Developing the Future Workforce: Thinking *Design* at Harvey Mudd

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In the interests of full disclosure:

- ✓ Harvey Mudd College's Department of Engineering offers (only) a broad, unspecialized, design- and systems-oriented BSE degree, which can be viewed as ***non-disciplinary*** or ***interdisciplinary*** or ***multidisciplinary***.

- ✓ ***Design*** is the ***distinguishing*** activity of engineering.

Herbert A. Simon

- ✓ Design ought to be the ***cornerstone*** (or the ***backbone***) of engineering education; it ought to be present each each and every year.

Clive L. Dym

Engineering: Thinking *Design* @ HMC (I):

Macro-Challenges as the World Flattens

Micro-Challenges as Understanding Deepens

Project-Centered Design at Harvey Mudd

Closing Remarks

The environment *has* changed (i):

- ✓ in terms of ***devices*** and ***artifacts*** (e.g., computers, wireless, genetically-engineered drugs, nano-scale devices);
- ✓ in terms of ***processes*** (e.g., knowledge representation, ***dissemination***, dispersion, ***democratization***, and management); and
- ✓ with the world getting ***flatter***, with individuals ***empowered***, and with the ***commoditization*** of many products and services.

The environment *has* changed (ii):

- ✓ Thomas L. Friedman notes a ***triple convergence*** of . . .
  - ❑ ***new flattening forces***, heralded by transformation to knowledge society, with value created horizontally rather than vertically, enhanced by "steroids" in computer usage at all levels;
  - ❑ ***new business habits***, wherein companies and people develop new business habits; and
  - ❑ whole new ***populations of new players*** from China, India, and the former Soviet Empire.

The environment *has* changed (iii):

- ✓ ***Globalization 1.0*** **—** you have a ticket agent;
- ✓ ***Globalization 2.0*** **—** you go to an e-ticket kiosk; and
- ✓ ***Globalization 3.0*** **—** you are your own ticket agent.

The environment *has really* changed (iv):

- ✓ As Friedman notes, ***the playing field has been leveled*** because . . .
  - ❑ talent in the former Soviet empire, China, India, etc., is now available to US firms because of the ***Internet***;
  - ❑ many tasks have become ***commodities*** that can be ***outsourced*** to Russia, China, India, etc.; and
  - ❑ firms will retain these many tasks stateside ***only*** if they ***add value*** and ***differentiate themselves in the market***.

The environment *has* changed (v-a):

- ✓ The late John H. McMasters cited a ***perfect storm*** (or ***quadruple convergence***) of . . .
  - ❑ ***global warming***, with its impacts on the environment and the global economy;
  - ❑ ***increasing world population***, wherein rising populations and changing demographics develop different needs and habits;
  - ❑ ***finite supply of natural resources,*** because we will run out fossil fuels, various minerals, and water; and
  - ❑ and ***cultures and institutions being unable (?) and/or unwilling (?) to change!!***

The environment *has* changed (v-b):

✓ McMasters also depicted that ***perfect storm*** (while noting that **engineers are fundamental to solving or ameliorating!**) . . .

Increasing World Population

Cultures/Institutions Unable/Unwilling to Change

Global Climate Change

Finite Supply of Key Natural Resources (Oil, Water, Minerals)

The environment *has* changed (vi):

- ✓ US ***bachelor's degrees in engineering*** (***BSE***s) from 77,572 (***7.8%***) in 1985 to 72,893 (***4%***) in 2004;
- ✓ in ***China***, more than 200,000 (***44%***) ***BSE***'s in 2004, and planning for more than 1,000,000 (***!***);
- ✓ of ***2,800,000 first degrees in science/engineering*** granted world wide, 1,200,000 in Asian universities, 830,000 in Europe, ***400,000 in US***; and
- ✓ Asian universities produce eight (***8!***) times as many ***BSE*** degrees as do American universities.

Engineering: Thinking *Design* @ HMC (II):

Macro-Challenges as the World Flattens

Micro-Challenges as Understanding Deepens

Project-Centered Design at Harvey Mudd

Closing Remarks

Science-based *analysis* is done well . . .

- ✓ . . . through ***systematic questioning*** reaching ***true***, verifiable (and typically ***unique***) answers in. . .
  - ❑ mathematics, physics, chemistry, biology, etc.;
  - ❑ disciplinary knowledge (e.g., structures, chips, gears);
  - ❑ initial development of ***compiled*** (expert) knowledge;
- ✓ . . . which is the process of ***reductionism***, of ***convergent thinking*** in the (largely) ***deterministic***, ***knowledge domain***.

