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DEPARTMENT OF
MECHANICAL ENGINEERING

Compliant Mechanisms

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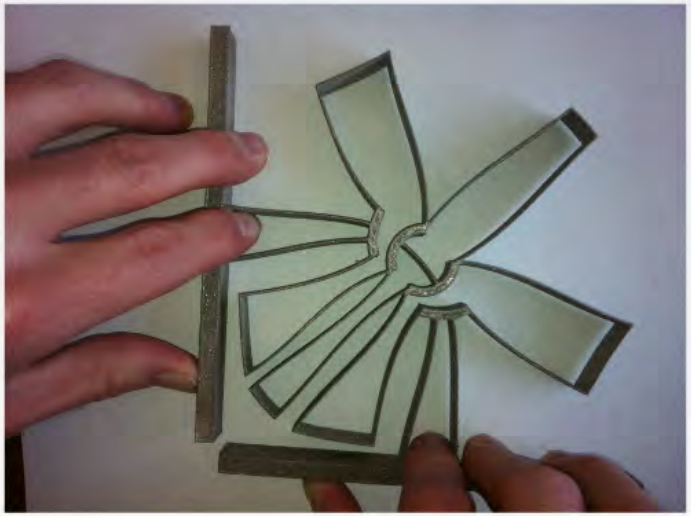
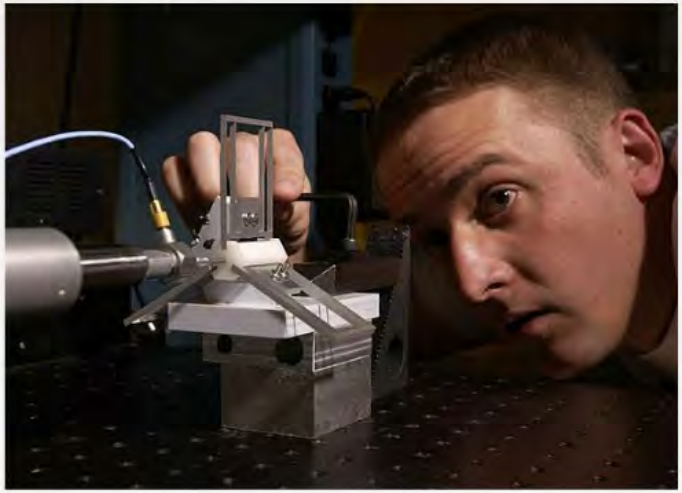
COMPLIANT MECHANISMS RESEARCH

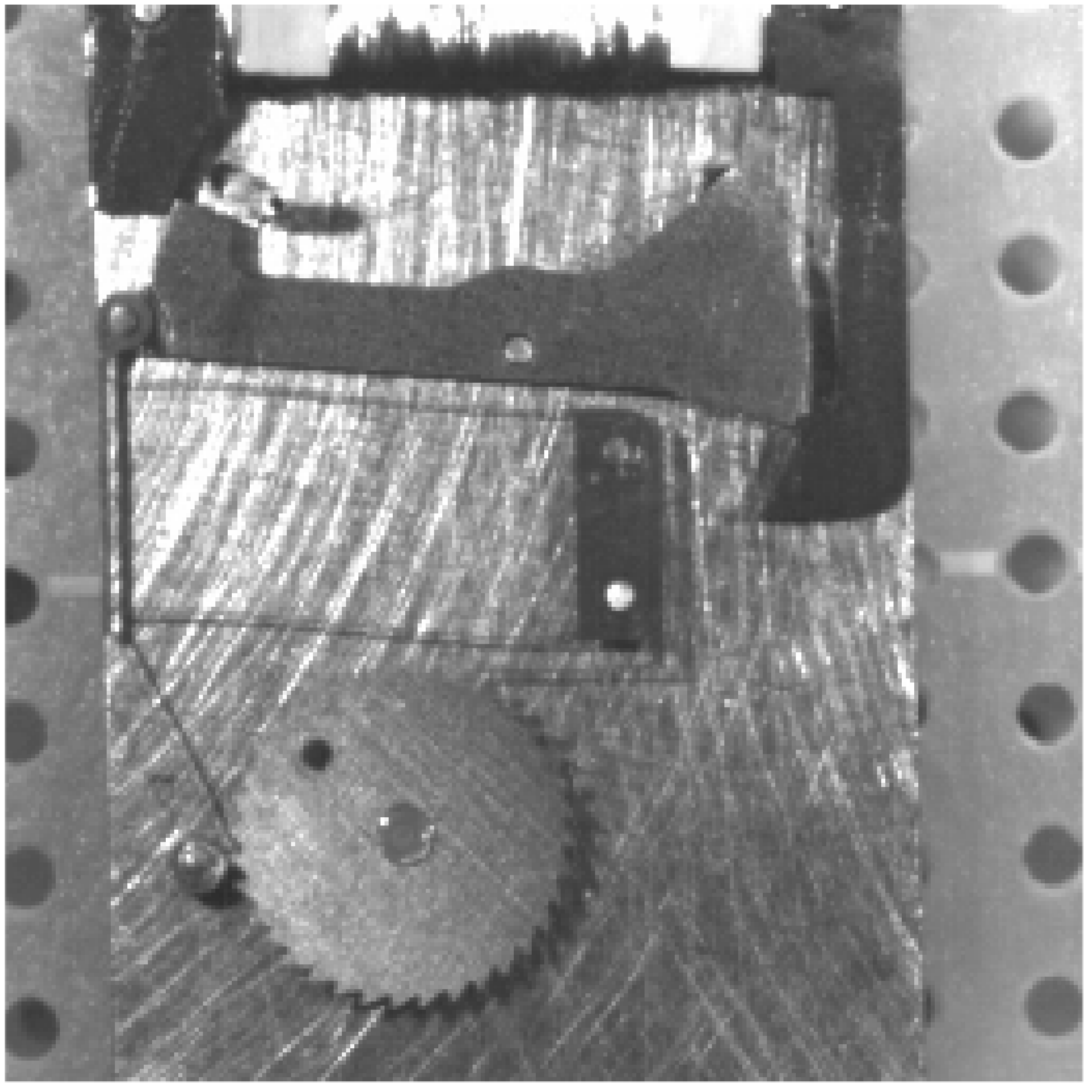
Compliant Mechanisms





A compliant mechanism gains some or all of its motion from the deflection of flexible members

