or other similar objects.
- The geometric parameters of the components in the catapult will have an effect on its performance.
- Using mostly standard parts in your design.

What Have You to Do?

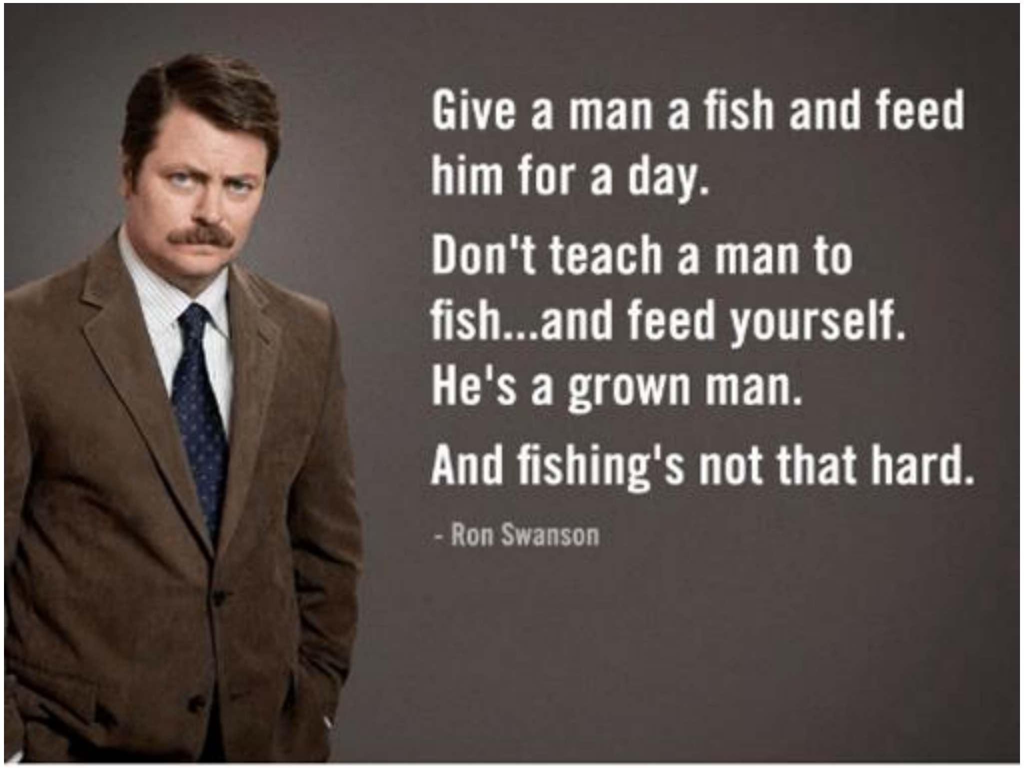
Come to the next class with a piece of paper outlining the design, including the following:

- Components, their sizes and specs.
- Your considerations in choosing those particular dimensions and sizes.
- 2 or 3 written lines describing the operating mechanism.

Objective of the Case Study

One of the popular wisdoms says: "Give a man a fish, he eats for a day. Teach a man to fish, he eats for a lifetime."

This philosophy applies to engineering and physical sciences too.



Review

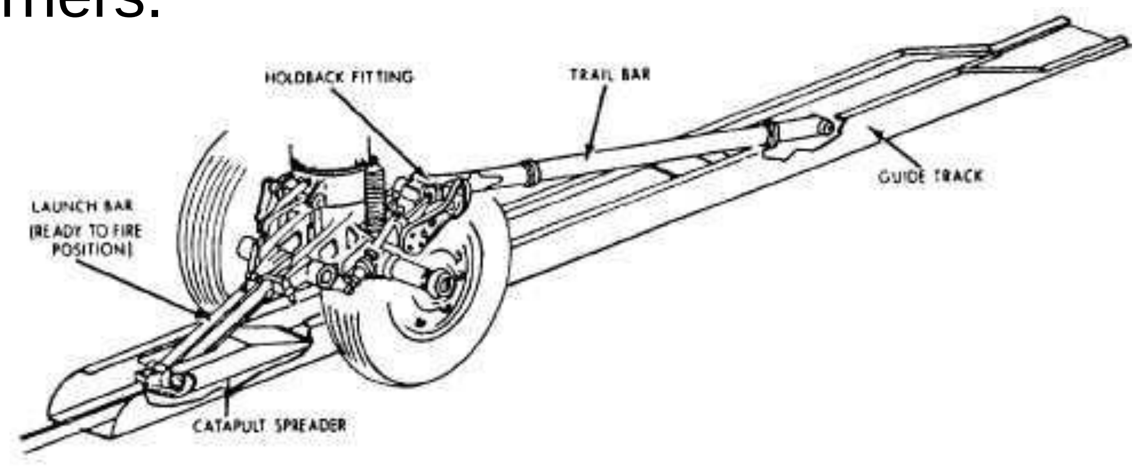
- Over 2000 years ago the Greeks and Romans had not discovered gunpowder, yet they were able to hurl projectiles over large distances using elastic energy storage devices.
- Throughout the years, some modifications were made to improve the accuracy and throwing distance of these machines.
- The first two types of throwing machines were the catapult and the ballista. The catapult started out as a large cross bow to shoot oversize arrows at the enemy.

Review

- A ballista design consists of two pieces of wood, each fastened at one end to a torsion device that rotates around a horizontal axis. The free ends of the wooden pieces are connected with a rope. The launched object is held by the connecting rope, used as a sling.
- The onager was typically a single spar held in a vertical position by a torsion device rotating around a horizontal axis. The projectile was located in either a pocket at the top end of the spar or in a sling.
- The trebuchet was the weapon of choice in the Middle Ages. This device used gravity to provide propulsion energy instead of torsion springs.

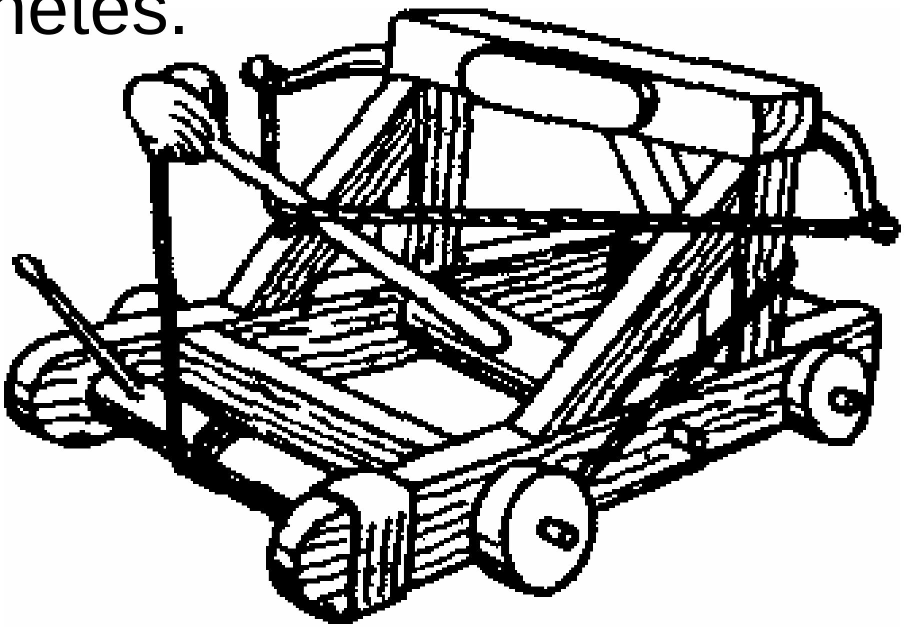
Review

- The theory is simple; place a heavy weight at the short end of a lever arm and put the projectile in some kind of basket at the other end of the lever.
- The velocity of the projectile can become quit large when the ratio of the lengths of the lever arm is great.
- Catapults are still in use today, although they are radically different from those used in history. The modern catapult is used to launch aircraft from the deck of aircraft carriers.