On the other hand, *design* . . .

- ✓ . . . is the process of ***synthesis***, which incorporates ***divergent inquiry*** in the ***concept domain****,* which means*. . .*
- ✓ . . . that ***questioning*** does not necessarily produce ***true***, verifiable answers, and that . . .
- ✓ . . . experts develop reflective, *tacit* knowledge that evolves from . . .
- ✓ . . . repeated ***iteration*** of convergent and divergent thinking that results in the (net) ***transformation*** of concept knowledge into domain knowledge.

Being a ***design team member*** means . . .

- ✓ . . . understanding design as *a* ***social process***,
- ✓ . . . seeing early parts of design as ***inherently argumentative***,
- ✓ . . . accepting that ***ambiguity*** and ***negotiation*** are central,
- ✓ . . . understanding that ***good design*** means that technology should serve ***all*** members of (targeted) user community, and
- ✓ . . . understanding that ***diversity*** (gender, ethnicity, experience, discipline, MBTI, locale; complementary roles, plurality of views) is conducive to good design.

Design is also a great context for . . .

- ✓ . . . exploring **ethics** as conflicting obligations, and
- ✓ . . . examining and assessing **societal impacts**.

Engineering: Thinking *Design* @ HMC (III):

Macro-Challenges as the World Flattens

Micro-Challenges as Understanding Deepens

Project-Centered Design at Harvey Mudd

Closing Remarks

The educational environment *is* changing:

HARVEY MUDD COLLEGE CENTER FOR DESIGN EDUCATION

- ✓ Clive L. Dym notes a ***triple convergence*** of . . .
  - ❑ ***curricular pressures*** (e.g., credit shifts from 144 to 128 to 120 (?), emerging emphases on communication and teams, ASCE Policy 465);
  - ❑ ***increased computer 'skills' of incoming students*** (e.g., lesser mathematical skills, library research to web surfing); and
  - ❑ engineering graduates face a changing world as ***engineering tasks to commodities*** that are being ***outsourced*** to Russia, India, China, etc.

Even ABET has ***new attributes*** for engineers:

- ✓ have a good foundation in the engineering sciences,
- ✓ be able to design to meet desired needs,
- ✓ be able to function on interdisciplinary or ***multidisciplinary*** teams,
- ✓ have communication skills,
- ✓ understand the social impact of their work, and
- ✓ understand their ethical obligations.

Thus, even ABET recognizes the value of *. . .*

. . . ***soft*** skills**,** or as better put by **McMasters . . .**

. . . skills of ***professional practice*!!**

The *it* we want to teach is . . .

- ✓ . . . engineering is both a ***body of knowledge*** and a ***process*** . . .

  William A. Wulf

- ✓ . . . and that beyond being ***theoretical carpenters***, engineers must be able to ***synthesize and integrate systems*** or to ***design*** . . .

  John H. McMasters

- ✓ . . . that the engineering curriculum should be understood as the sum of a set of ***experiences*** in which students participate and a set of ***skills*** they will acquire.

  Clive L. Dym

Engineering: Thinking *Design* @ HMC (III):

Macro-Challenges as the World Flattens

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Project-Centered Design at Harvey Mudd

Closing Remarks

HMC design experiences integrate . . .

- ✓ . . . traditional, ***experiential*** approaches, ***and***
- ✓ . . . modern, ***process / methods*** approaches.

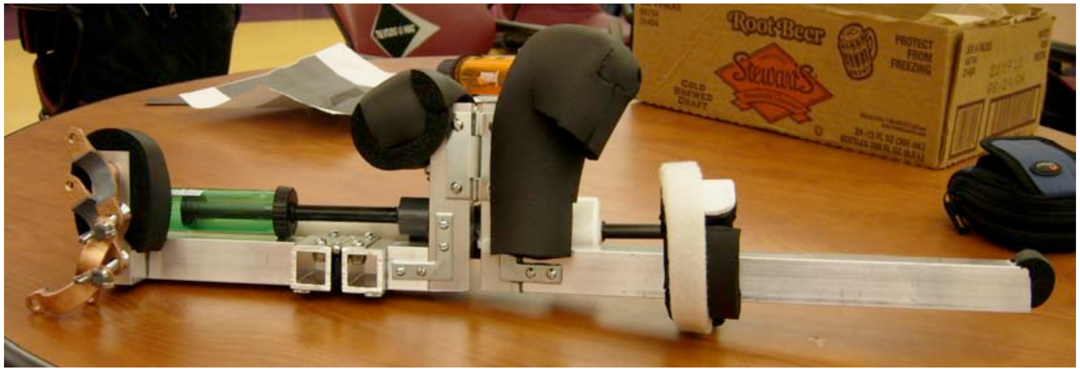
HMC design projects, experiences provide opportunities for students to . . .