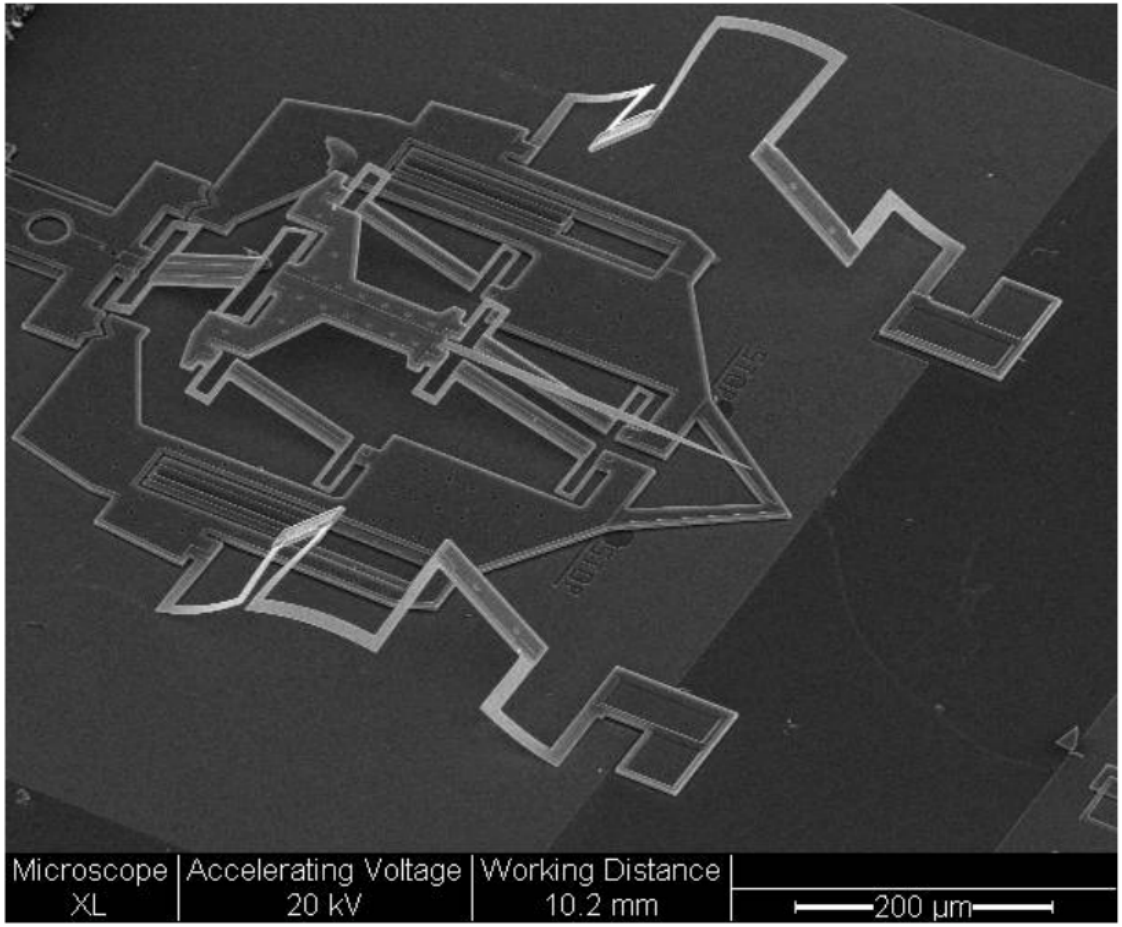
Low cost
Minimal assembly



Compact
High precision

Reduced wear
Harsh environments

Light weight
Tailored force response



Easily minaturized

One key thing to remember

Stiffness and
strength are

NOT

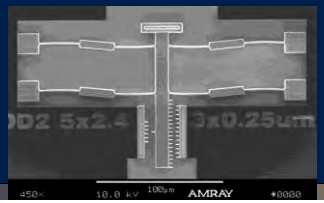
the same thing

It is possible to make something both

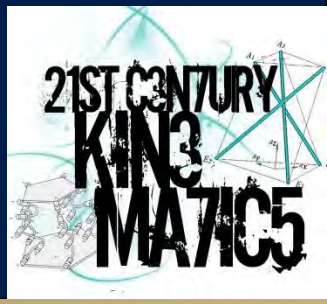
Flexible

and

Strong



Pseudo-Rigid-Body Model



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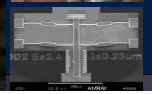
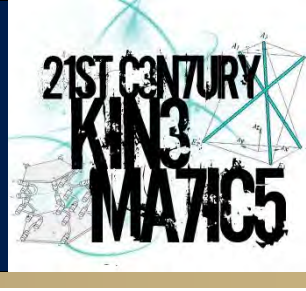
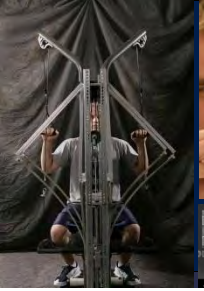


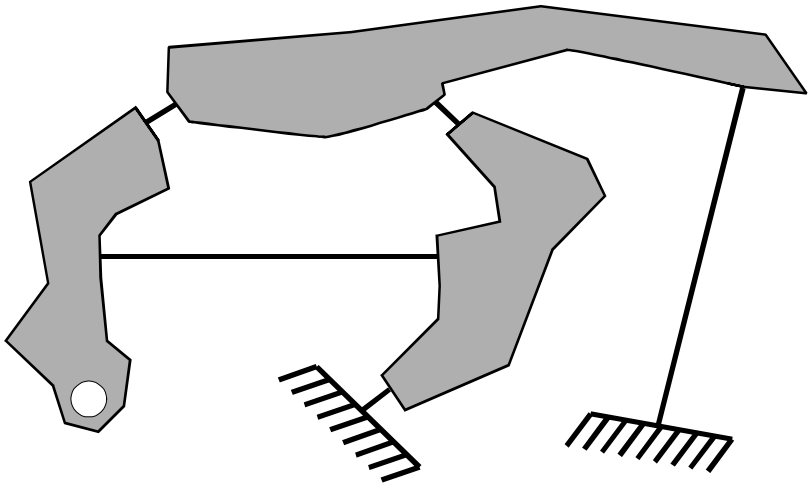
Pseudo-Rigid-Body Model

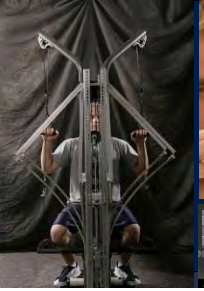


- Models compliant mechanisms as rigid-body mechanisms
- Allows use of decades of research in mechanical systems
- Unifies compliant mechanism and rigid-body mechanism theories



Example





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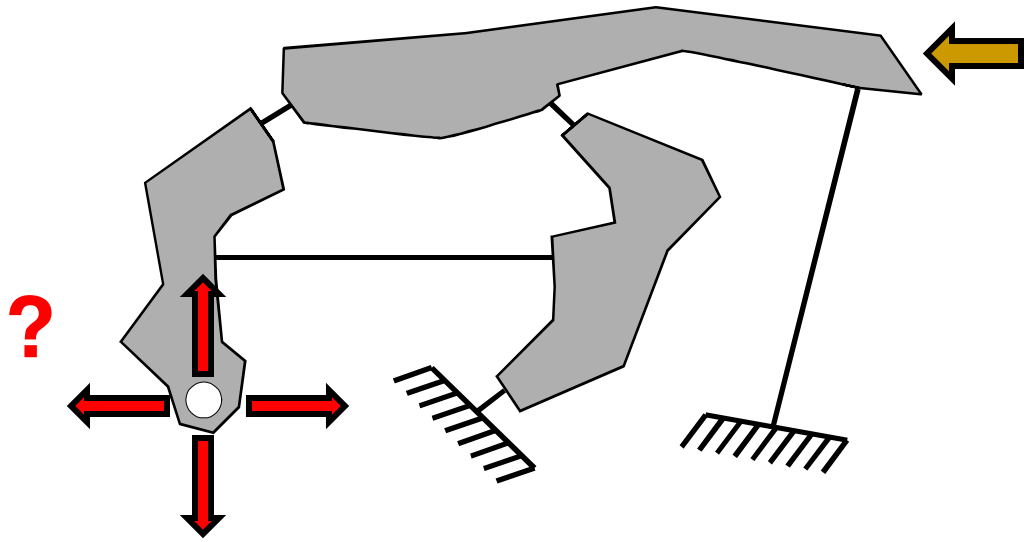

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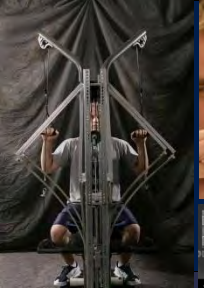
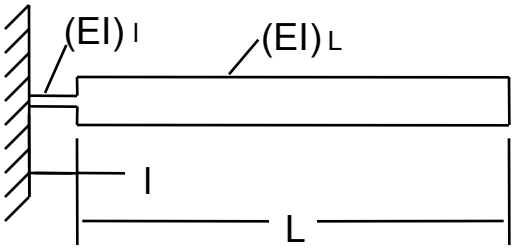
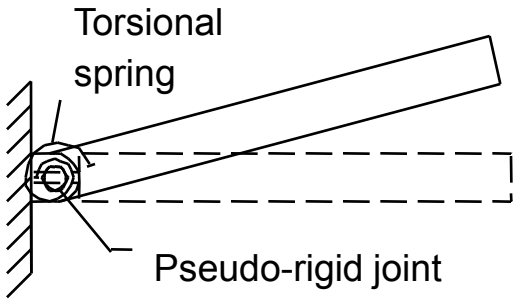


PRBM:
Small-Length Flexural Pivot



l<<L



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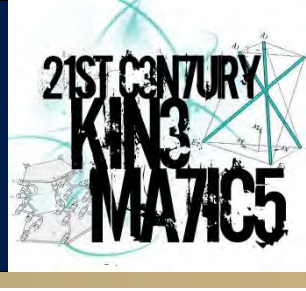
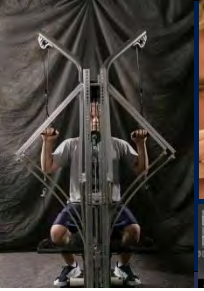
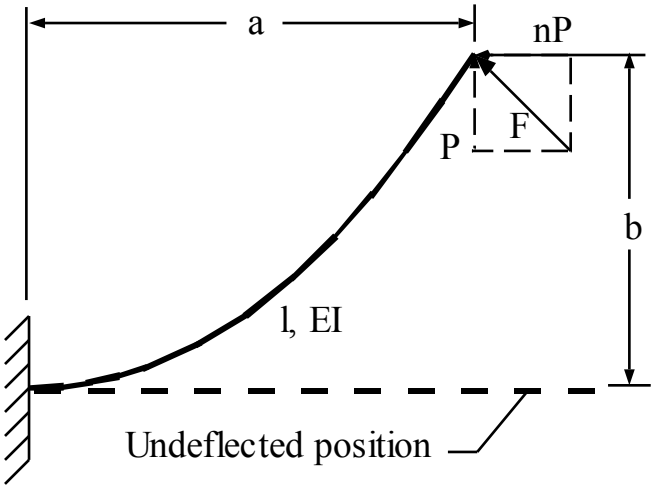
Living Hinges

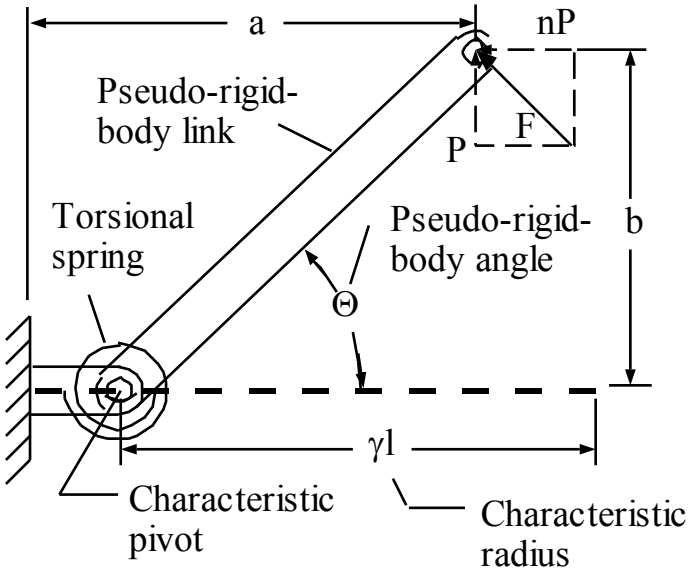


- Living hinge: extremely short and thin small-length flexural pivots
- PRBM is a pin joint at the center of the flexible segment.
- If other compliant elements are present, then can ignore spring for living hinge



