Term Project
Final Presentation

- Visual aids available on-campus
  - Computer projection
  - Document camera
  - Camera
- Visual aids available off-campus
  - Camera
  - OR -- Send me your slides electronically and I'll project them from my laptop

Term Project Grading

- Term project is 30% of course grade
- Written report is 75% of term project
  - Due on last Lecture day.
  - 10% penalty per day late
- Final presentation is 25% of term project

Term Project
Final Presentation Schedule

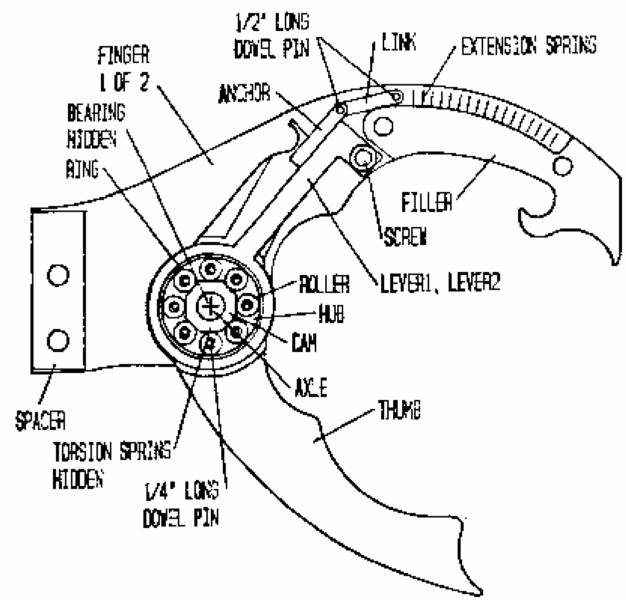
- Tom Hoag, “Designing a Robust Business”
- Chip Clampitt, “The Use of Orthogonal Arrays to Optimize Nonlinear Functions Iteratively”
- Karl Hauenstein, “Robust Design of a Voltage Controlled Oscillator”
- Boran, Goran, Pepin, Shashlo, Wickenheiser, “Robust System Design Application / Integration - Ford Motor Company”
- Joe Distefano, “Application of Robust Design Techniques to a Paper Winding Simulation”
- Garth Grover, “HPT Dovetail 2-D Form Robust Design”
- Shelley Hayes, “Taguchi Method Meets Publish and Subscribe”

Term Project
Final Presentation Schedule, Cont.

- Wei Zhao, “Taguchi and Beyond - Methodologies for Experimental Designs”
- J. Philip Perschbacher, “Robust Design of Blade Attachment Device”
- Michelle Martuccio, “Allied Signal's Six Sigma Initiative: A Robust Design Case Study”
- Steve Sides, Bob Slack, “Coating Technology for Jet Aircraft Engines”
- Ebad Jahangir, “Robust Design and its Relationship with Axiomatic Design”.
- Tom Courtney “Robust Thermal Inkjet Printhead Design”
- David Markham, “Robustness Testing of a Film-Scanner Magnetic Module”

Robust Conceptual Design

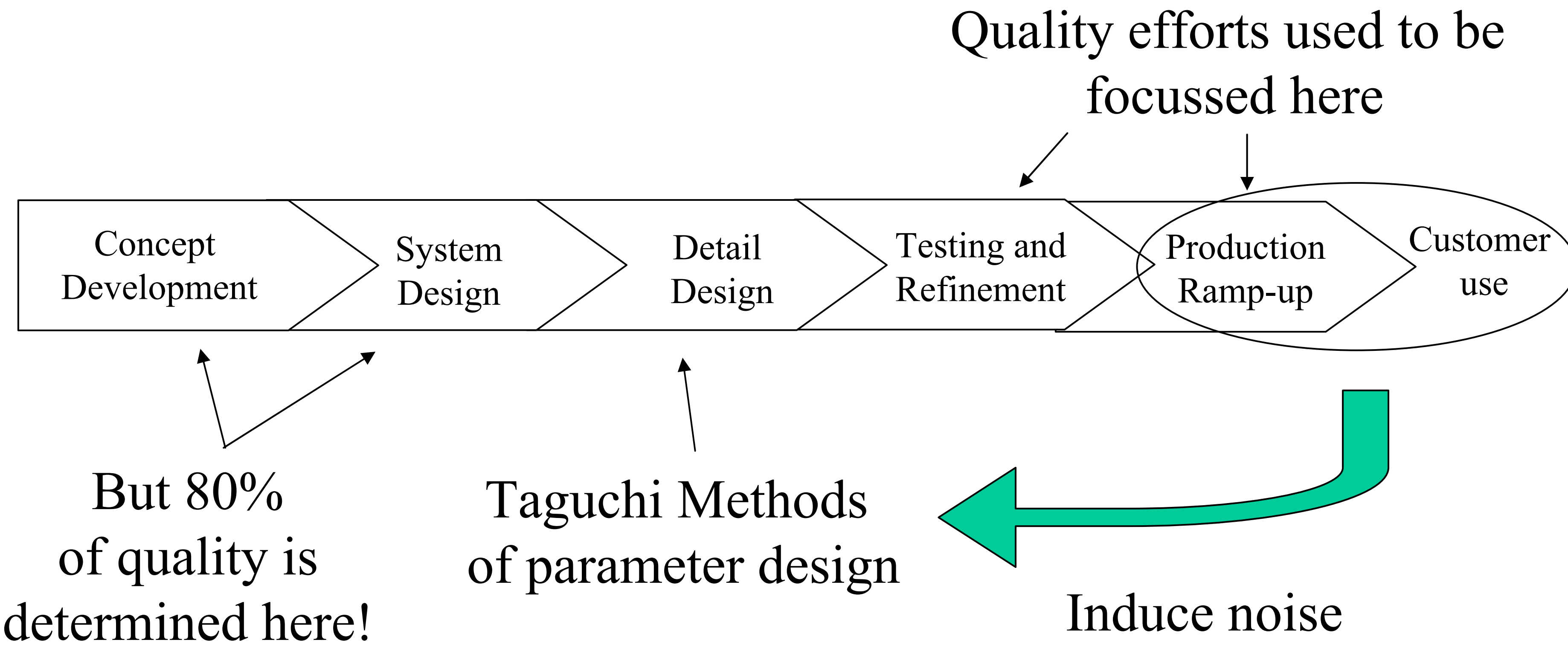
Considering Variation
Early in the Design Process



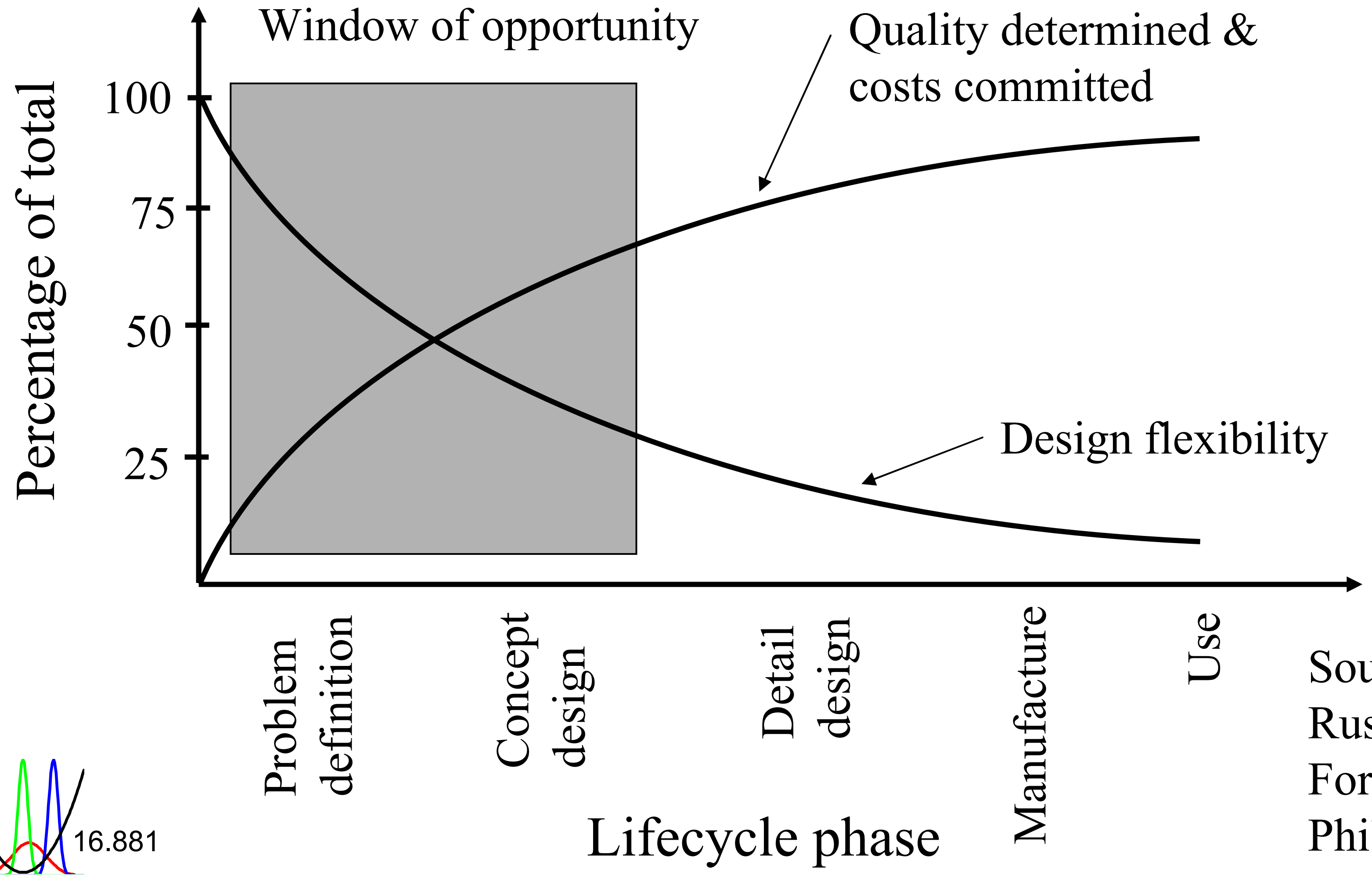
Outline

- Motivation
- Tools and tricks -- TRIZ, etc.
- A framework -- RCDM & wafer handling case
- Case study -- VMA prehensor
- Case study -- Adhesive application in LBPs

Quality in Product Development



Concept Design: The Window of Opportunity



Source: Russell B. Ford and Philip Barkan

Concept versus Parameter Design

Concept Design

- Begins with broad specs
- Free wheeling, intuitive
- One off experiments
- Rough analysis
- Requires insight

Parameter Design

- Begins with system design
- Bounded, systematic
- Orthogonal arrays
- Precise analysis
- Can be implemented as a "black box"

Source: Russell B. Ford and Philip Barkan

Biggest Roadblocks in Concept Design

- Poor problem formulation
- Stopping with too few alternatives
- Failure to search existing solutions
- Missing entire categories of solutions
- Inability to merge solutions

 Source: Ulrich and Eppinger, “Product Design and Development”

Properties of a Good Problem Statement

- Solution neutral
- Quantitative
- Clear
- Concise
- Complete

Techniques for Concept Generation

- Brainstorming
- Analogy
- Seek related and unrelated stimuli
- Use appropriate media to convey & explore
  - Sketching / Foam / Lego
- Circulate concepts & create galleries
- Systematically classify & search

 Source: Ulrich and Eppinger, “Product Design and Development”

Theory of Inventive Problem Solving (TRIZ)

- Genrich Altshuller
  - Sought to identify patterns in the patent literature (1946)
  - "Creativity as an Exact Science" translated in 1988.
- The basic concept
  - Define problems as contradictions
  - Compare them to solutions of a similar form
  - Provide a large database of physical phenomena
  - Anticipate trends in technical evolution

