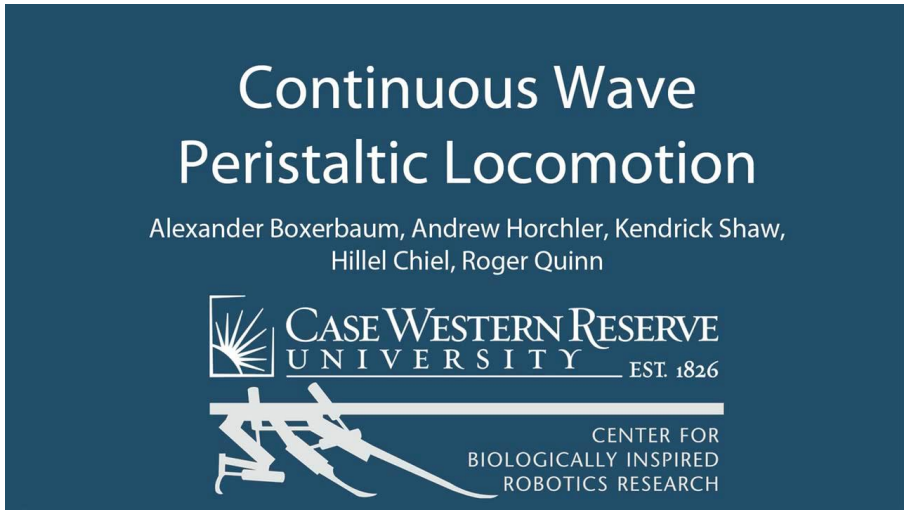
CASE WESTERN RESERVE UNIVERSITY

DARPA NASA NSF U.S. AIR FORCE ONR

Climbing robots with animal inspired feet for ISS internal inspection

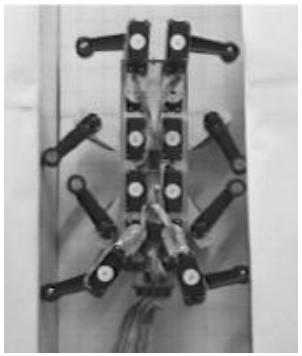
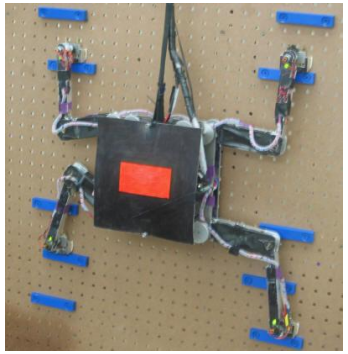
Roger Quinn
Biologically Inspired Robotics Group

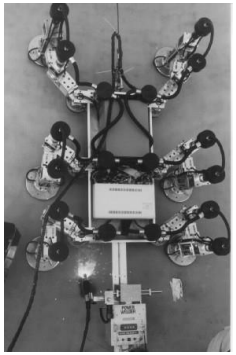
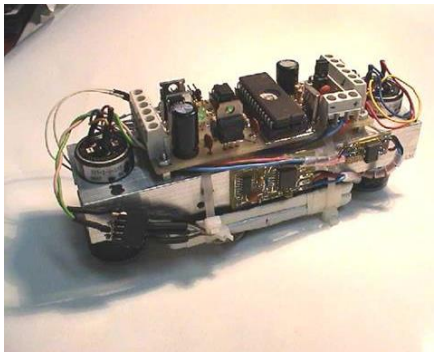
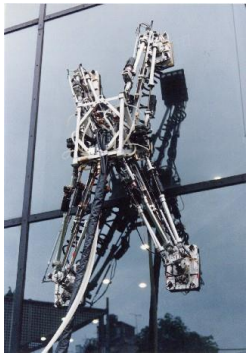


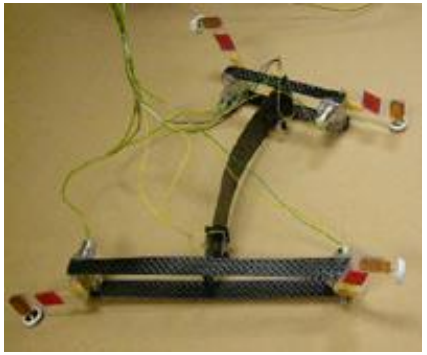
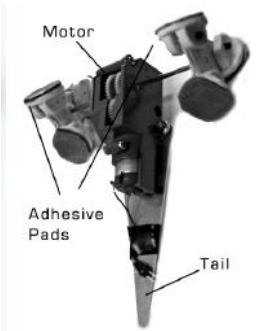
Outline

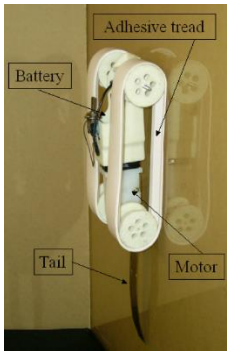
- Why animal-inspired adhesion?
- Our previous work ~ 2005 with first generation microstructured material
- Development of improved material
- New results for climbing
- Other inspection vehicles

Climbing Robots

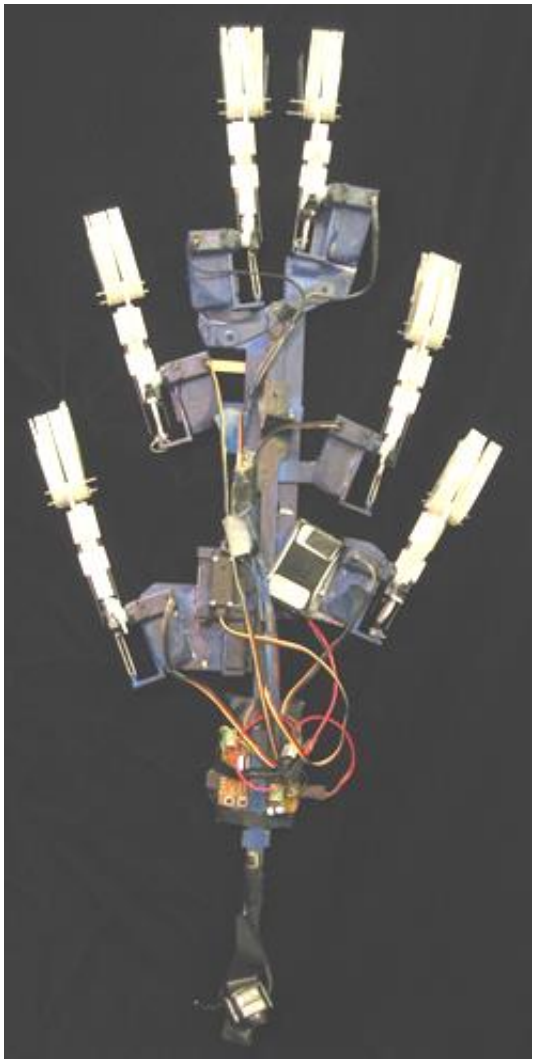



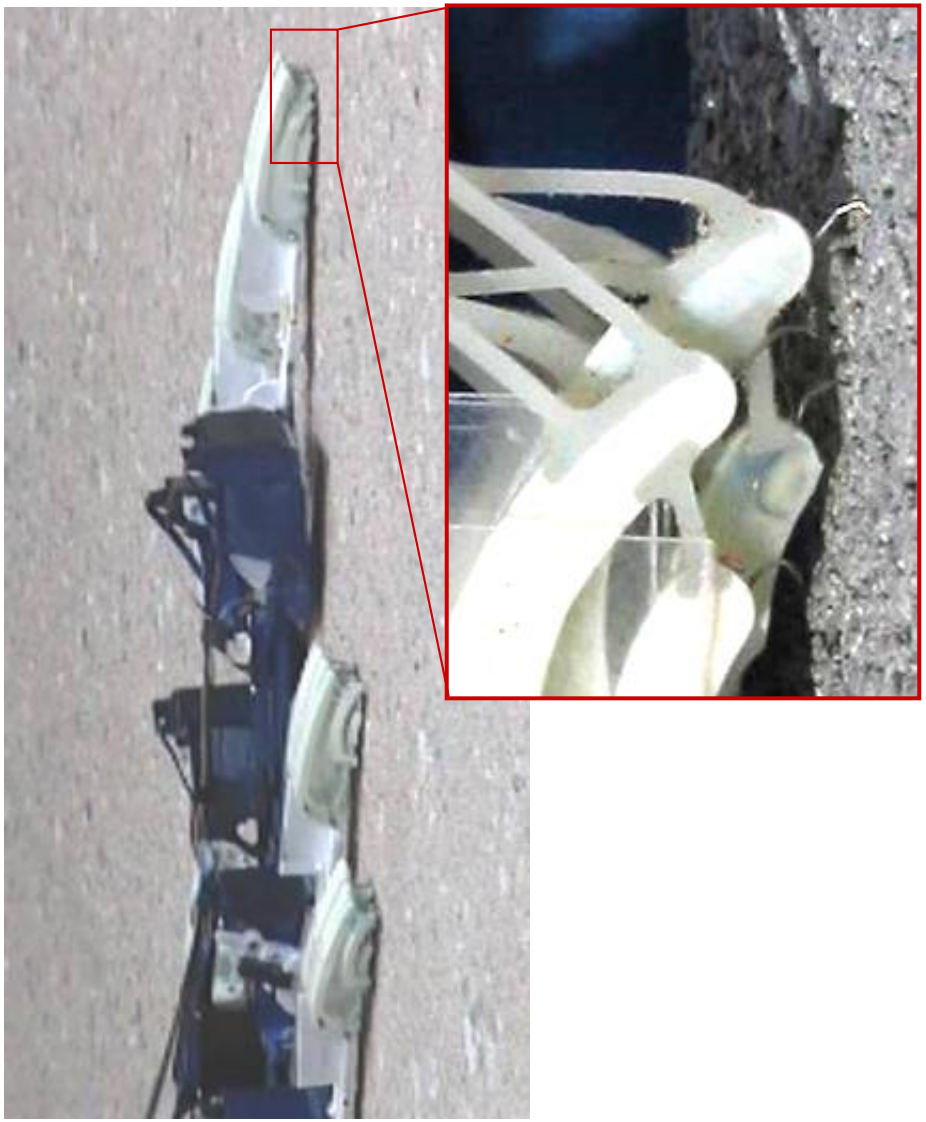






SpinyBot: Stanford

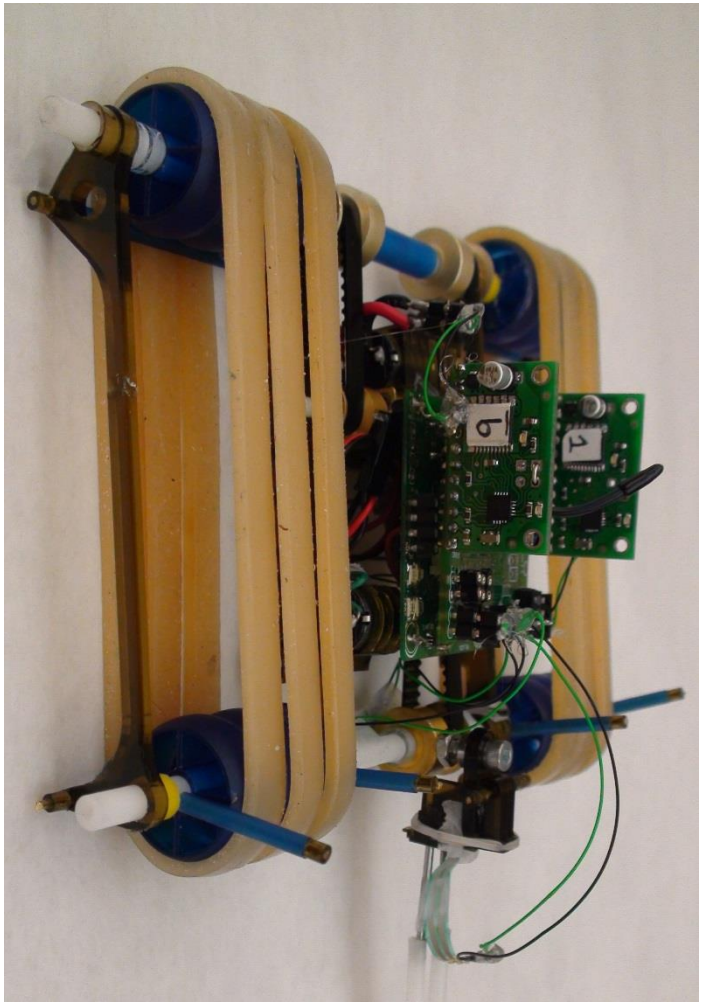




Other Climbers

Stickybot: Stanford 2006

Rise: Boston Dynamics, University of Pennsylvania, Carnegie Mellon, UC Berkeley, Stanford, and Lewis and Clark University.
2007