PRBM: Fixed-Pinned





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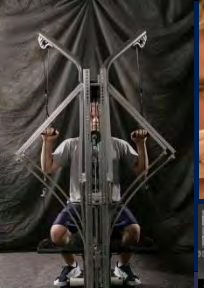
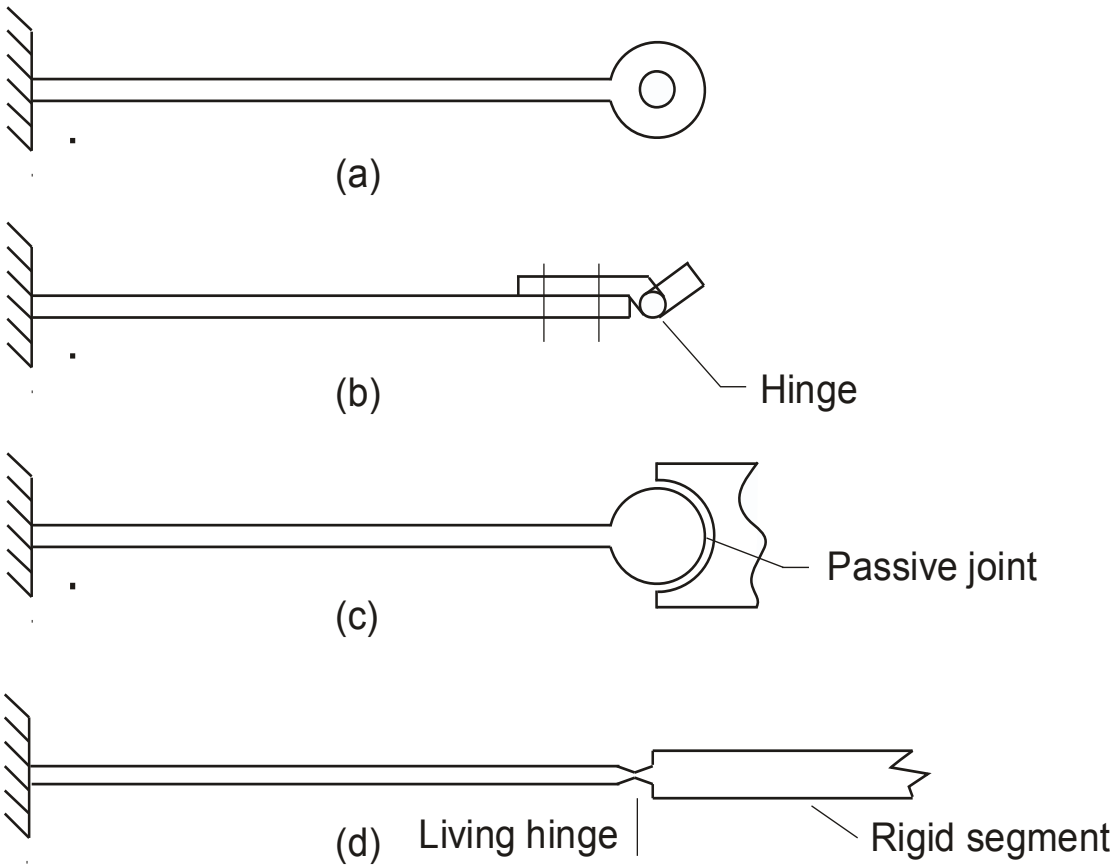
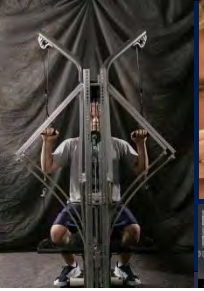
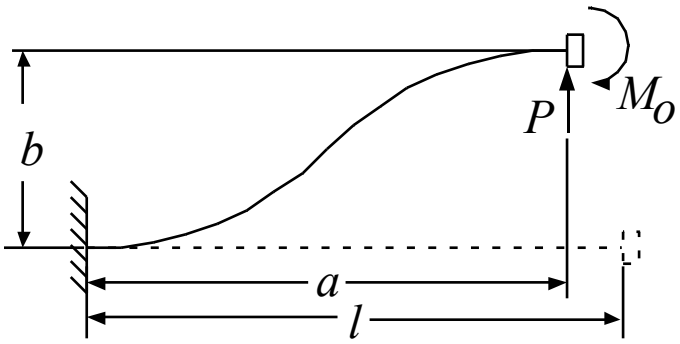


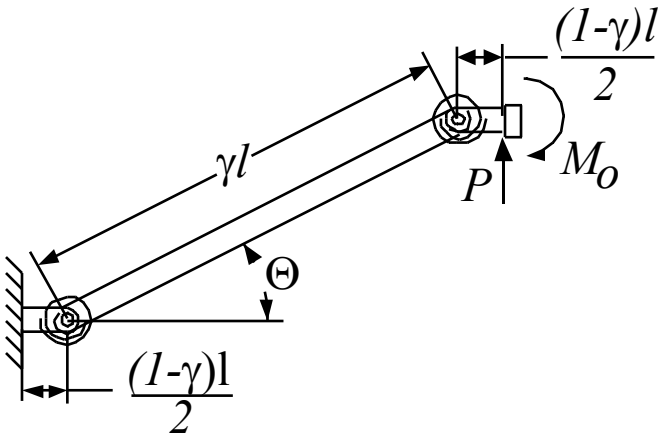
Practical Implementation





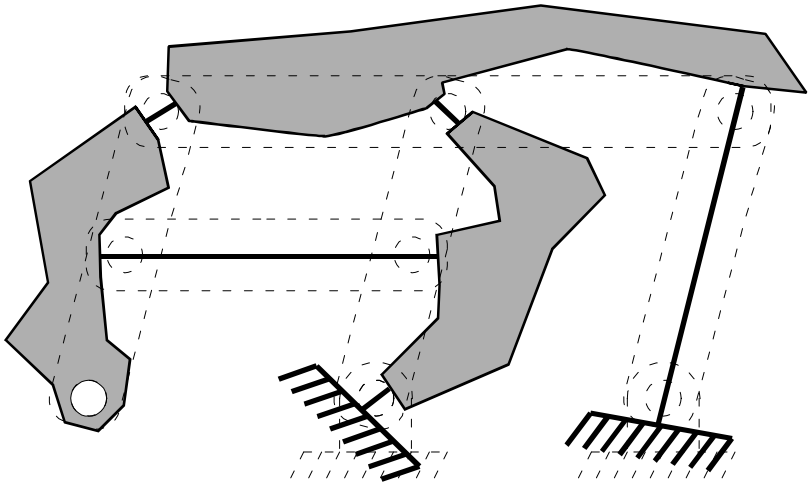
PRBM: Fixed-Guided

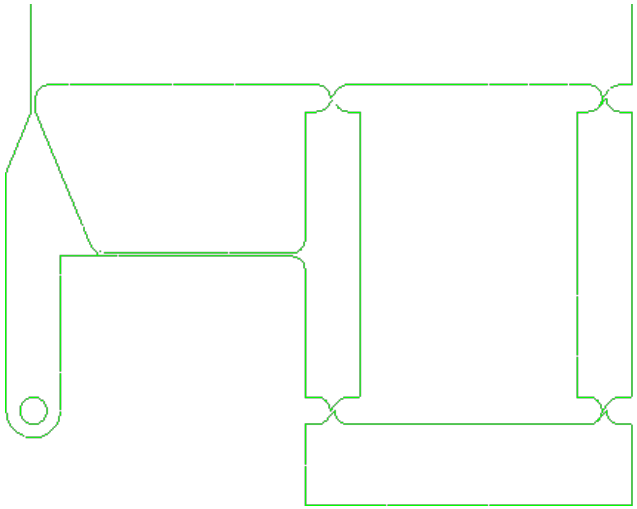


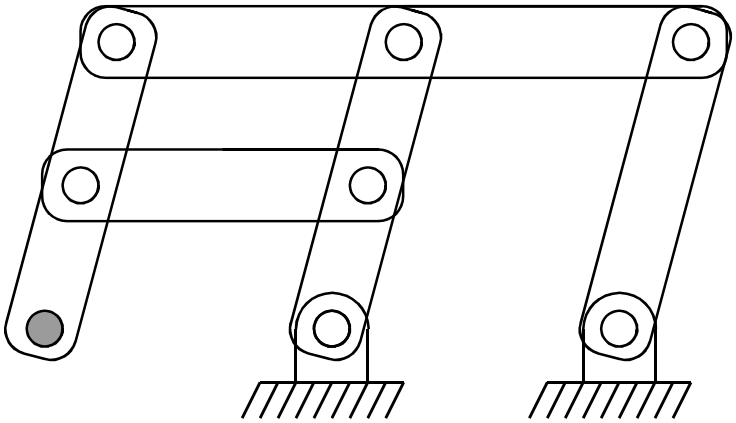


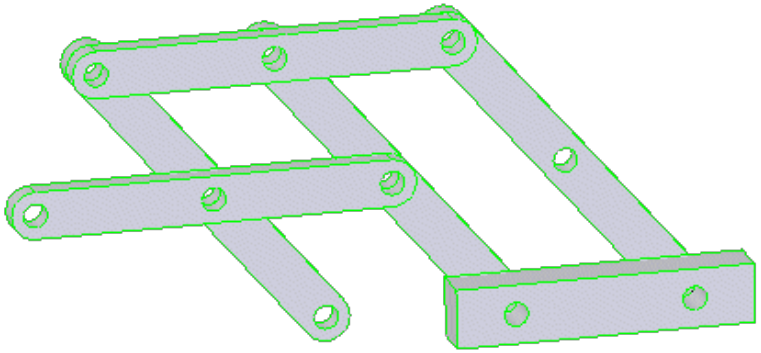


Example









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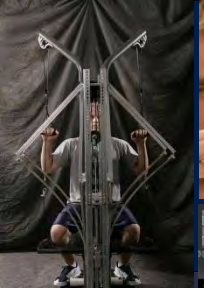
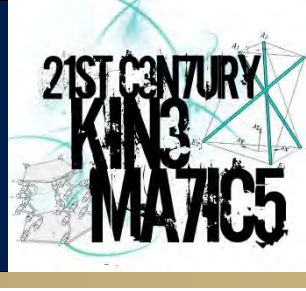