TRIZ Software

- Ideation International (http://www.ideationtriz.com/)
- Invention Machine (http://www.invention-machine.com/)
  - Effects
  - Principles
  - Prediction

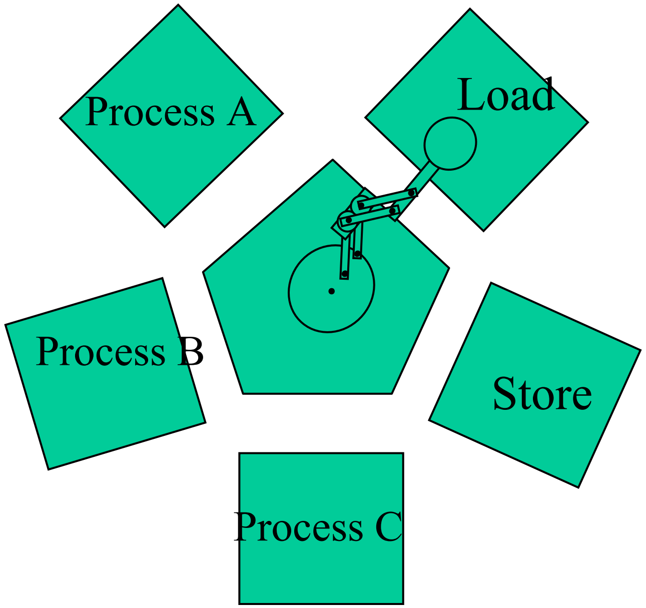
Tricks for Robust Concept Design

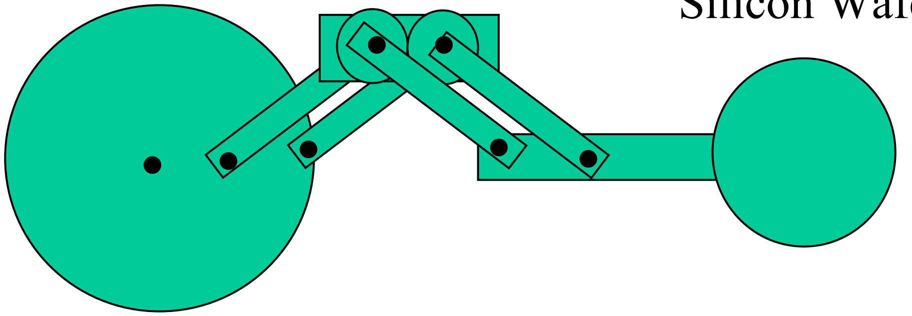
- Create lots of concepts with noise in mind
- Build breadboards & experiment (quickly)
- Don’t be afraid to revisit concept design stage
- Eliminate dependence on non-robust physical effects & technologies
- Design in non-linearities to exploit in parameter design

Robust Concept Design Methodology

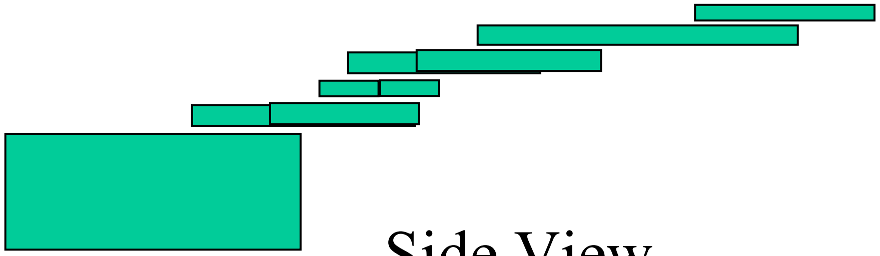
- Russell B. Ford and Philip Barkan at Stanford
- Four Stages
  - Definition of the robustness problem
  - Derivation of guiding principles
  - New concept synthesis
  - Concept evaluation and selection

Wafer Handling Robot





Top View



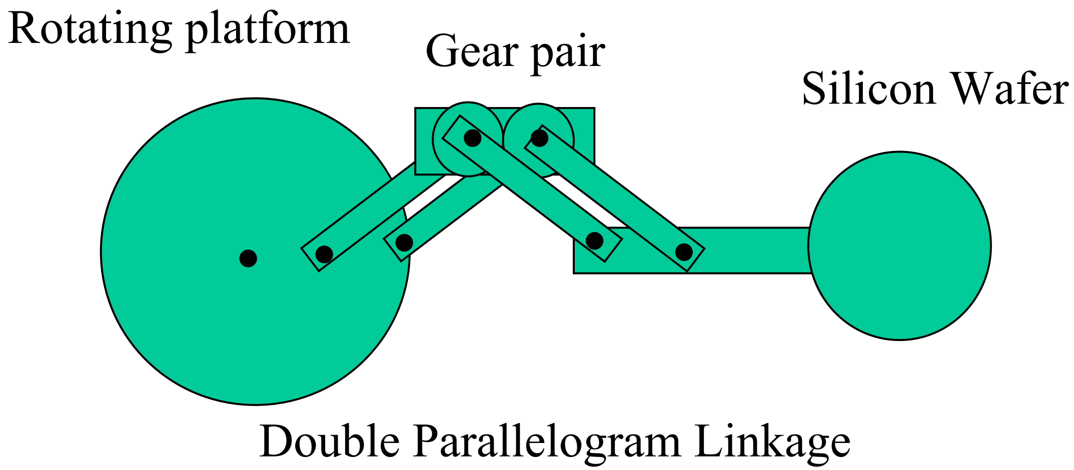
Side View

Stage 1
Definition of the Robustness Problem

- Identify robustness as a primary goal
- Incorporate critical performance metrics into the problem definition
- Target needed improvements in robustness
- Quantify key robustness goals

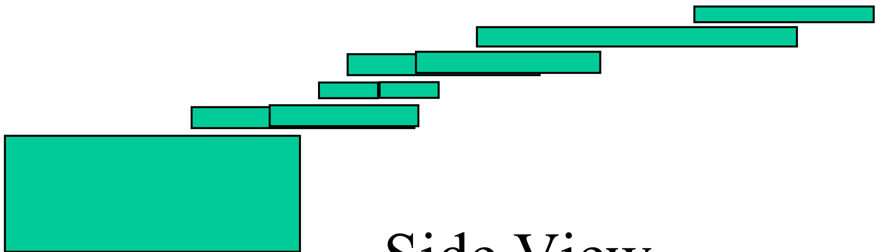
$$R = \frac{T_y}{6\sigma_y}$$

Stage 1



Top View

How will you specify robustness?

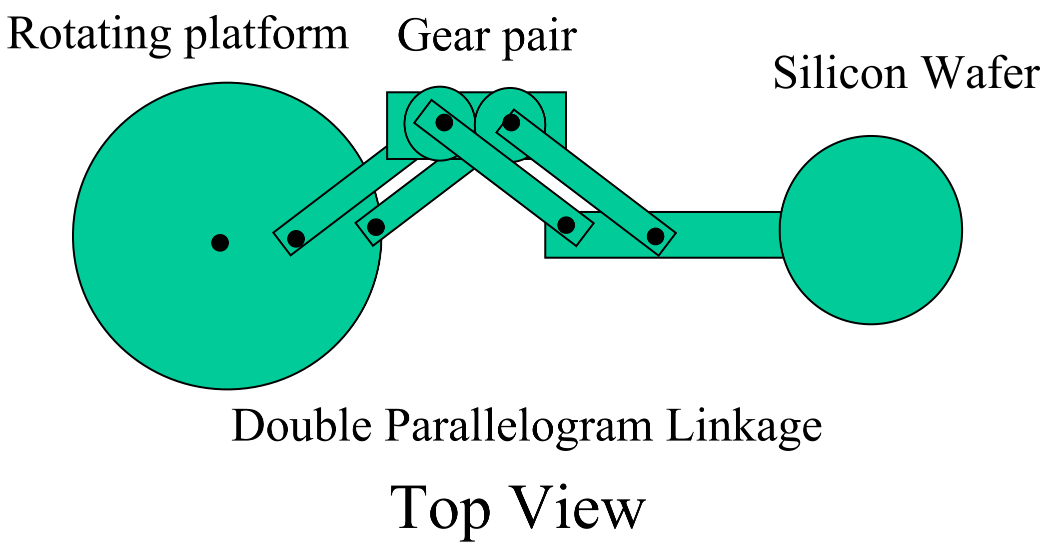


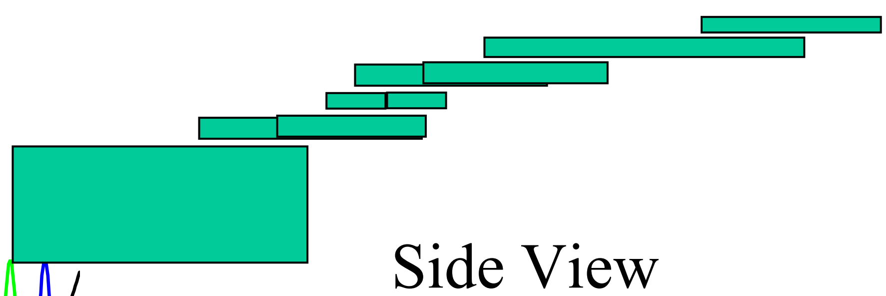
Side View

Stage 2
Derivation of Guiding Principles

- Identify dominant error propagation mechanisms
- Derive insight into the root causes of performance variation
- Predict the effect of design parameters and error sources on performance variation
- Single out limiting constraints
- Substantiate the predicted behavior

Stage 2





What are the root causes?

What are the mechanisms of propagation?

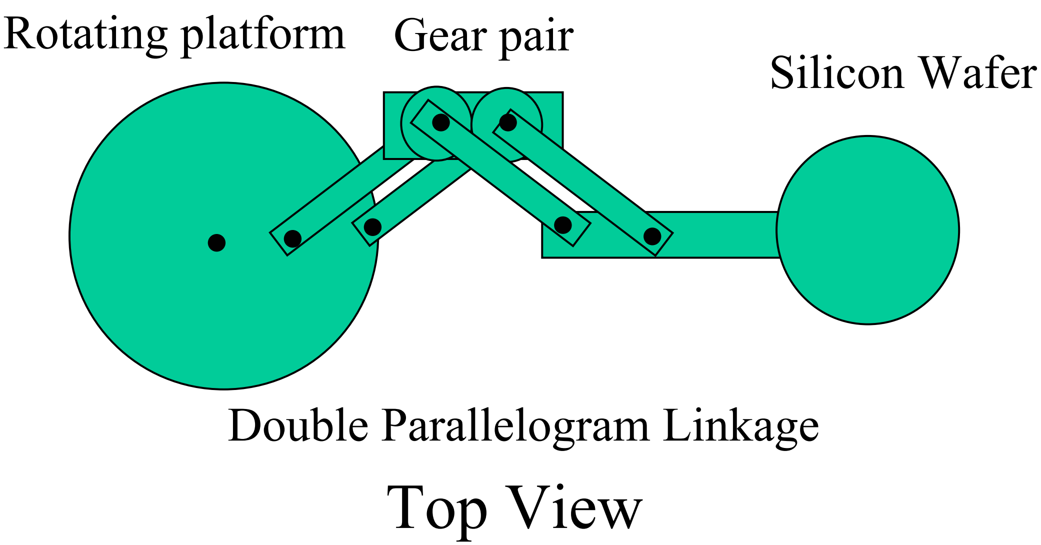
How would you predict effects?