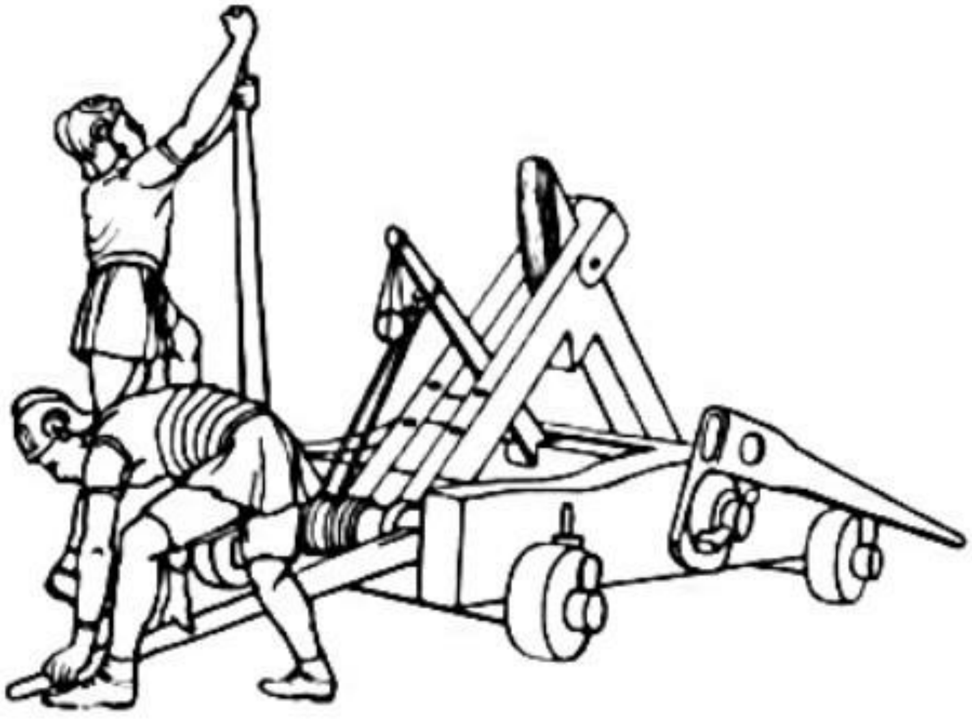
Review

- Catapults are defined on physical concept that they are used to store and release energy which is required to propel the projectile.
- The first catapult that were distinct from hand-held launchers (bows, crossbows, slings etc.) was the Greek gastrophetes.
- These catapults are tensional, in that the energy is stored as tension and compression in the bow.



Review

- Subsequently, torsional catapults were developed.
- The bottom end of the throwing arm or the inner ends arms are inserted into rope or fibers that are twisted, providing torsional energy storage.
- Torsional catapults were operationally equivalent to their tensional cousins, except that the torsional energy stored greater power.



Review

- The last type of catapult is the trebuchet, which used gravity or traction rather than tension or torsion to propel the throwing arm. A falling counterweight, or the effort of the one or more operators, pulls the bottom end of the arm downwards and the projectile is thrown from a sling attached to a rope hanging from the top end of the arm.
- The counterweight was usually much heavier than the projectile. More modern trebuchets often replace the counterweight with industrial springs to create tension.

Artillery Catapult

Catapults were very effective weapons in ancient times.

Their size meant that they capable to produce significant damage.

Speed and mass capabilities were basic requirements.

DaVinci's Catapult

refused to open the gates to Ala'uddin Khilji in 1296, he loaded his engines with bags of gold and shot them into the fortress, a measure which put an end to the opposition.'

Figs. 18, 20. pp.28, 32, explain the construction and working of a trebuchet.

