2.00AJ / 16.00AJ Exploring Sea, Space, & Earth: Fundamentals of Engineering Design
Spring 2009

Exploring Sea, Space & Earth: FUNdaMENTALs of Engineering Design

2.00AJ/16.00AJ

Spring 2009

Lecture # 2

Prof. Alex Techet

FUNdaMENTALs of Design

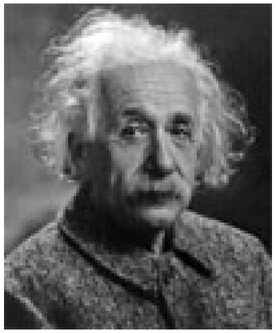


Image from Wikimedia Commons, http://commons.wikimedia.org

I have no special talents. I am only *passionately curious*. -Einstein

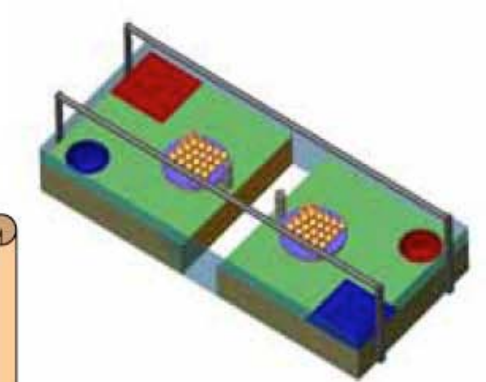
- *"Design is a Passionate process" -Prof. Slocum*
- Never stop asking questions, seeking a better, simpler solution!
- (Play, SKETCH, Model, Detail, Build, Test)^N
- Design is an iterative process.

Image from Open Clip Art Library, http://openclipart.org

Henry Maudslay

from J. Roe English and American Tool Builders, © 1916 Yale University Press

♥Passion♥ FOCUS!
Keep Your Eye on the Prize



"You can't always get what you want
But if you try sometimes well you might find
You get what you need"

Mick Jagger & Keith Richards 1969
http://lyrics.all-lyrics.net/r/rollingstones/letitbleed.txt

Get a clear notion of what you desire to accomplish, then you will probably get it

Keep a sharp look-out upon your materials: Get rid of every pound of material you can do without. Put yourself to the question, 'What business has it there?'

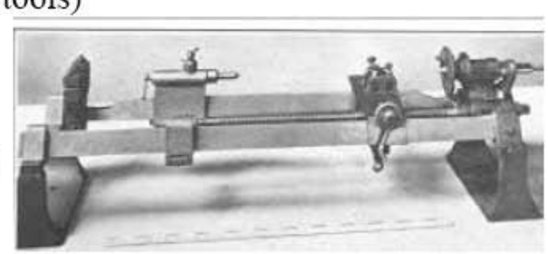
Avoid complexities and make everything as simple as possible

Remember the get-ability of parts

Henry Maudslay's Maxims (1700's, a father of modern machine tools)

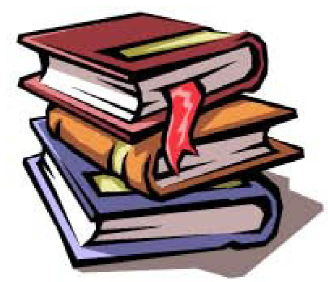
Maudslay's screw cutting lathe

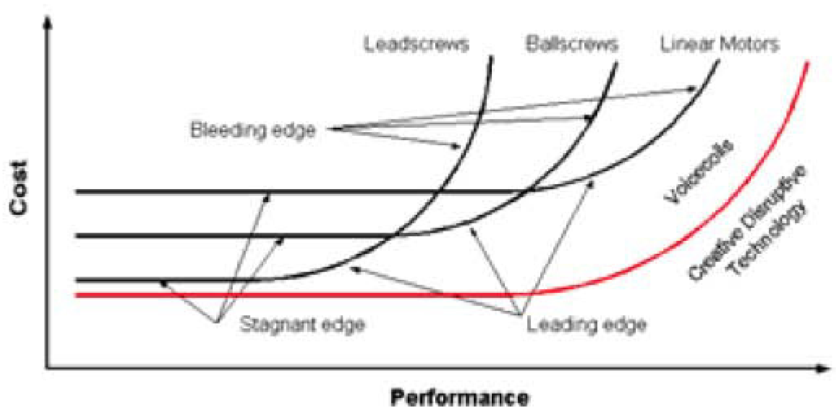
from J. Roe English and American Tool Builders, © 1916 Yale University Press

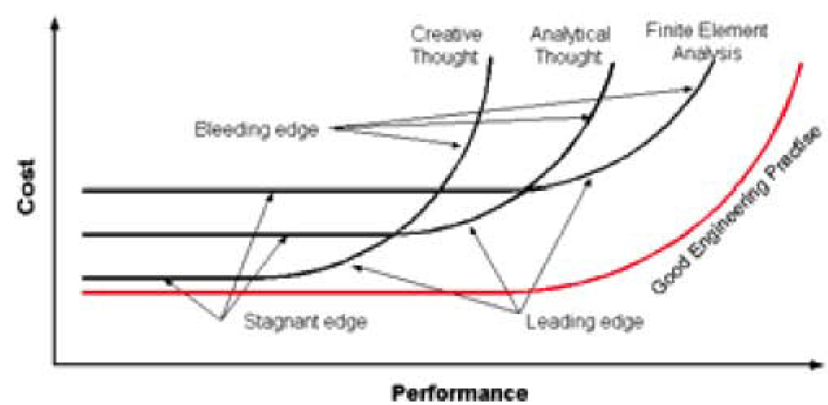


Deterministic Design

- Everything has a cost, and everything performs (to at least some degree)
  - If you spend all your time on a single tree, you will have no time for the forest
  - If you do not pay attention to the trees, soon you will have no forest!
  - You have to pay attention to the overall system and to the details
- Successful projects keep a close watch on budgets (time, money, performance)
  - Do not spend a lot of effort (money) to get a small increase in performance
    - "Bleeding edge" designs can drain you!
  - Do not be shy about taking all the performance you can get for the same cost!
- Stay nimble (modular!) and be ready to switch technology streams
  - It is at the intersection of the streams that things often get exciting!
  - *"If you board the wrong train, there's no use running along the corridor in the opposite direction"* Dietrich Bonhoeffer

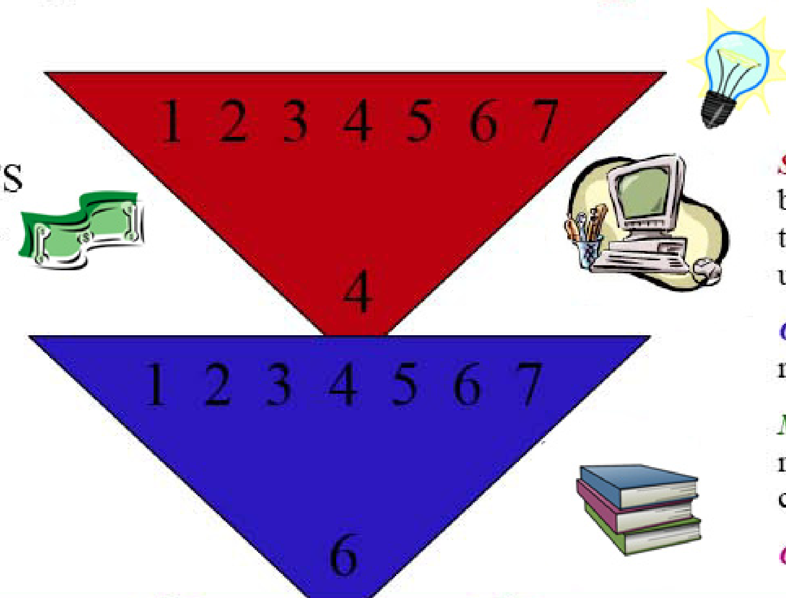






Deterministic Design: *Funnels:* ***Strategies*** *Concepts* *Modules* *Components*

- Deterministic Design leaves LOTS of room for the wild free creative spirit, and LOTS of room for experimentation and play
- Deterministic Design is a catalyst to funnel creativity into a *successful* design