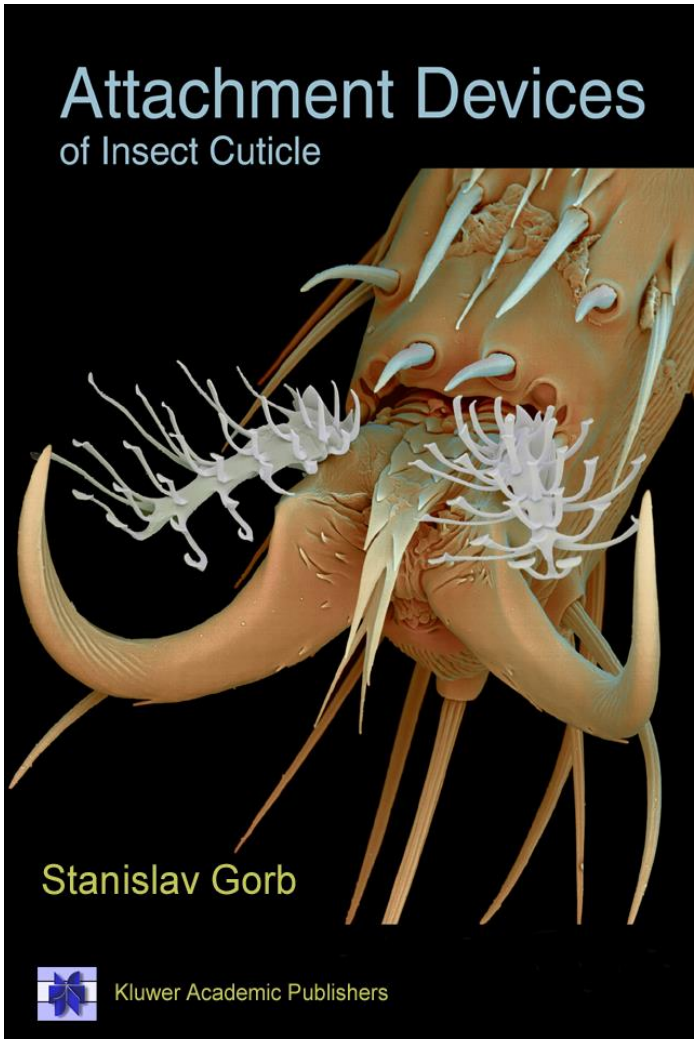
Tankbot: CMU 2009

Climbing Vertical and Inverted Surfaces Using Adhesive Mechanisms

For climbing hard smooth surfaces, animals use either:

Hairy pads (e.g. geckos, flies, beetles)
or
Smooth pads (e.g. cockroaches)

Autumn, K., Liang, Y. A., Hsieh, S. T., Zesch, W., Chan, W.-P., Kenny, W. T., Fearing, R. and Full, R. J. (2000). Adhesive force of a single gecko foot-hair. *Nature* **405**, 681-685.



Climbing Insects

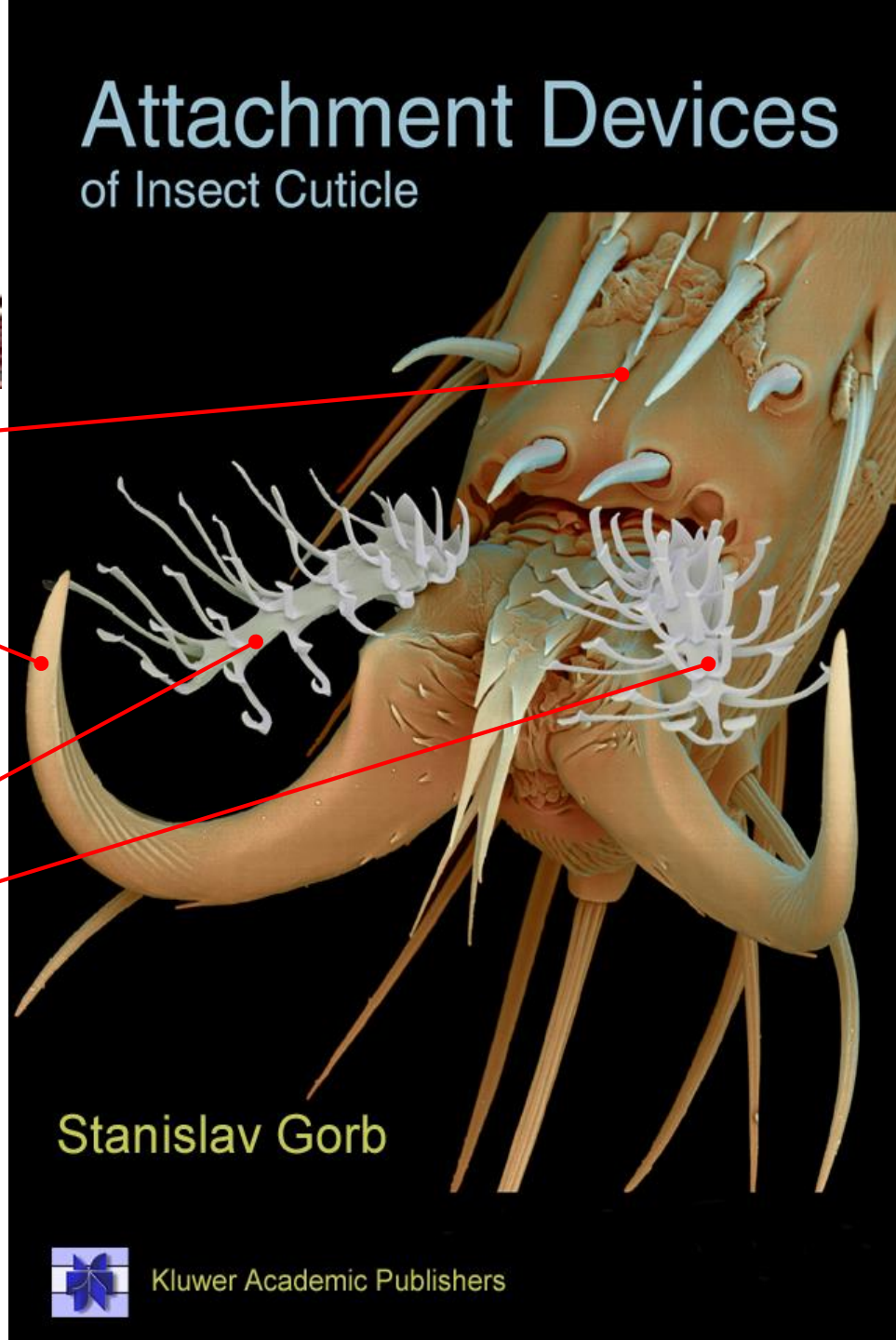
Stas Gorb

structures for interlocking and friction enhancement on rough substrata

- claws
- stiff pointed hairs

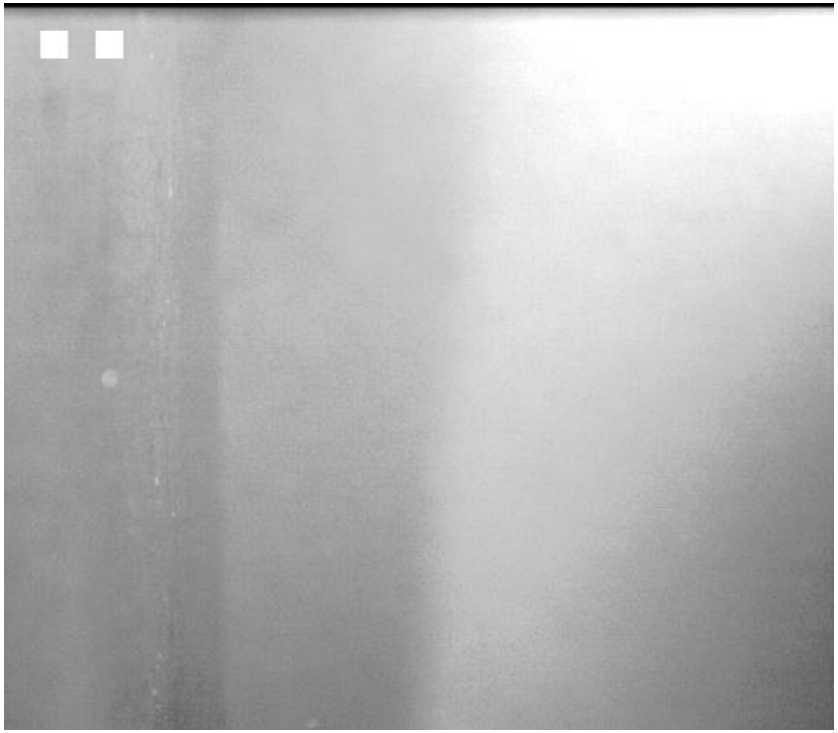
structures for adhesion and friction enhancement on smooth substrata

- pulvilli
- arolia
- euplantulae
- etc, etc.