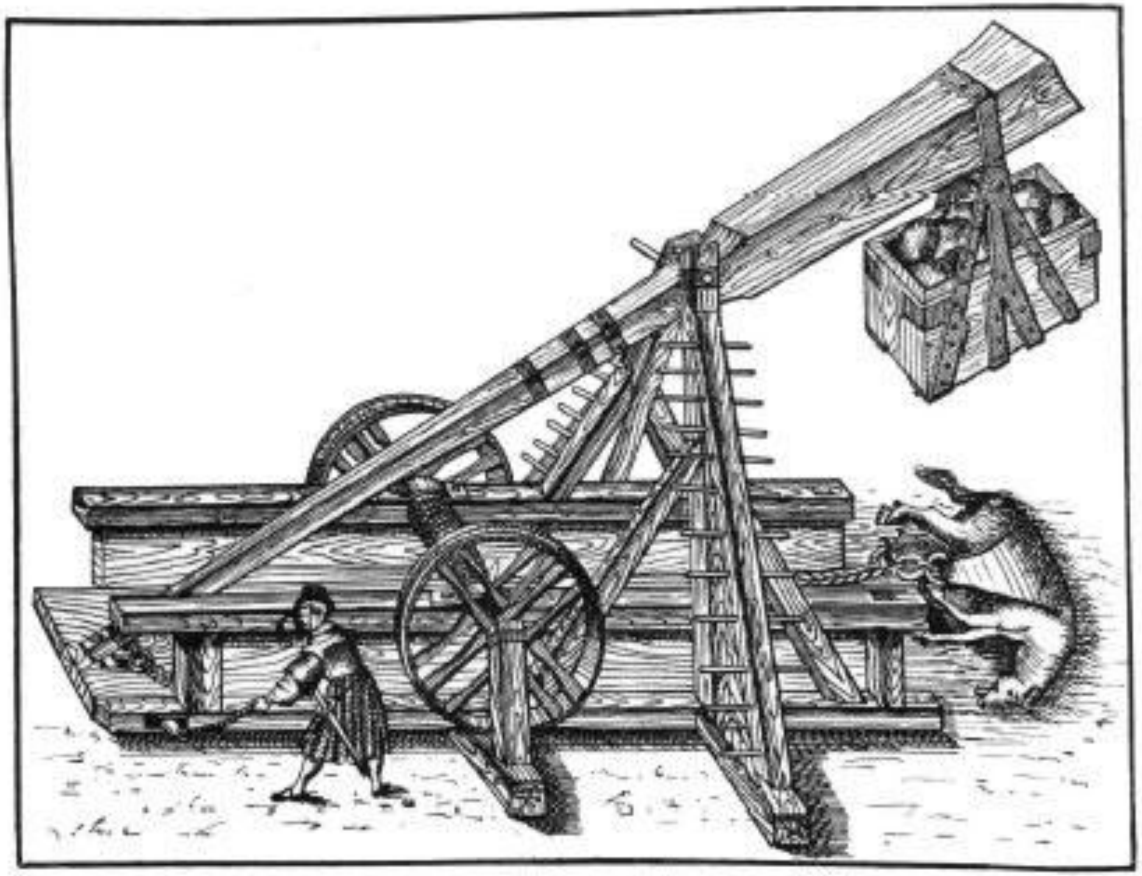
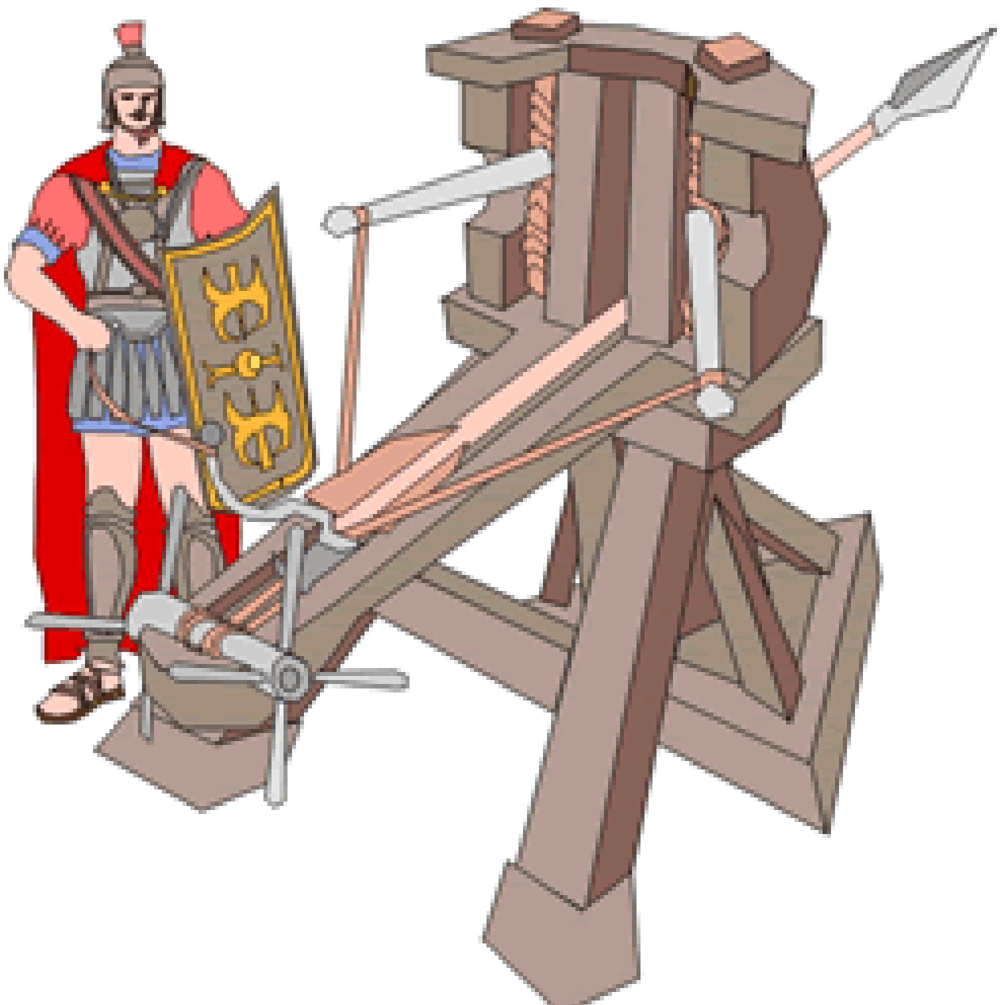
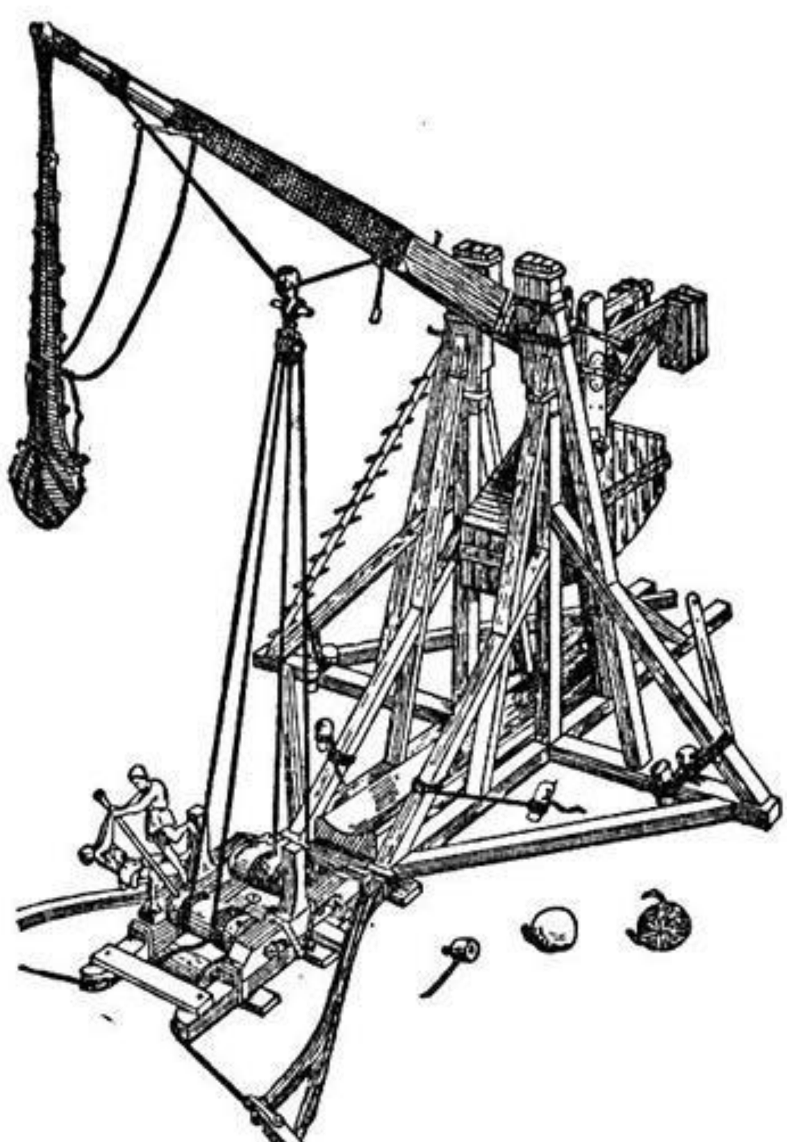