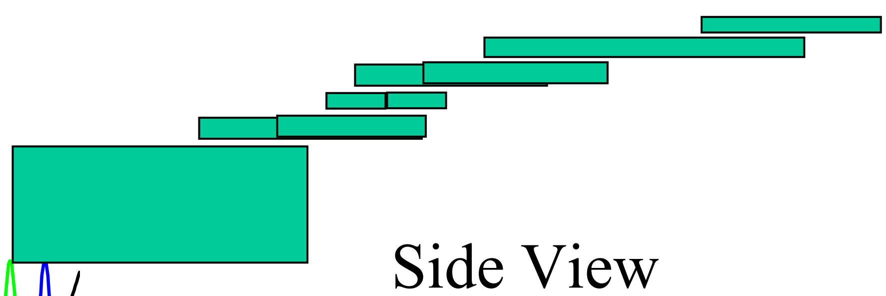
What are the constraints on the design?

Stage 3
New Concept Synthesis

- Modify error propagation mechanisms to reduce or eliminate transmission
- Eliminate or reduce error sources
- Circumvent limiting constraints
- Draw upon new technology
- Add extra degrees of freedom as necessary

Stage 3





How can you modify propagation?

Can you circumvent constraints?

Are there new technologies to employ?

Develop 3 other concepts.

Stage 4
Concept Evaluation and Selection

- Reconcile robustness requirements with al other critical performance specifications
- Select the best concept from all alternatives
- Predict the effect of design parameters and error sources on performance variation
- Decide whether further improvement is required

References -- Conceptual Robustness

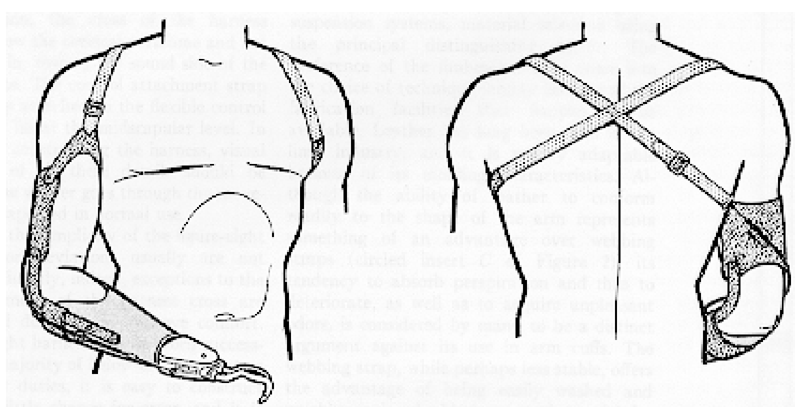
- Ford, Russell B., and Philip Barkan “Beyond Parameter Design -- A Methodology Addressing Product Robustness at the Concept Formation Stage”, DE-Vol. 81, *Design for Manufacturability*, ASME, 1995.
- Andersson, Peder, “A Semi-Analytic Approach to Robust Design in the Conceptual Design Phase”, Research in Engineering Design, *Research in Engineering Design*, vol. 8, pp. 229-239.
- Stoll, Henry W., “Strategies for Robust Product Design,” *Journal of Applied Manufacturing Systems*, Winter, 1994, pp. 3-8.

Case Study
VMA Prehensor

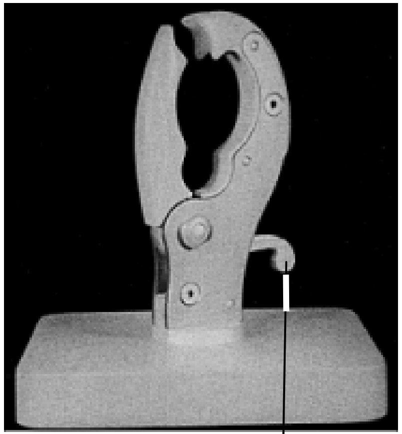
- Dan Frey and Larry Carlson
- The authors wish to thank the NCMRR (grant no. 1-RO1-HD30101-01) for its financial support
- The contributions of Bob Radocy as both design consultant and field evaluator are gratefully acknowledged

Body Powered Prosthetic Prehension

- Amputee wears a harness to which a cable is attached
- Cable routed through a housing, down the arm, to a prehensor
- Body motions create cable excursion & apply force



The TRS Grip

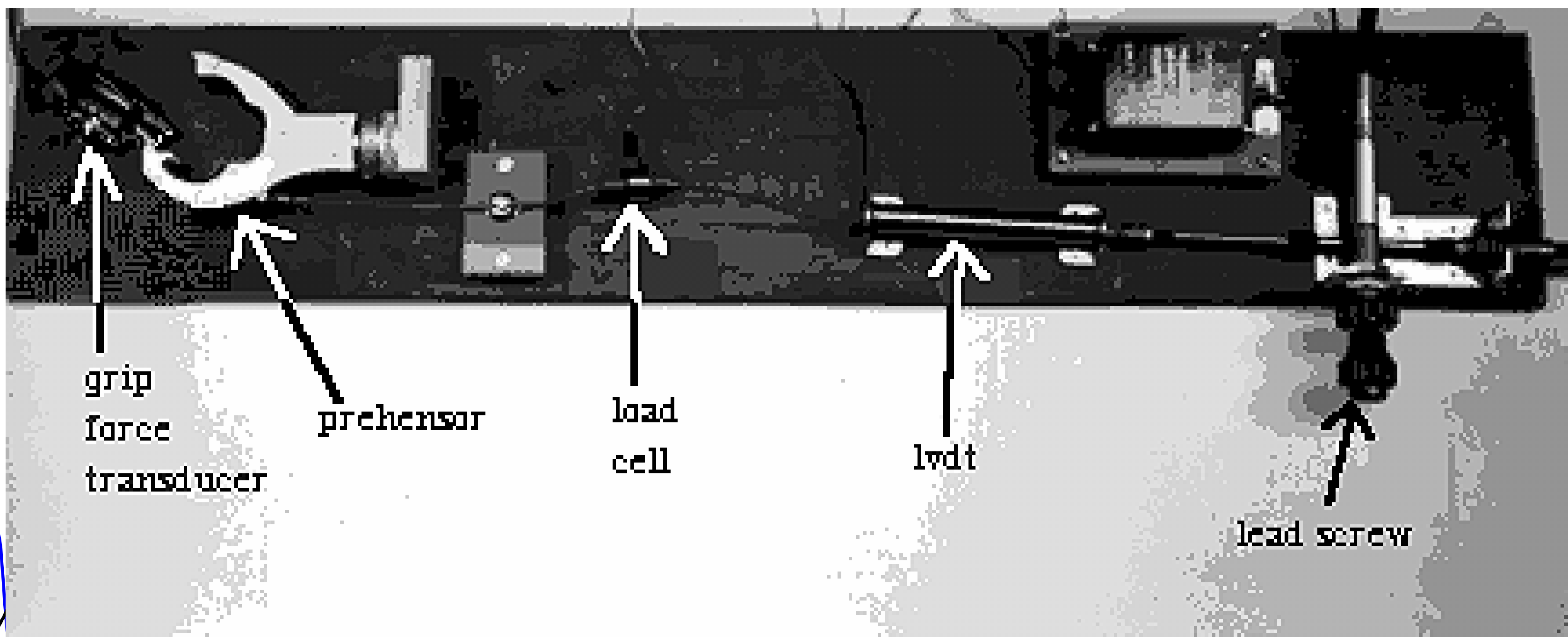


Cable tension

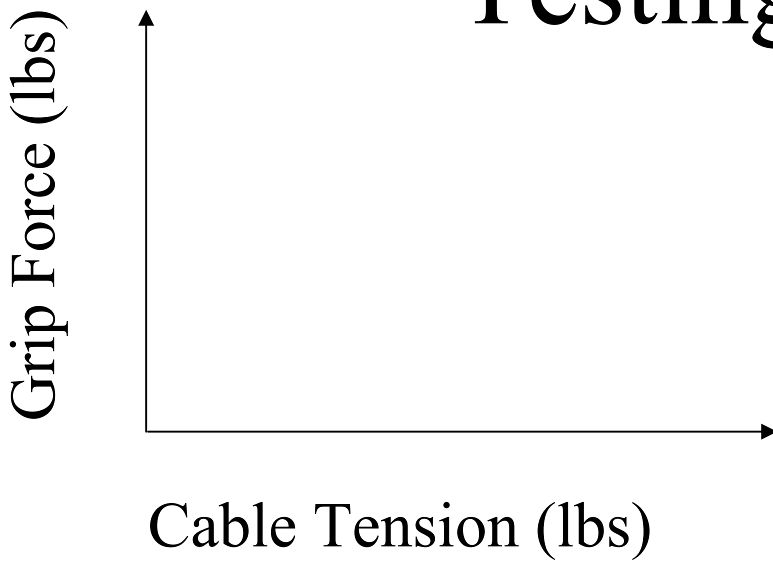
- A "voluntary closing" prehensor
  - Lightly spring loaded to open position
  - User applies cable force
- Often users want to change body position while grasping objects
- How will variations in cable excursion affect grip force?

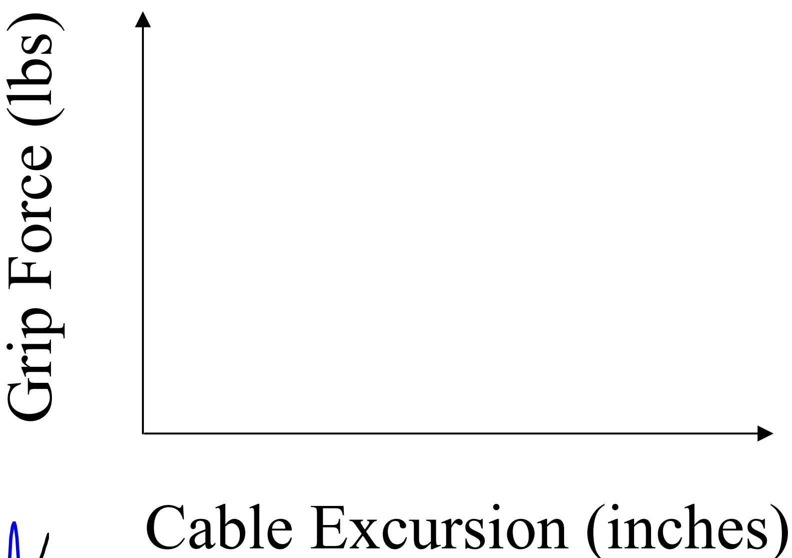
Testing Apparatus

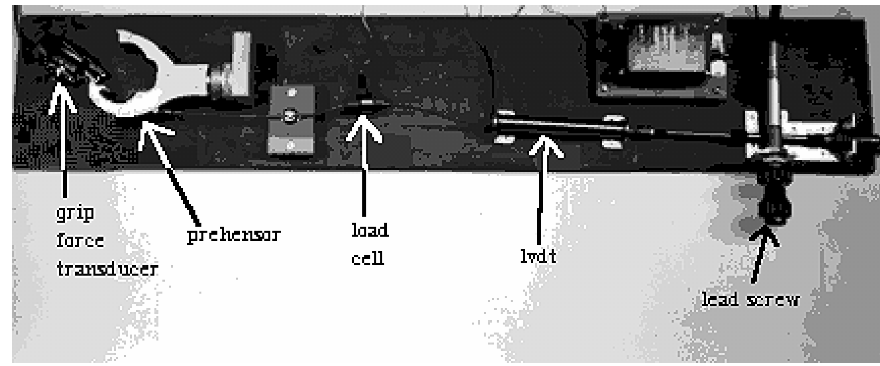
- Lead screw applies force / displacement
- Load cell measures applied tension
- LVTD measures applied displacement
- Resulting grip force measured



Testing the Grip







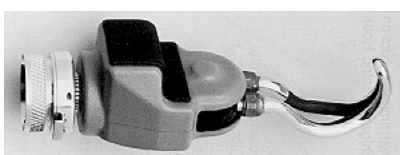
Amputees can generate
2" of excursion
and 40 lbs tension

How would you design the Grip?
What form will the plots take?
What determines robustness
to body motions?