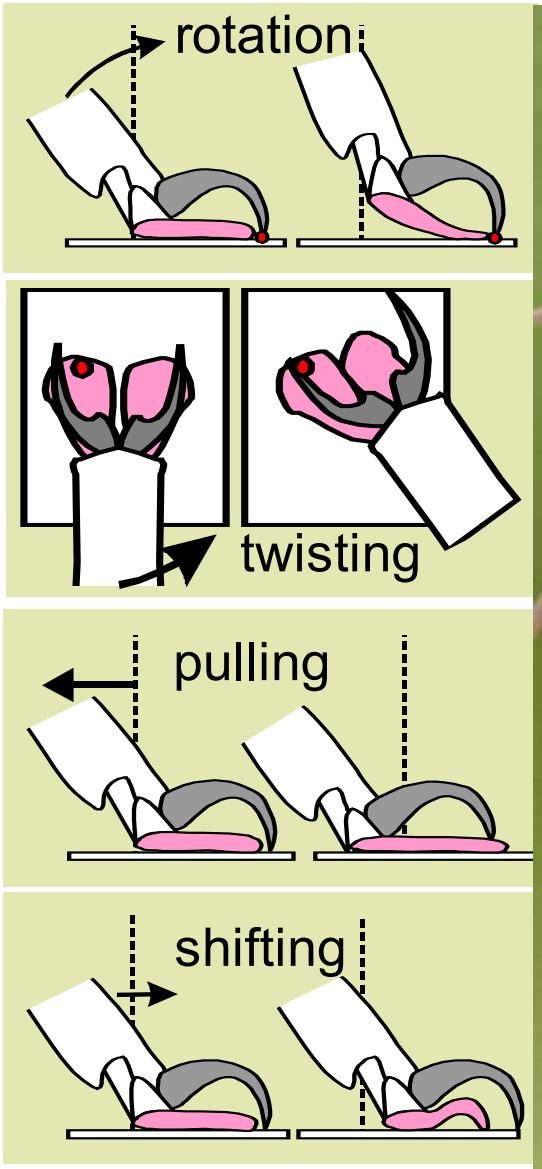


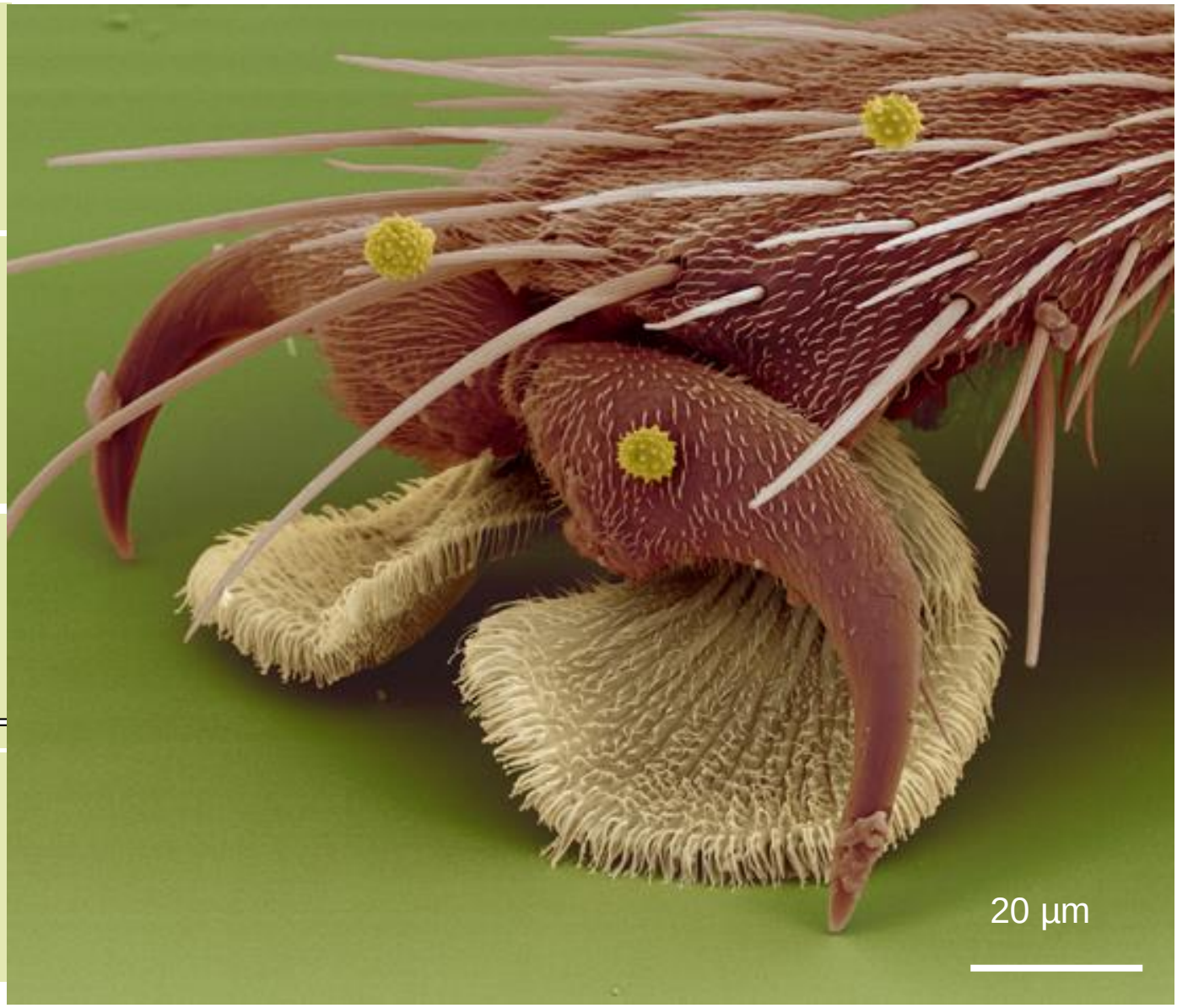
Roy Ritzmann

Cockroaches use smooth pads

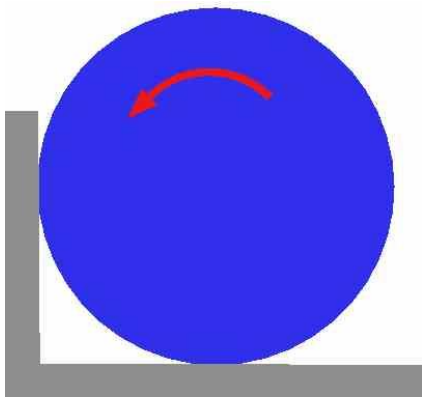


Fly Tarsus

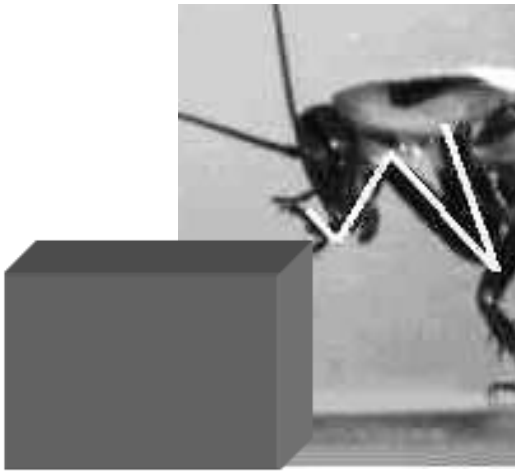




Wheel + Leg



Legs:
discontinuous,
uneven terrain

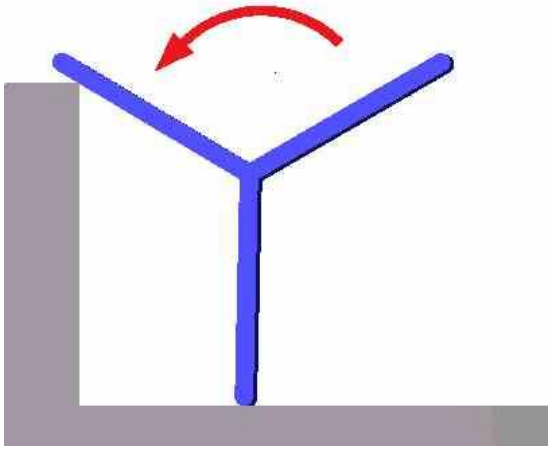


Wheels : continuous, firm
smooth terrain

Video

Wheel-leg:

- **multiple spokes**
- **climbs like leg**
- **rolls like wheel**
- **leg cycle function with constant motor speed**

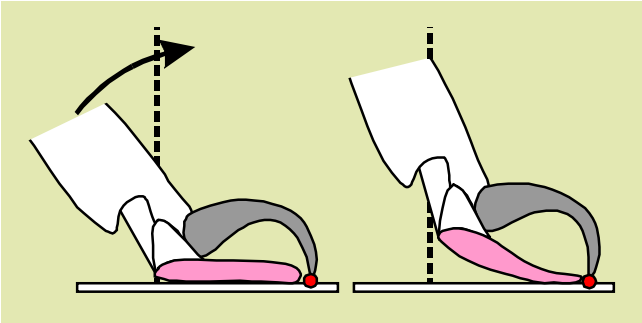


Whegs™ are Fieldable

Mini-Whegs: 9cm Long

Search and Rescue

Insects Attach/Peel Feet in Climbing



Model of fly tarsus peeling – Stas Gorb

Climbing with tape PSA

Corners Body-Joint

PVS Whegs™

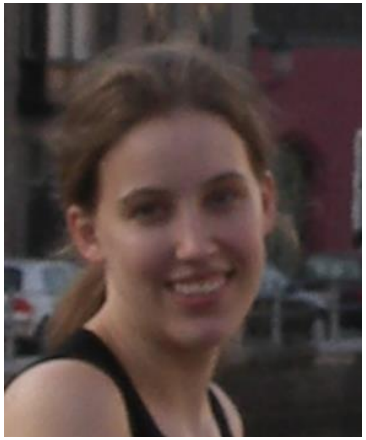
No Barbs

Barbs

Screen-bot

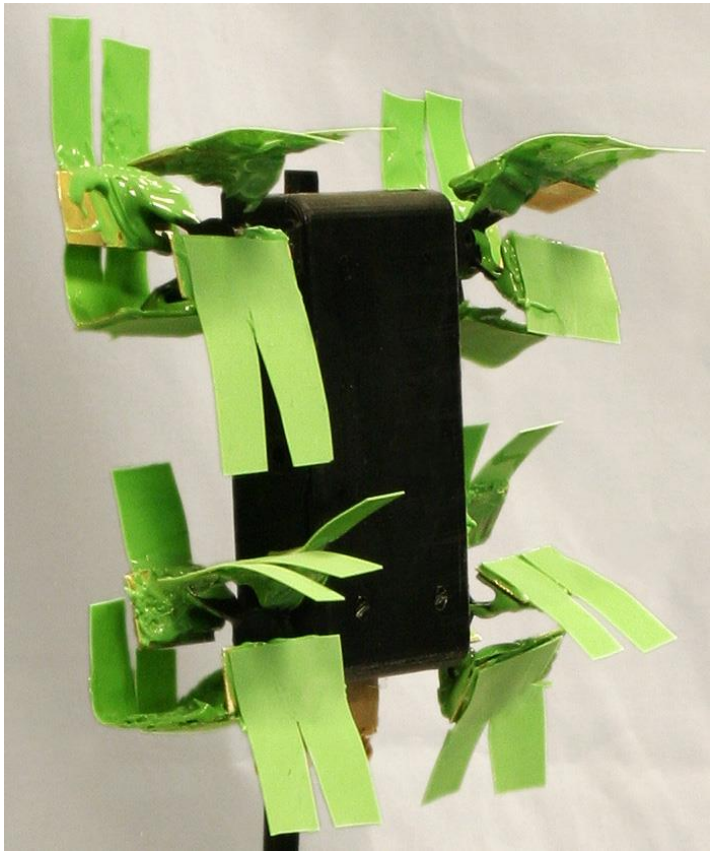
Proof of concept:
Mini-Whegs with Scotch Tape