Fig.19- CASTING A DEAD HORSE INTO A BESIEGED TOWN BY MEANS OF A TREBUCHET

From 'Il Codice Atlantico,' Leonardo da Vinci, 1445-1520

Some Ancient Catapults





Definitions of Terms

- The **Trajectory** is the path or curve described by a body (as a planet or projectile) under the action of given forces.
- **Potential Energy** is the kind of energy that a body has by virtue of its position. When a body is raised to a higher level, it is able to do a certain amount of work in falling back again, and hence it was given a certain amount of potential energy in raising it.
- **Kinetic Energy** is the energy that a body has by virtue of its motion

Definitions of Terms

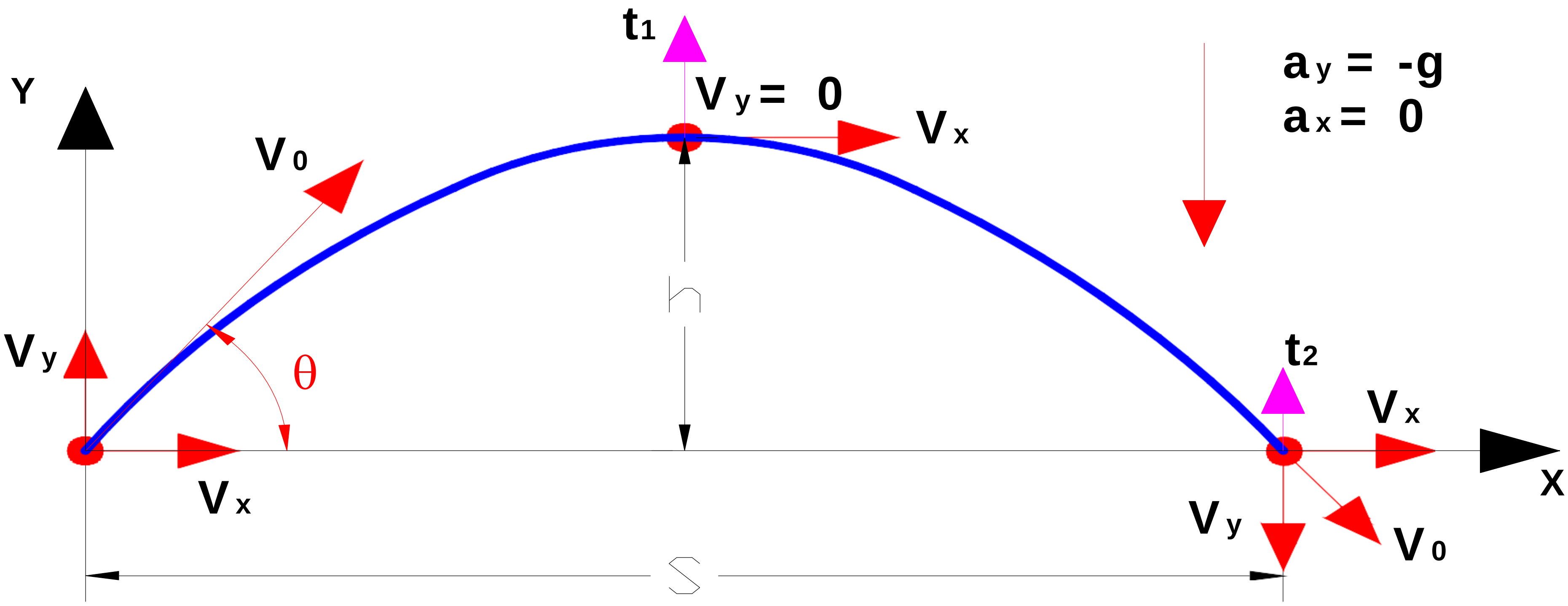
- **Energy Storage**: by compressing a spring and forcing it to stay in a compressed configuration, the spring is said to have "stored" energy. Once it is released, it will return to its original configuration (generally releasing the energy as rapidly as possible).
- The same goes for stretching a spring: when released, it will collapse back to its original configuration.

Definitions of Terms

- **Trigger**: The device used to release the catapult once it has been loaded and charged to launch the projectile.
- **Ballistics**: The science of projectiles.
- **Range**: Distance for which a projectile can be thrown.

Theory

- Motion of projectiles is composed of two forces, one uniform (gravity) and the other variable (acceleration).
- The study of these two forces comprise the study of ballistics. The science of ballistics is to determine the range of projectiles and to determine their paths.



Theory

1. $v_f = v_o + gt$

2. $s = v_o t + 1/2\, gt^2$

3. $v_f^2 = v_o^2 + 2gs$

Where

v_f = Final velocity, feet per second
v_o = Initial velocity, feet per second
t = Time in seconds
g = Gravity at 32.2 ft /sec/sec
s = Distance in feet

Theory

- The vertical component of the projection velocity is $\mathbf{v \sin \theta}$ and its horizontal component is $\mathbf{v \cos \theta}$ as shown above.
- If **t** is the time of flight, as yet unknown, the horizontal distance travelled will be the range $\mathbf{X = vt \cos \theta}$.
- To find the time of flight, use the equation above and select a direction, say upwards, as positive.
- Find $\mathbf{t_1}$ in which the projectile reaches the highest point of its flight, where its vertical velocity is zero, from the expression $\mathbf{v \sin \theta = gt_1}$.
- During this period $\mathbf{t_1}$ the projectile rises to a height given by this equation, written as: $h = 1/2\, gt_1^{\,2}$

Theory

- Time $\mathbf{t_2}$ required for the projectile to return to ground is found from: $h = -1/2\, g t_2^2$
- and since **h** in the last two equations represents the same height, it follows that $\mathbf{t_1 = t_2}$, or the time of flight to reach maximum elevation is the same as the time to drop from that level to the datum plane.
- The total flight time is therefore $\mathbf{t = 2t_1}$. Combining this result with the first two equations of this derivation, gives the range of the projectile as:

$$X = vt \cos\theta = 2vt_1 \cos\theta = 2v(v \sin\theta / g) \cos\theta$$

OR

$$X = v^2 / g \sin 2\theta$$

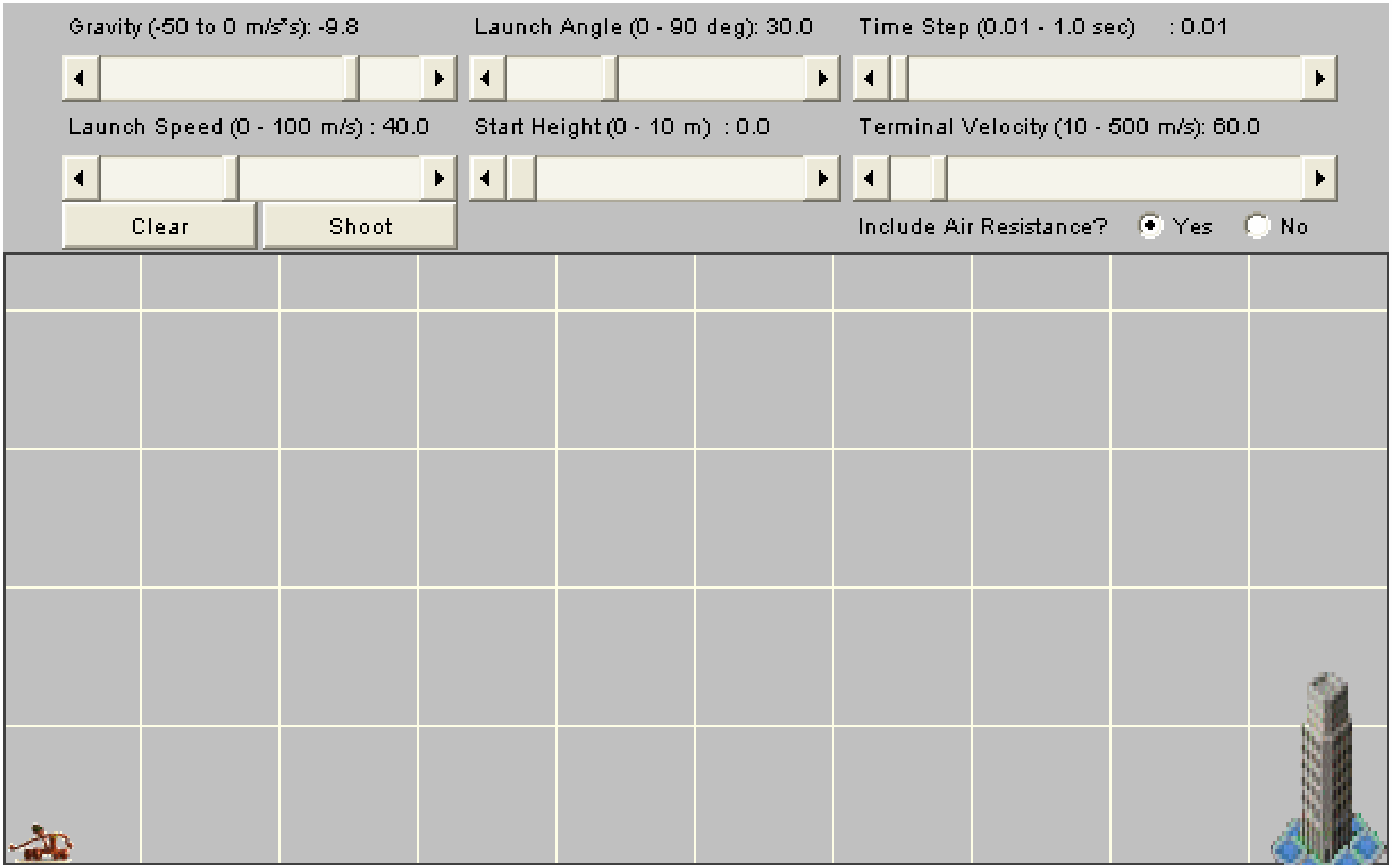
Theory

further, by eliminating $\mathbf{t_1}$ from the equations

$$v \sin \theta = g t_1 \text{ and } h = 1/2 g t_1^2$$

- the maximum elevation of the projectile is found to be $\mathbf{h = (v_2 / 2g) \sin(2\theta)}$
- It should be noted that for maximum distance, the release angle of the projectile should be 45°.

Air Resistance



Design Requirements

- Specific needs are required at the conceptual design level.
- Performance related requirements and operation and maintenance may be all initially defined.
- Some requirements are imposed by fabrication, usage or cost.
- All the specs must be clearly indicated at the beginning of the design process.

Design Documentation

Based on meaningful calculations that take into consideration the physics of phenomena.

In our project:

- Ballistics calculation for the performances in launching, forces developed within the mechanism, energy balance – Statics and Dynamics, ENGR 242 and ENGR 243.
- Optimal configuration of the linkages and mechanisms – Theory of Machines, MECH 343.
- Modeling of the flying projectile for more accurate evaluation of the trajectory: Modeling and Analysis of Physical Systems, MECH 370.