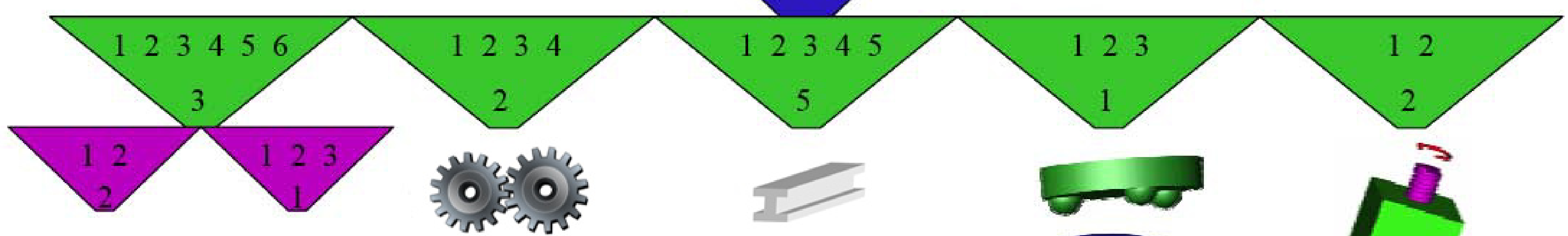


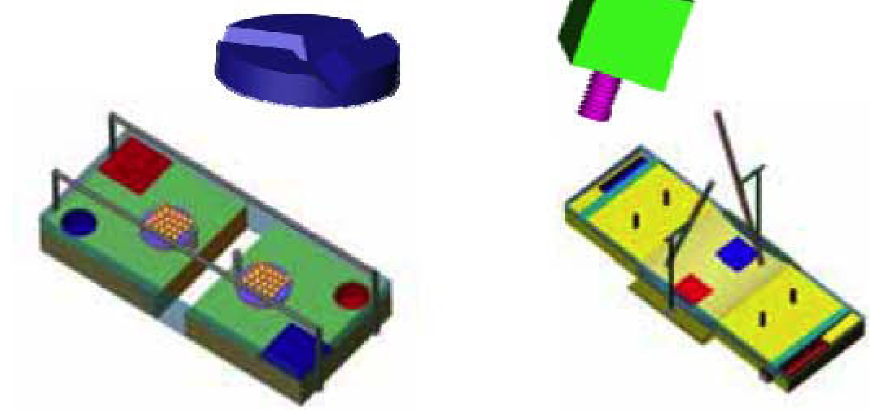
Strategy: Plan or tactics to score but there may be many different types of machines that could be used

Concept: An idea for a specific machine that can execute a strategy

Module: A sub assembly of a machine that by itself executes a certain function

Component: An individual part

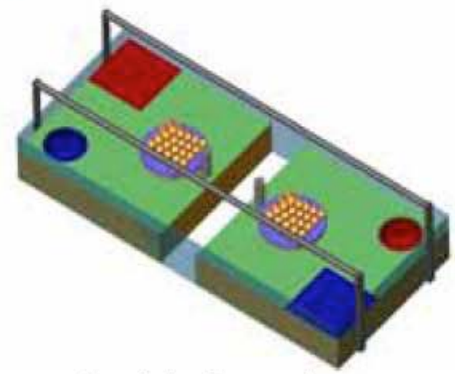


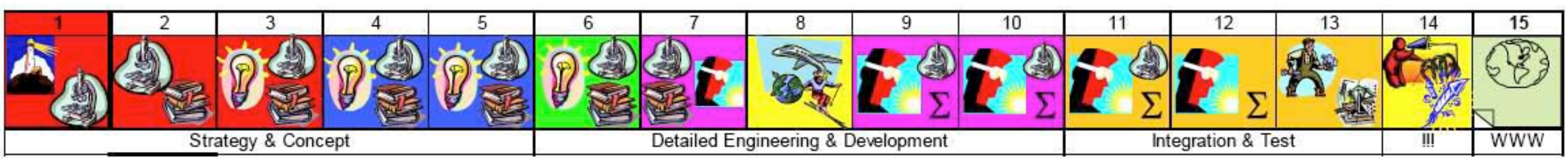


- It is OK to iterate…
  - A *goal* is to never have to backtrack
    - A good engineer, however, knows when its time to let go…

Deterministic Design: *Schedules*

- Time is relative, but you will soon run out of it if you keep missing deadlines!
  - No matter how good your ideas are, their value decays exponentially with every day they are late
    - Once a customer starts buying a product, if the manufacturer maintains diligence, you will find it extremely difficult to regain market share
- The process of getting a product to market involves phases
  - Identify & study problem, develop solution strategies and evolve "best one"
  - Create concepts and evolve "best one"
  - Create modules
  - Detail design, build, & test the modules starting with the most risky
  - Assemble, integrate, test, and modify as needed
  - Document and ship
- You must create a schedule and stick to it!
  - This is true in ALL pursuits
  - Yes, sometimes the schedule will slip…this is why you have countermeasures for risky items that fail, and you build in capacitances (float time) to allow for troubles…



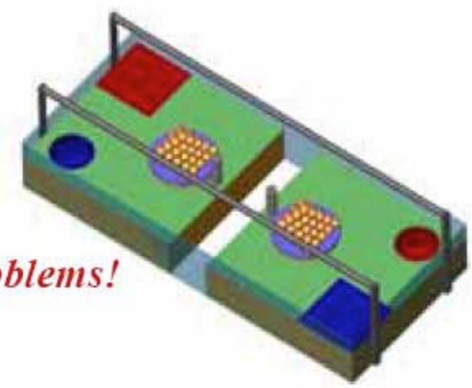


Systematic Organization of Ideas: *FRDPARRC*

Functional Requirements (Events) ***Words***	***Design Parameters (Idea)*** ***Words & Drawings***	***Analysis*** ***Experiments, Words, FEA, Equations, Spreadsheets…***	***References*** ***Historical documents, www…***	***Risk*** ***Words, Drawings, Analysis…***	***Counter-measures*** ***Words, Drawings, Analysis…***
A list of independent functions that the design is to accomplish. Series (1,2,3…) and Parallel (4a, 4b..) FRs (Events) can be listed to create the *Function Structure*	Ideally independent means to accomplish each FR. AN FR CAN HAVE SEVERAL POTENTIAL DPs. The "best one" ultimately must be selected	Economic (financial or maximizing score etc), time & motion, power, stress… EACH DP's FEASABILITY MUST BE PROVEN. **Analysis can be used to create DPs!**	Anything that can help develop the idea including personal contacts, articles, patents, web sites….	High, Medium, Low (explain why) risk of development assessment for each DP	Ideas or plan to mitigate each risk, including use of off-the-shelf known solutions

- To actually use the FRDPARRC Table:
  - Create one actual table that becomes your development roadmap
  - Dedicate one sheet to each FR/DP pair

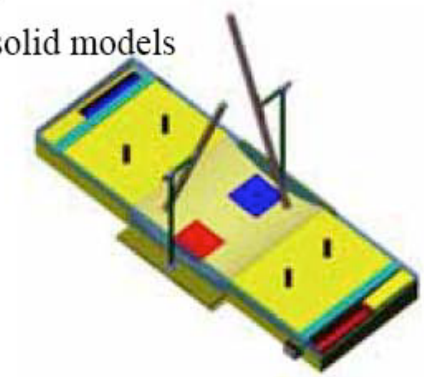
The FRDPARRC table is an exceptional catalyst to help you identify opportunities for applying reciprocity to uncover new ideas and solve problems!



Design is a Series of Steps Blended Together

- Follow a design process to develop an idea in stages from **COARSE** to fine:
  - ***First Step:*** Take stock of the resources that are available
  - ***Second Step: S***tudy the problem and make sure you have a clear understanding of what needs to be done, what are the constraints (rules, limits), and what are the physics of the problem!
    - Steps 1 & 2 are often interchangeable
  - ***Third Step:*** Start by creating possible ***strategies*** (ways to approach the problem) using words, analysis, and simple diagrams
    - Imagine motions, data flows, and energy flows from start to finish or from finish back to start!
    - Continually ask "Who?", "What?", "Why?", "Where", "How?"
    - Simple exploratory analysis and experiments can be most enlightening!
    - Whatever you think of, others will too, so think about how to defeat that about which you think!
  - ***Fourth Step:*** Create ***concepts,*** specific ideas for machines, to implement the best ***strategies,*** using words, analysis, and sketches
    - Use same methods as for ***strategies***, but now sketch specific ideas for machines
    - Often simple experiments or analysis are done to investigate effectiveness or feasibility
    - Select and detail the best ***concept***…
  - ***Fifth Step:*** Develop ***modules,*** using words, analysis, sketches, and solid models
  - ***Sixth step:*** Develop ***components,*** using words, detailed analysis, sketches, and solid models
  - ***Seventh Step:*** Detailed engineering & manufacturing review
  - ***Eighth Step:*** Detailed drawings
  - ***Ninth Step:*** Build, test, modify…
  - ***Tenth Step:*** Fully document process and create service manuals…

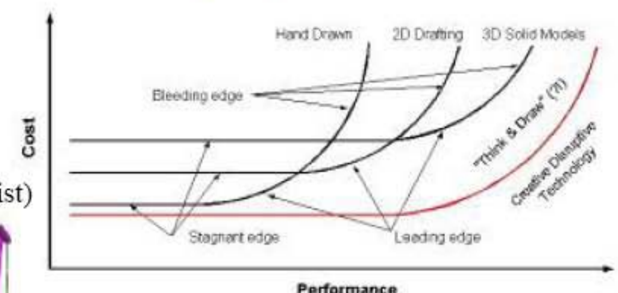
Explore *Experiment* *Create* *Detail* *Build & test*

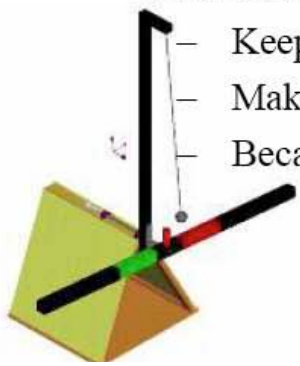


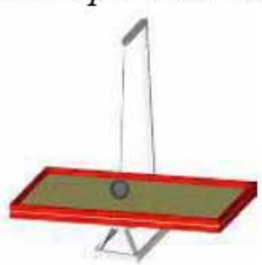
Occam's Razor

- William of Occam (or Ockham) (1284-1347) was an English philosopher and theologian
  - Ockham stressed the Aristotelian principle that *entities must not be multiplied beyond what is necessary (see Maudslay's maxims on page 1-4)*
  - "Ockham wrote fervently against the Papacy in a series of treatises on Papal power and civil sovereignty. The medieval rule of parsimony, or principle of economy, frequently used by Ockham came to be known as **Ockham's razor**. The rule, which said that *plurality should not be assumed without necessity* (or, in modern English, *keep it simple, stupid*), was used to eliminate many pseudo-explanatory entities" (http://wotug.ukc.ac.uk/parallel/www/occam/occam-bio.html)