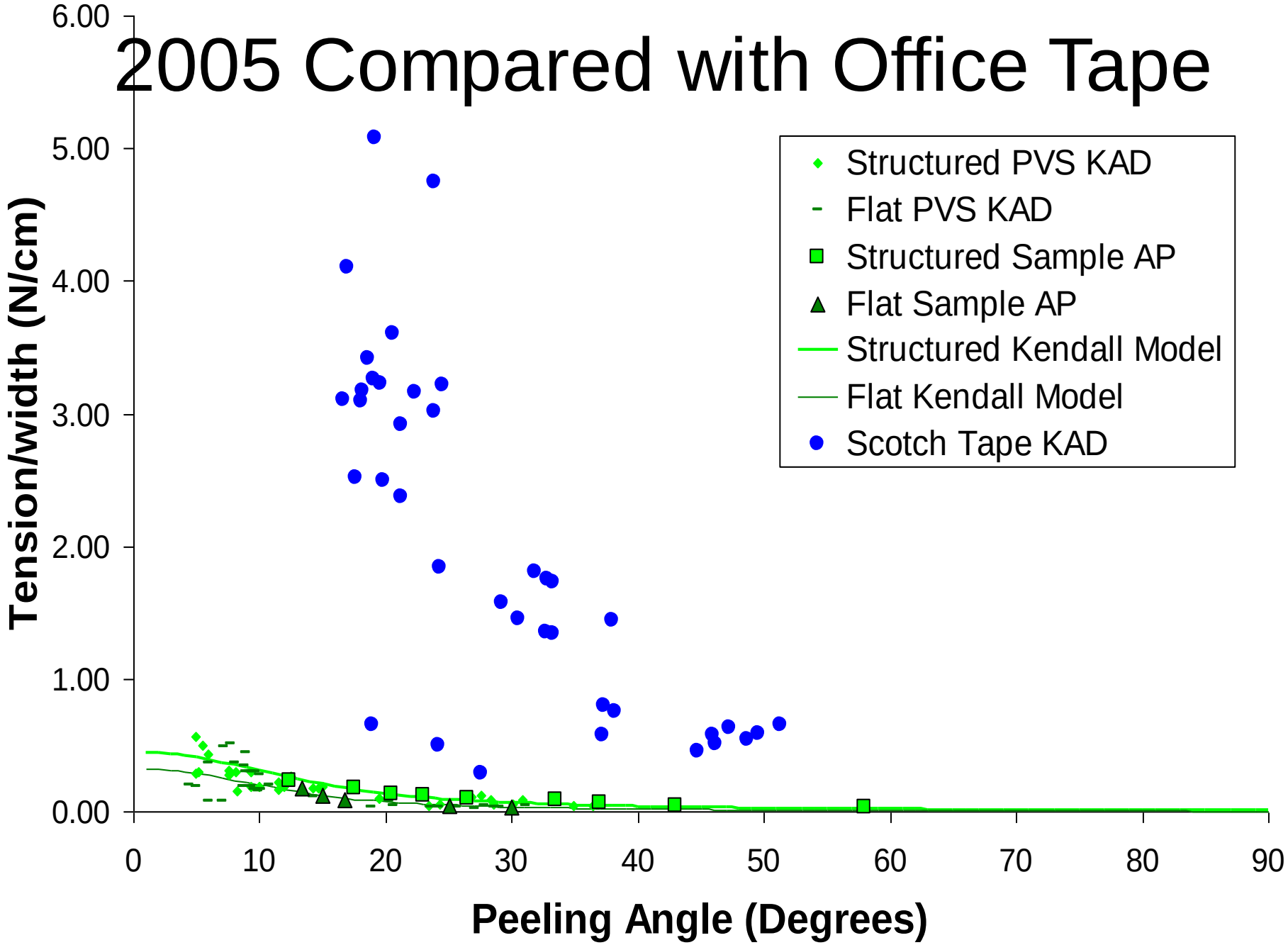
Robot with microstructured PVS feet



Kati Daltorio

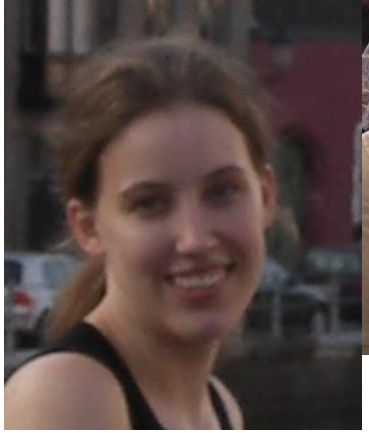
Stas Gorb




2005 Compared with Office Tape
Tension/width (N/cm)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
Peeling Angle (Degrees)
Structured PVS KAD
Flat PVS KAD
Structured Sample AP
Flat Sample AP
Structured Kendall Model
Flat Kendall Model
Scotch Tape KAD

Wall Climbing with structured PVS

2005



Kati Daltorio

Greg Wile

Stas Gorb

CASE
CASE WESTERN RESERVE UNIVERSITY
CENTER FOR BIOLOGICALLY INSPIRED ROBOTICS RESEARCH

Mini-Whegs 7 (2003)

Specifications from 2005

- Ascend a smooth, clean vertical surfaces using adhesive feet
- Non-directional (up, down, sideways)
- Steering
- Overcome small obstacles
- Walk inverted on horizontal surfaces
- Transition between orthogonal surfaces

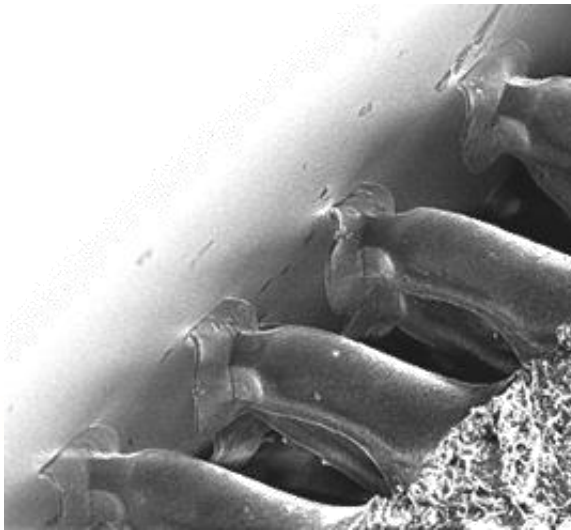
- **Conclusion: 2005 material not nearly good enough**

Zoological Institute, Universität zu Kiel, Germany

Great Progress in Material Design and Performance since 2005

Stanislav Gorb

Biomimetic Adhesive Microstructures



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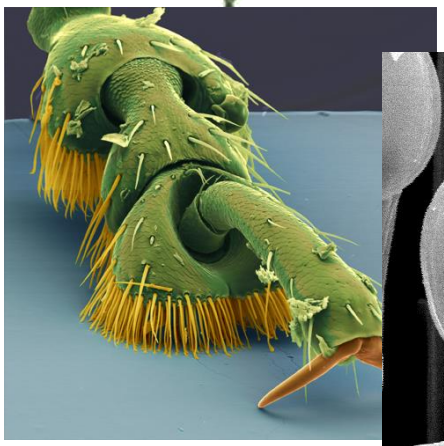
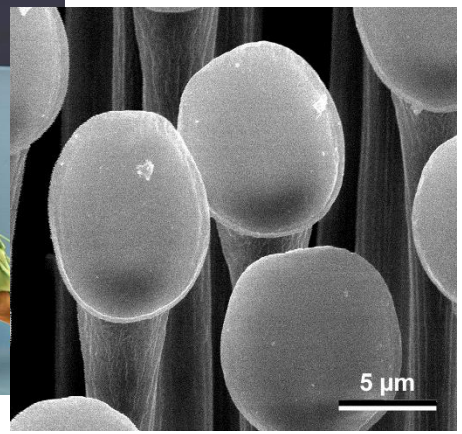
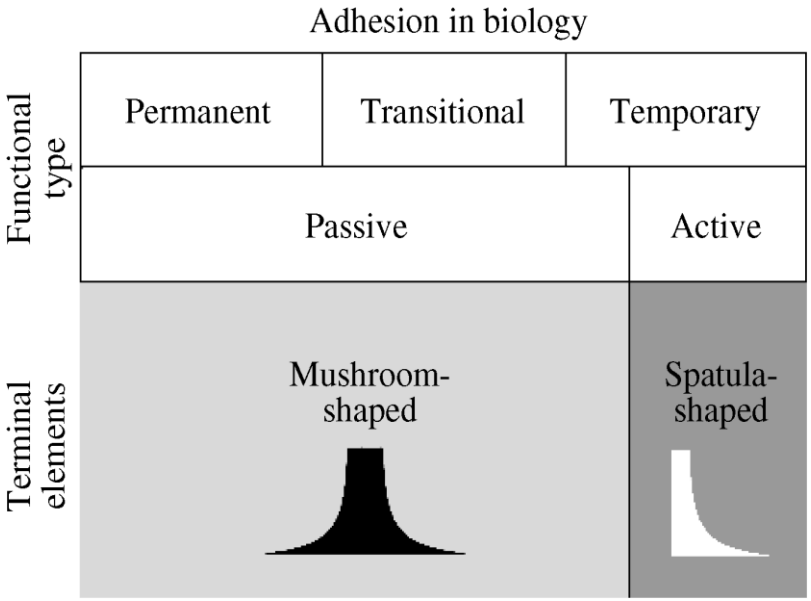
Mushrooms versus Spatulae

Male beetle
Gastrophysa viridula





Gorb and Varenberg, 2008 Phil. Trans. Roy. Soc.



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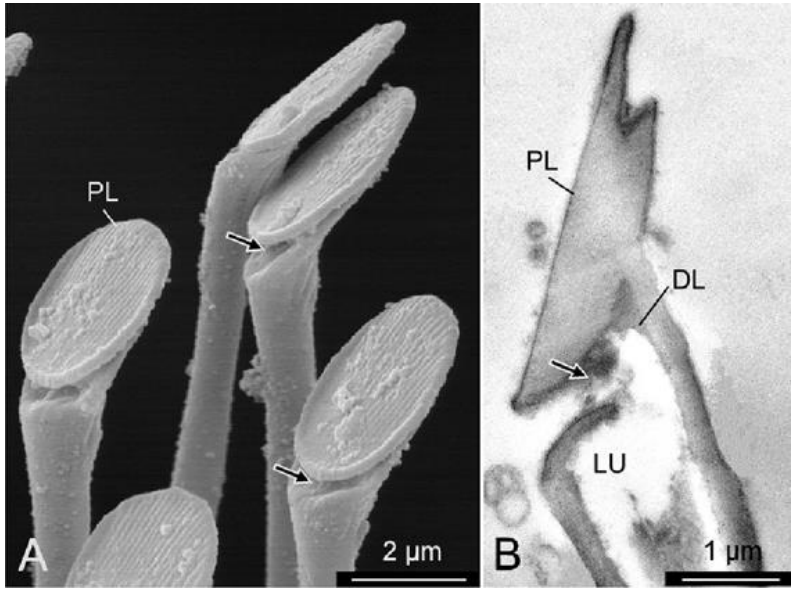
Mushroom-like Contacts: Macro, Micro, Nano