- ✓ . . . work in teams on ***multidisciplinary*** design projects;
- ✓ . . . work in broader, more ambiguous contexts;
- ✓ . . . work with other professionals in teams;
- ✓ . . . make qualitative judgments and assessments;
- ✓ . . . make oral and written presentations of design results; and
- ✓ . . . learn about and identify with what engineers do;

E4 Projects (1):

- ✓ **Client: Western University of Health Sciences**
  Project: Design a "Visual Stethoscope"

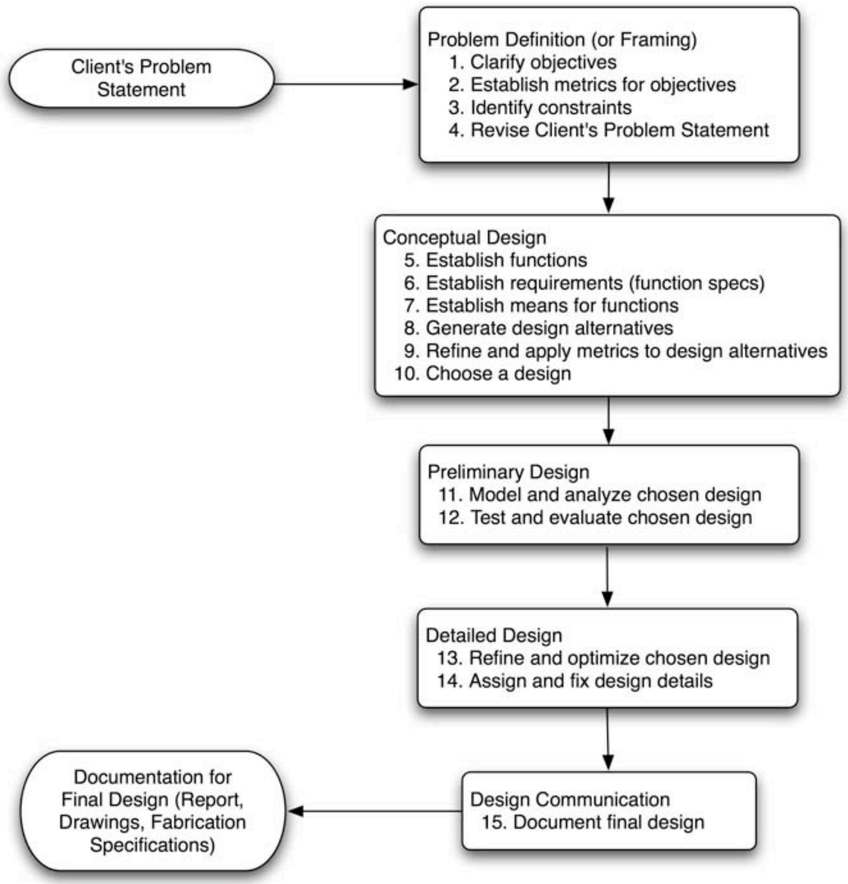
- ✓ **Client: Danbury (Special Education) School**
  Project: Design an Arm Support Device for Student with CP