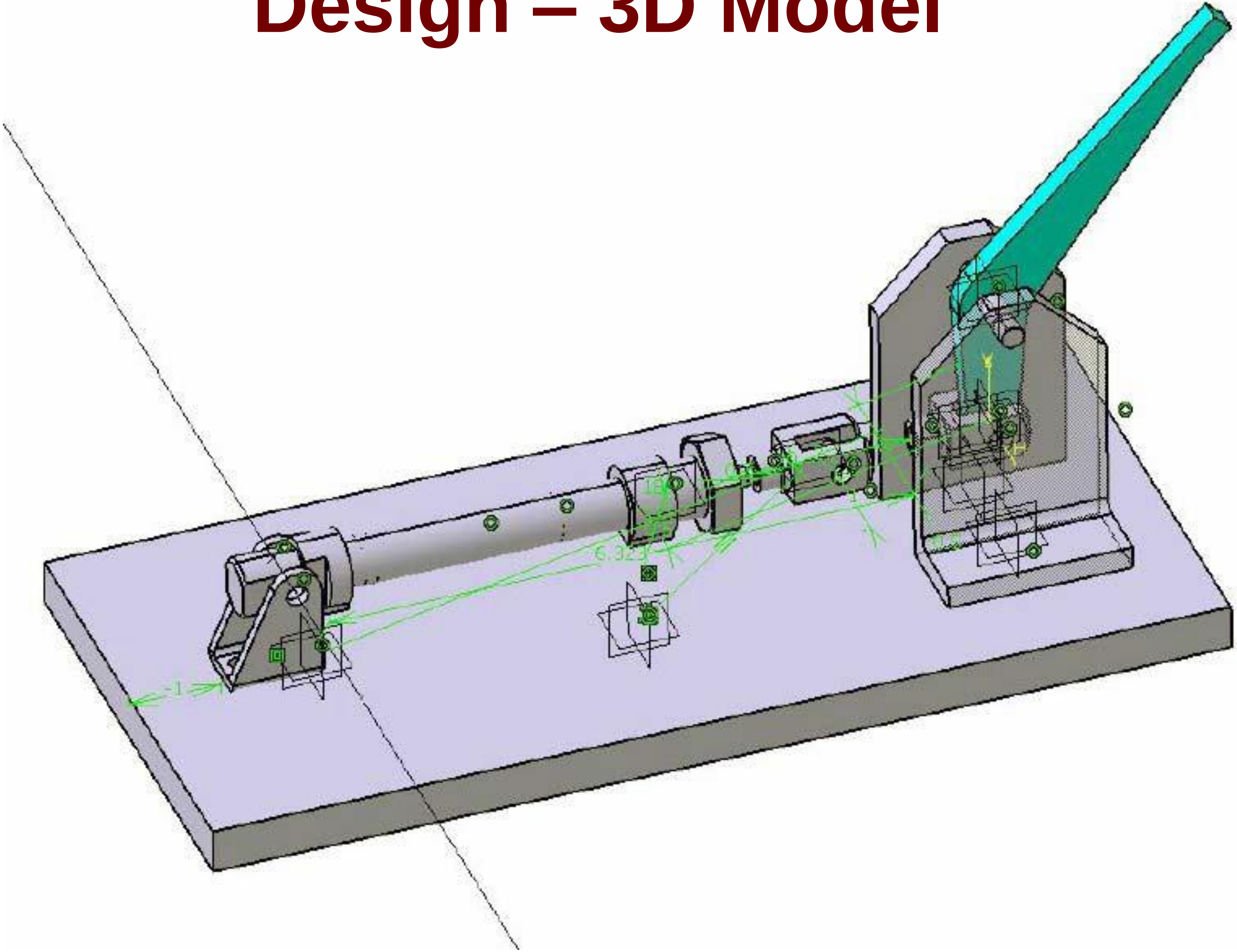
Development

- Solve the equations associated with the model: Transform Calculus and Partial Differential Equations, ENGR 311; Ordinary Differential Equations EMAT 213; Advanced Calculus EMAT 233; Programming for Mechanical Engineering MECH 215; Numerical Methods in Engineering ENCS 391.
- Refine the model including lift and drag: Fluid Mechanics I and II, ENGR 361, MECH 361.
- In the case that fast burning process is used to generate energy: Thermodynamics I and II, ENGR 251 and MECH 315, Heat Transfer MECH 352.
- Selection of materials – based on strength capability; Mechanics of Materials, MECH244; Materials Science MECH 211, Properties and Failure of Materials MECH 321.

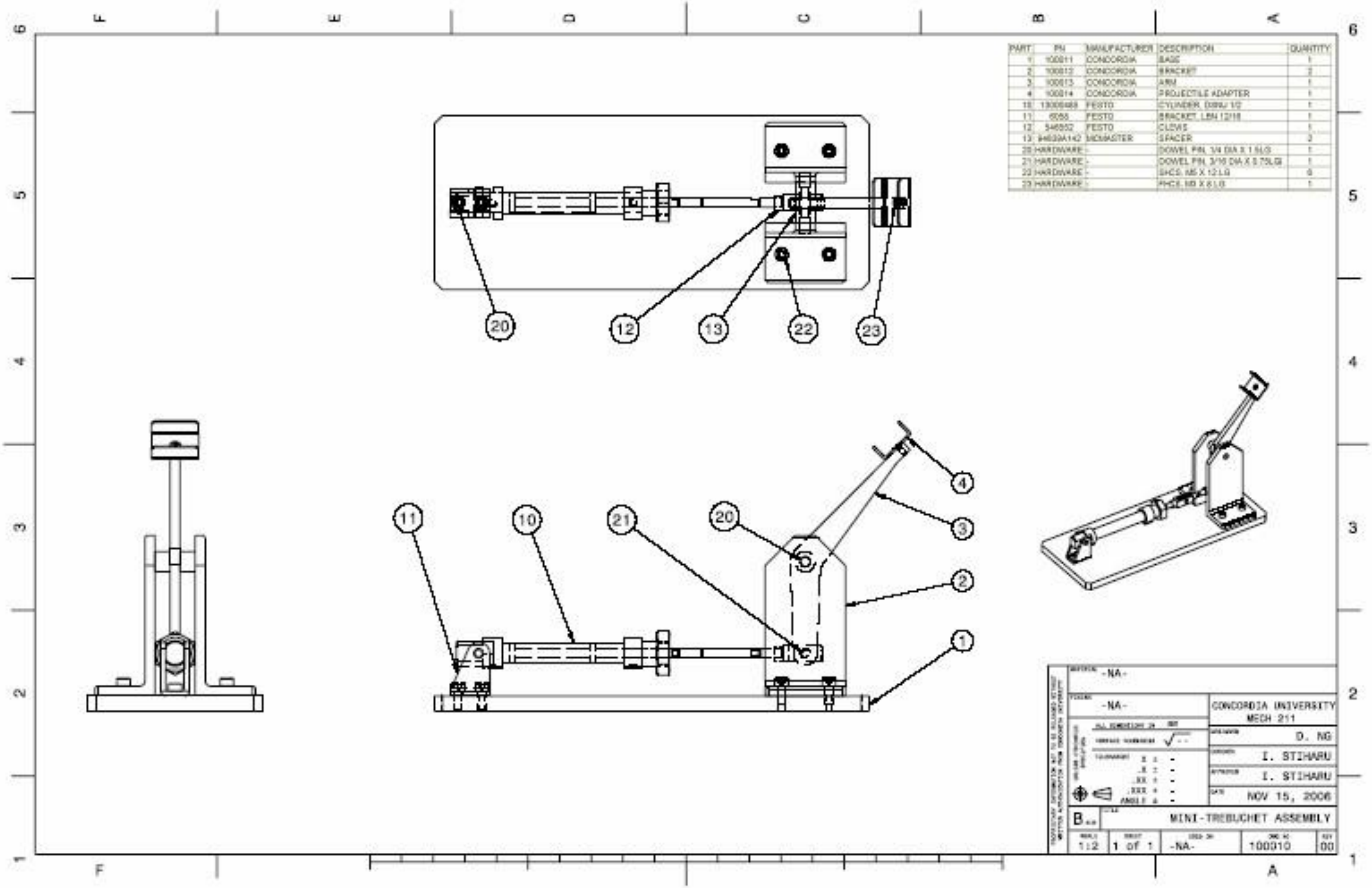
Development

- Include some intelligence to the equipment: Fundamentals of Control Systems MECH 371, Instrumentation and Measurement MECH 373.
- Design and produce the technical documentation for the product to be manufactured: Mechanical Engineering Graphics MECH 211, Machine Drawing and Design MECH 313, Technical Writing and Communications ENCS 282, Mechanical Engineering Design MECH 441.
- Manufacture economically the catapult: Manufacturing Processes MECH 311, Engineering Management Principles and Economics ENGR 301.
- Learn how the catapult will behave when transported or used: Probability and Statistics in Engineering ENGR 371, Mechanical Vibrations MECH 443.