Pre-existing Approaches

APRL Hook

Allows the user to lock the prehensor
- First stroke applies force and locks
- Second, harder stoke unlocks
- Safety compromised!
- Poor reliability

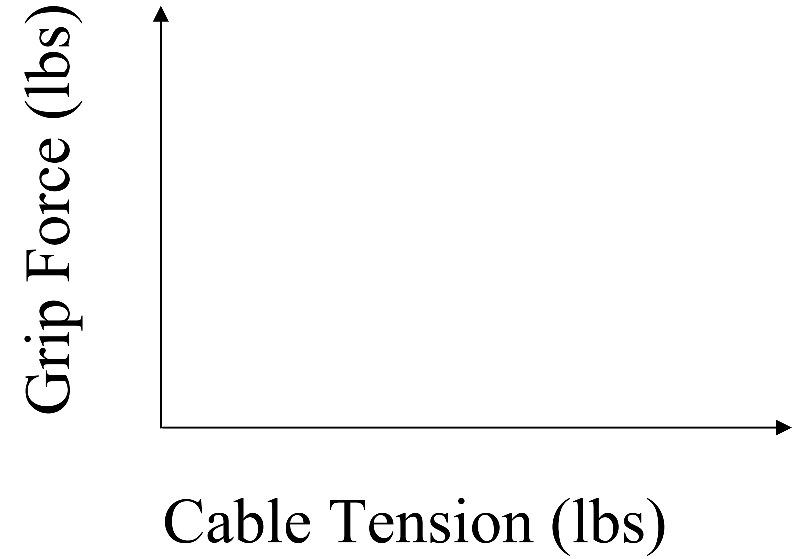


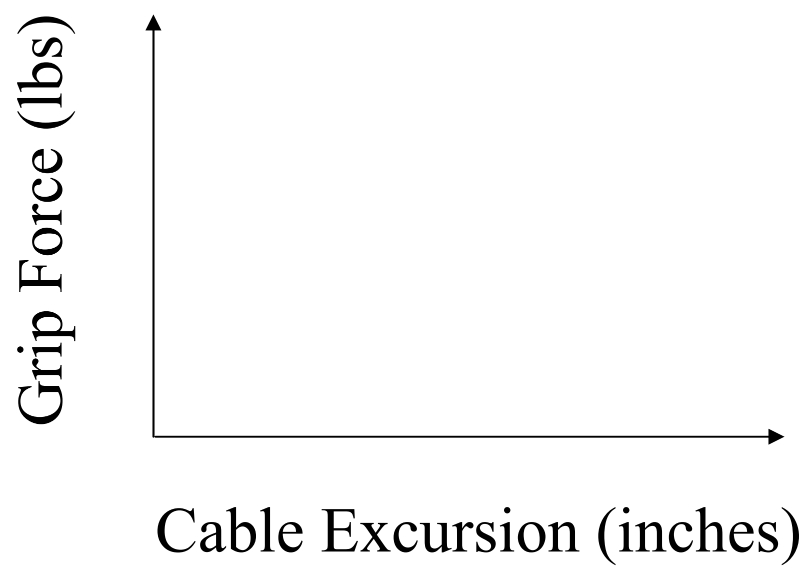
Northwestern U.
"Synergetic Prehensor"

Myo-electrically operated hand
- *Sizing* and *gripping* are distinct phases of grasp
- Both require minimal mechanical energy
- Longer battery life

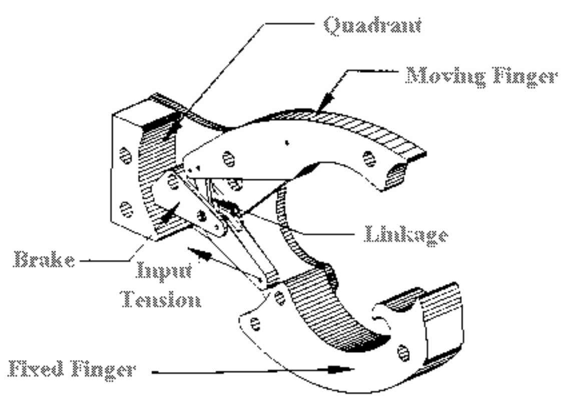
Variable Mechanical Advantage

- Idea -- break up the task into sizing and gripping
- How can one use this to improve robustness to body position error?

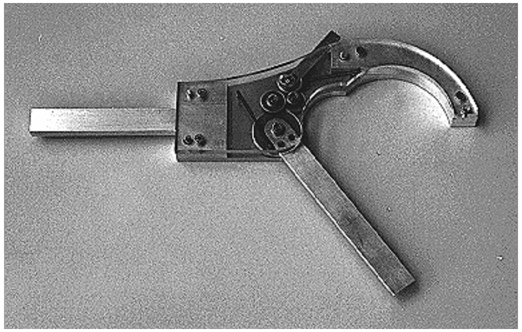




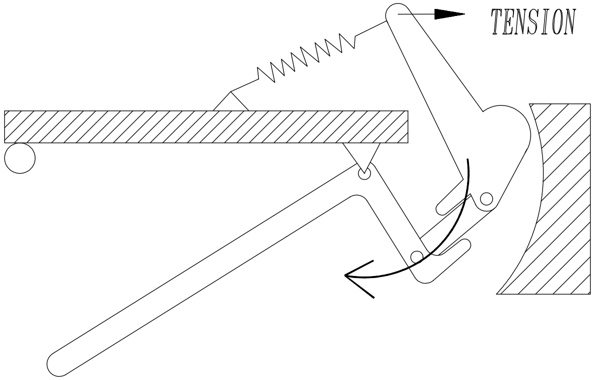
VMA Design Concepts



Linkage Based Design
(Carlson)

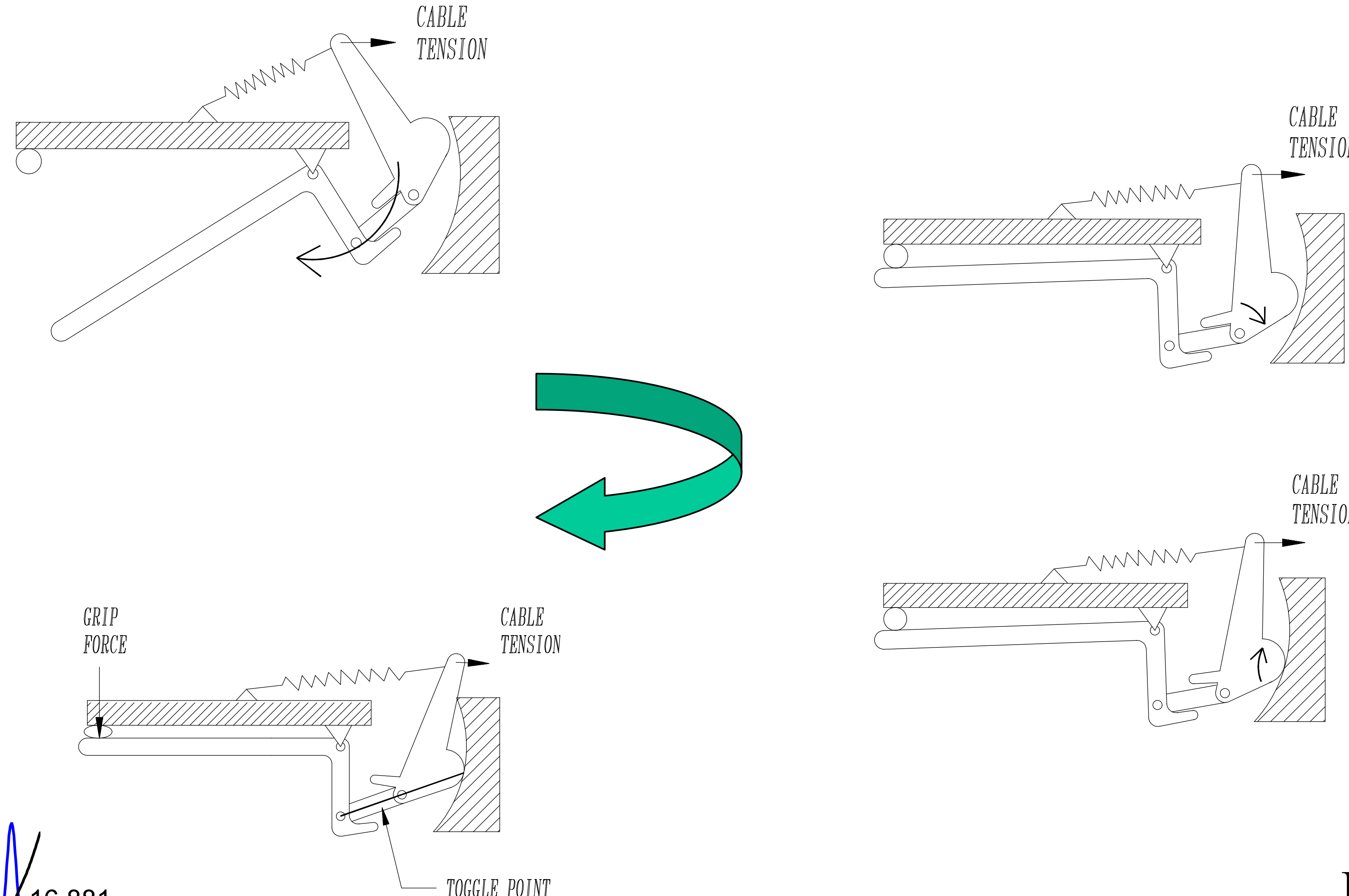


Gear Based Design
(Frey / Carlson)



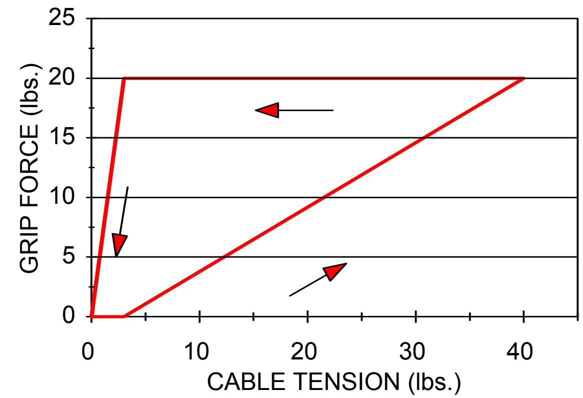
Simplified Linkage
Based Design
(Frey / Carlson)

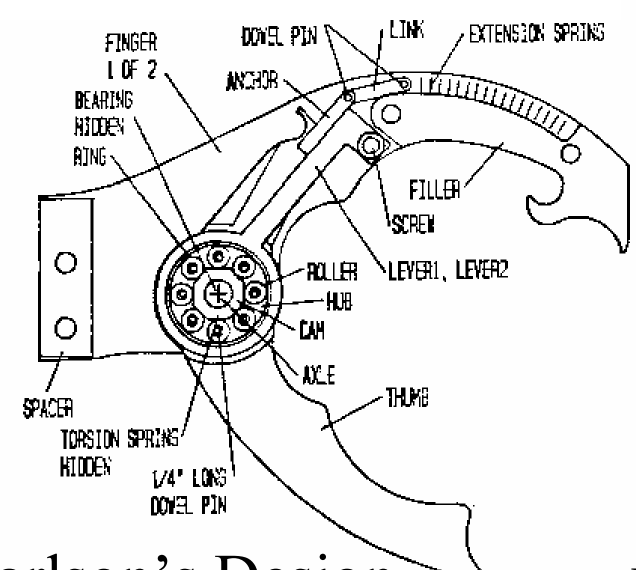
Operation of the VMA Prehensor



Holding Assist Concept

- Over-running clutch used to hold force
- Performance very sensitive to shape of rollers
- Flat spots due to wear rendered design unreliable