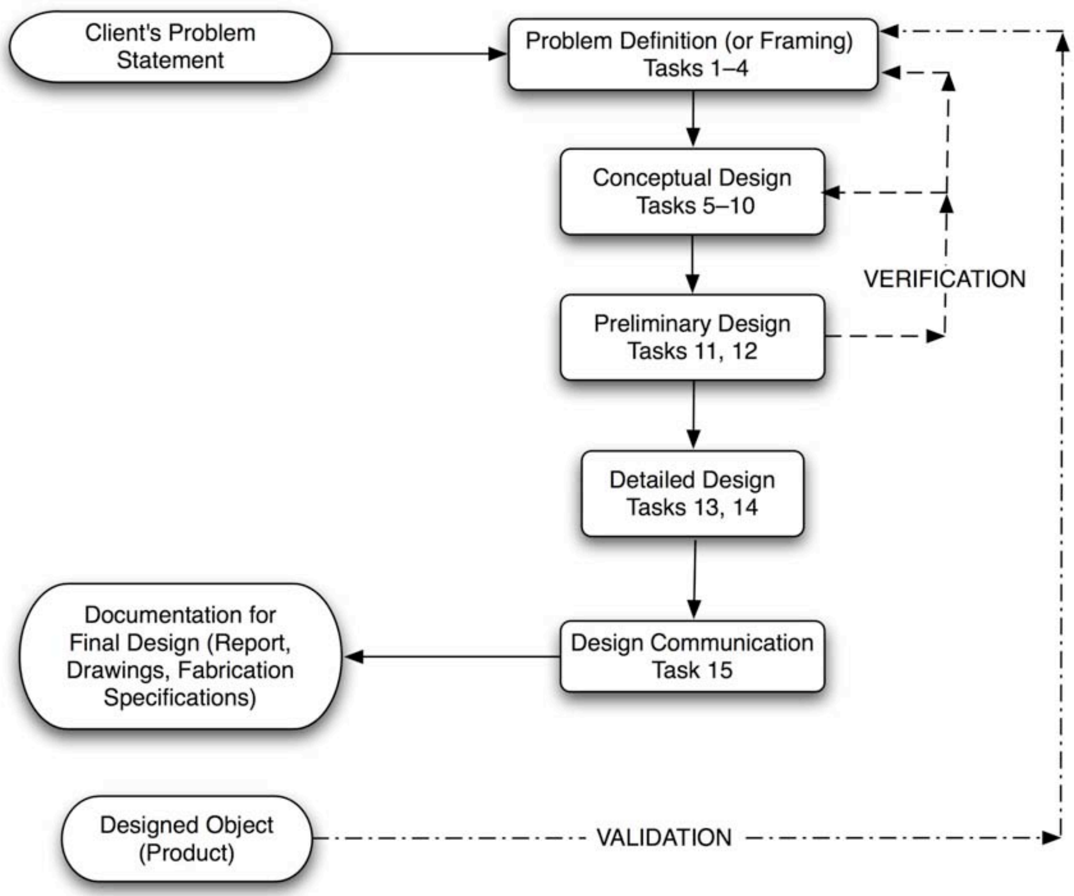
E4 experiences include:

- ✓ executing a design process;
- ✓ defining (framing) problem, objectives, constraints;
- ✓ establishing functions and requirements;
- ✓ generating and evaluating design alternatives;
- ✓ modeling, prototyping, building proofs of concept;
- ✓ team behaviors, dynamics;
- ✓ reporting on, documenting design projects;
- ✓ identifying conflicting obligations (ethics); and
- ✓ managing design projects.

The Design Process (v. 1.0):



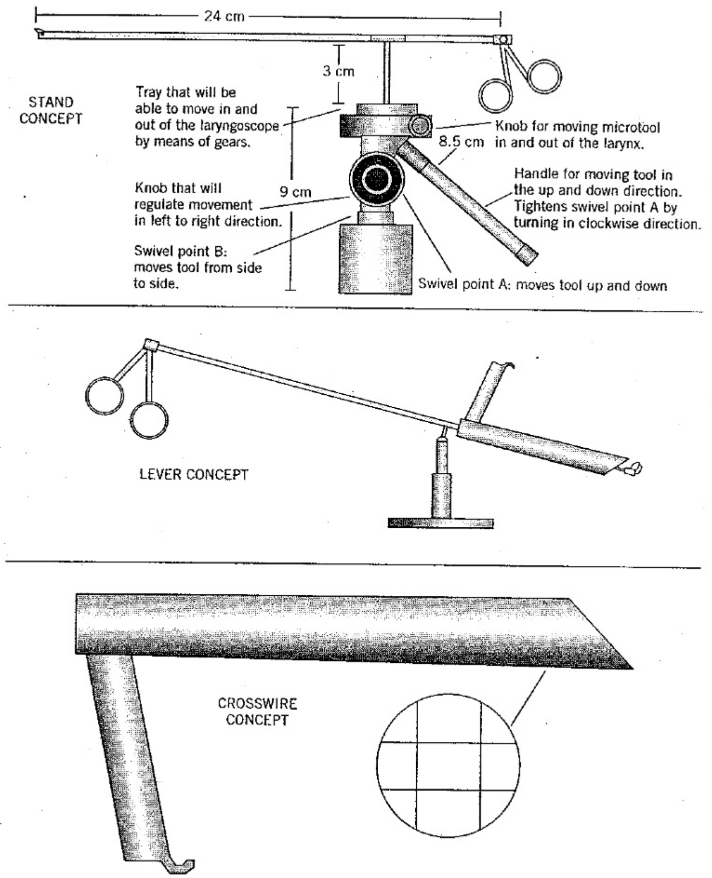
The Design Process (v. 1.5):