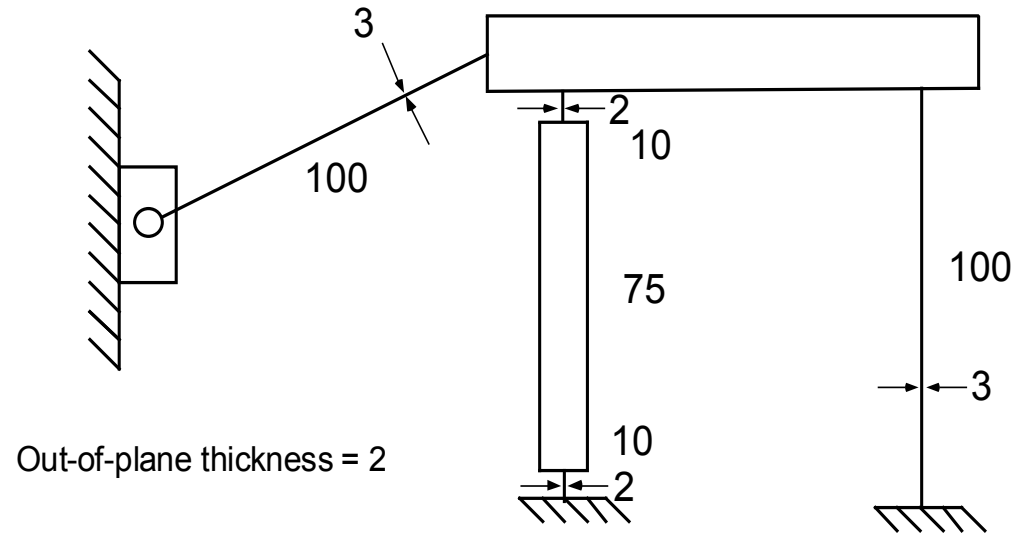
Exercise

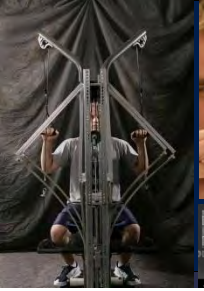


(a) Sketch the PRBM
(b) Calculate the lengths of the links
(c) Write equations for spring constants symbolically
(d) Calculate numerical values of spring constants

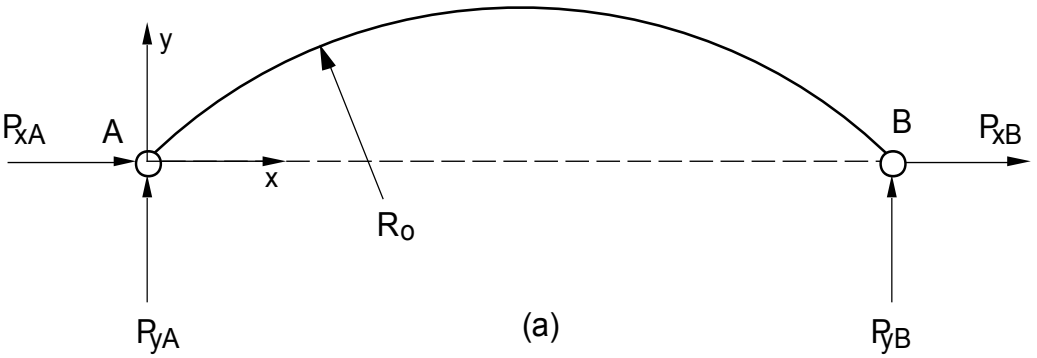
Assume dimensions in mm and material is Aluminum (E=72 GPa)

$I=bh^3/12$

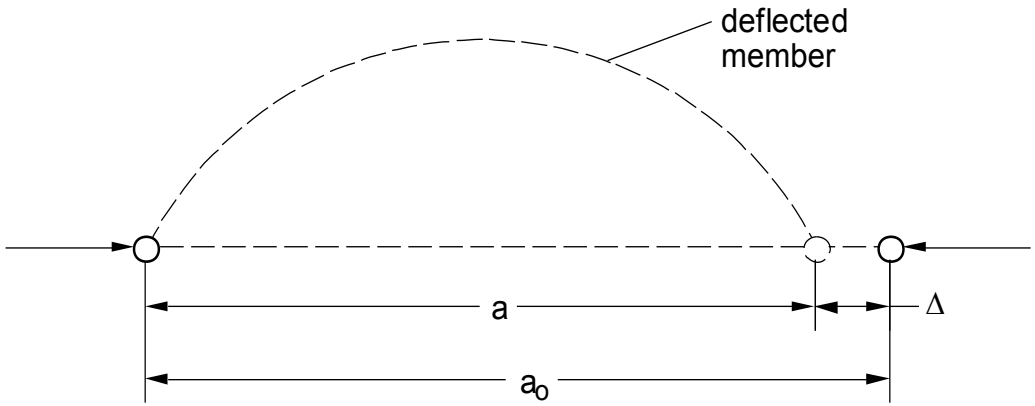




PRBM: Pinned-pinned



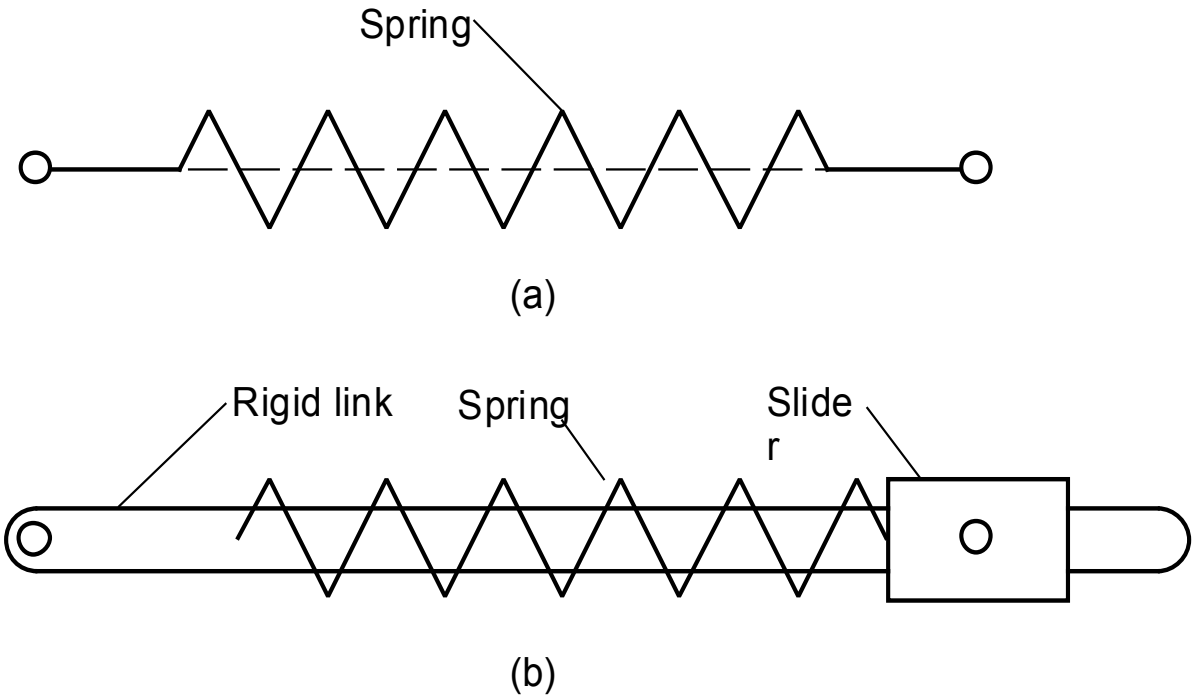
(a)

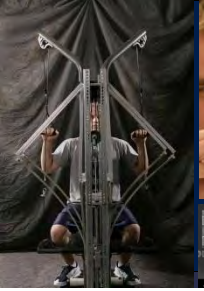


(b)