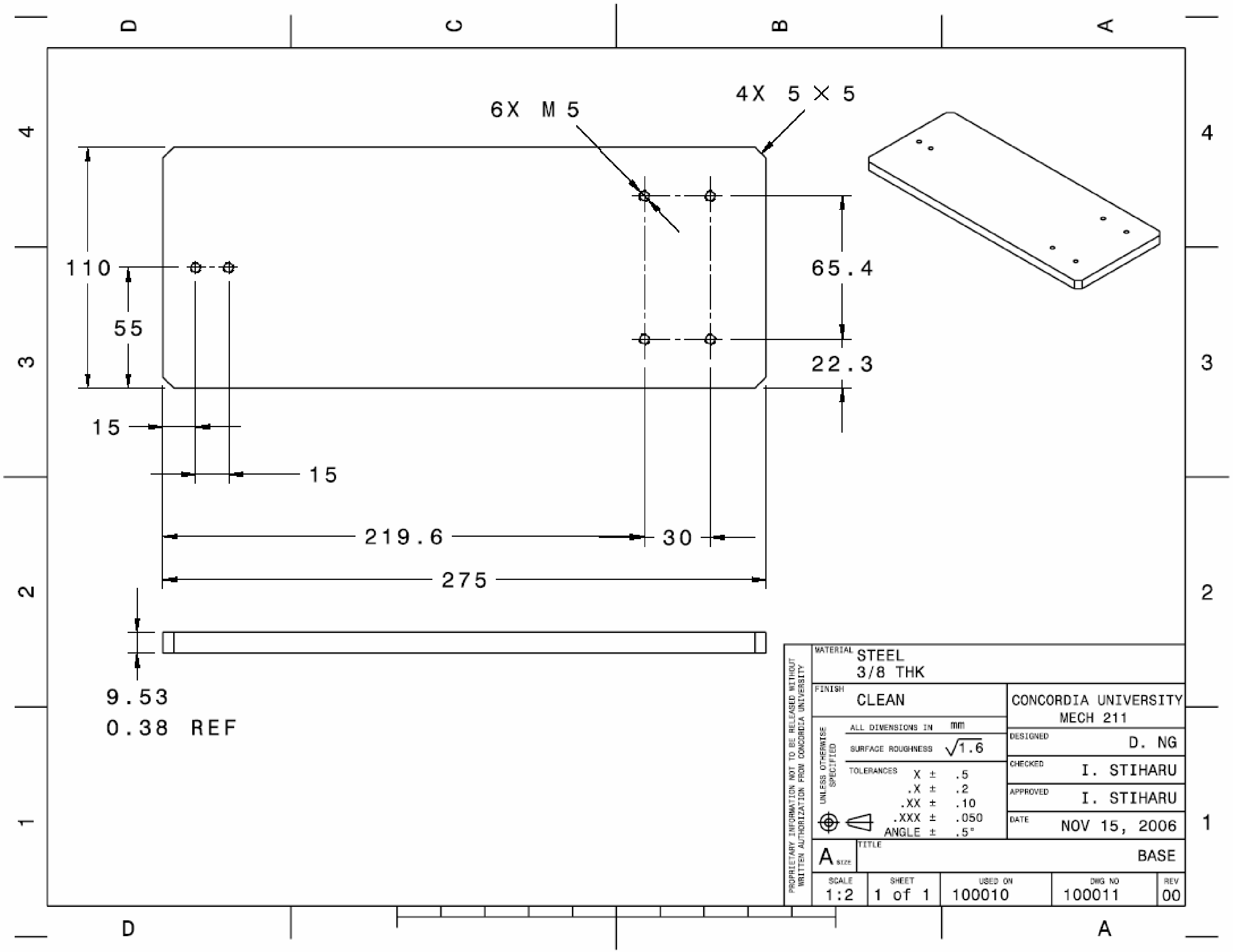
Design – 3D Model



Assembly Drawing



Working or Part Drawings



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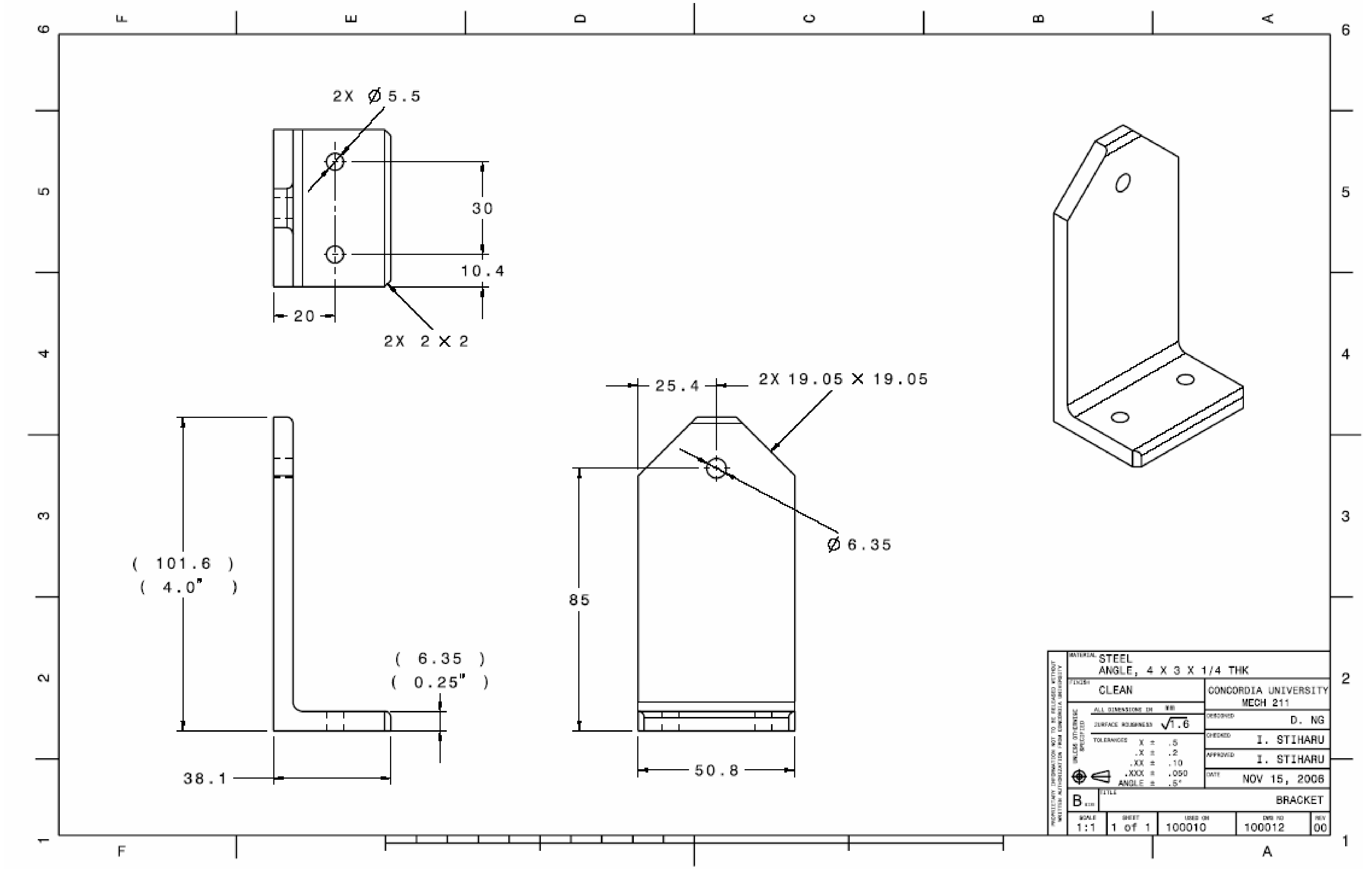