E4 Projects (2):

✓ **Client:** **University of California, Irvine, Medical Center**

Project: Design of a Microlaryngeal Surgical Stabilizer



Some Clinic Design Projects:

- ✓ **Client:** **Direct Methanol Fuel Cell Corporation**
  Project: **Design Authentication and Child-Proofing for a Direct Methanol Fuel Cell Cartridge**

- ✓ **Client:** **Space Systems / Loral**
  Project: **Design a Low-Shock Release Mechanism for Satellite-Based Solar Arrays**

Direct Methanol Fuel Cell Corporation

Students: Kenneth Maples, Michael Bigelow, Wayne Tanaka, Laurel Fullerton, Mike Saldana, Yosuke Sato (Fall)
Advisor: Clive Dym   *Liaisons*: Manel Arranz, Huyen Dinh

What are Fuel Cell Cartridges?

A direct methanol fuel cell utilizes methanol fuel, stored in cartridges, to provide power. The fuel cartridge must house the methanol and prevent accidental spillage.

Our Project

DMFCC requested that we help them develop new ideas for their line of methanol fuel cartridges. In the first semester, we generated over 30 new ideas for fuel cartridge features in the following areas

•Housing

•Fuel Delivery

•Child Safety

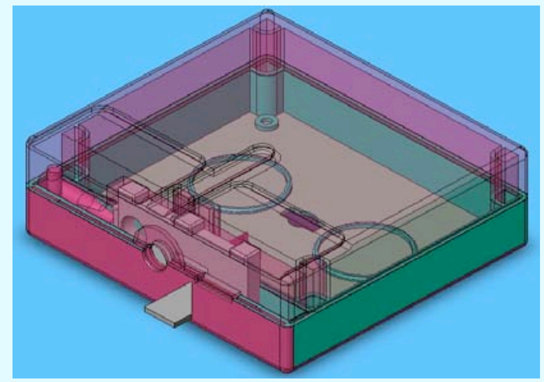
•Authentication

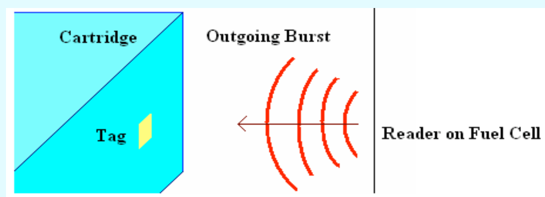
In the second semester, we took the first generation prototype that DFMCC developed in December and designed child safety and authentication devices based on our preliminary ideas.

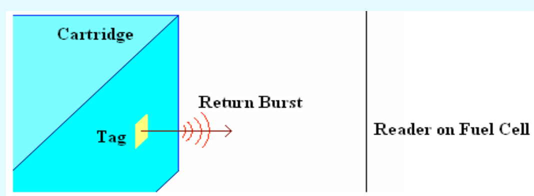
Our Results

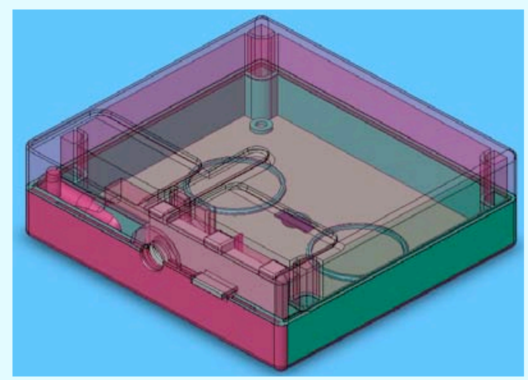
We developed a new automatic child safety system using a sliding door opened by inserting the cartridge into the fuel cell. The design adds only two parts to the cartridge and prevents children from accessing the methanol valve.