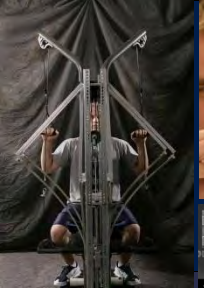
PRBM: Pinned-pinned



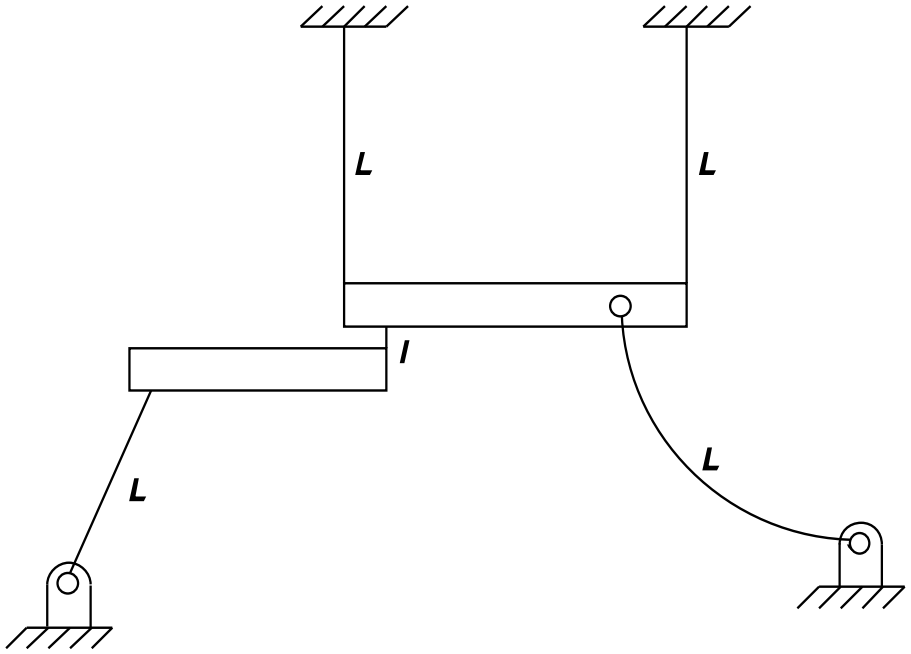


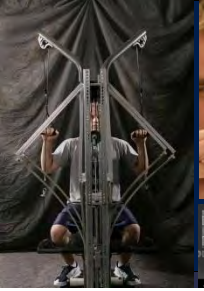
Other Pseudo-rigid-body Models

- Pure moment load
- Initially curved beam
- Other

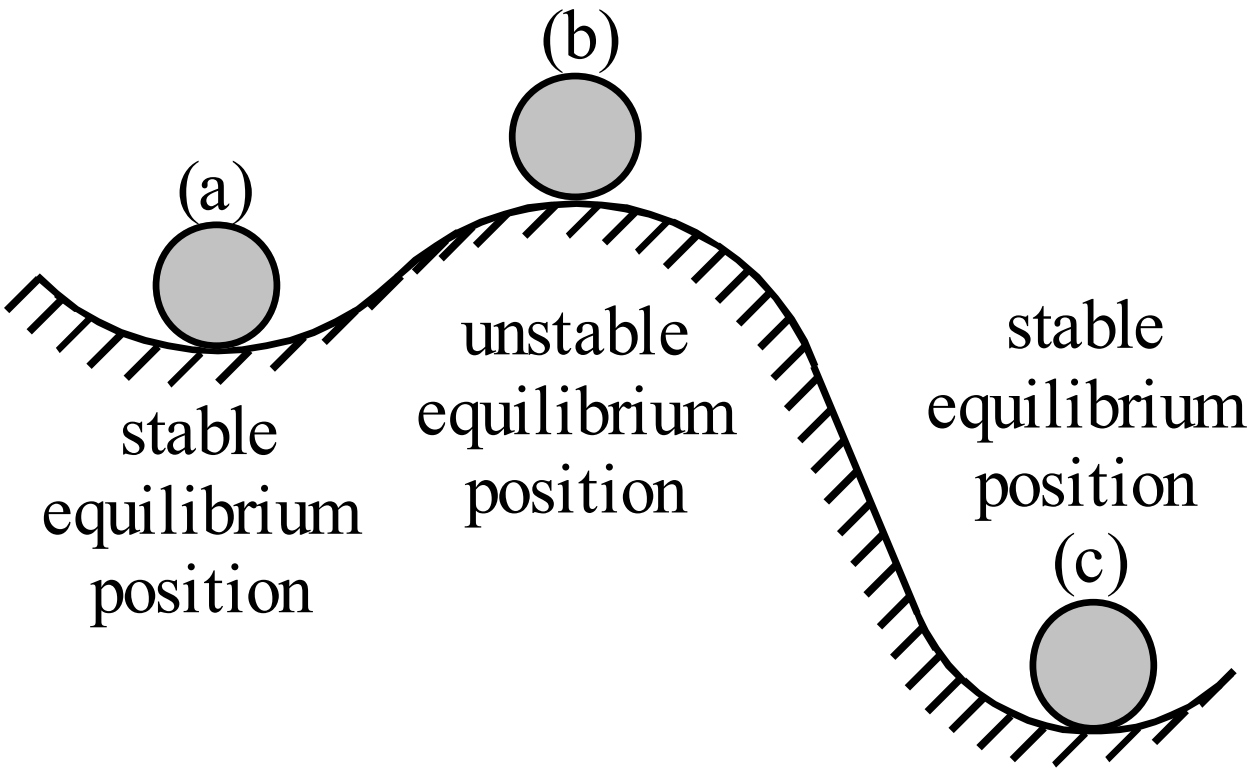


Exercise





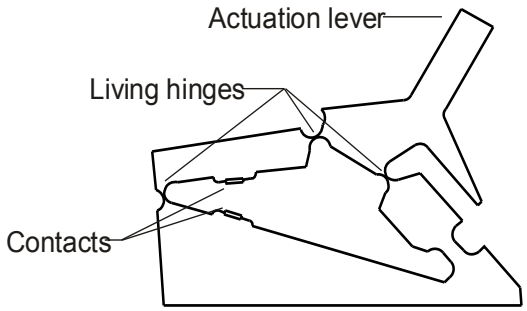
Example: Bistable Switch

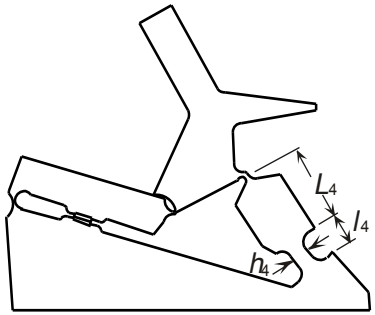


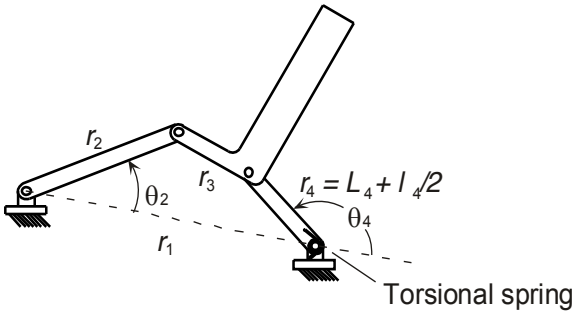


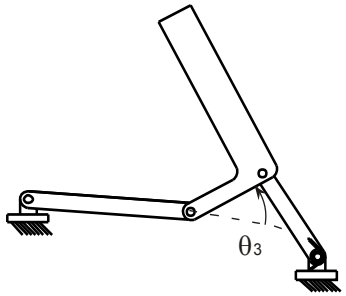
Example


21ST CENTURY
KING
MACHINE


Actuation lever
Living hinges
Contacts


L_4
l_4
h_4

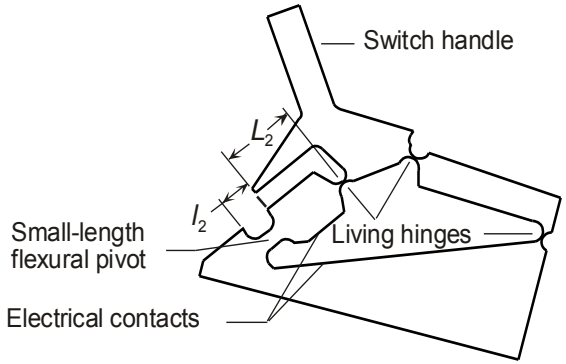

r_2
r_3
$r_4 = L_4 + l_4/2$
θ_2
θ_4
r_1
Torsional spring

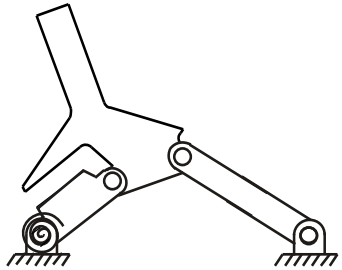

θ_3

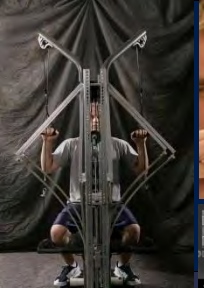


Example

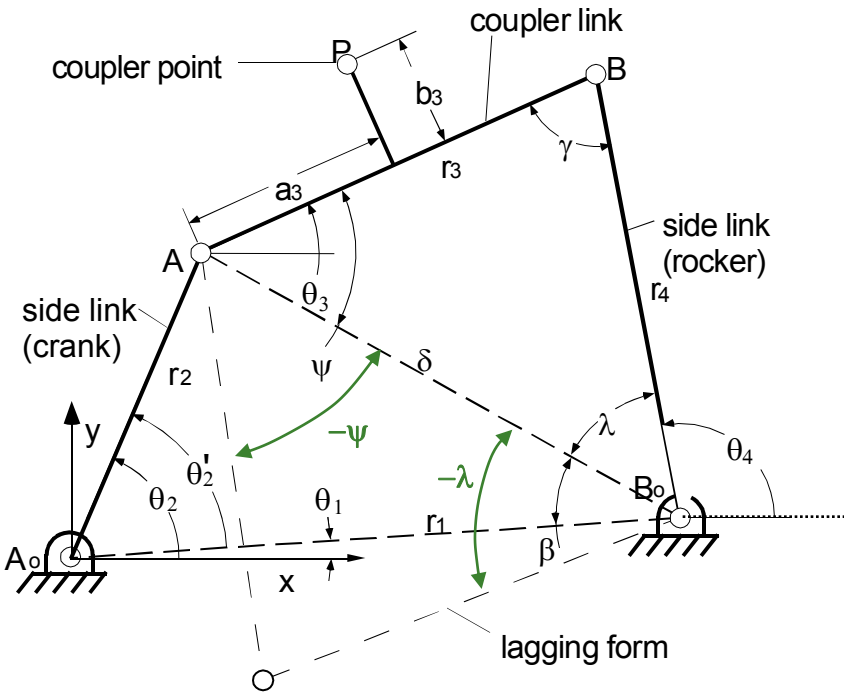
- The pseudo-rigid-body model is a four-bar mechanism
- The potential energy is a function of the deflection of the torsional spring
- PRBM provides simple model that allows the design of needed position and force control