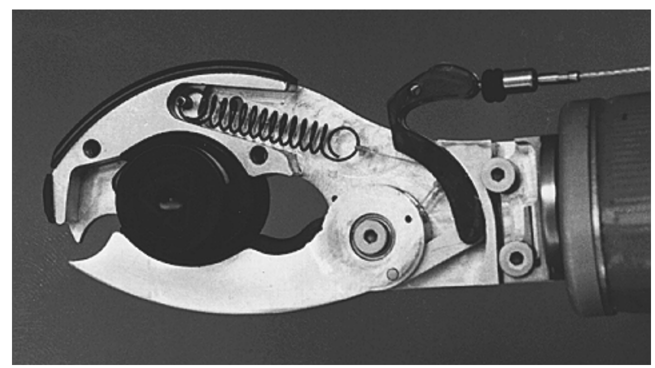




Carlson's Design

VMA Prehensor
First Prototype

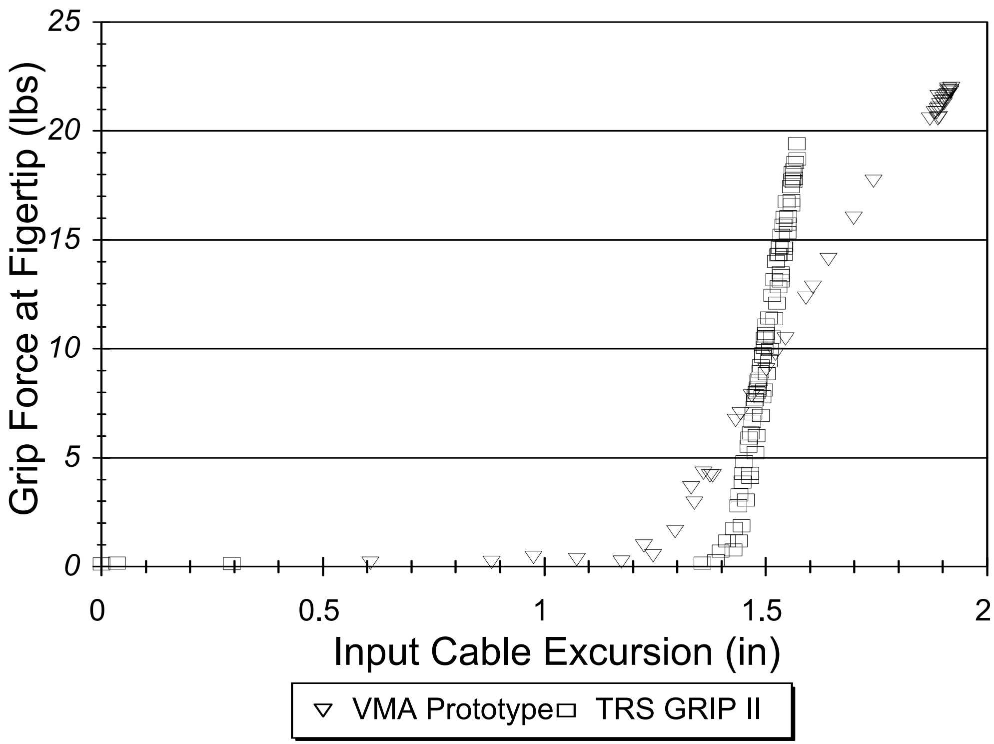
- 2D profile allowed quick CNC prototyping
- $200 in machining costs
- Aluminum components
- Stock bearings
- ~$100 materials



VMA prototype with face plate removed

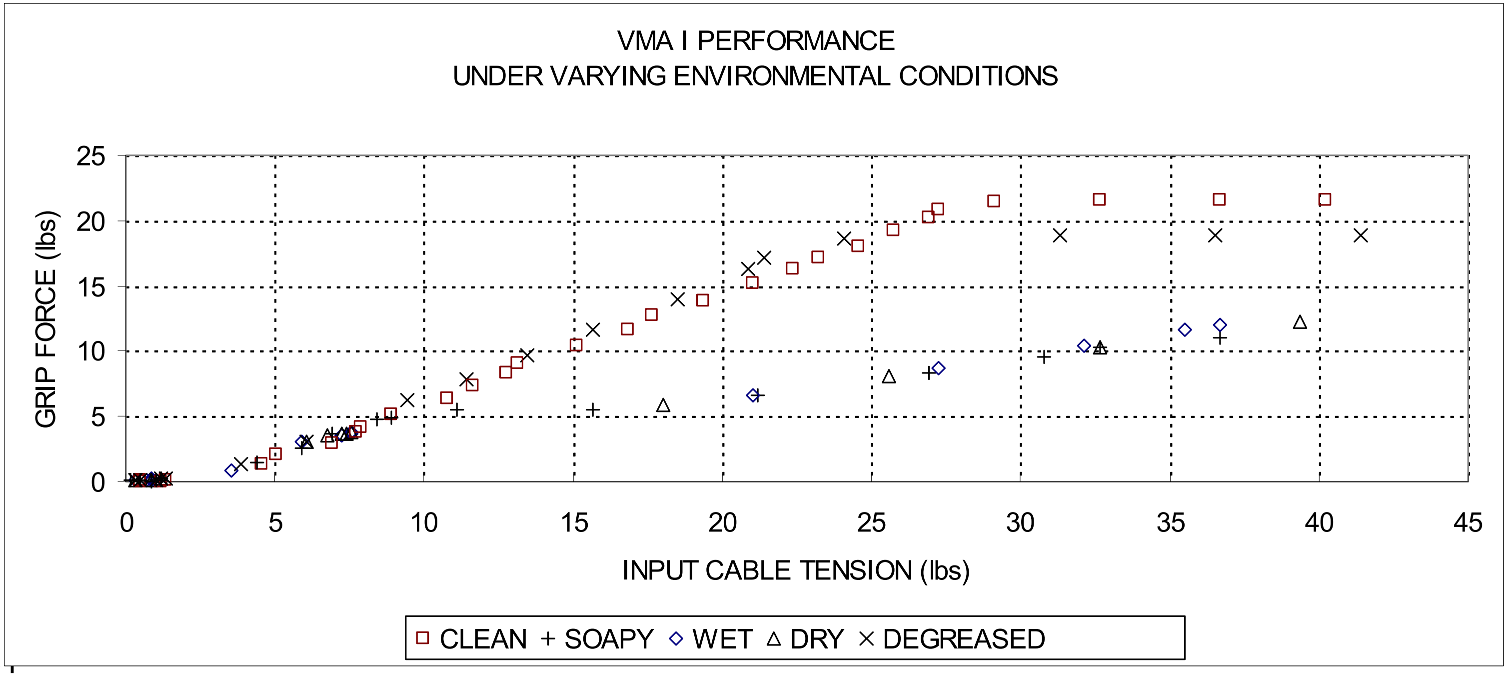
Robustness to Error in Excursion

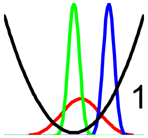
- Excursion saved in sizing
- Employed later to lower sensitivity to excursion by more than a factor of three



Robustness to Environment

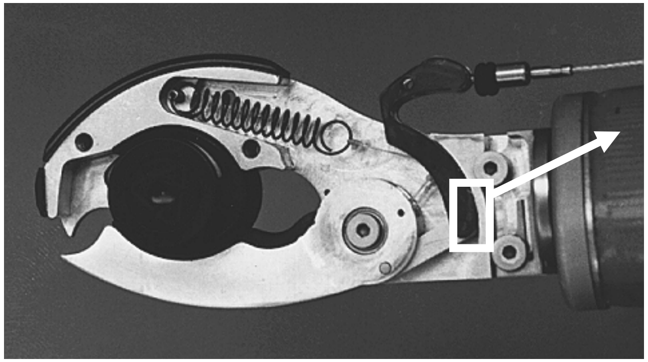
- Users subject prehensors to varying conditions
- Such conditions adversely affected performance

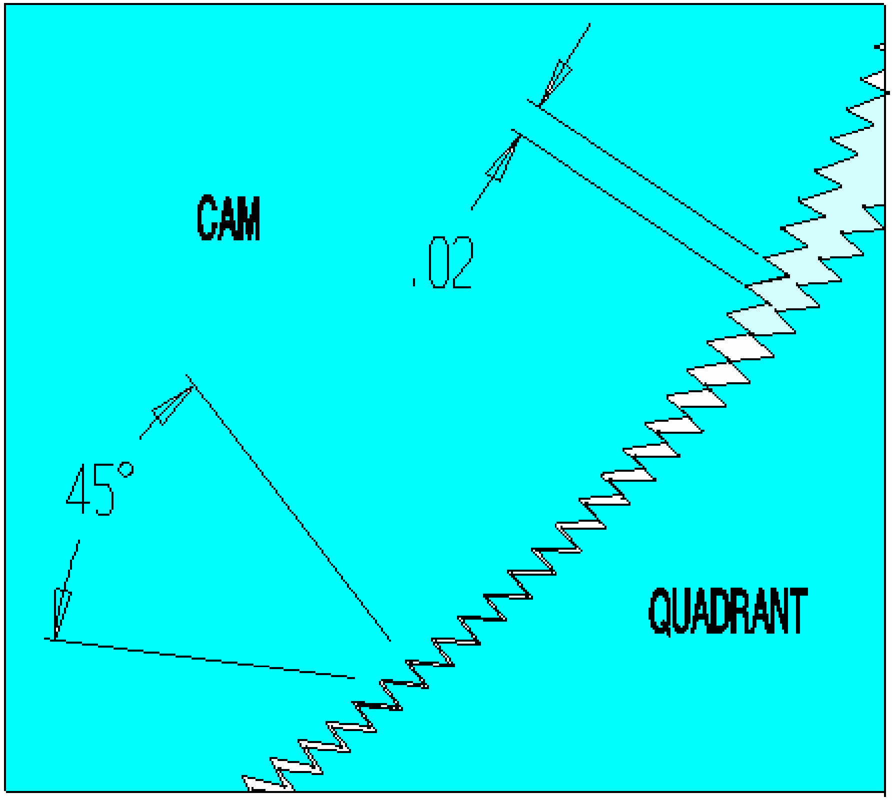




Ratchet Teeth

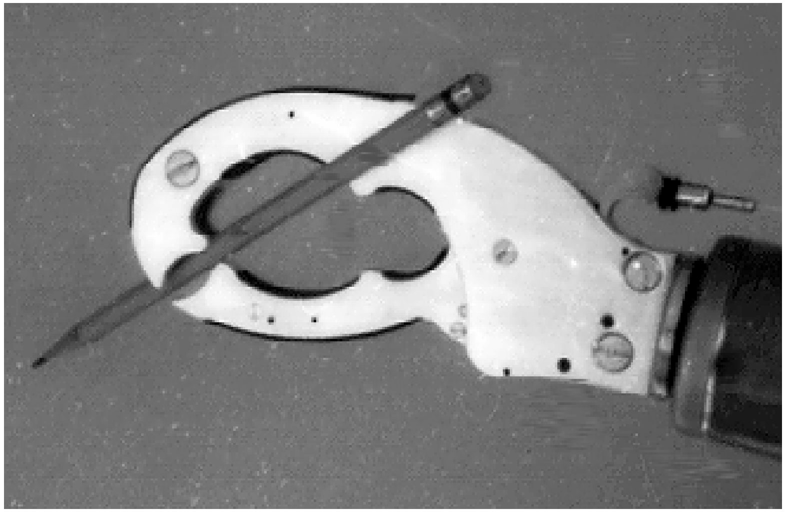
- Broached fine teeth into mating surfaces
- Friction no longer determines performance