    - ***A problem should be stated in its most basic and simplest terms***
    - ***The simplest theory that fits the facts of a problem is the one that should be selected***
    - ***Limit Analysis is an invaluable way to identify and check simplicity***
- Use fundamental principles as catalysts to help you
  - Keep It Super Simple (KISS)
  - Make It Super Simple (MISS)
  - Because *"Silicon is cheaper than cast iron"* (Don Blomquist)

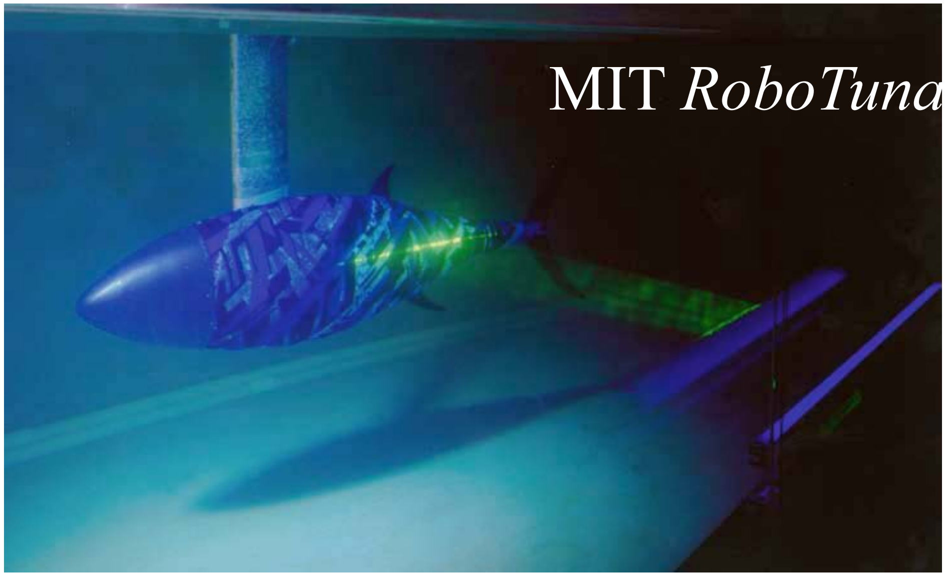


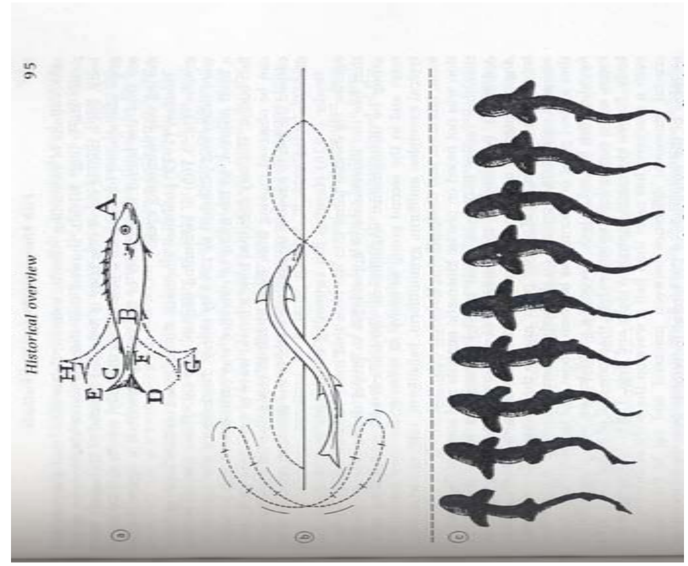




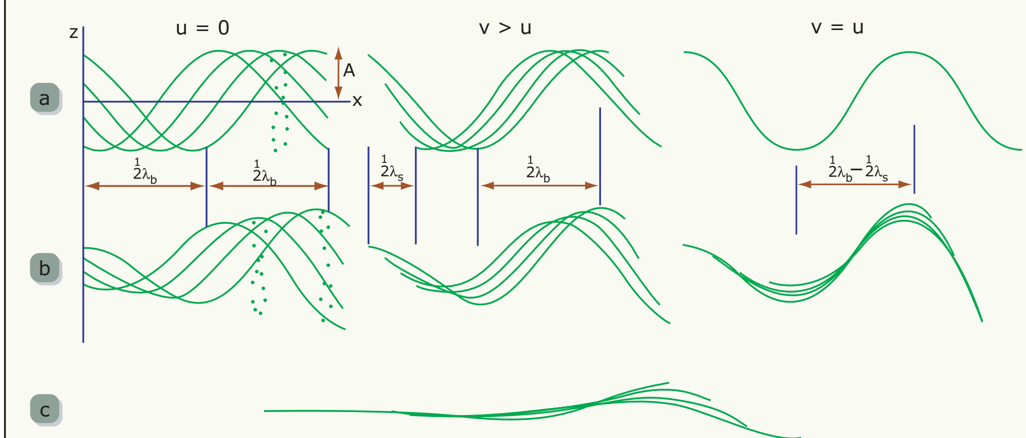
Example: Experimental Design

- Design an apparatus that mimics the motion of a fish backbone





Images from: Borelli, Giovanni. *De Motu Animalium*. Rome, Italy: Angeli Bernabo, 1680.
Pettigrew, James Bell. *Animal Locomotion*. New York, NY: D. Appleton & Co., 1873.
Houssay, F. *Forme, Puissance, et Stabilité des Poissons*. Paris, France: A. Hermann et fils, 1912.



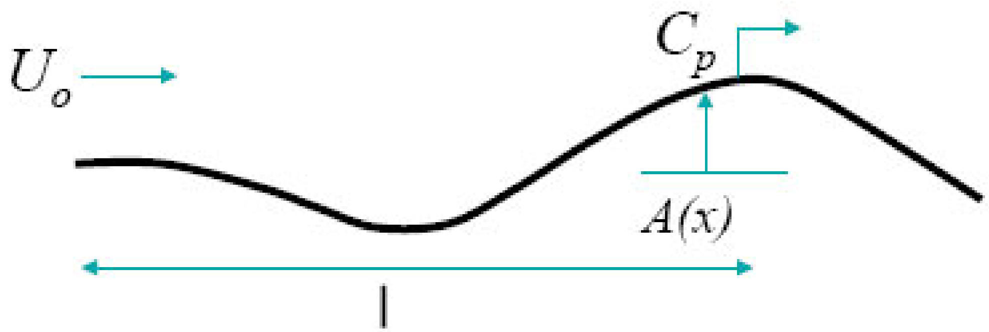
The motion of a fish can be described as a sinusoidal wave of the body with backward velocity v, moving the fish forward with overall velocity u. (a) Demonstrations of this motion with constant amplitude A, for different values of u. (b) In reality, the amplitude increases linearly along the fish's body. (c) Recorded movements of a cod 0.42 m in length, swimming at 0.9 m/s.

Figure by MIT OpenCourseWare.

Fish Swimming: Hypothesis

Flow over a waving boundary tends to laminarize flow

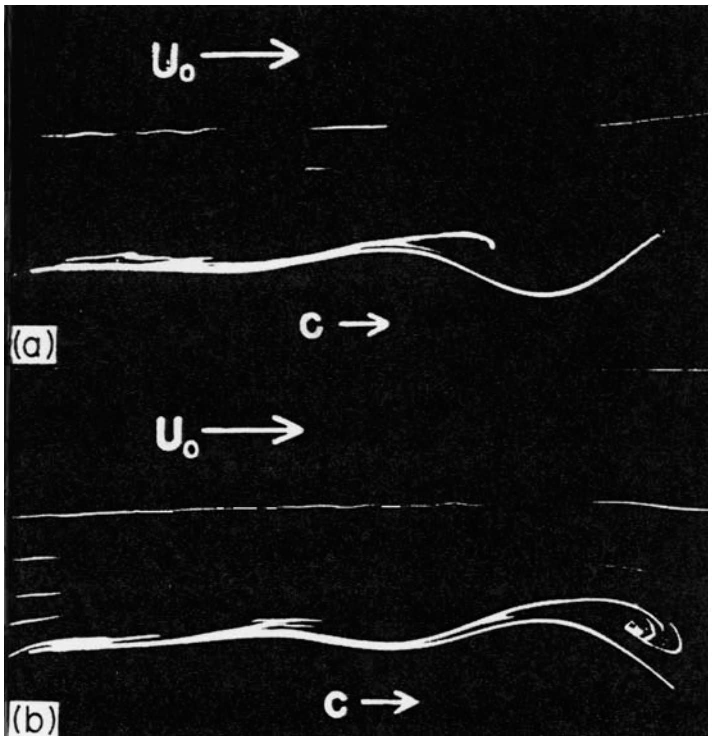
Traveling wave motion:



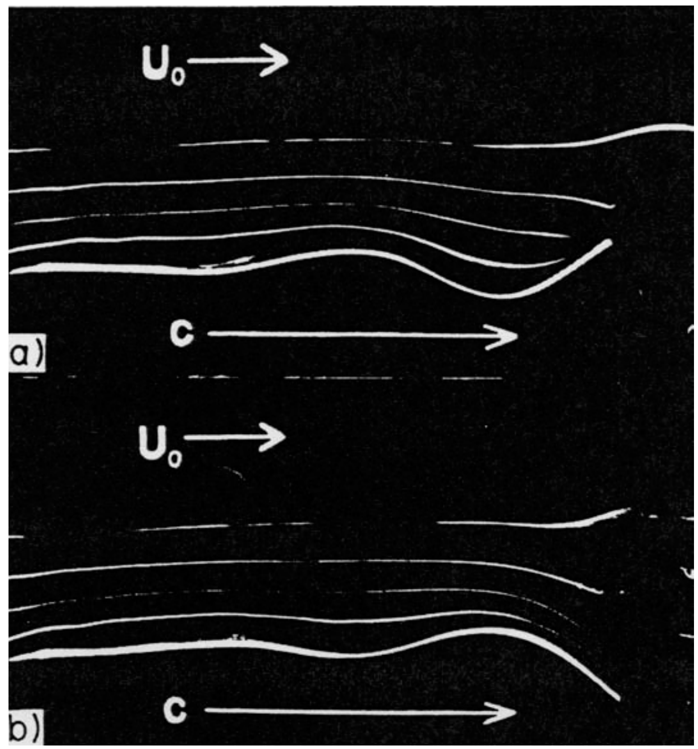
$$C_p = w/k$$

- Taneda (1974) shows that flow does not separate off the crest of a waving boundary if the wave phase speed is greater than the free stream speed.
- Numerical simulations by Zhang (2000) illustrate a decrease in turbulence intensity for phase speeds greater than U_o.($C_p/U_o = 1.2$) at $R_L = 6000$.

Evidence: Flow separation is deterred by traveling wave motion



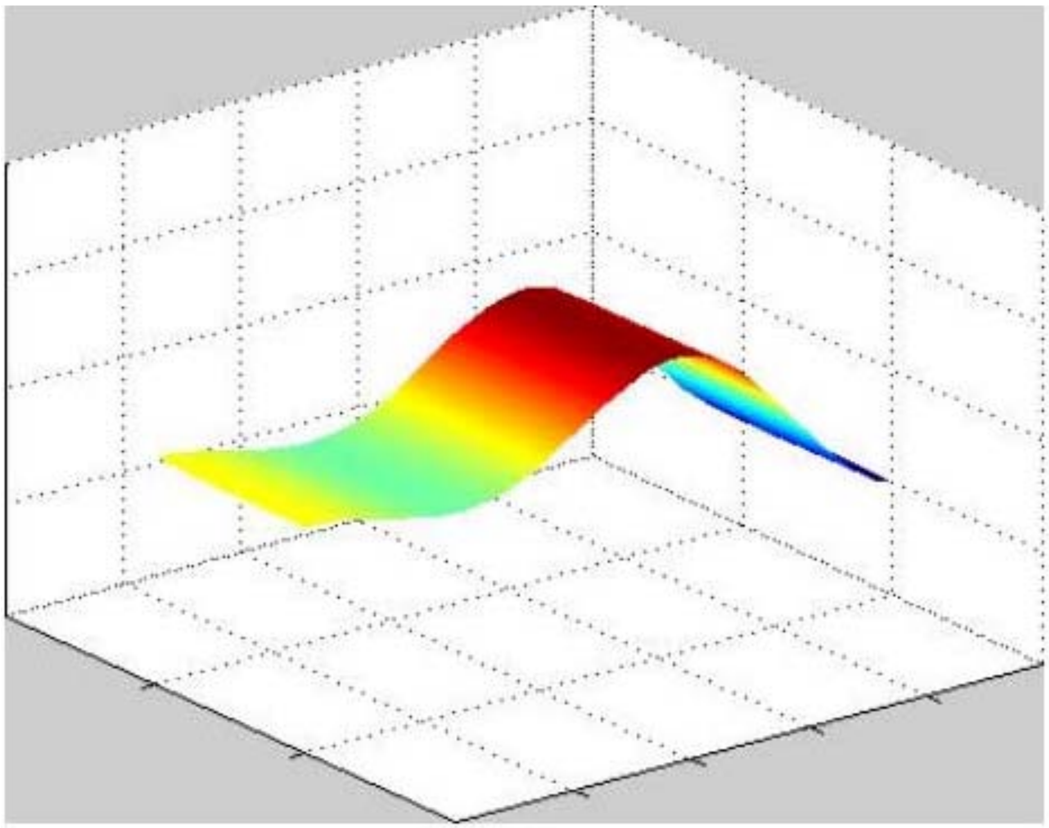
$U_o > C_p$



$U_o < C_p$

Taneda (1977)

Design an Experimental Study to get qualitative answers



Reynolds numbers up to 10^6

$y(x)=a(x)\sin(kx-wt)$

$L = 1.25*l$ (Mat Length)