Position Analysis: 4-bar



The lagging (crossed) form is determined by -ψ and -λ, using the second solutions from the $\cos^{-1}(\ )$ equations.

$$\delta = \sqrt{r_1^2 + r_2^2 - 2r_1 r_2 \cos\theta_2'}\ ; \qquad \beta = \cos^{-1}\frac{r_1^2 + \delta^2 - r_2^2}{2r_1\delta}$$

$$\psi = \cos^{-1}\frac{r_3^2 + \delta^2 - r_4^2}{2r_3\delta}\ ; \qquad \lambda = \cos^{-1}\frac{r_4^2 + \delta^2 - r_3^2}{2r_4\delta}$$

For $0 \le \theta_2' \le \pi$

$$\theta_3 = \psi - (\beta - \theta_1)\ ; \qquad \theta_4 = \pi - \lambda - (\beta - \theta_1)$$

For $\pi \le \theta_2' \le 2\pi$

$$\theta_3 = \psi + (\beta + \theta_1)\ ; \qquad \theta_4 = \pi - \lambda + (\beta + \theta_1)$$

also

$$\gamma = \pm\cos^{-1}\frac{r_3^2 + r_4^2 - \delta^2}{2r_3 r_4}$$

$$x_p = r_2\cos\theta_2 + a_3\cos\theta_3 - b_3\sin\theta_3$$

$$y_p = r_2\sin\theta_2 + a_3\sin\theta_3 + b_3\cos\theta_3$$

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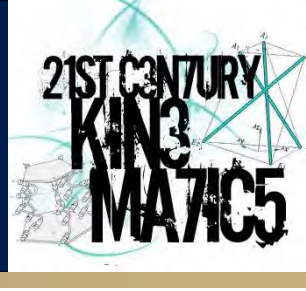
Parametric Models

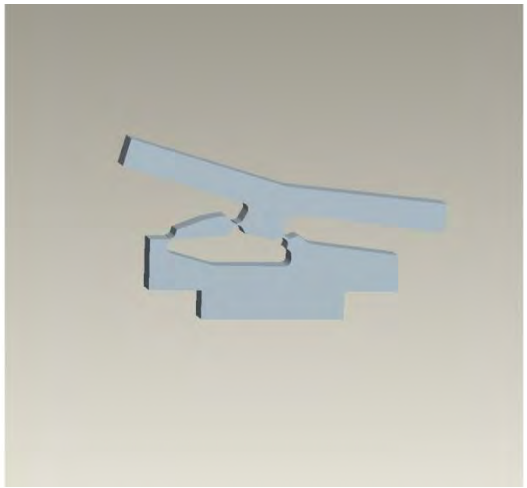


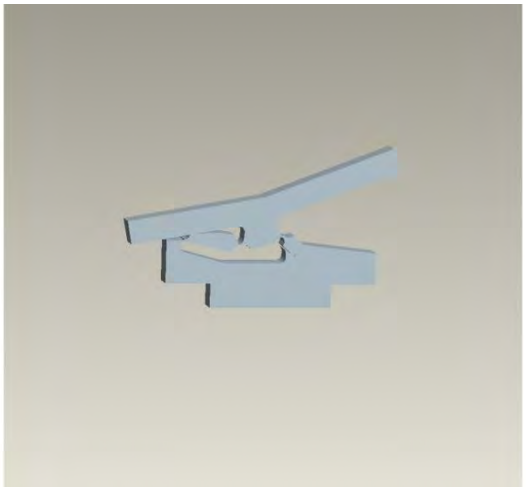
- Powerful design tool
- Analyze many different designs quickly
- Integration with optimization tools
- Convert between different configurations



Example: Rocker Switch

- Same parametric models apply to move from a toggle switch to a rocker switch





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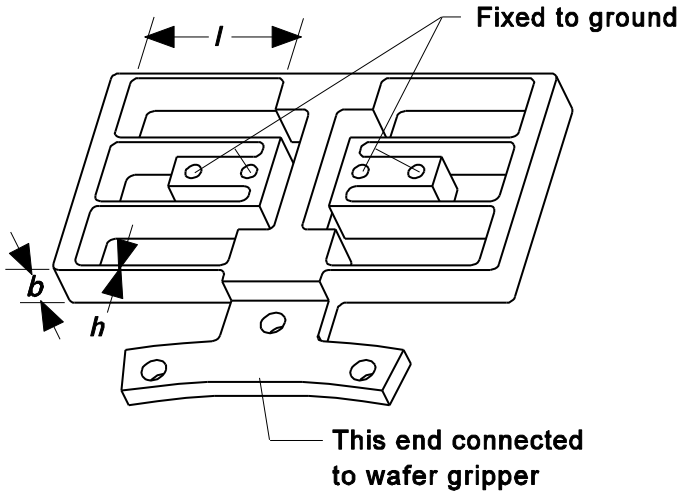
PRBM with CAE tools

- Spreadsheets, Matlab, etc
  - Switch example

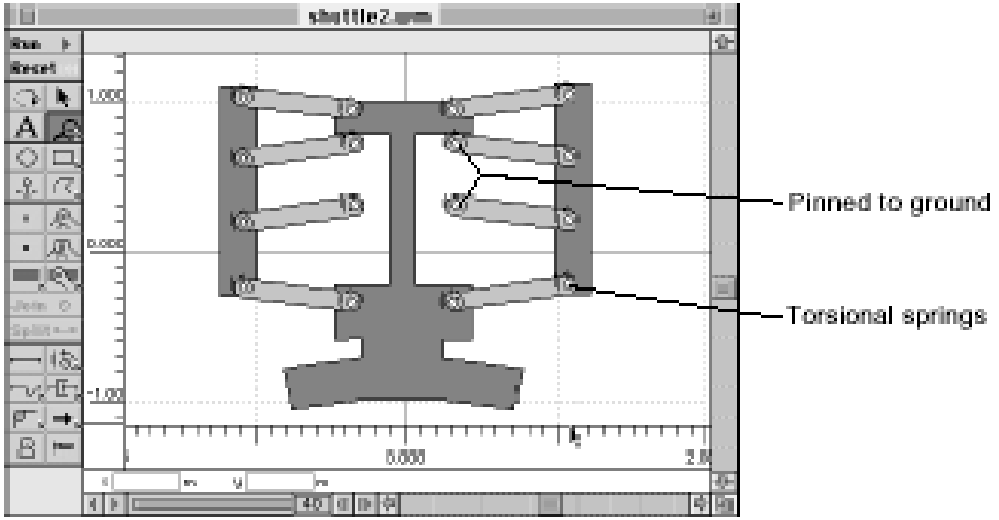


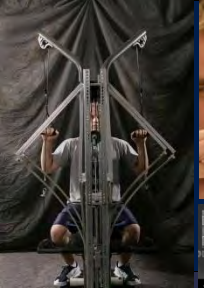
PRBM with CAE tools

- Multi-body dynamics tools (ADAMS, etc.)
  - Examples
    - folded-beam suspension
    - switch

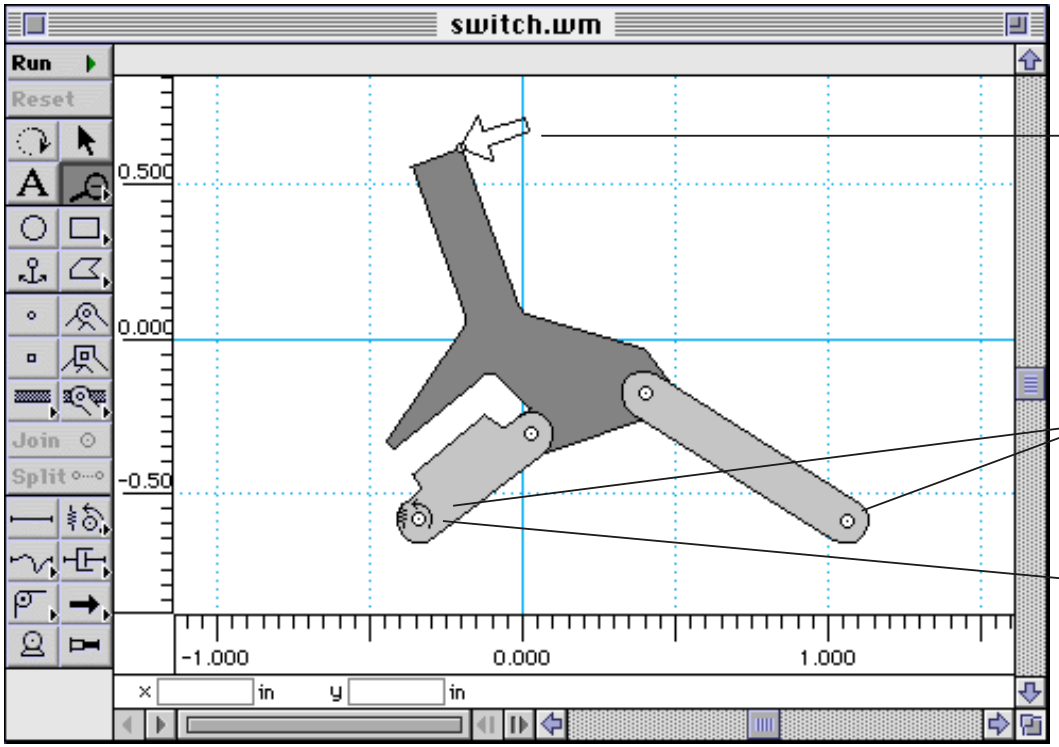

l
Fixed to ground
b
h
This end connected
to wafer gripper

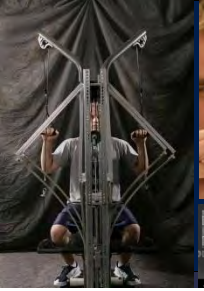
(a)


shuttle2.grm
Run
Reset
1.000
0.000
-1.000
0.000
Pinned to ground
Torsional springs