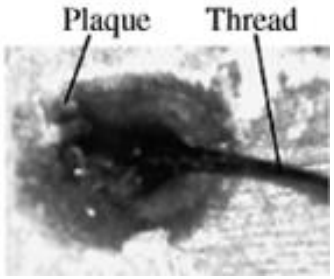
MICRO

Gorb (1998) PRSB



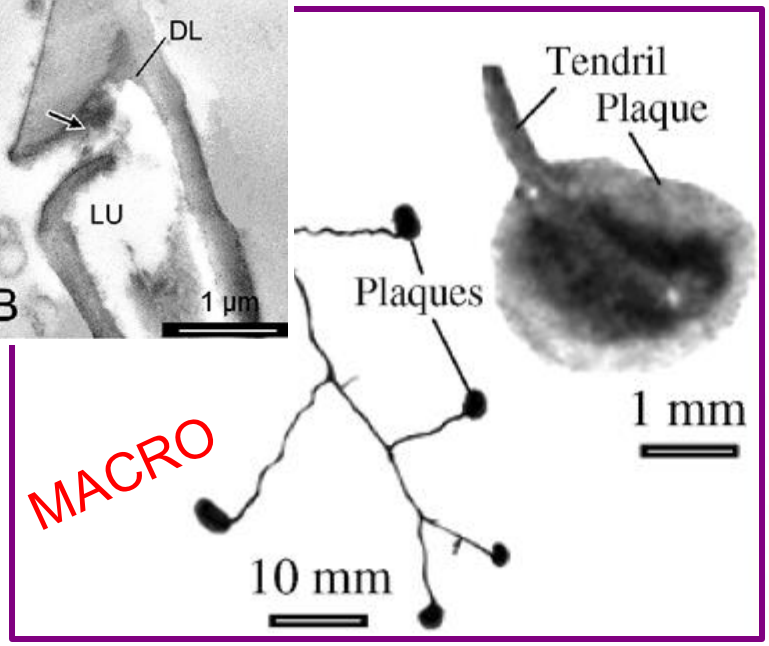
fly pad
Episyrphus balteatus

MACRO



plaque terminating byssal threads of the mussel *Mytilus edulis*

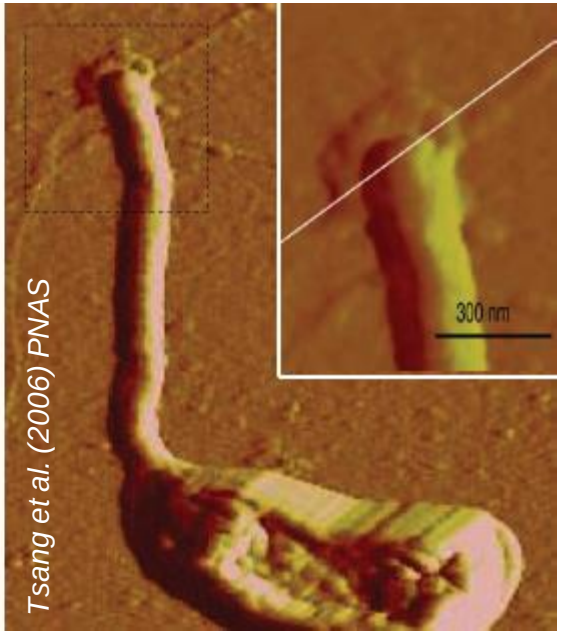
vine plant
Parthenocissus tricuspidatus



MACRO

bacterium
Caulobacter crescentus

NANO



Tsang et al. (2006) PNAS

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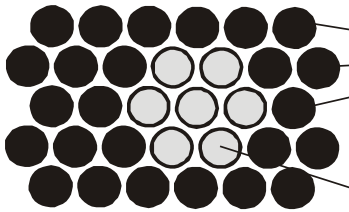
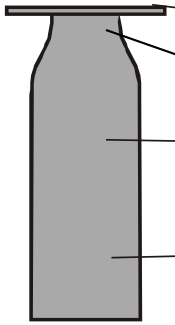
Bioinspired Features of MSAMS: Mushroom shaped adhesive microstructures



BIOINSPIRED FEATURES	FUNCTION
contact subdivision	increase of the total perimeter of contact
	prevention of the crack propagation
	tolerance to the contamination
hexagonal pattern	the highest packaging density of structures



thin plate-like head	tolerance to the contamination
	prevention of the crack propagation
joint-like neck	adaptability to uneven surfaces
high aspect ratio	decrease of stored elastic energy

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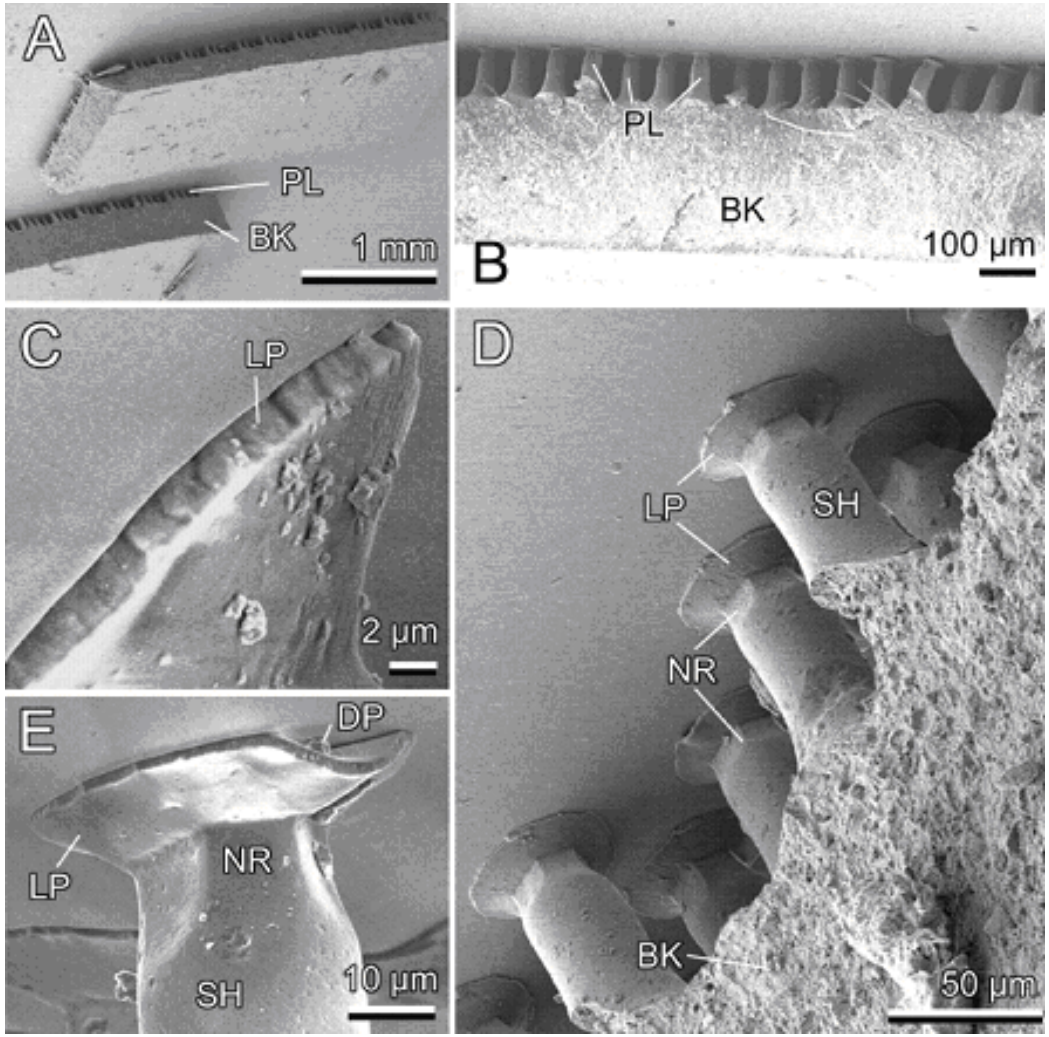
MSAMS in Action

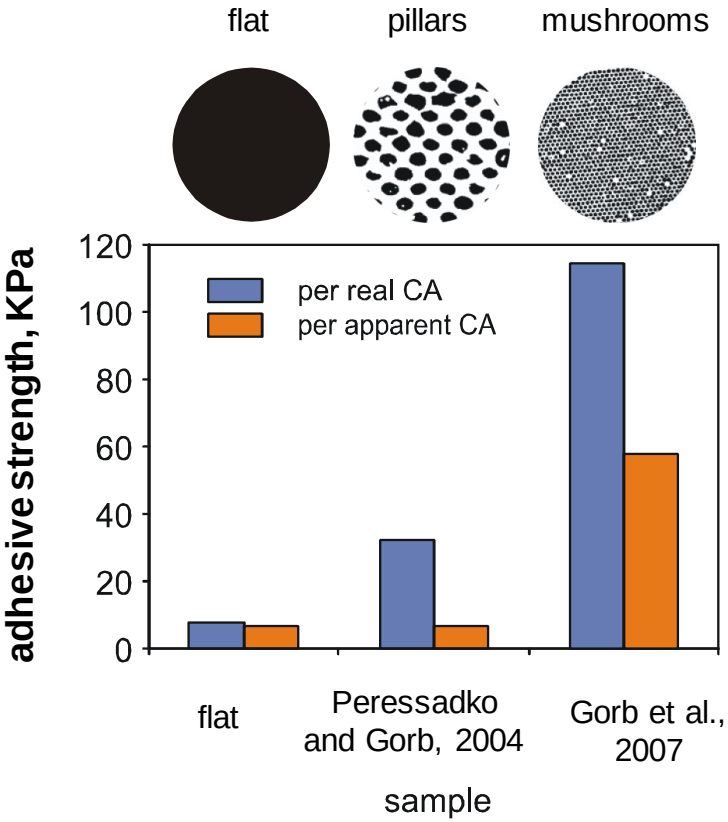
Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface

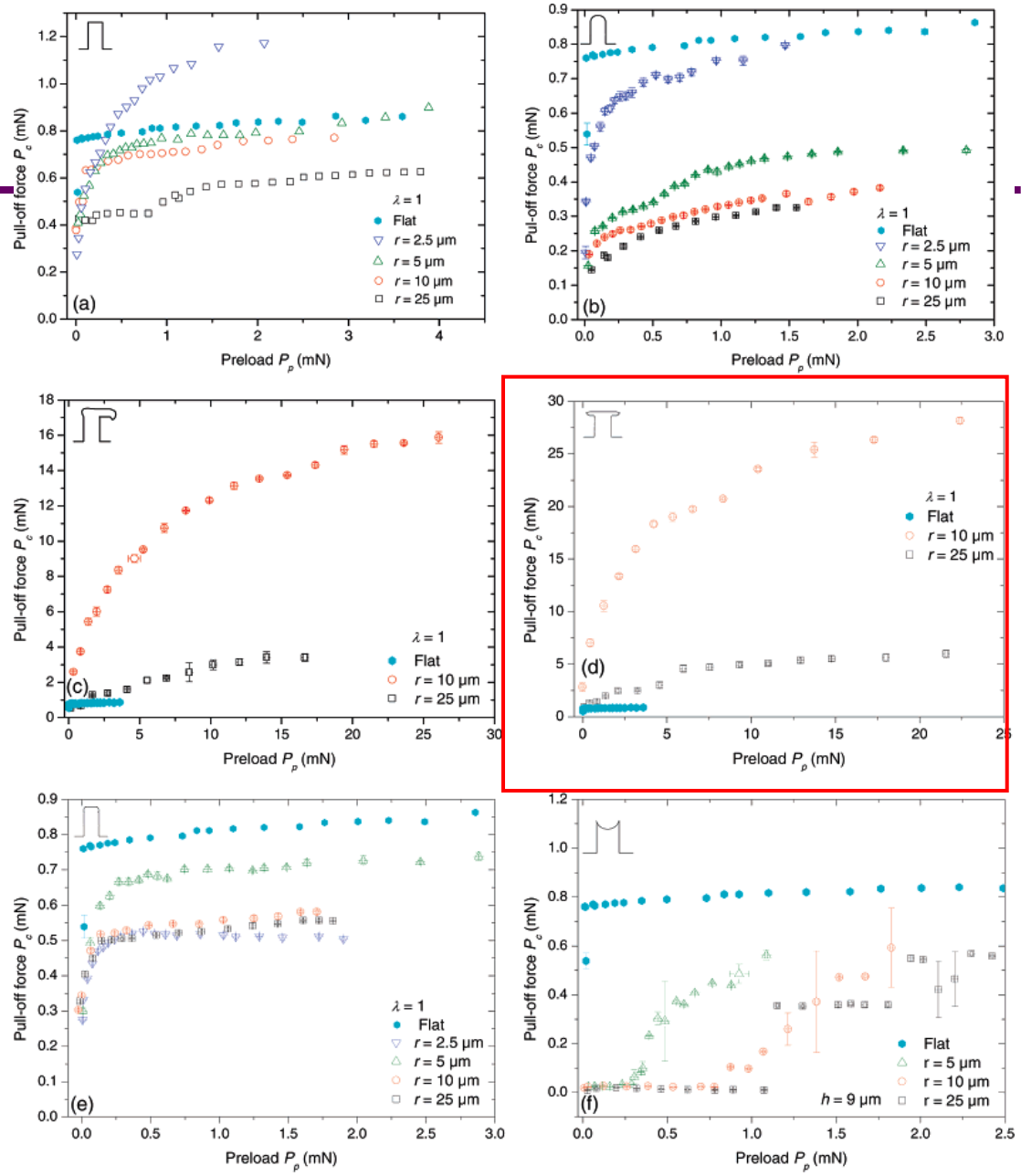


- **BK**, backing
- **DP**, dust particle
- **LP**, lip at the margin of the pillar tip
- **NR**, narrowing of the pillar close to the tip
- **PL**, pillars
- **SH**, shaft