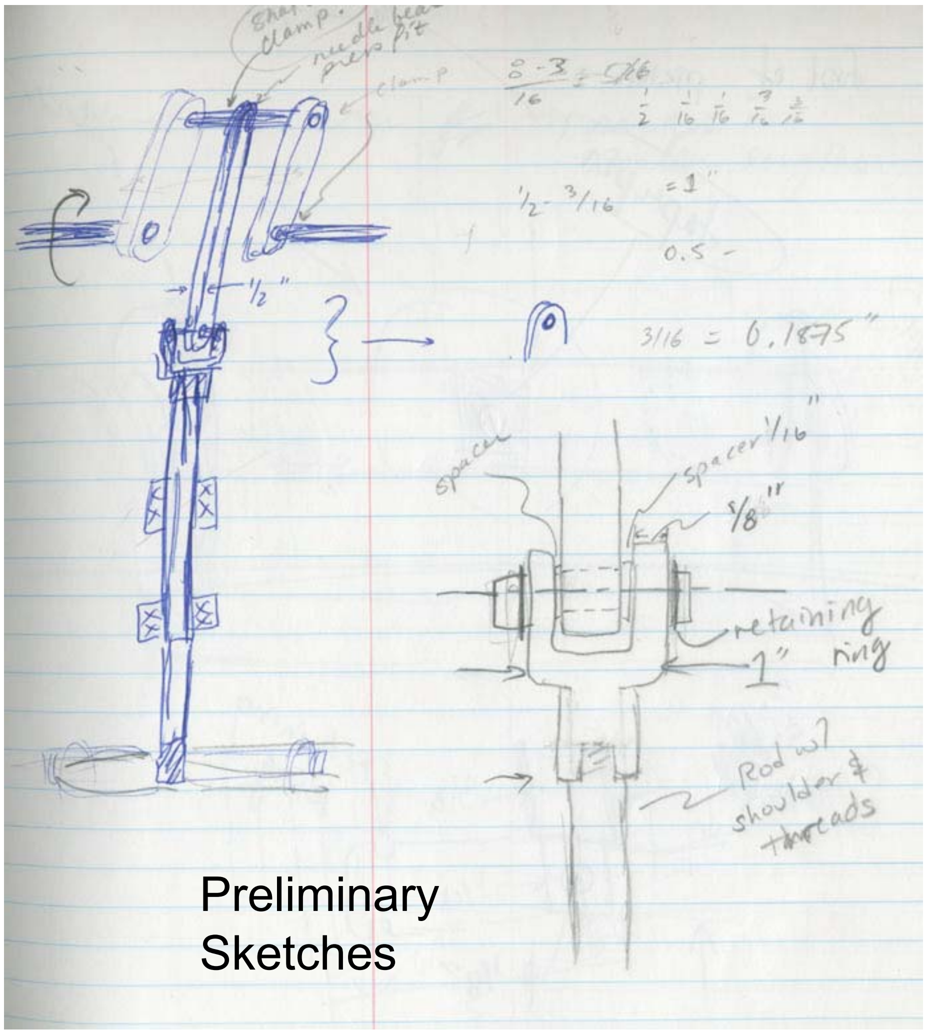
$l = 1.0\ m$

$a(x) = x/16$

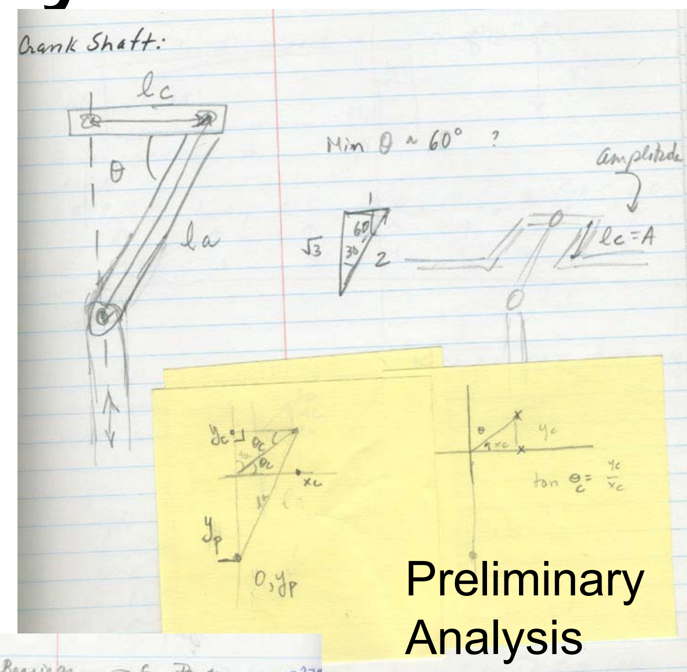
$a_{max} = 0.064\ m$

$w=2pf;\ \ k = 2p/l$

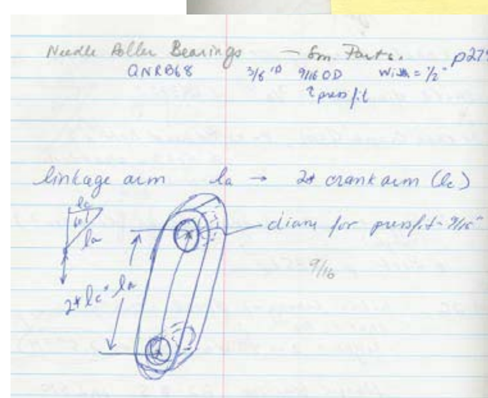
Sketches: Crank-Arm-Piston Assembly



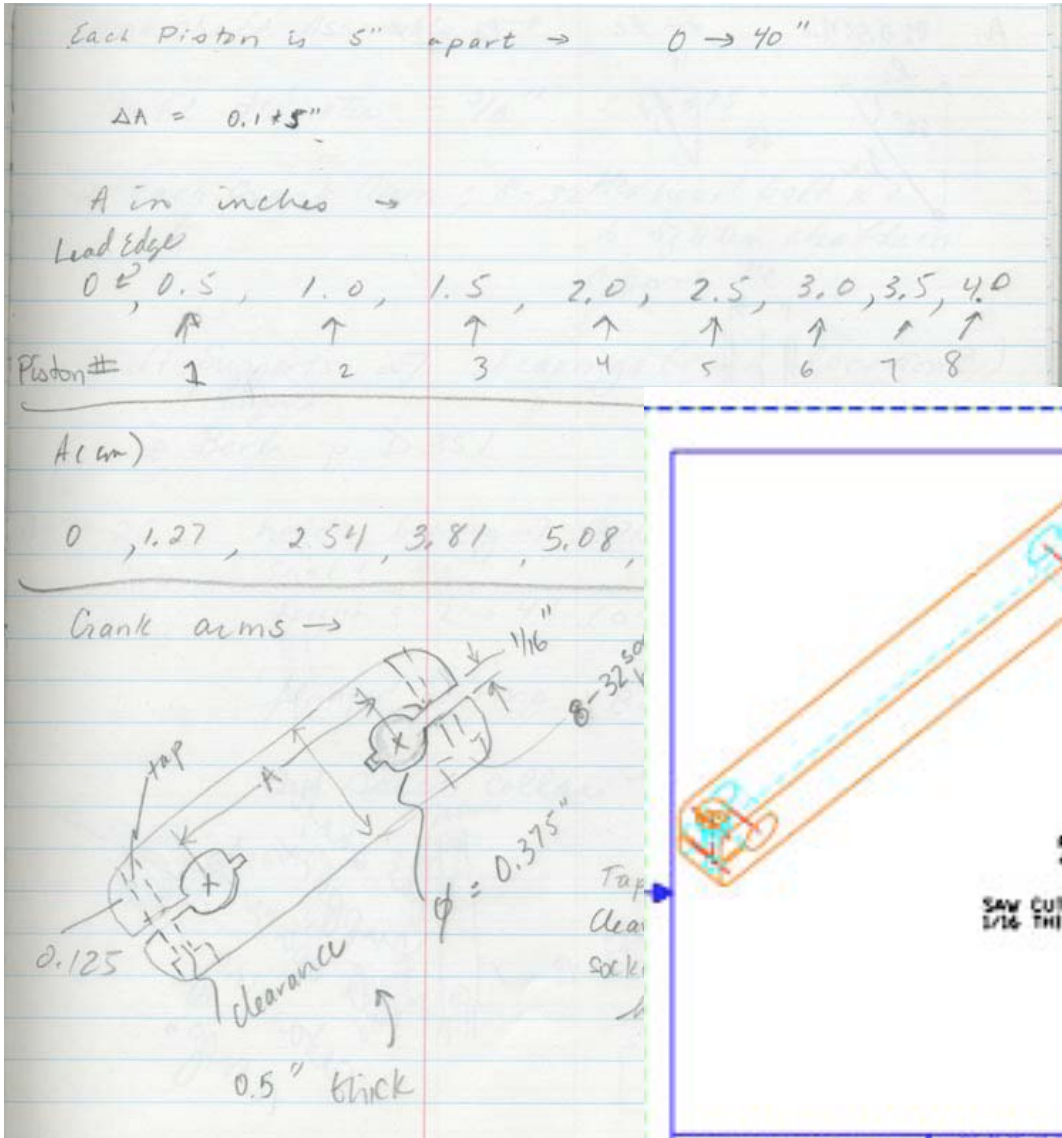
Preliminary Sketches

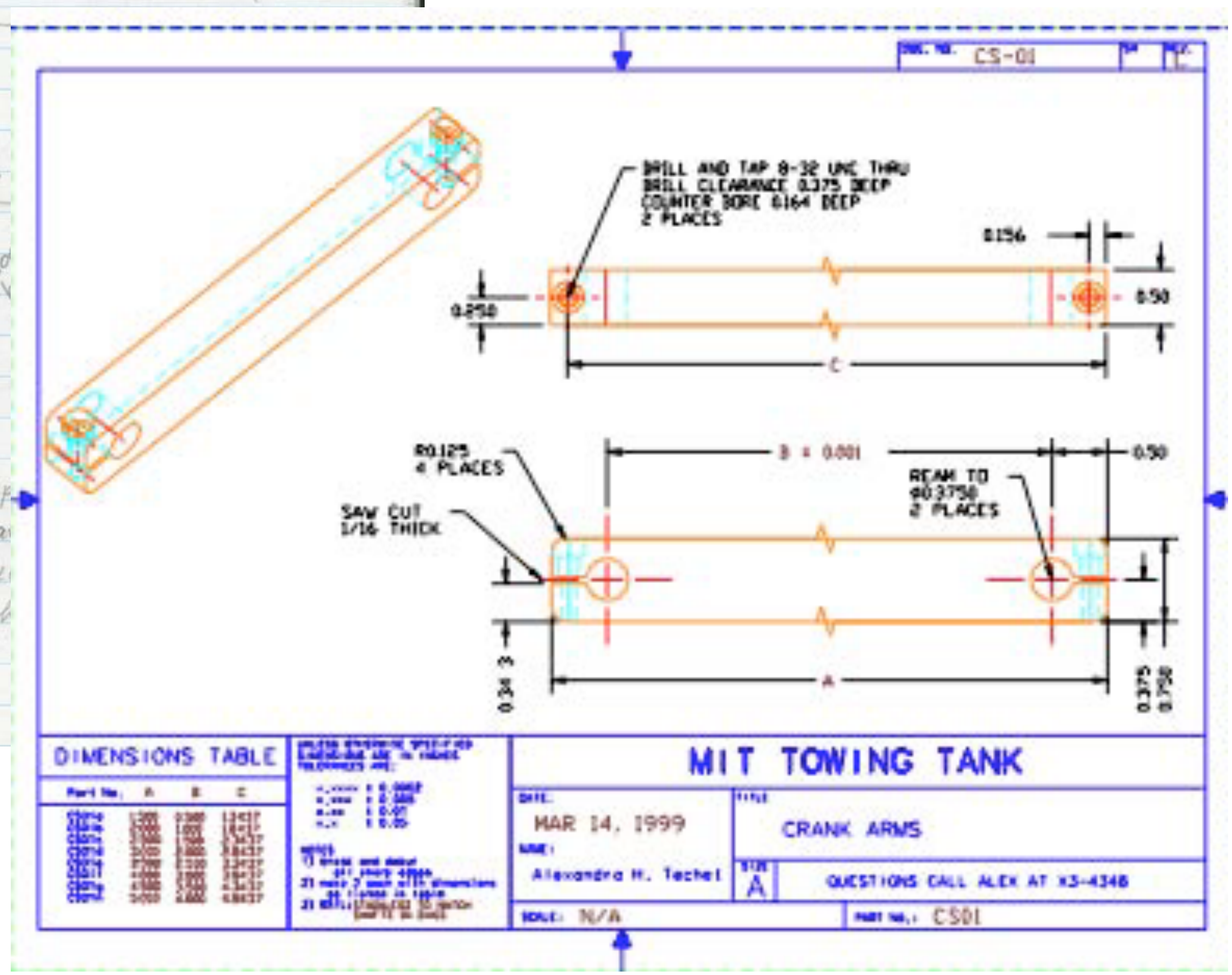


Preliminary Analysis



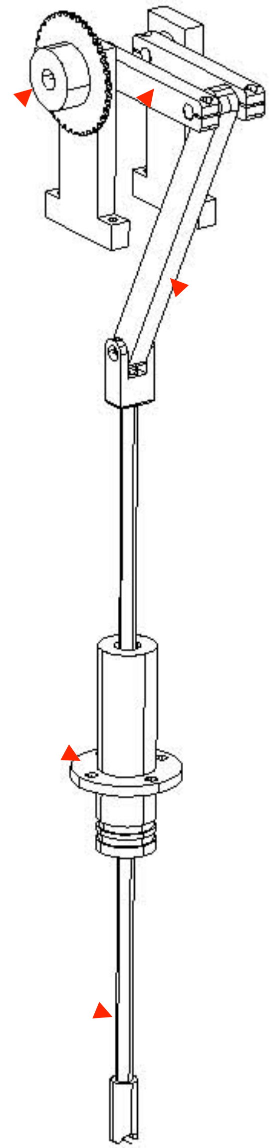
Crank Arms


Each Piston is 5" apart → 0 → 40"
ΔA = 0.175"
A in inches →
Lead Edge
0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0
Piston # 1 2 3 4 5 6 7 8
A (cm)
0, 1.27, 2.54, 3.81, 5.08,
Crank arms →
tap
A
1/16"
8-32
φ = 0.375"
0.125
clearance
0.5" thick