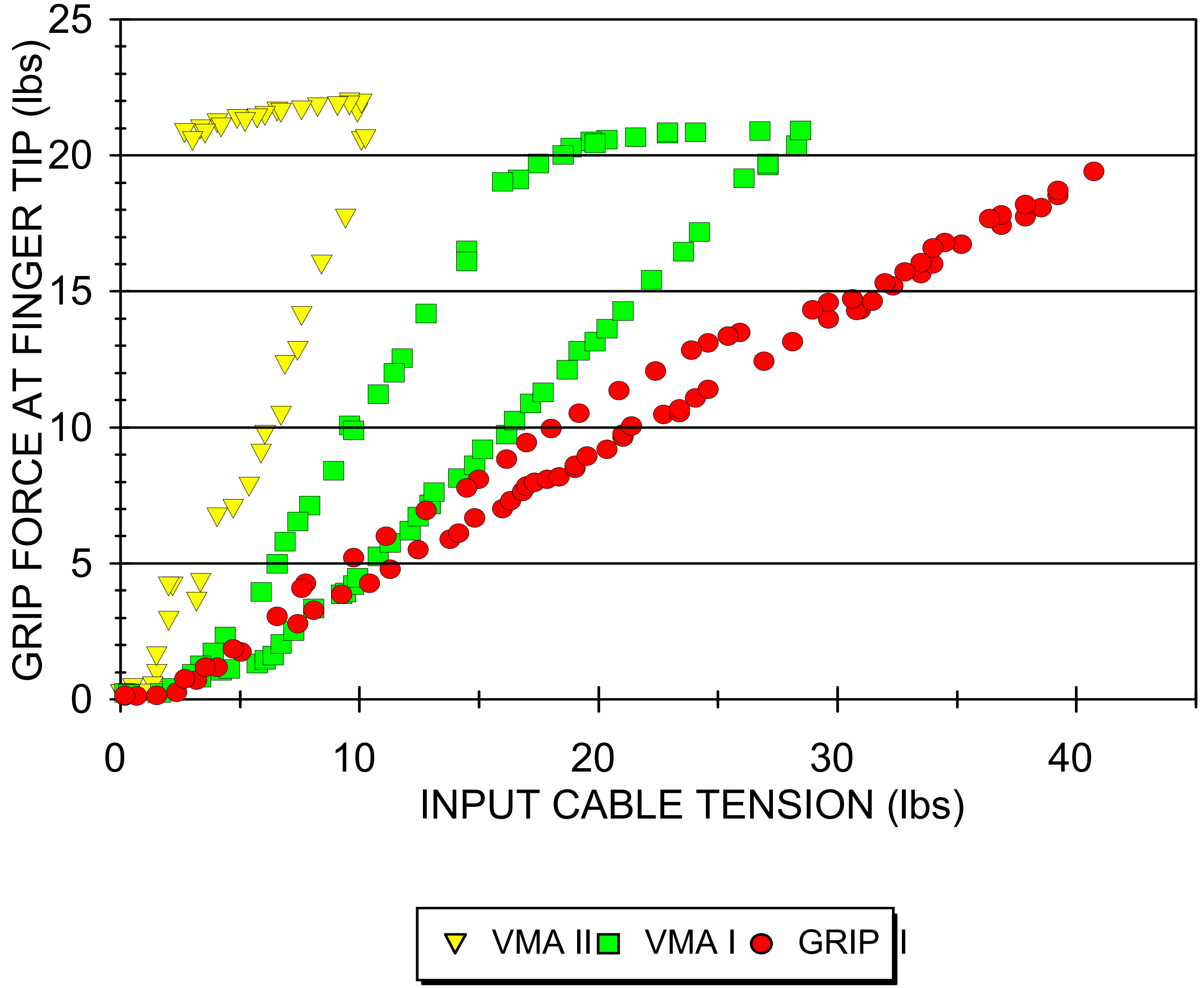
VMA Prehensor Second Generation Prototype

- More agressive increase in mechanical advantage
- Holding assist enhanced through mechanism design



VMA II PREHENSOR

COMPARED TO VMA I & GRIP II



Results of Amputee Evaluation VMA Prehensor

- Provides greater range of motion while maintaining grasp
- Works reliably under wide range of environmental conditions
- Shifts prematurely with compliant objects
- “Free-wheel” switch convenient to use
  - Provides alternate mode of operation

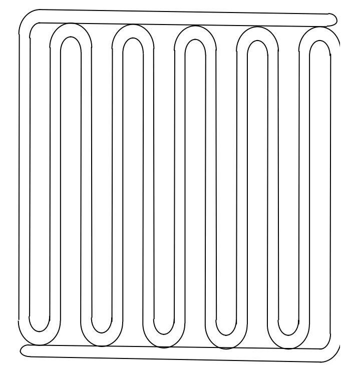
References -- VMA Prehensor

- Frey, D. D. and L. E. Carlson, 1994, "A body powered prehensor with variable mechanical advantage," Prosthetics and Orthotics International, vol. 18, pp. 118-123.
- Carlson, L. E. and R. Heim (1989). "Holding assist for a voluntary-closing prosthetic prehensor," *Issues in the Modeling and Control of Biomechanical Systems*, American Society of Mechanical Engineers, DSC-Vol. 17:79-87.
- Childress, D. S., and E. C. Grahn (1985). "Development of a powered prehensor". In *38th Annual Conference on Engineering in Medicine and Biology*, p. 50.
- Taylor, C.L. (1954). "The biomechanics of the normal and of the amputated upper extremity," ***Human Limbs and Their Substitutes***, McGraw Hill, New York, pp. 169-221.

Case Study
Adhesive Application for Surface Mount of Large Body Packages

- Dan Frey and Stan Taketani
- The authors wish to thank the Hughes Doctoral Fellowship program for its financial support.

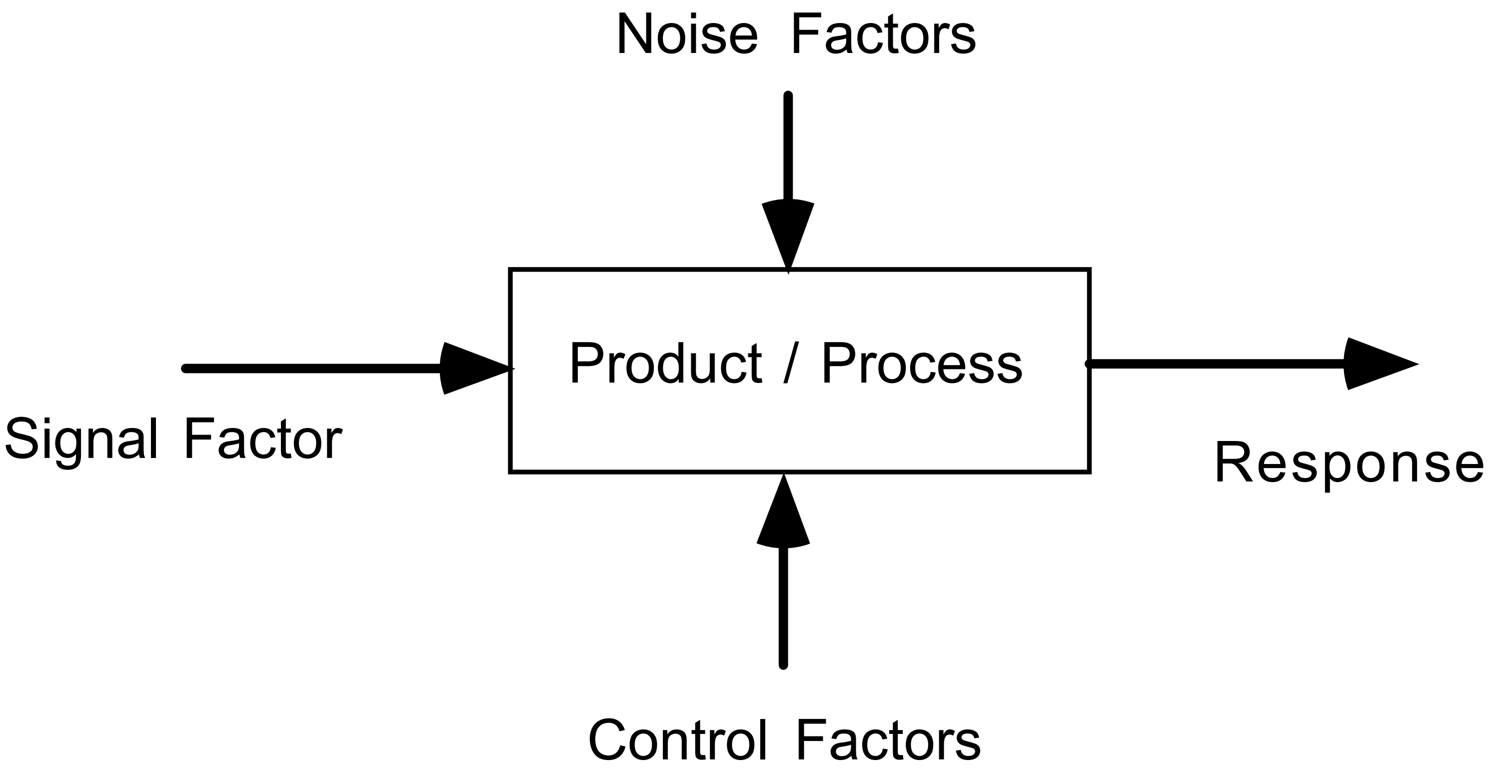
Adhesive Application Design Issues



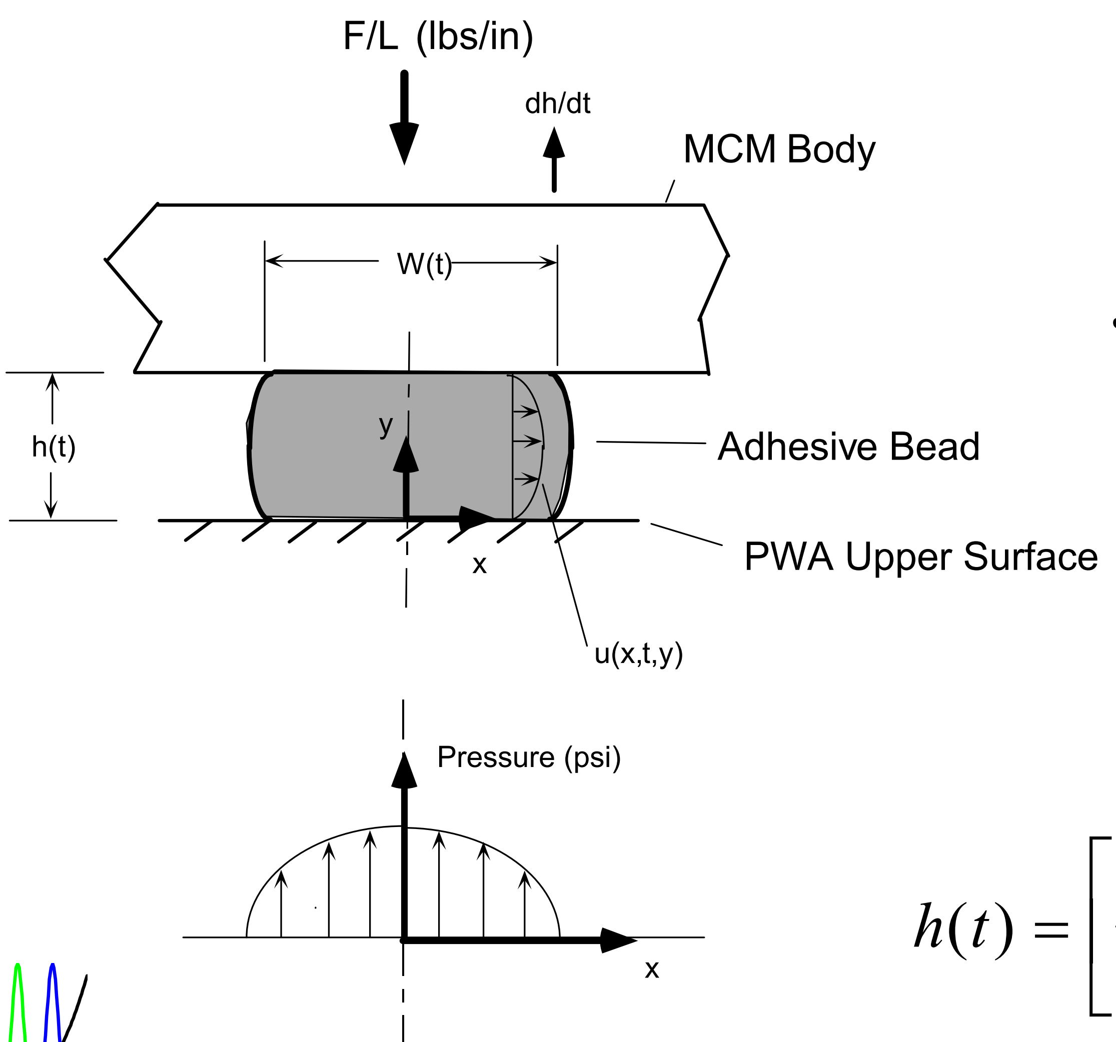
Typical adhesive pattern

- Adhesives are required to:
  - Support mechanical loads
  - Transfer heat to sink
- Robustness problems
  - Epoxy thickens during application
  - Air sometimes "burps"
  - Air gap height not repeatible
  - LBPs