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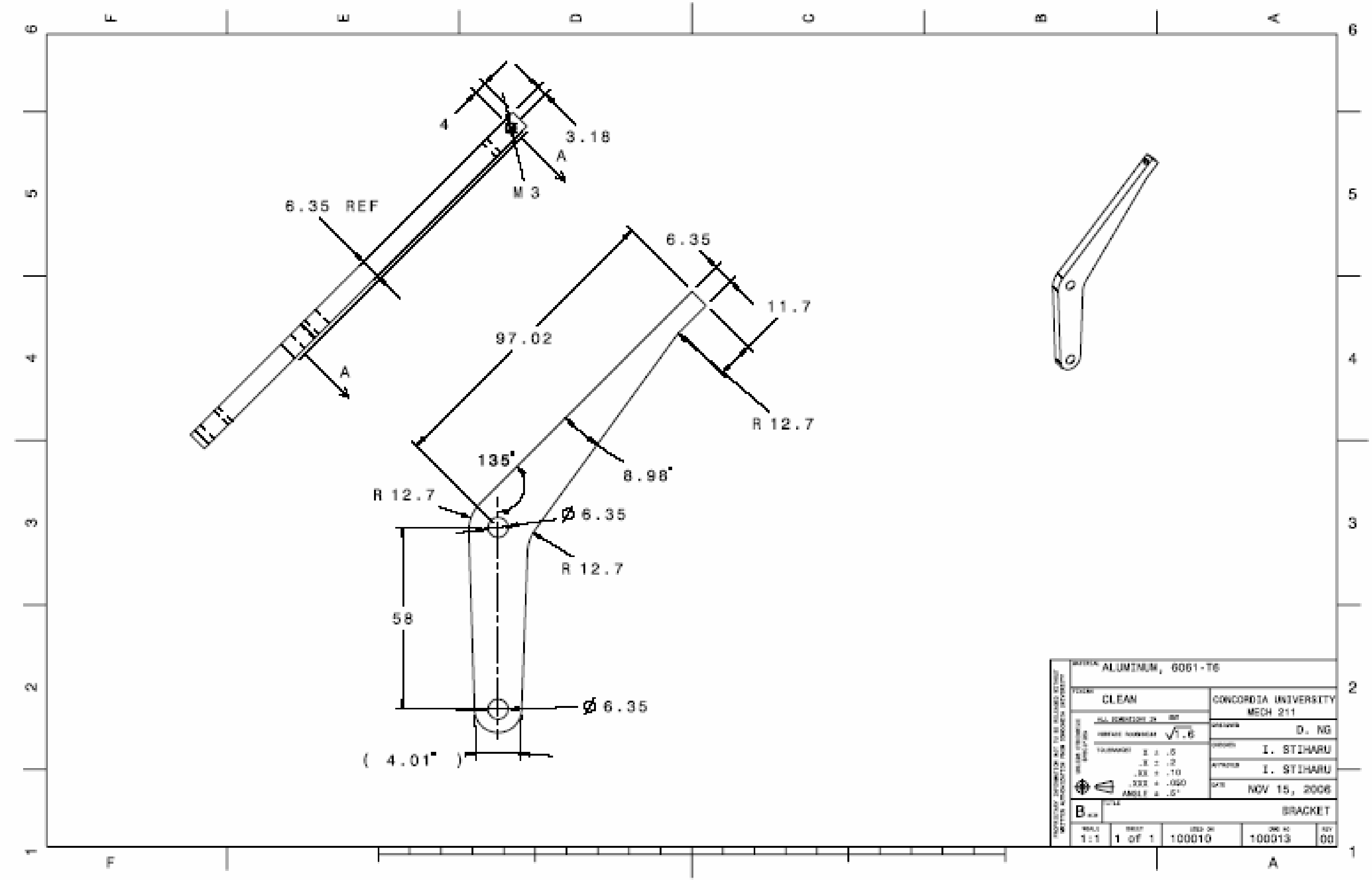

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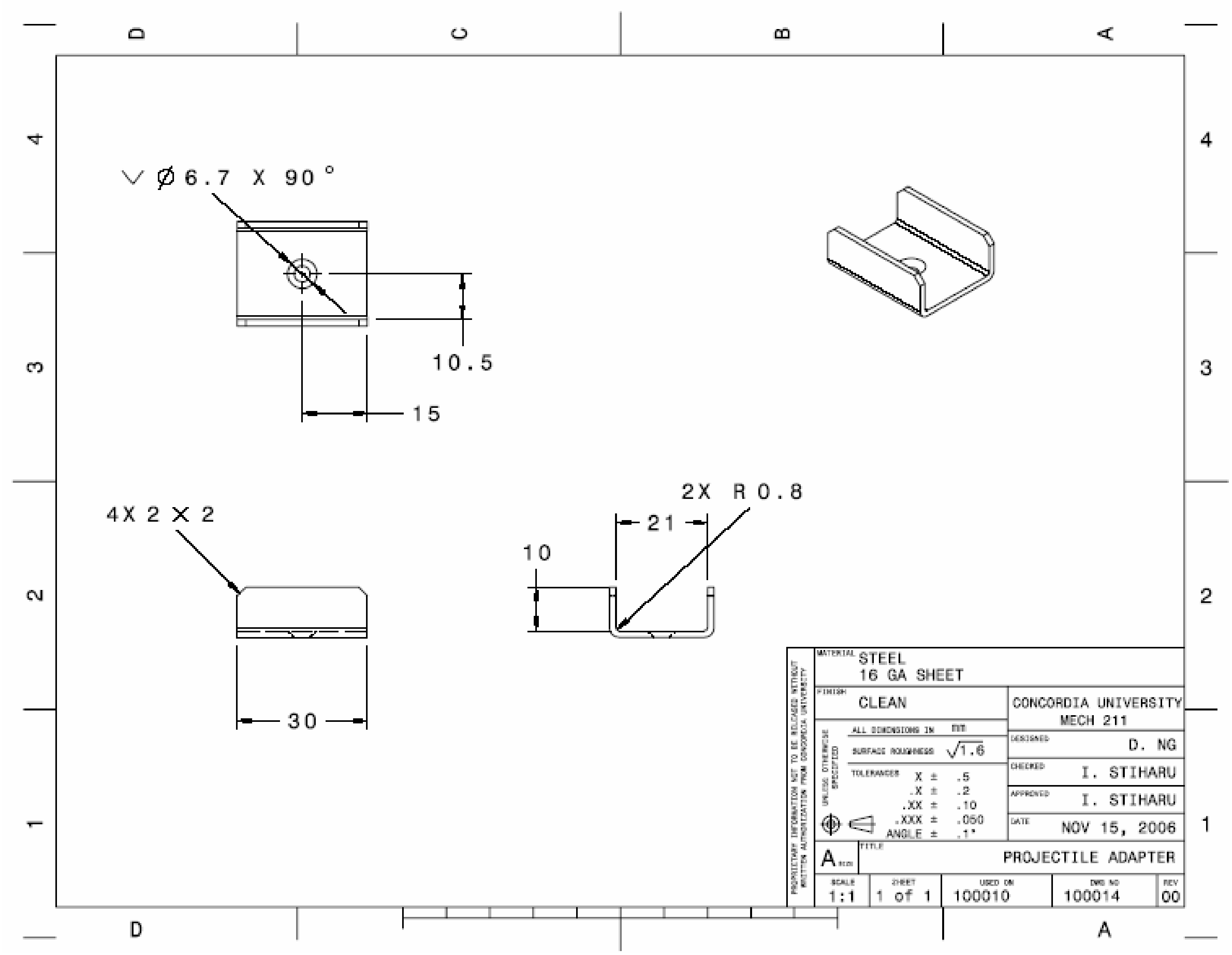

Conclusion

Think practical when you do maintenance work as well