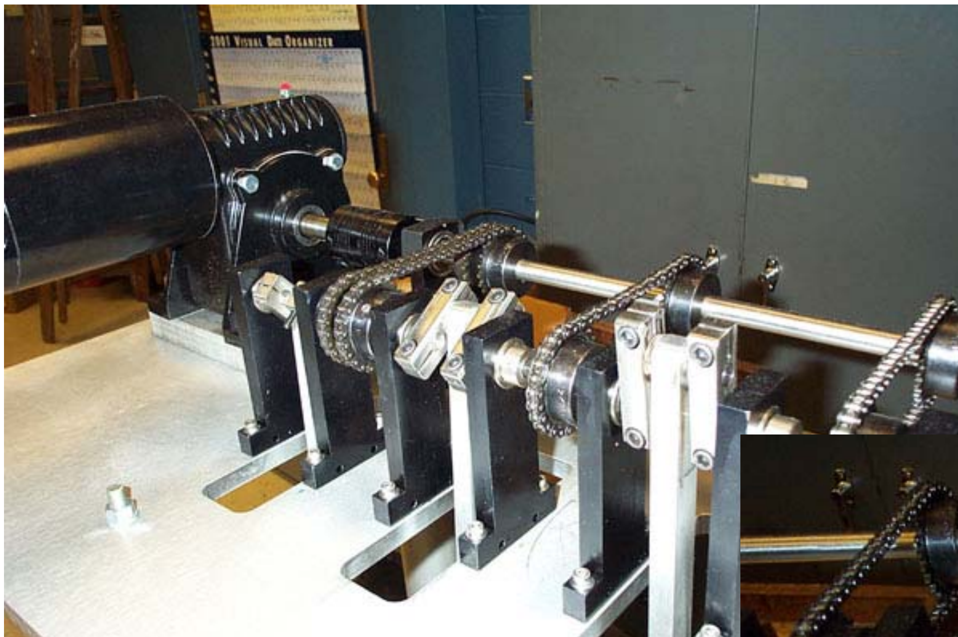

CS-01
DRILL AND TAP 8-32 UNC THRU
DRILL CLEARANCE 0.375 DEEP
COUNTER BORE 0.164 DEEP
2 PLACES
R0.125
4 PLACES
SAW CUT
1/16 THICK
REAM TO
Ø0.3750
2 PLACES
DIMENSIONS TABLE
MIT TOWING TANK
MAR 14, 1999
CRANK ARMS
Alexandra H. Techet
A
QUESTIONS CALL ALEX AT X3-4348
N/A
CS01

Final Piston Assembly

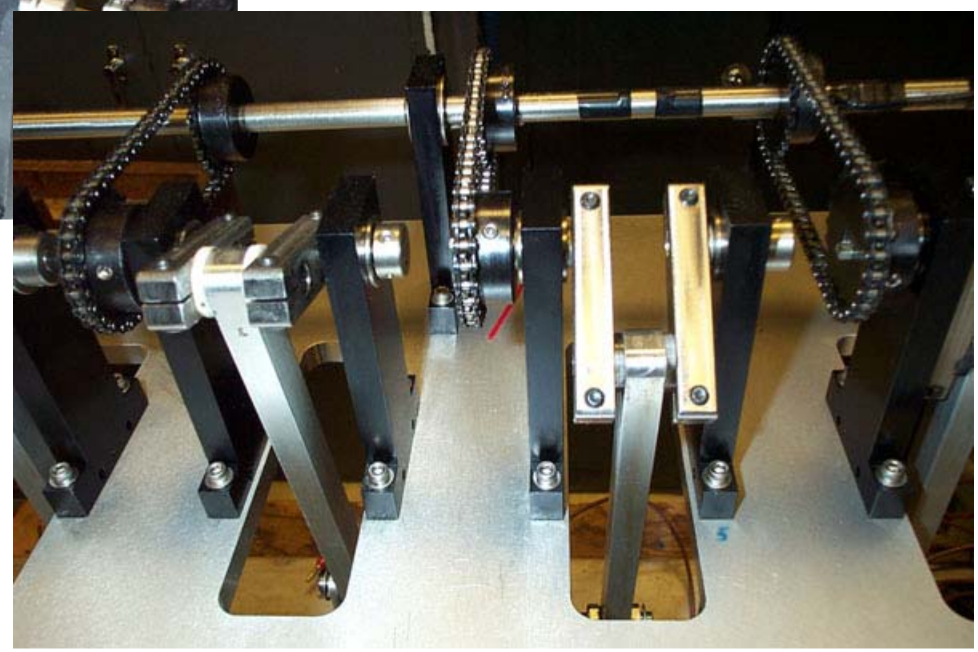
Traveling wave motion is created by a system of *eight* piston rods which are driven vertically by a crank-arm linkage mechanism.