P-Diagram


Noise Factors
Signal Factor
Product / Process
Response
Control Factors

Compression of a Single, Long Bead



Navier-Stokes

highly viscous

$$\int_0^h u(x,t,h) = \frac{-h^3}{12\mu} \cdot \frac{\mathrm{d}p}{\mathrm{d}x}$$

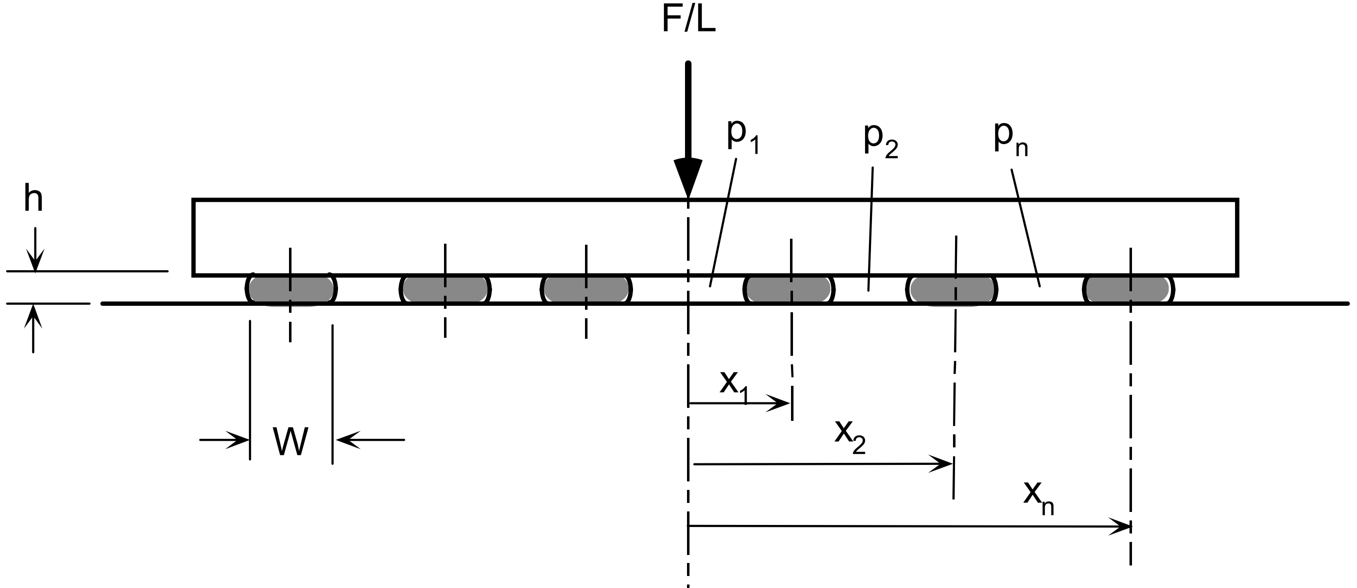
conserve mass

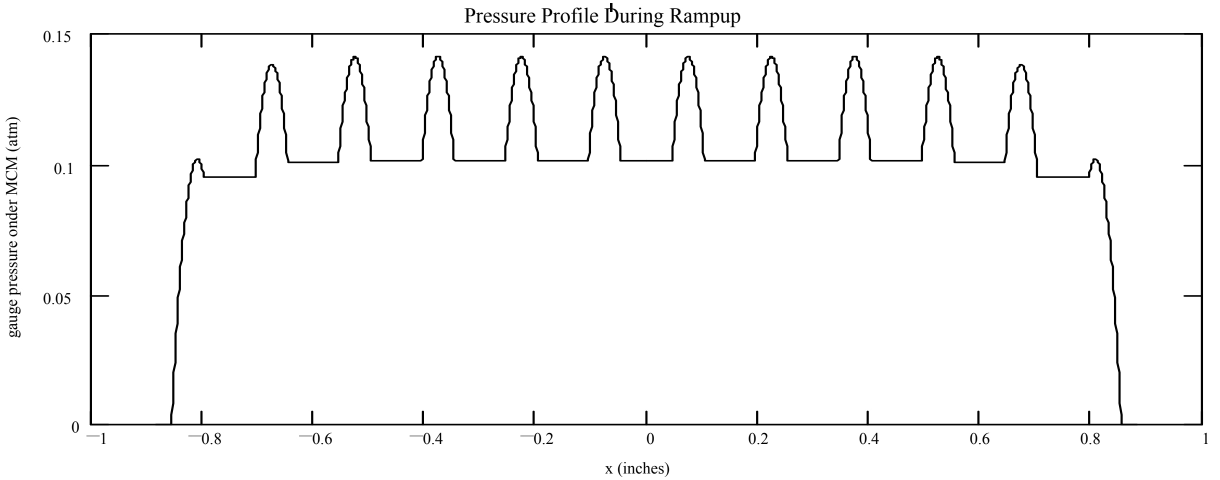
$$\frac{F}{L} = \frac{-\mu}{h^3} \cdot \frac{dh}{\mathrm{d}t} \cdot W^3$$

integrate

$$h(t) = \left[\frac{5F/L}{\mu W_o^{\,3} h_o^{\,3}} t + \frac{1}{h_o^{\,5}} \right]^{-1/5}$$

Multiple Beads with Air Pockets

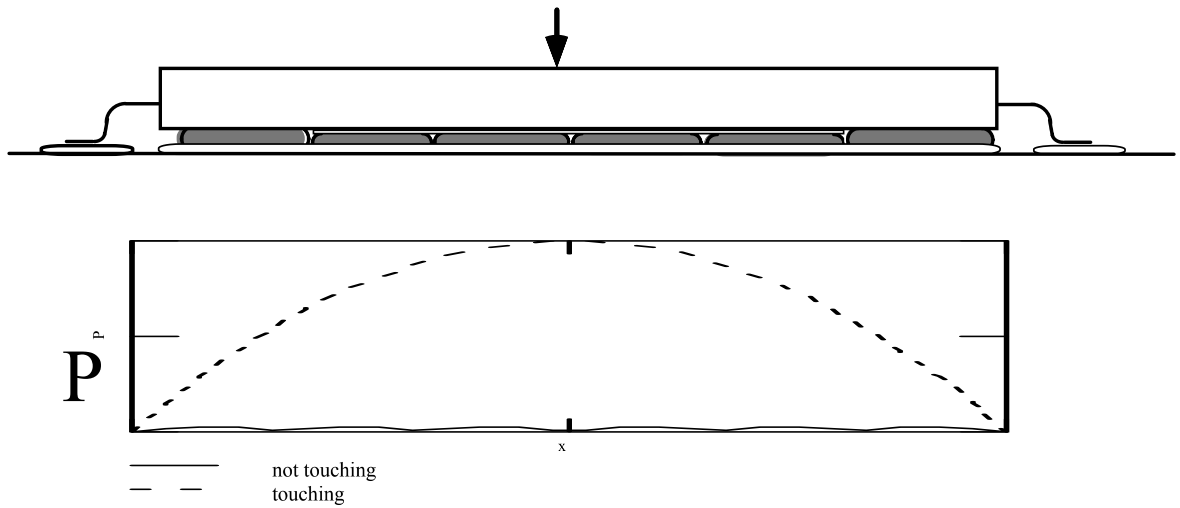




Eliminating “Squeeze-Out”
Despite Viscosity Variation

- When beads touch one another, downward motion is arrested

$$\frac{\left.\frac{\mathrm{d}h}{\mathrm{d}t}\right|_{touching}}{\left.\frac{\mathrm{d}h}{\mathrm{d}t}\right|_{nottouching}} = \frac{1}{n^2}$$

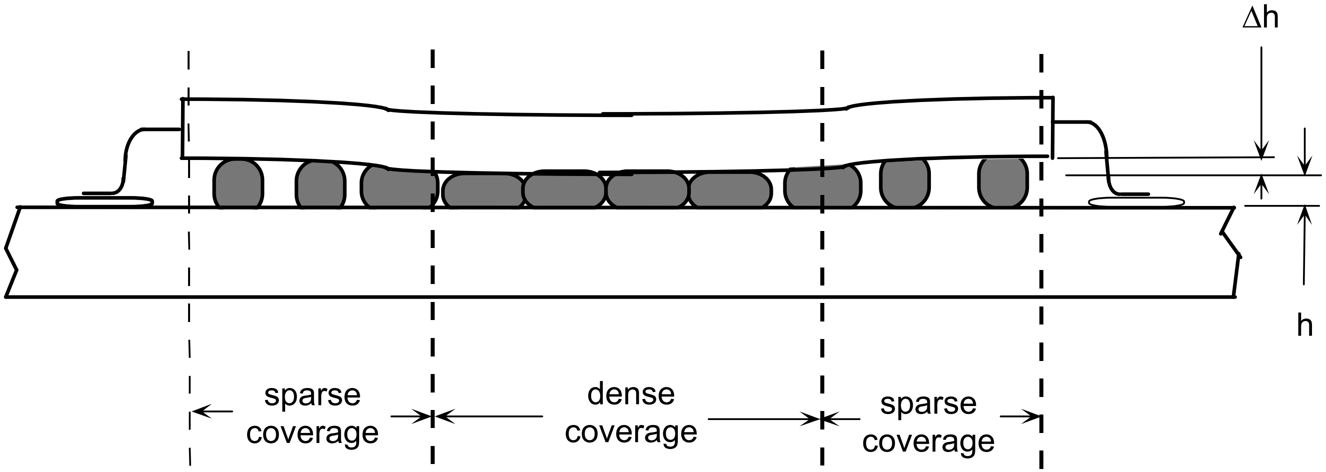


- Design rules exploit this phenomena

margin>bead pitch

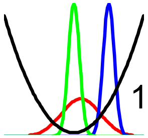
$$\int F\mathrm{d}t = \frac{-3\pi\mu}{2h_f^{\;2}} \cdot \left(\frac{W}{2}\right)^4 \left(1 - \frac{W}{W + \text{margin}}\right)$$

Estimating Percent Coverage



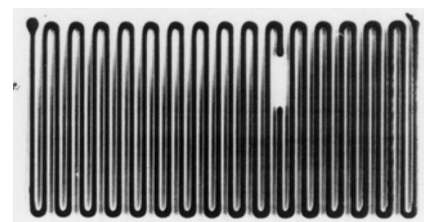
$$\text{sparse coverage} = \frac{h}{h + \Delta h}$$

- Thinnest air gaps set component height
- Wider air gaps are areas of sparse coverage