Additionally, we developed an authentication system using passive RFID tags. This system allows the fuel cell to distinguish between real and potentially dangerous pirate copies of fuel cartridges.









Nitinol Actuated Preload Release

Team Members: Mike Chan, Michael Crockett, Noel Godinez, Daniel Rodriguez
Team Leader: Casey Schilling
Advisor: Professor Clive Dym
Liaisons: Mark Zanella, Gerrit Van Ommering

Background

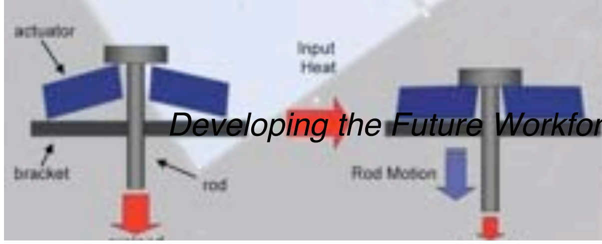
Hold-downs keep satellite components in place during launch and then release the components once in orbit. Current hold-downs use pyrotechnic cutters to release the components, and produce more shock than desired. A low-shock hold-down is needed to accommodate communication equipment that is becoming much smaller and more sensitive to shock due to release.

Problem Statement

The goal of this project was to reduce preload in a hold-down prior to release, thus reducing shock. The design must hold a high preload during storage and launch. Components must fit within the current footprint and be easily integrated into current solar array architecture. Designs must also maximize reliability, minimize shock during release, and be marketable to SS/L.

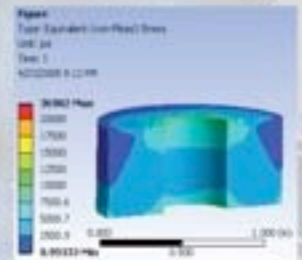
Nitinol Actuator Design

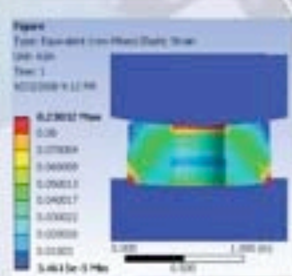
The final design modifies the existing SS/L hold-down to include a Nitinol actuator. The actuator is a thick washer with an initial deformation. When heated, the Nitinol's shape memory properties restore the actuator to its predeformed state. This shape transformation reduces the preload within the rod, which in effect attenuates the resultant shock when the rod is cut.



Structural Modeling

Initial structural modeling was performed in ANSYS, a finite element software package. Static stress modeling was used to ensure the actuator stays within material constraints when preloaded in SS/L's current apparatus.

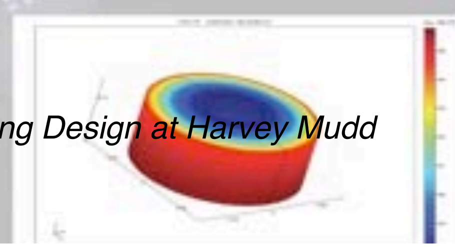




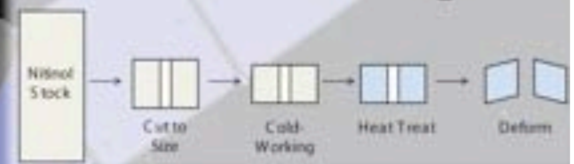
Additionally, there is a limit to the amount of recoverable displacement in the Nitinol actuator. A model of the strain distribution in the actuator as it is deformed ensures that the displacements are within the recoverable range of motion.

Thermal Modeling

COMSOL Multiphysics was used to model the time required to transfer the necessary amount of heat to activate the Nitinol. Heat was applied to the outer of the actuator using a flexible cable heater.



Actuator Manufacturing



Testing

A test aparatus with a load cell and titanium rod were used to simulate the hold-down application. Several different actuators were tested and relieved preload in the titanium rod. Up to 75% of the initial strain energy was gradually released and heating of the actuator took 480 seconds at 100 Watts of power.

Nitinol Actuators

Engineering: Thinking *Design* @ HMC (IV):

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Closing Remarks

Closing remarks (i):

✓ . . . the engineering curriculum is an ***artifact***, worthy of design.

after *Lynn Conway and Mark Stefik*

Closing remarks (ii):

- ✓ "Where a mule can go, I can make a locomotive go."
- ✓ In England and in Europe, after George Stephenson launched the first locomotive in 1829, little of significance in [railroad] design change took place for the next thirty years. In America nearly everything did, because of the contempt for authority among American **engineers**, ***who invented new ways to deal with old problems regardless of precedent***.