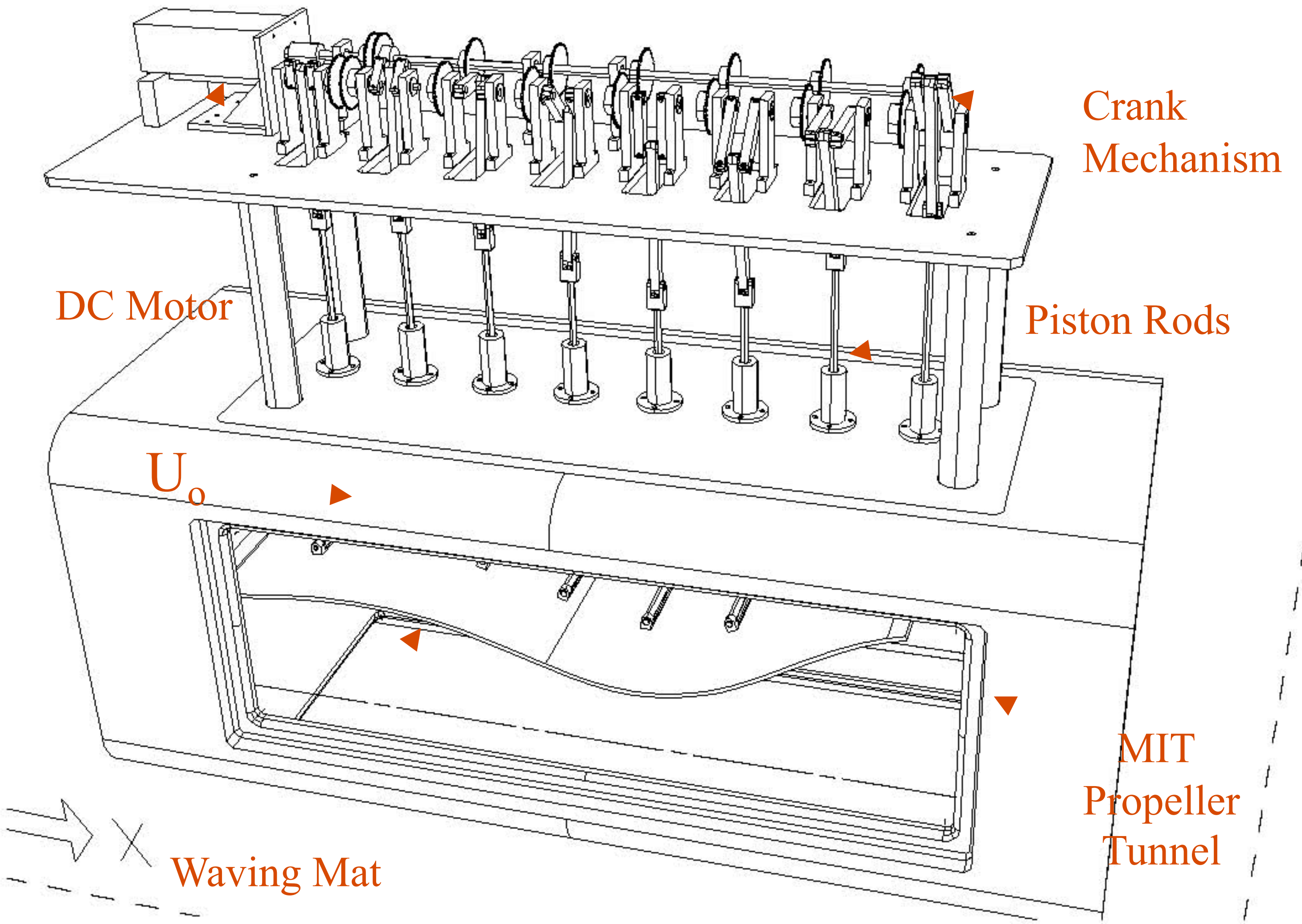
Drive Mechanism



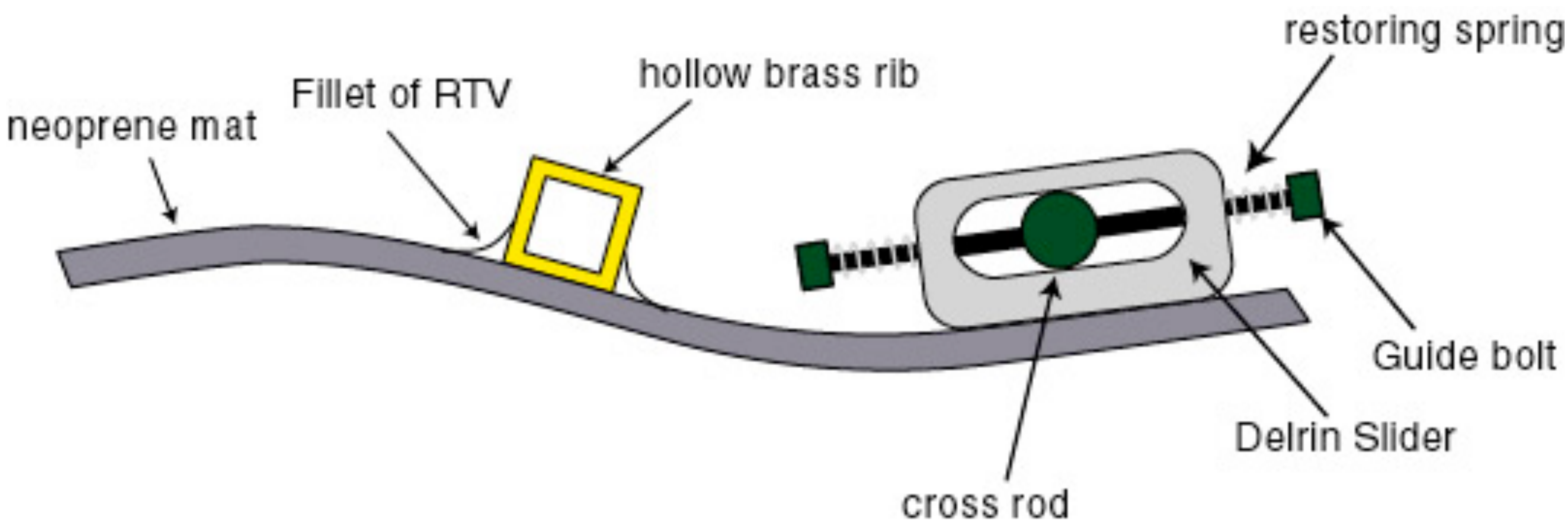
The plate is driven by a 1/3-Hp DC motor and common drive shaft



Waving Mat Mechanism



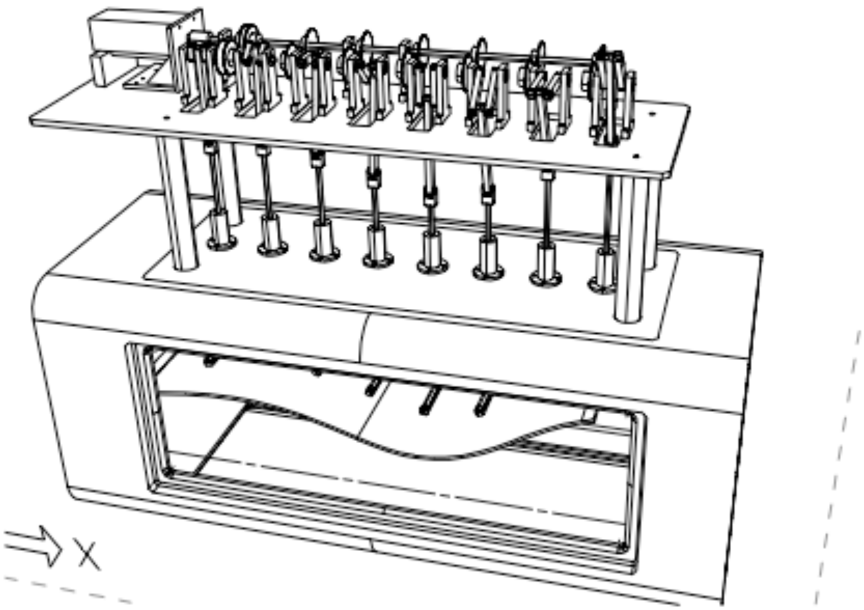
Waving Mat Construction

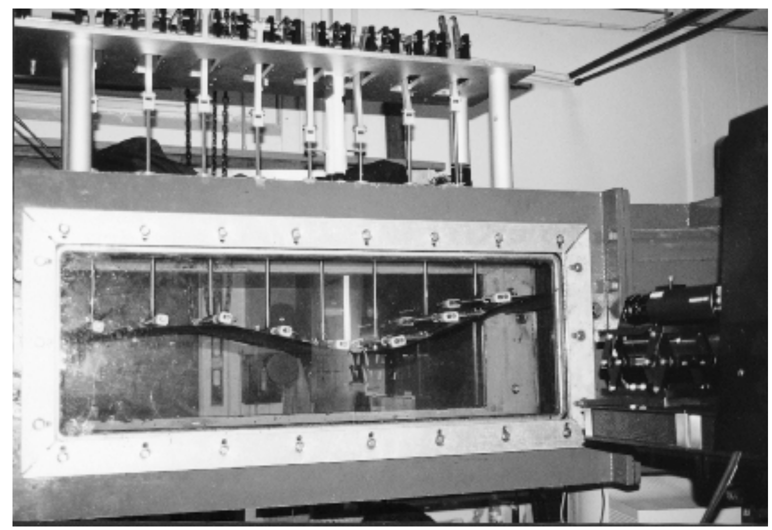


Over one wave cycle the mat must be allowed to change length to avoid being stretched, so sliders are built to accommodate this motion, springs enforce smooth motion.