MSAMS Adhesion

Gorb et al., 2007, JRS Interface
del Campo et al., 2007 Langmuir





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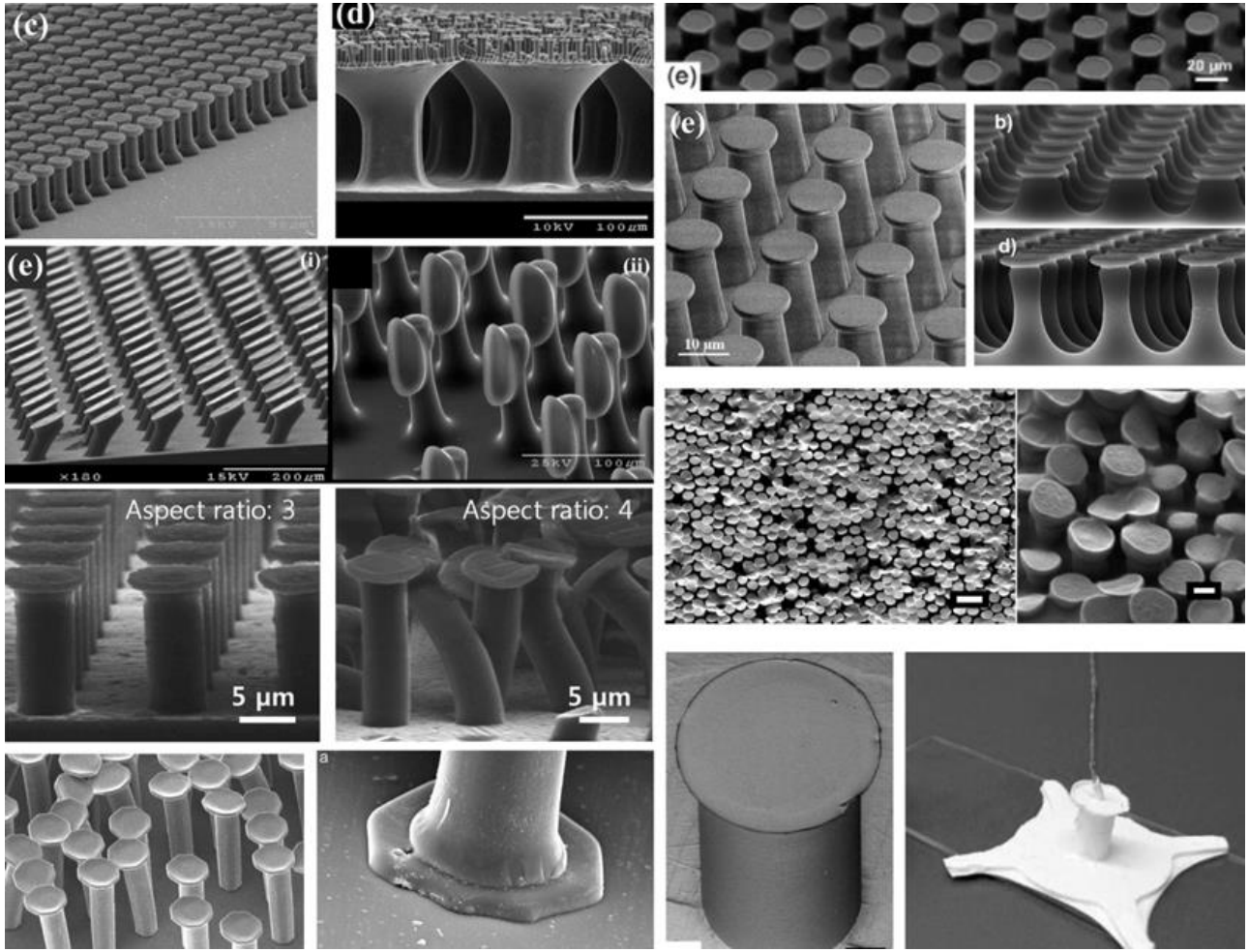
MSAMS "Evolution"



Enhanced adhesion of mushroom-shaped microstructure relies on combination of **van der Waals forces** and **crack-trapping mechanism** (e.g. *Hui et al. 2004, J. R. Soc. Interface; Carbone et al. 2011, Soft Matter*)

Daltorio et al. 2005, CLAWAR
Kim, Sitti 2006, Appl. Phys. Lett.
Gorb et al. 2007, J. R. Soc Interface
Varenberg, Gorb 2007, J. R. Soc Interface
Gorb, Varenberg 2007, JAST
del Campo et al. 2007, Langmuir
Varenberg, Gorb 2008a, J. R. Soc Interface
Varenberg, Gorb 2008b, J. R. Soc Interface
Davies et al. 2009, Int. J. Adhes. Adhes.
Sameoto, Menon 2009, J. Microm. Microeng.
Murphy et al. 2009, Appl. Mater. Interfaces
Murphy et al. 2009, Small
Kim et al. 2009, Langmuir
…….
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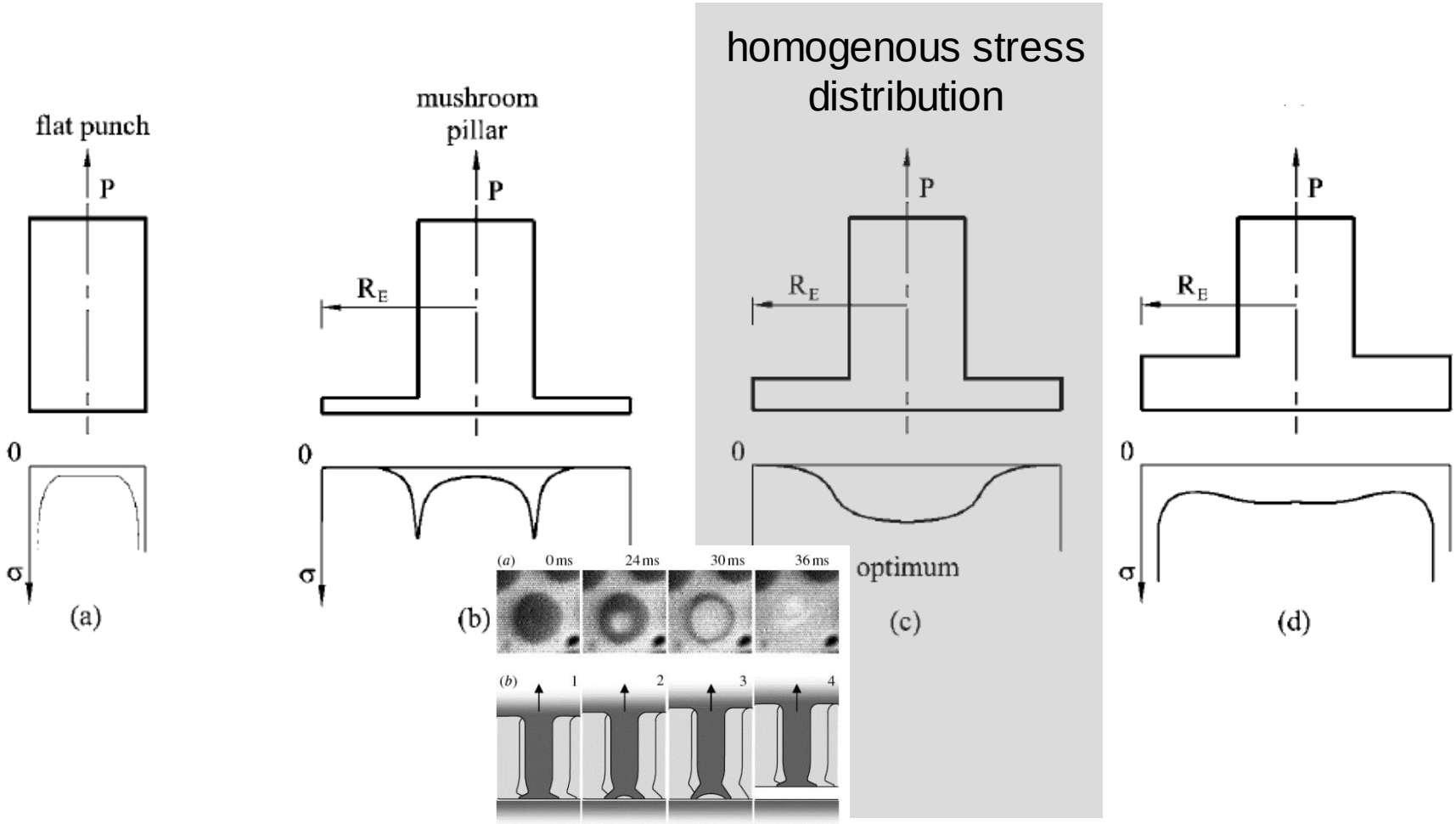
MSAMS: Contact Breakage