Ambrose, *Nothing Like It in the World*

Closing remarks (iii):

- ✓ **57** NASA Clinics (JPL **30**, Ames **21**, Dryden **6**)
- ✓ **41** HMC alumni @ NASA (JPL **34**, Ames **6**, in DC **1**)
- ✓ **Astronaut** George (“Pinky”) Nelson, HMC ‘74
- ✓ **Astronaut** Stanley G. (Stan”) Love, HMC ‘87

Closing remarks (iv):

$$\nabla^4 w + 2\left(\frac{\sigma}{\sigma_{cl}}\right)\frac{\partial^2 w}{\partial x^2} - \frac{\partial^2 F}{\partial x^2} = \nabla^4 w_0 + \varphi\left[\frac{\partial^2 F}{\partial x^2}\frac{\partial^2 w}{\partial y^2} - 2\frac{\partial^2 F}{\partial x \partial y}\frac{\partial^2 w}{\partial x \partial y} + \frac{\partial^2 F}{\partial y^2}\frac{\partial^2 w}{\partial x^2}\right]$$

$$\nabla^4 F + \frac{\partial^2 w}{\partial x^2} = \frac{\partial^2 w_0}{\partial x^2} + \varphi\left[\left(\frac{\partial^2 w}{\partial x \partial y}\right)^2 - \frac{\partial^2 w}{\partial x^2}\frac{\partial^2 w}{\partial y^2} - \left(\frac{\partial^2 w_0}{\partial x \partial y}\right)^2 + \frac{\partial^2 w_0}{\partial x^2}\frac{\partial^2 w_0}{\partial y^2}\right]$$

Questions?

$$\varphi = \sqrt{12(1-\nu^2)}$$

Acknowledgements:

C. L. Dym, **A. M. Agogino**, **O. Eris**, **D. D. Frey**, and **L. J. Leifer**, "Engineering Design Thinking, Teaching, and Learning", *Journal of Engineering Education*, *94* (1), 103–120, January 2005.

C. L. Dym and **P. Little**, with **E. J. Orwin** and **R. E. Spjut**, *Engineering Design: A Project-Based Introduction*, 3rd Edition, John Wiley, New York, 2008.

Design thinking requires *skills*, abilities to:

- ✓ handle ambiguity,
- ✓ maintain a "big picture" or "systems" or ***multidisciplinary*** perspective,
- ✓ make decisions,
- ✓ think, communicate in the several languages of design, and
- ✓ think as part of a team in the social process of design . . .

. . . in context of applying science-based ***analysis*** to devices, systems, and processes.

Handling ***ambiguity*** in design means . . .

- ✓ . . . asking questions (e.g., as part of ***problem definition***) because "knowledge resides in the questions that can be asked and the answers that can be provided,"
- ✓ . . . accepting that answers are ***untrue*** (i.e., unverifiable), and
- ✓ . . . handling — even ***enjoying*** — the iteration of divergent and convergent thinking that is central to the acquisition of engineering knowledge, that is, to design.

Maintaining a ***systems perspective*** means . . .

- ✓ . . . understanding ***system dynamics*** — unanticipated consequences from interactions between system components;
- ✓ . . . reasoning about ***uncertainty*** — using imperfect models, having incomplete information, and ambiguous or even conflicting objectives;
- ✓ . . . making good, reliable ***estimates****;* and
- ✓ . . . making good use of ***empirical*** and ***experimental*** data.

Making *decisions* in design means . . .

- ✓ . . . making ***rational choices*** or ***rational decisions***;
- ✓ . . . determining ***optimal*** results, if appropriate models exist;
- ✓ . . . using informal ***decision support aids***; and
- ✓ . . . continuing to ***generate*** design concepts and alternatives before any decisions are — or can be — made!

Thinking *in several languages* means . . .

- ✓ . . . ***verbal*** **or** ***textual statements,***
- ✓ . . . ***graphical representations,***
- ✓ . . . ***mathematical*** **or** ***analytical models,***
- ✓ . . . ***numbers,***
- ✓ . . . ***features,***
- ✓ . . . ***shape grammars,***
- ✓ . . . **etc.**