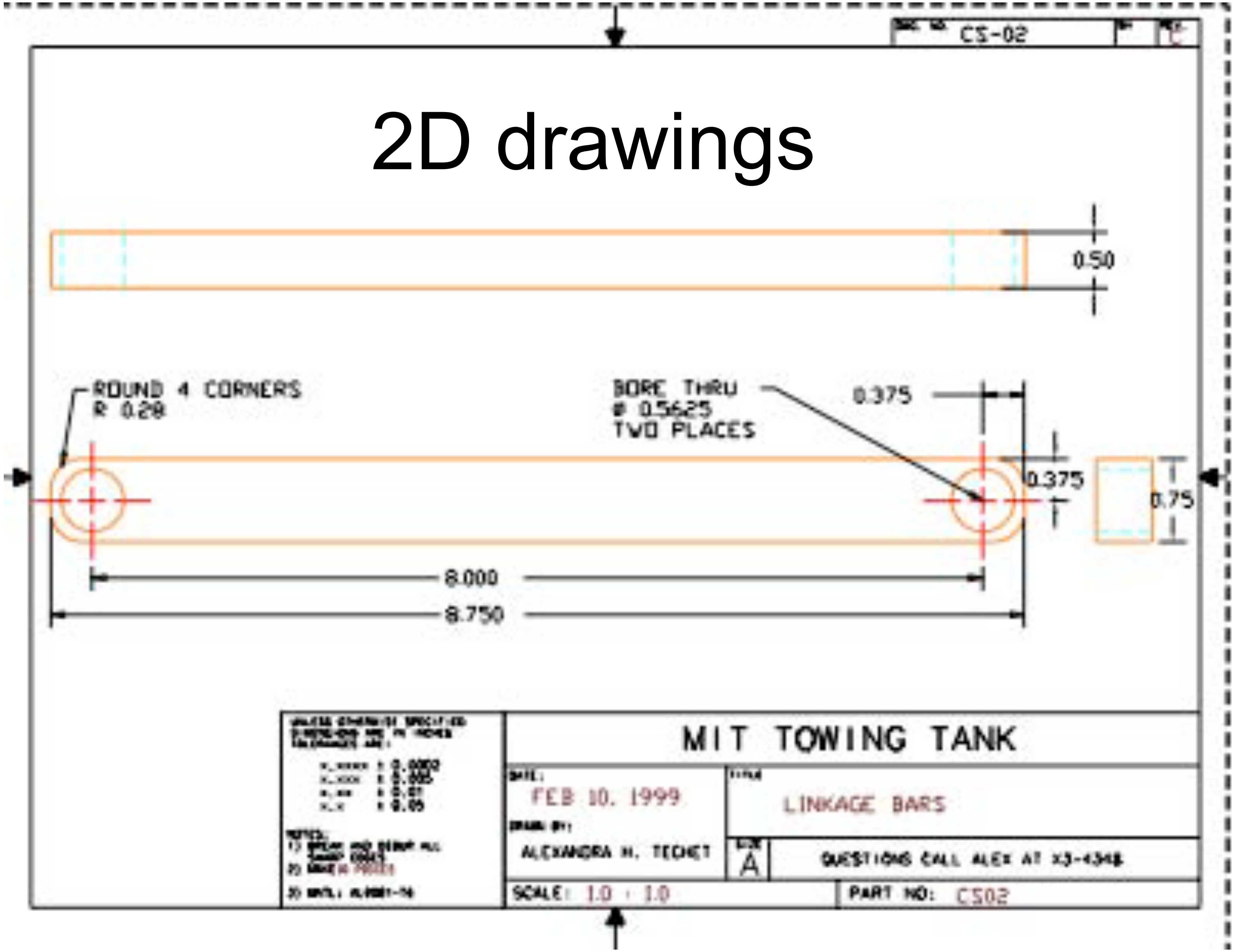

Delrin Sliders

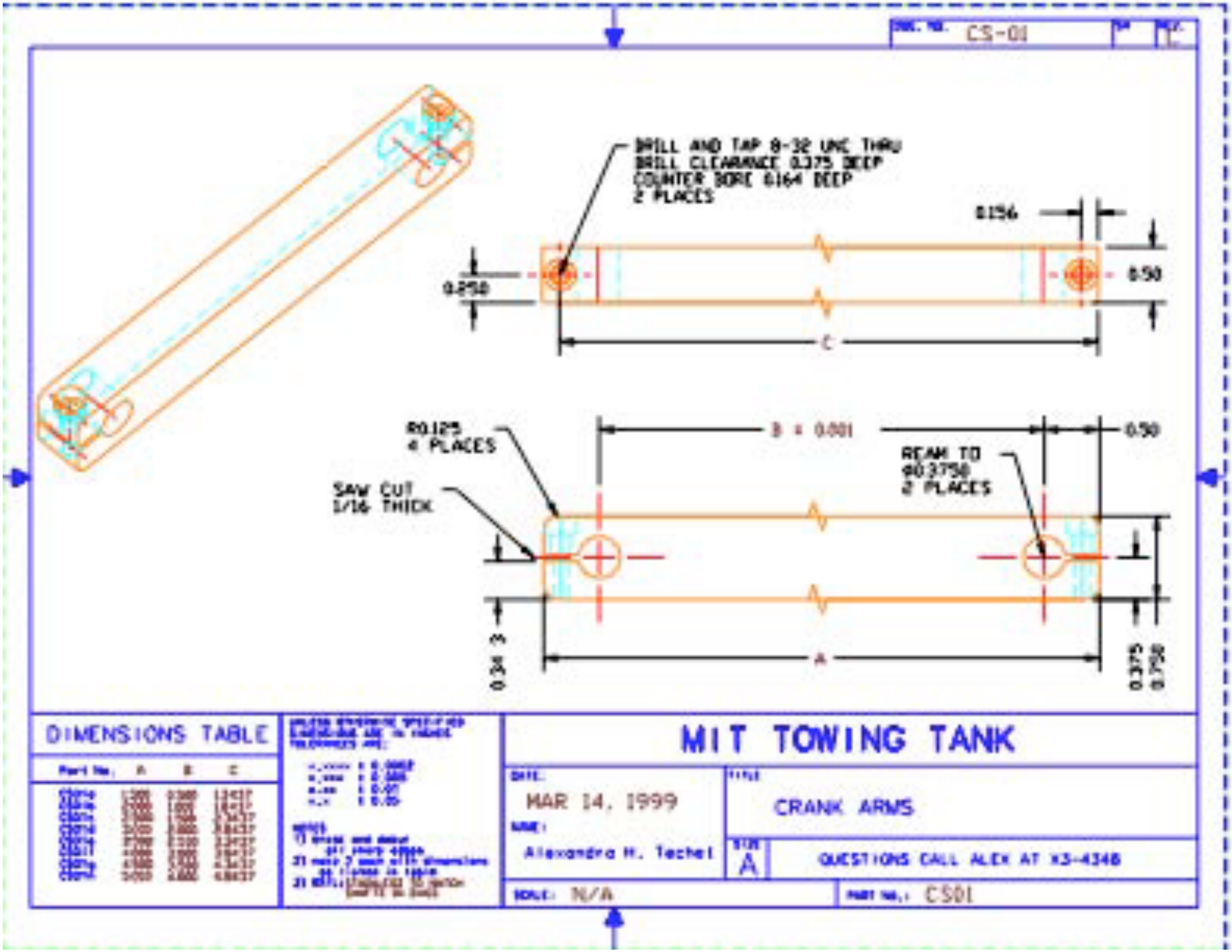
From 3D Cad to actual apparatus





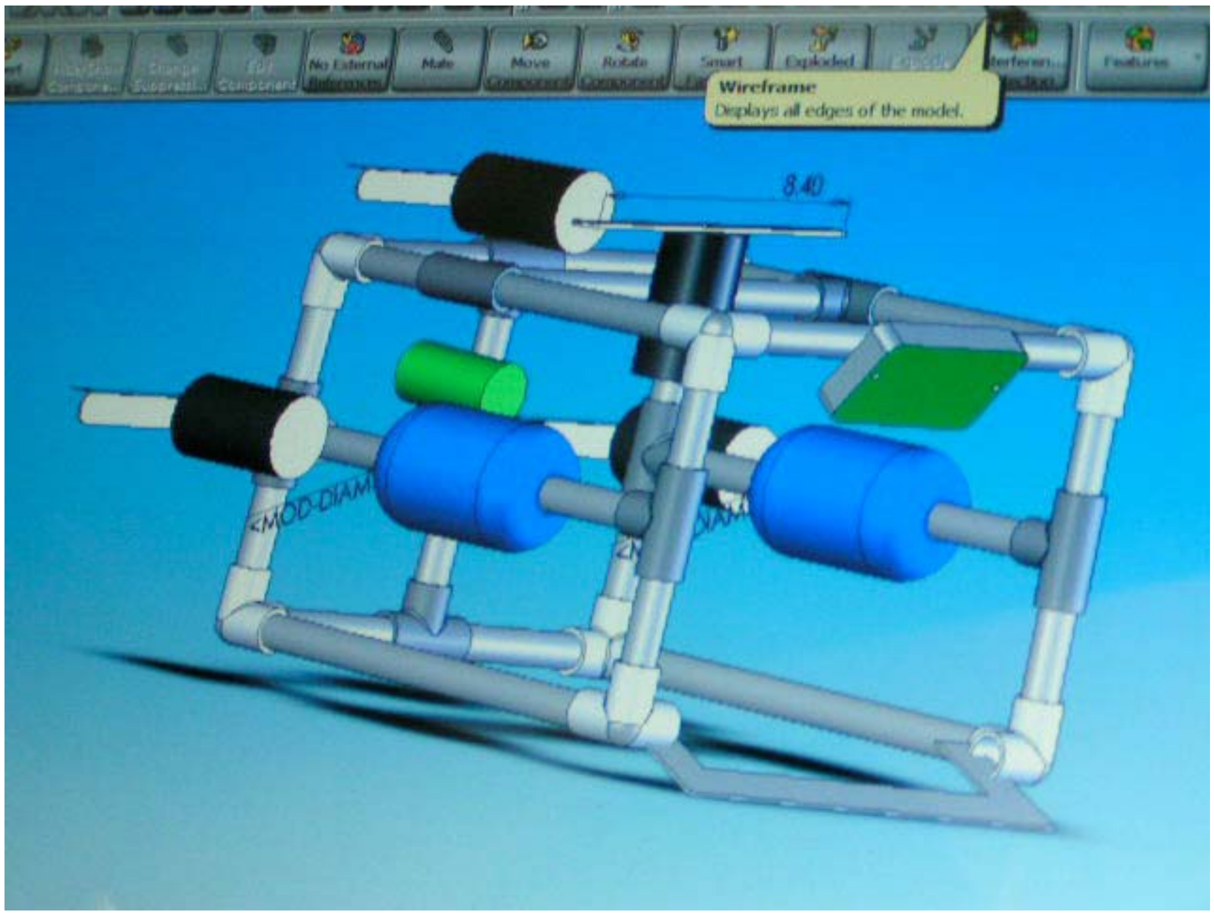
2D drawings


CS-02
0.50
ROUND 4 CORNERS
R 0.28
BORE THRU
Ø 0.5625
TWO PLACES
0.375
0.375
0.75
8.000
8.750
MIT TOWING TANK
FEB 10, 1999
LINKAGE BARS
ALEXANDRA H. TECHET
A
QUESTIONS CALL ALEX AT X3-4348
SCALE: 1.0 : 1.0
PART NO: CS02



CS-01
DRILL AND TAP 8-32 UNC THRU
DRILL CLEARANCE 0.375 DEEP
COUNTER BORE 0.164 DEEP
2 PLACES
0.156
0.250
0.50
C
R0.125
4 PLACES
B ± 0.001
0.50
REAM TO
Φ0.3750
2 PLACES
SAW CUT
1/16 THICK
A
0.375
0.750
DIMENSIONS TABLE
MIT TOWING TANK
DATE:
MAR 14, 1999
NAME:
Alexandra H. Techet
TITLE
CRANK ARMS
SIZE
A
QUESTIONS CALL ALEX AT X3-4348
SCALE: N/A
PART NO.: CS01

3D CAD


No External References
Mate
Move Component
Rotate Component
Exploded
Features
Wireframe
Displays all edges of the model.
8.40
<MOD-DIAM