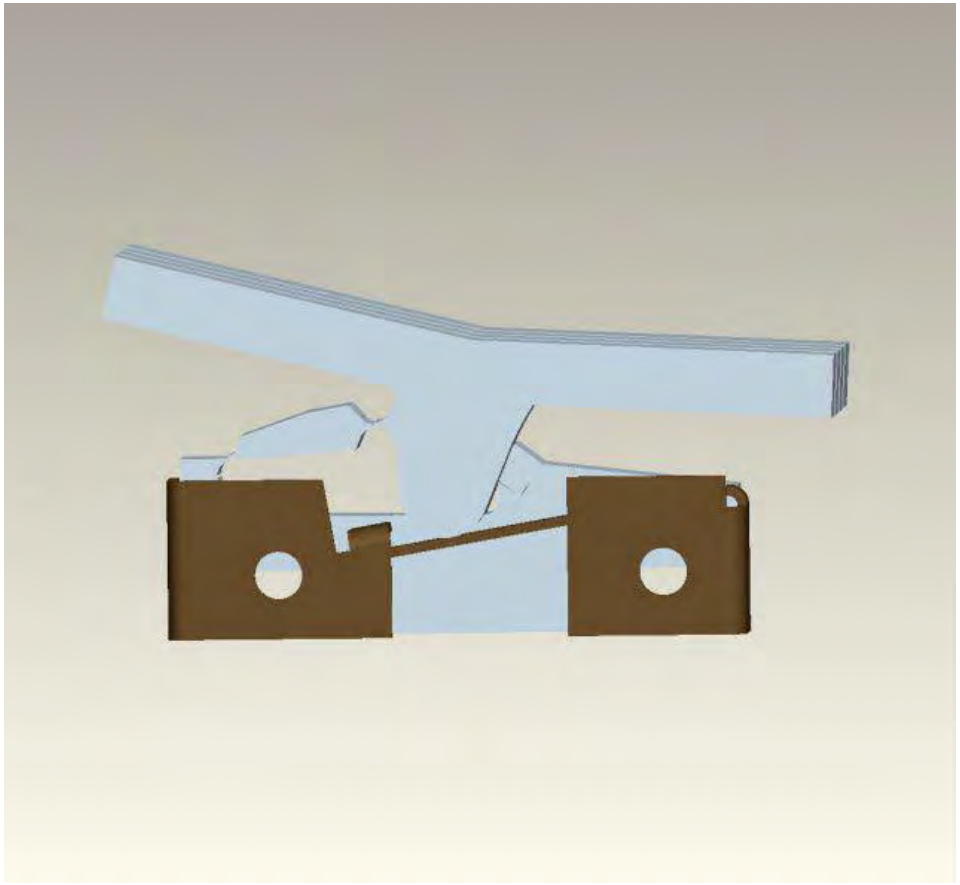


Example: Switch





Rocker Switch



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MECHANICAL ENGINEERING

So why compliant mechanisms now?

Computational capabilities

Materials and processes

Design methods

and . . .

New needs

High performance
- weight
- friction and wear
- precision

Size domains
- meso
- micro
- nano

Critical applications
- biomedical
- space
- economic

Cost
- part count
- assembly
- manufacturing

New motions
- morphing
- lamina emergent
- adaptive

High performance

- weight
- friction and wear
- precision

Size domains

- meso
- micro
- nano

Critical applications

- biomedical
- space
- economic

Co

-
-
-

Cost

- part count
- assembly
- manufacturing

New motions

- morphing
- lamina emergent
- adaptive

21st Century Compliant Mechanisms

Biomedical Implants

Microelectromechanical Systems (MEMS)

Biomedical Implants

FlexBAC

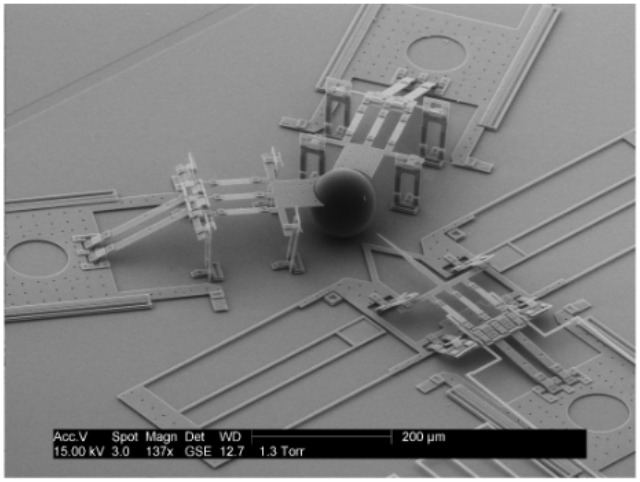
CROCKER
Spinal Technologies, Inc.

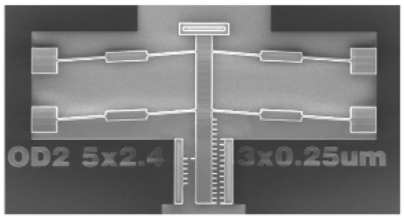
Biomedical Implants

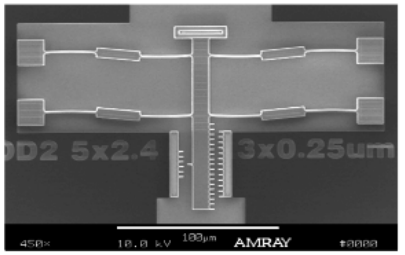
FlexBAC

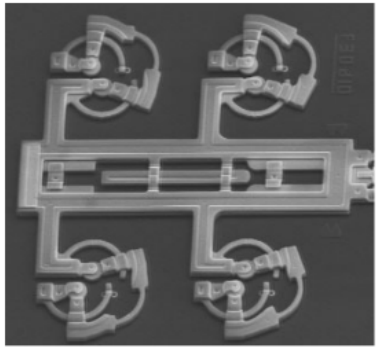
CROCKER
Spinal Technologies, Inc.

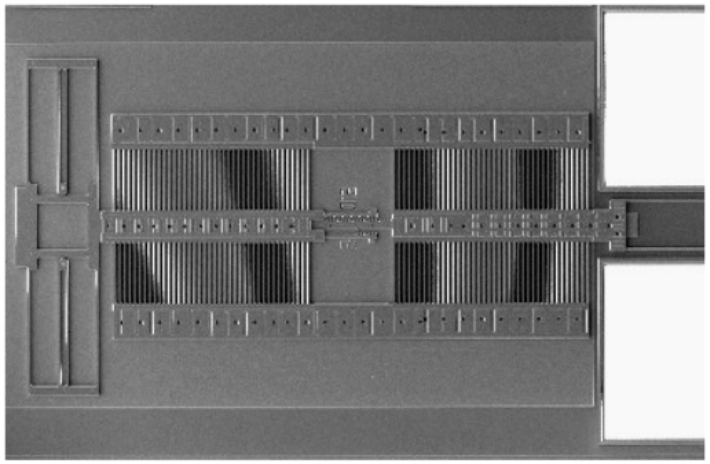
Microelectromechanical Systems (MEMS)