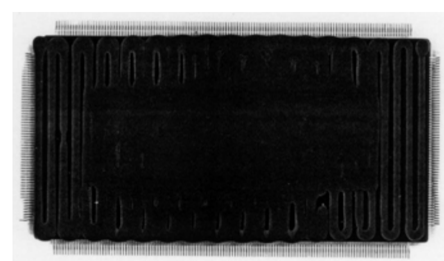


Adhesive Flow Model Preliminary Verification

- Used dispense test data to estimate μ
- Used μ, P, and V to calculate bead shape

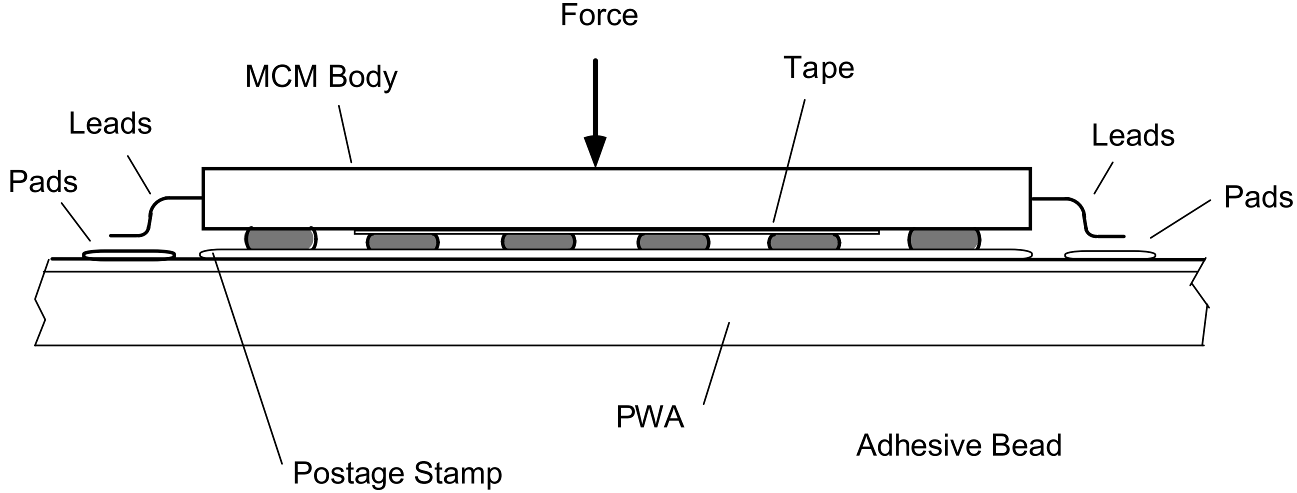


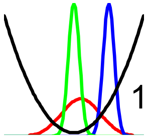
- Used force schedule to estimate final height and percent coverage



Postage Stamp and Tape

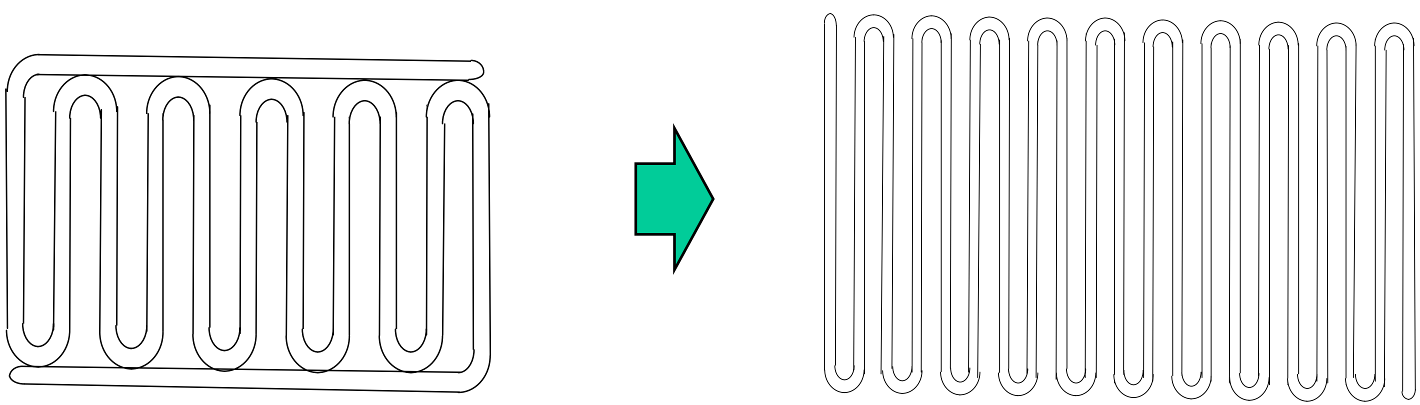
- Postage stamp protects the circuitry
- Tape allows easier rework
- BUT -- MCM to PWA gap cut from 13 mils to 7.5 mils
- $F \alpha 1/h^3$ -- over **400%**more force req'd





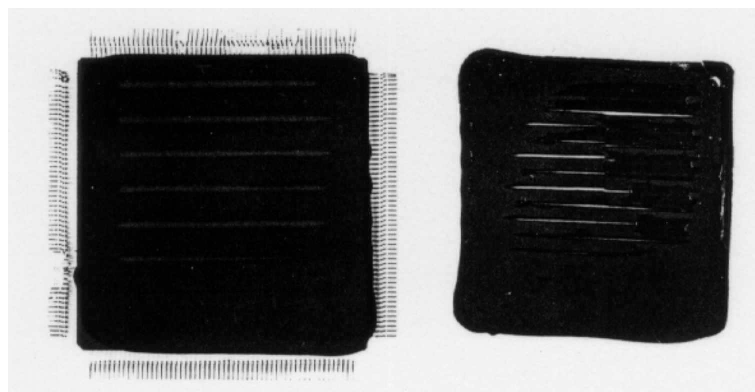
Accomodating Equipment Limitations

- Robot can only apply 7 lbs seating force
- Air pockets support substantial load (>50%)
  - Open air gaps (when practicable)
- $F \propto \frac{1}{W^3}$ - Switch to thinner beads



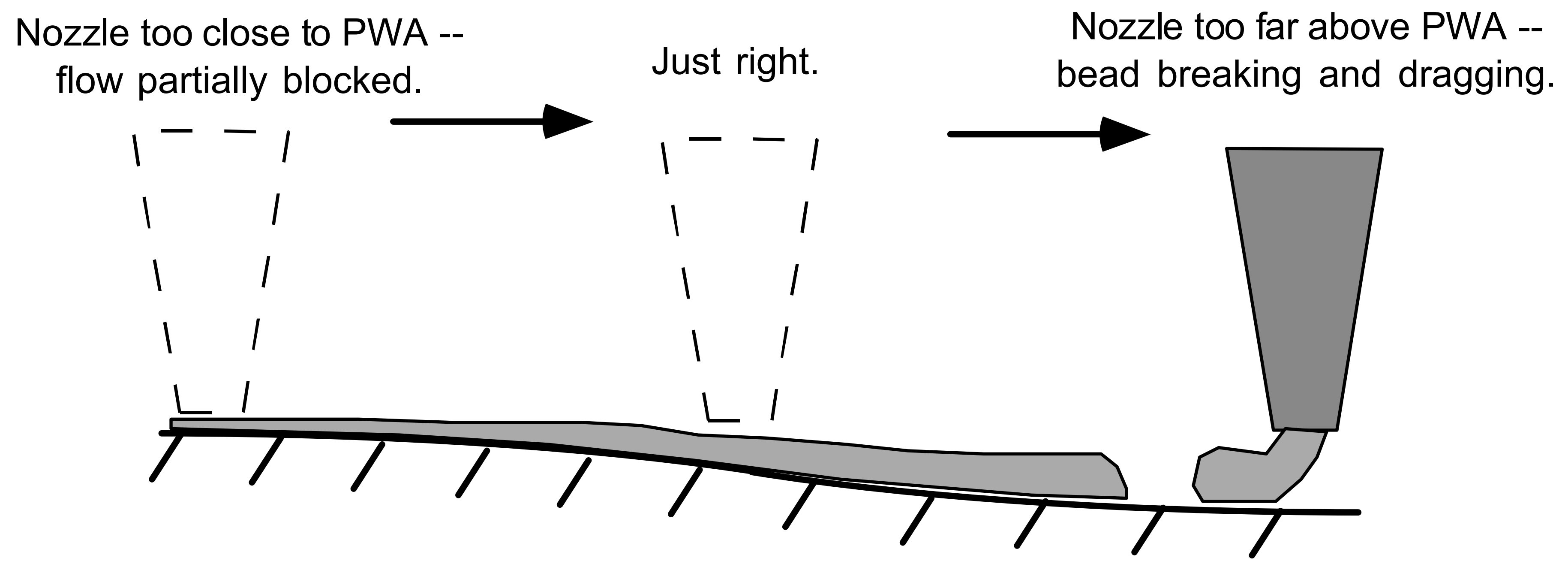
Gaps in Adhesive Coverage

- Model predicted existence of gaps in coverage under certain conditions
- Experimentally observed later

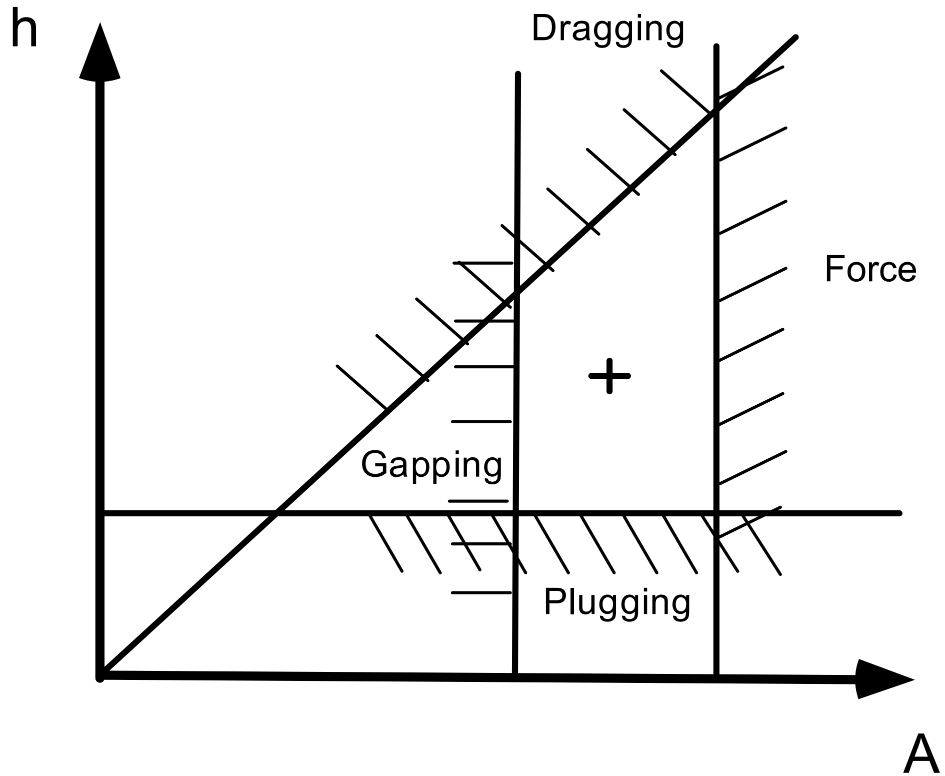


- Given gap location, they might not have been detected early enough

Dispense Problems Due to PWA Waviness



Dispense Parameter Selection



Force

$$A < A_{\max}(F_{\max}, \mu, \text{airgap})$$

Dragging

$$h < \frac{2A}{D_{nozzle}} - \Delta h$$

Plugging

$$h > \Delta h + \frac{D_{nozzle}}{2}$$

Gapping

$$(1-\cos\alpha)\sqrt{\frac{2A}{1-\sin 2\alpha}} > \text{airgap} + \Delta h$$

Next Steps

- Next off-campus session
- Course evaluations
- Term project presentations
- Good luck!