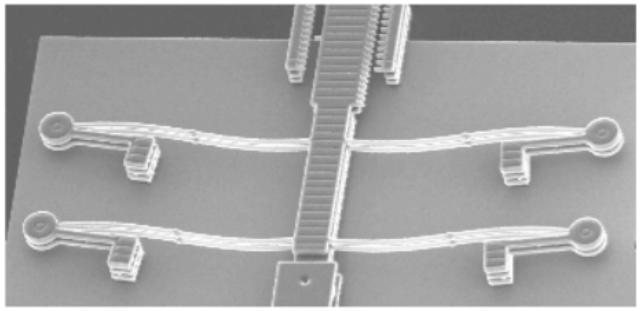








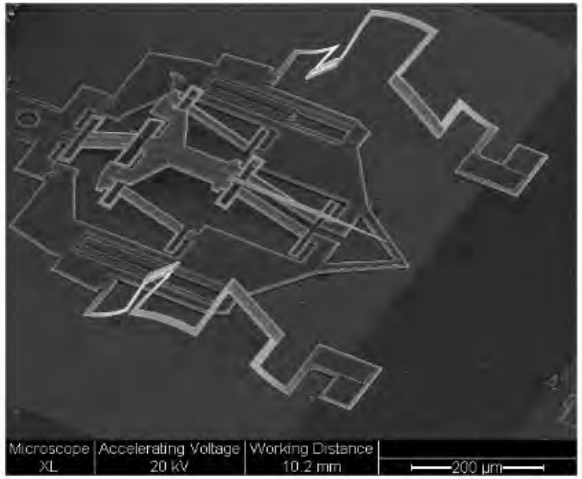




Engineering Tools of Scientific Discovery

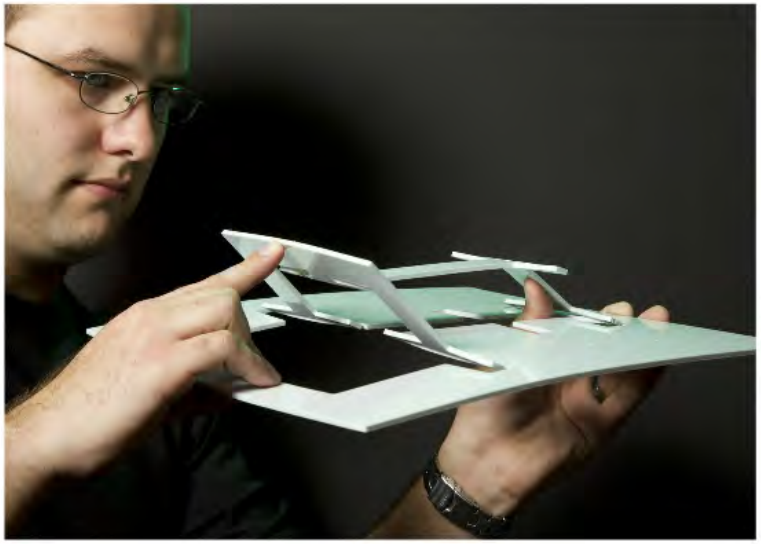
NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

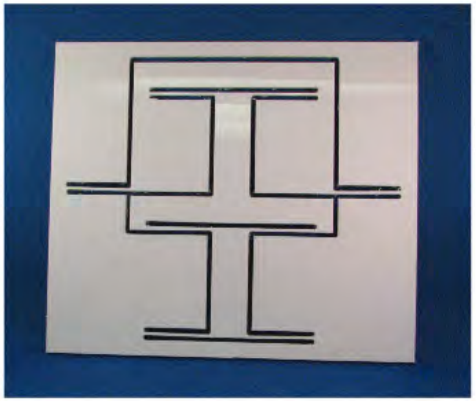
The Grand Challenges of Engineering

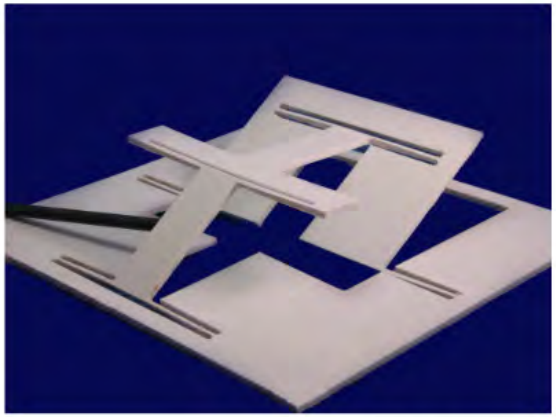


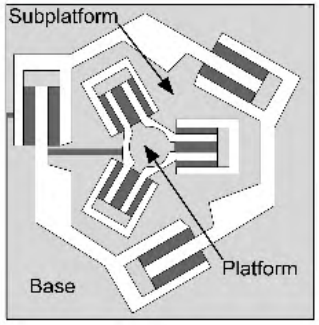
NanoInjection
TECHNOLOGIES, LLC

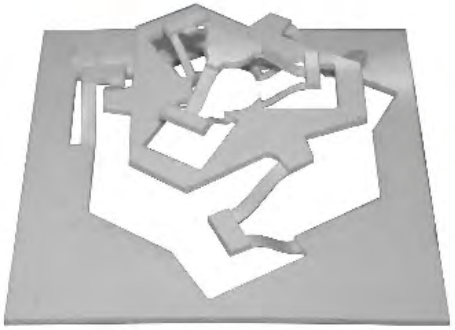
Lamina Emergent Mechanisms

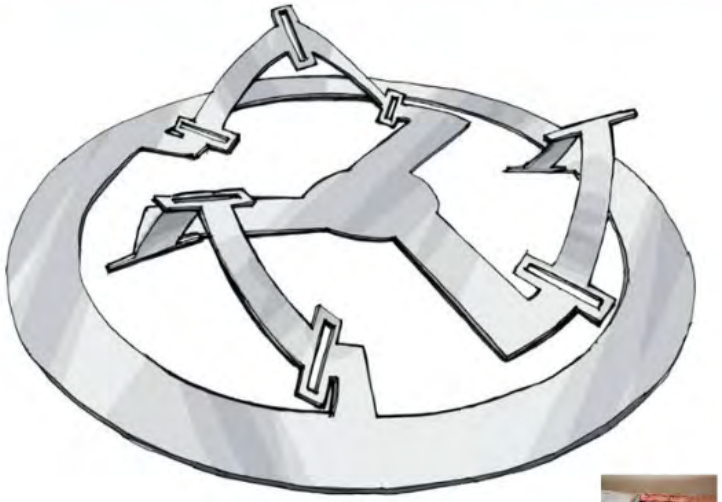


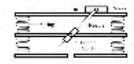


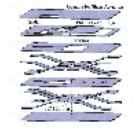












What do you think is next?

Hypercompact Mechanisms

Adaptive Morphing Systems

Disruptive Innovations

More Human-like Implants

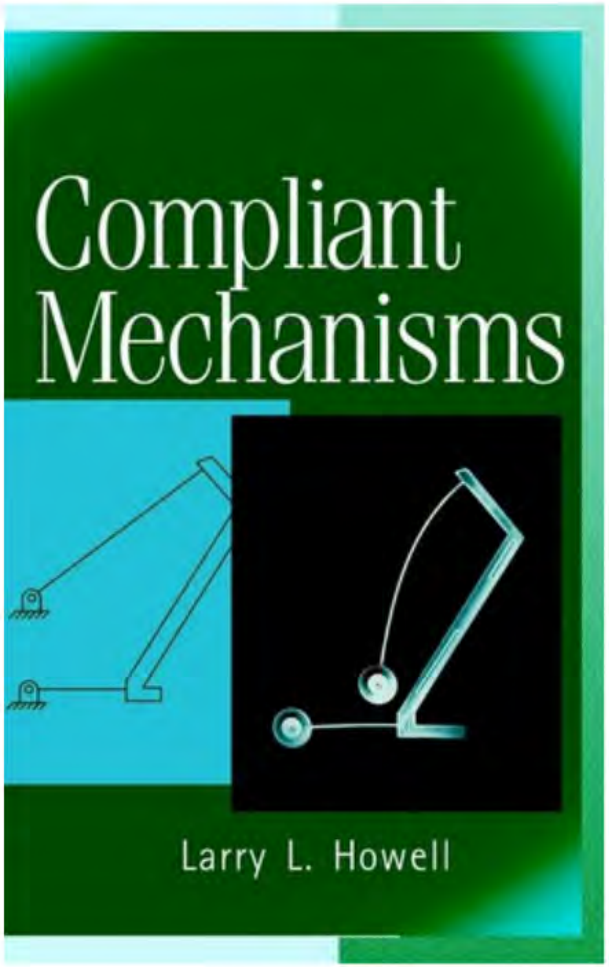
Nanomachines

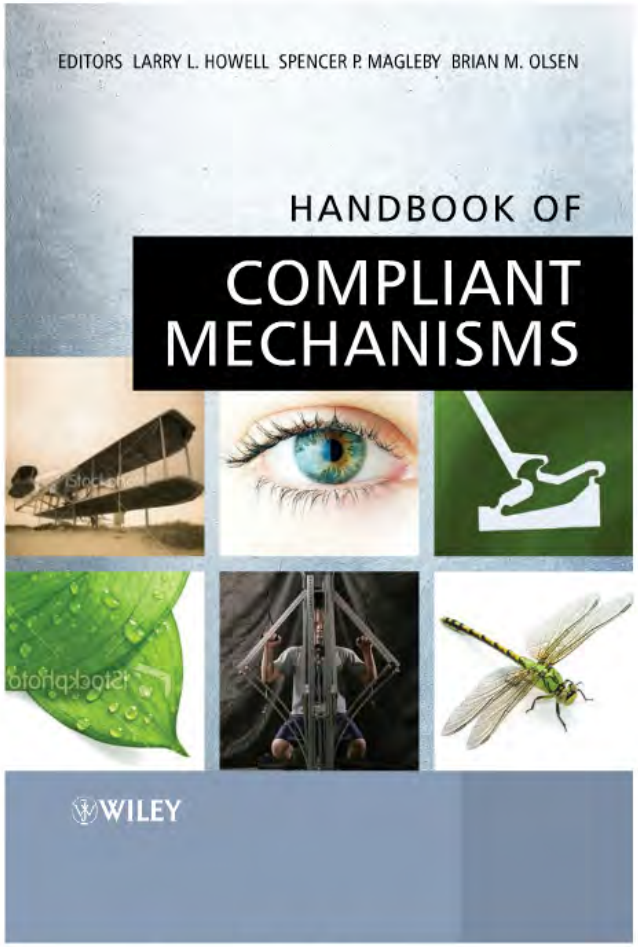
Advanced Materials

Human-Robot Interactions

Products using Local Materials

Resources





Available soon

Acknowledgements

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Collaborators:

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- Prof. Brian Jensen
- Prof. Anton Bowden
- Prof. Sandra Burnett

Thank you!