Carbone, Pierro and Gorb, 2011, Soft Matter



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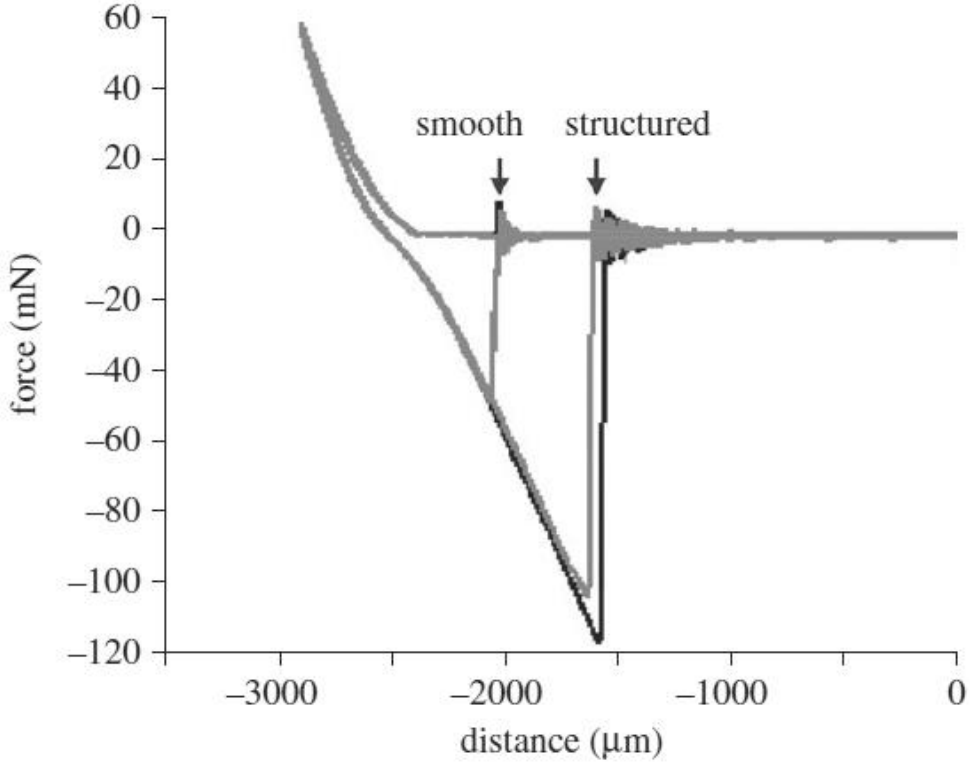
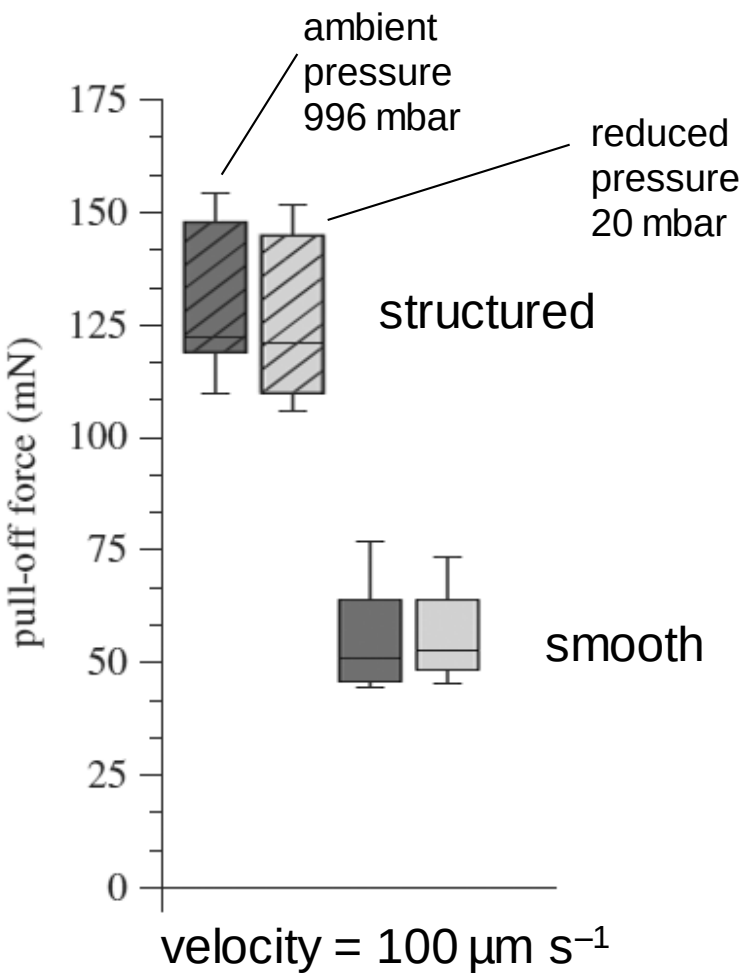
MSAMS Adheres in Vacuum

Heepe, Varenberg, Gorb, 2010, J. Roy. Soc. Interface





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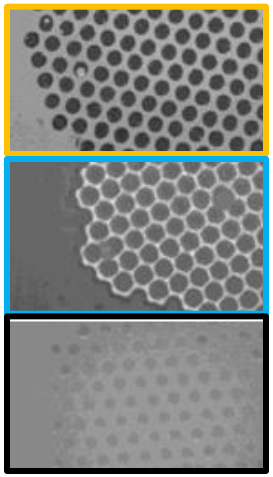
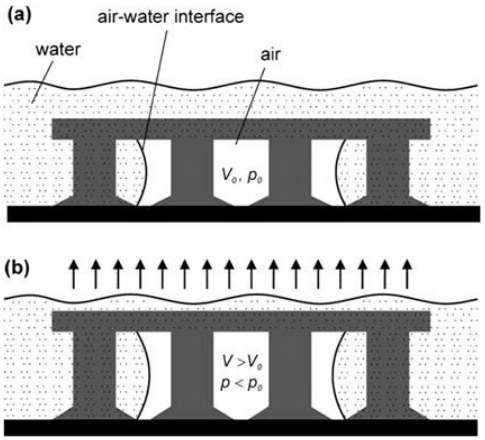
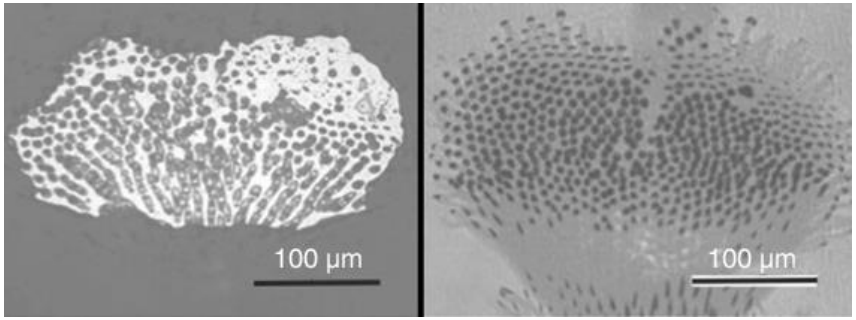
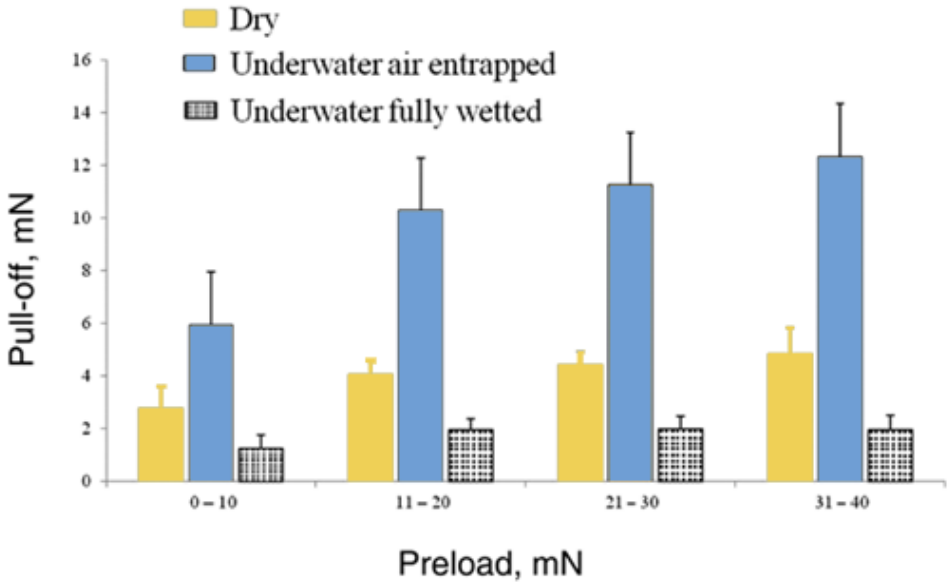
Air Entrapment Effect under Water

Kizilkan, Heepe and Gorb, 2013, Bioinspired Adhesion Book
Hosoda and Gorb, 2012, Proc. Roy. Soc. B









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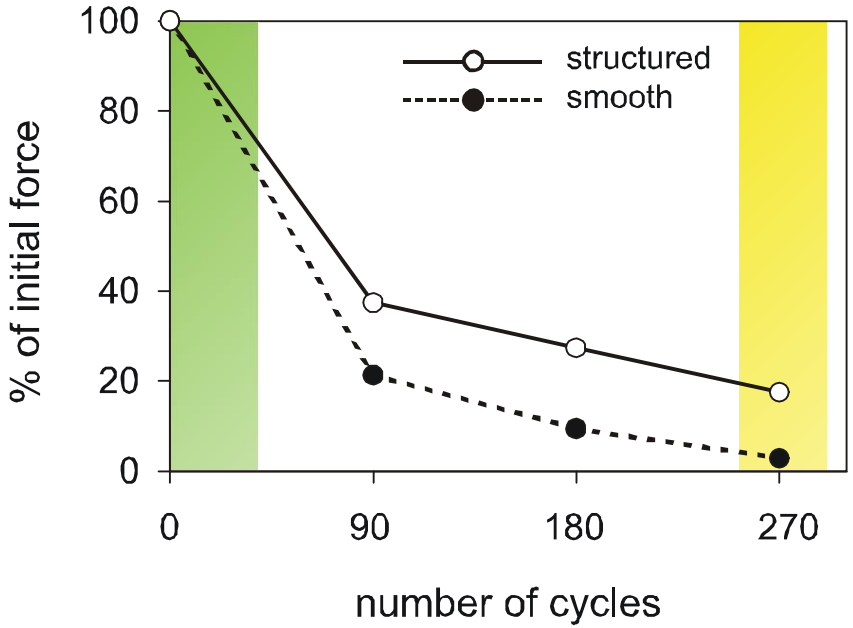
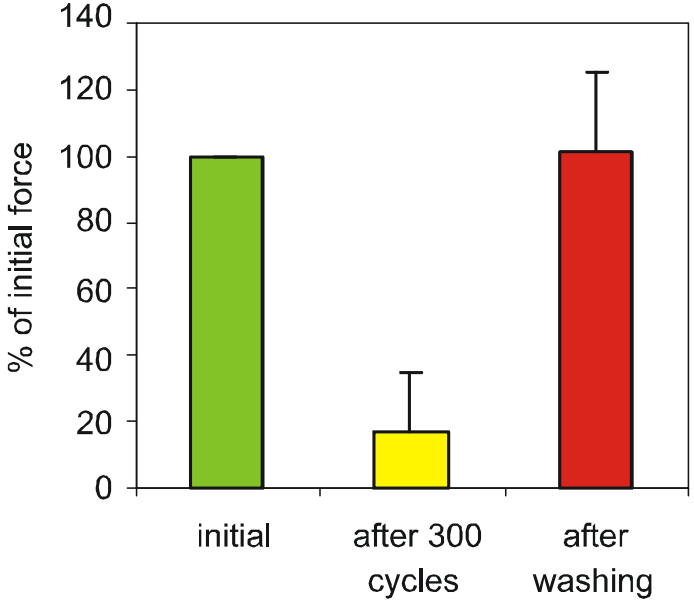
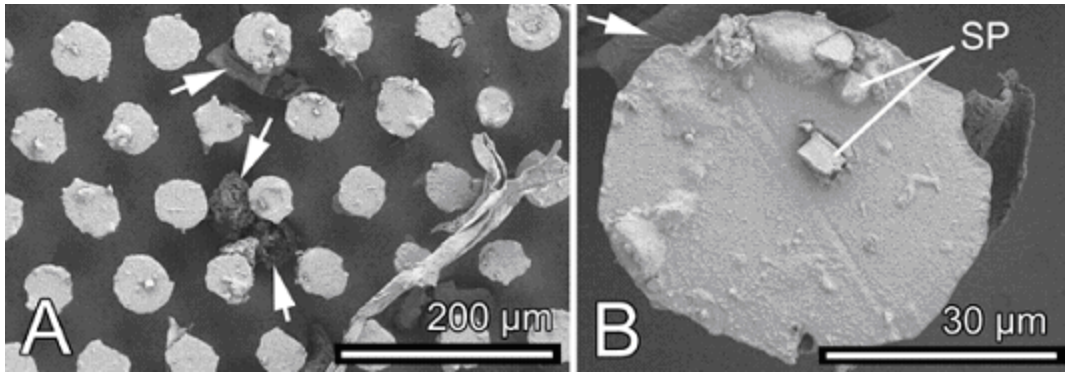
Contamination of MSAMS

Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface



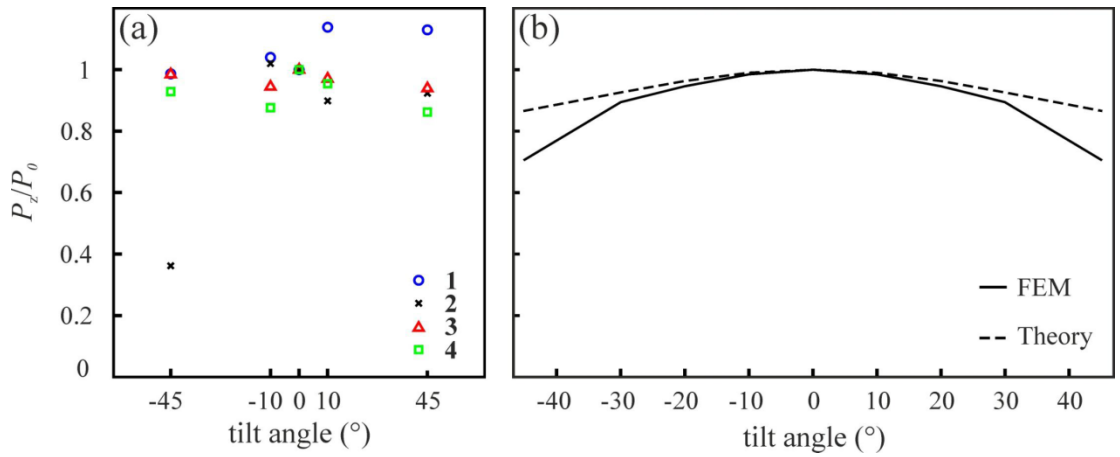


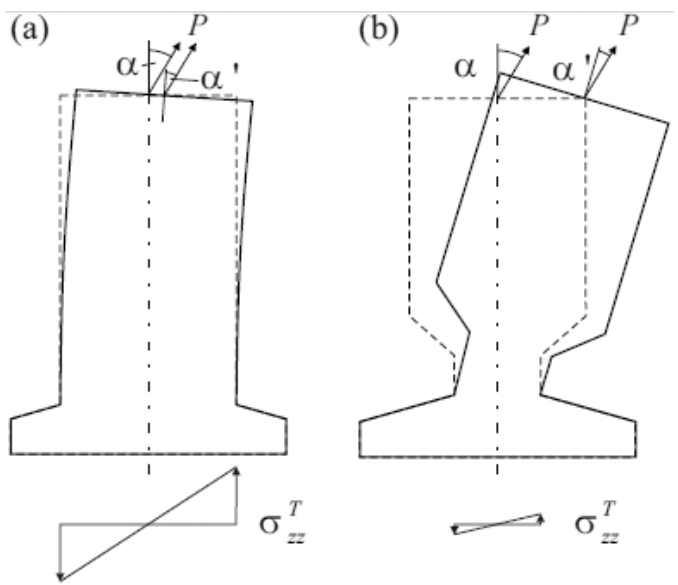


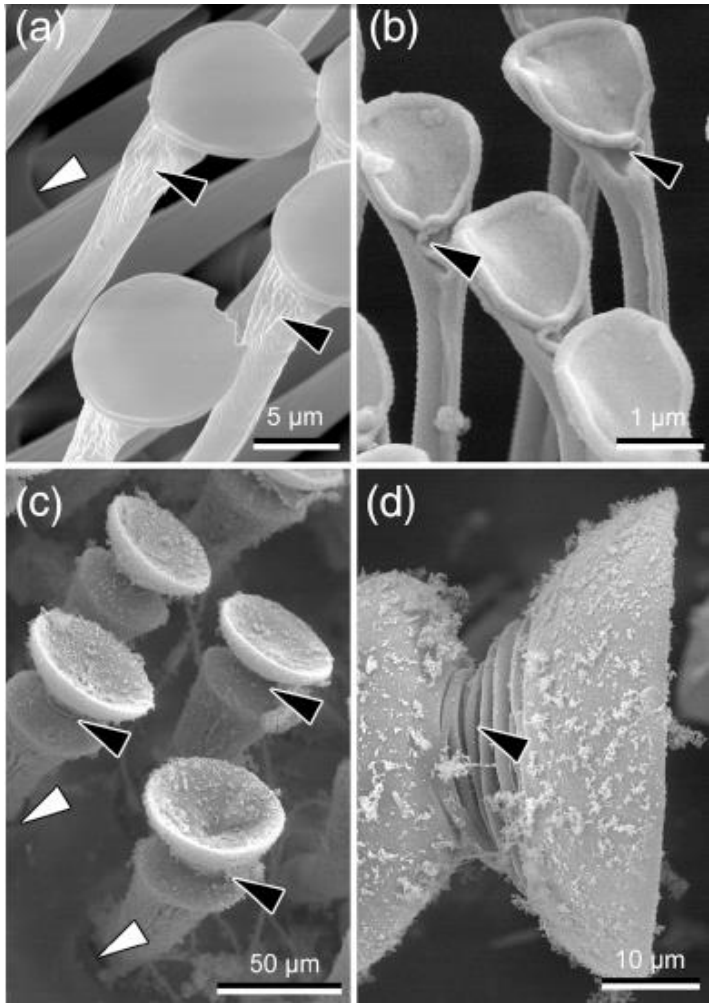
Zoological Institute,
Kiel

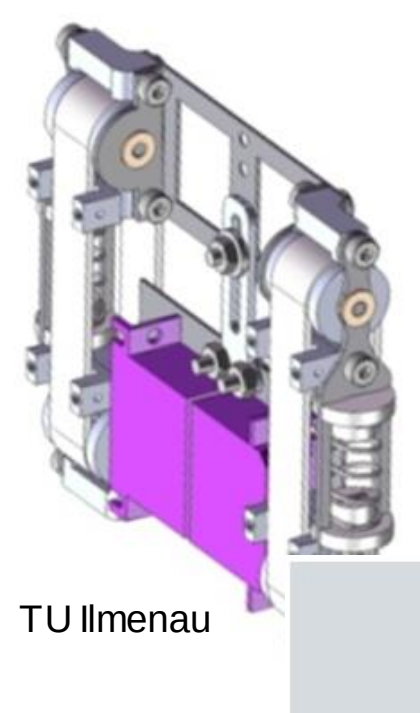
Tilting Tolerance

Heepe, et al., 2014, Appl. Phys. Lett.








TU Ilmenau

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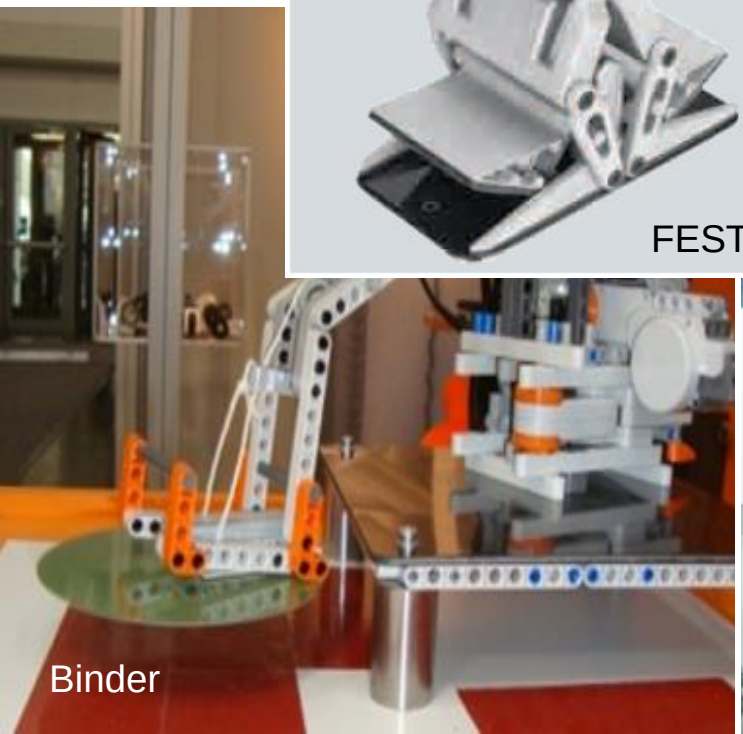
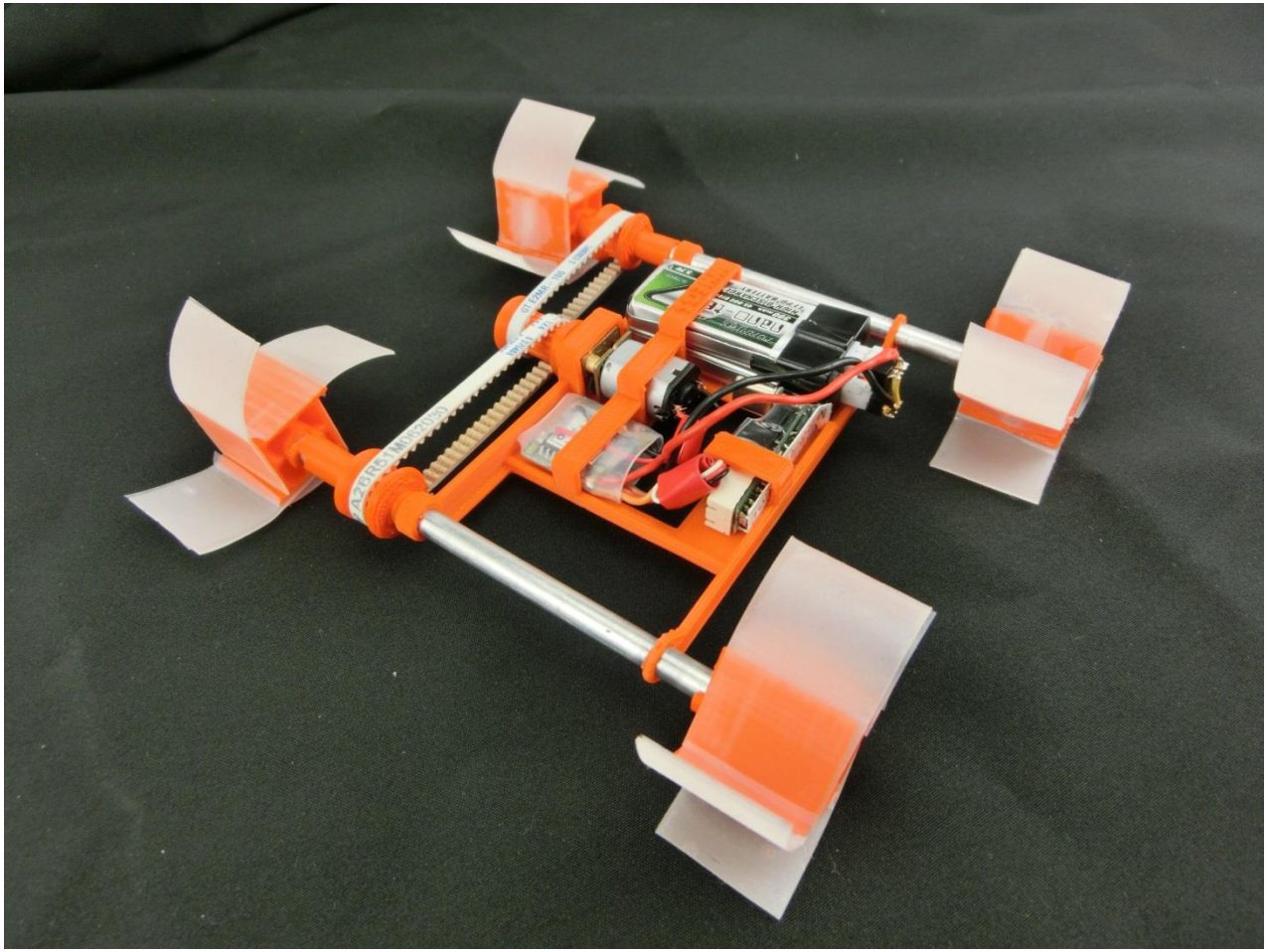
FESTO


Binder

Climbing with new generation material

William Breckwoldt



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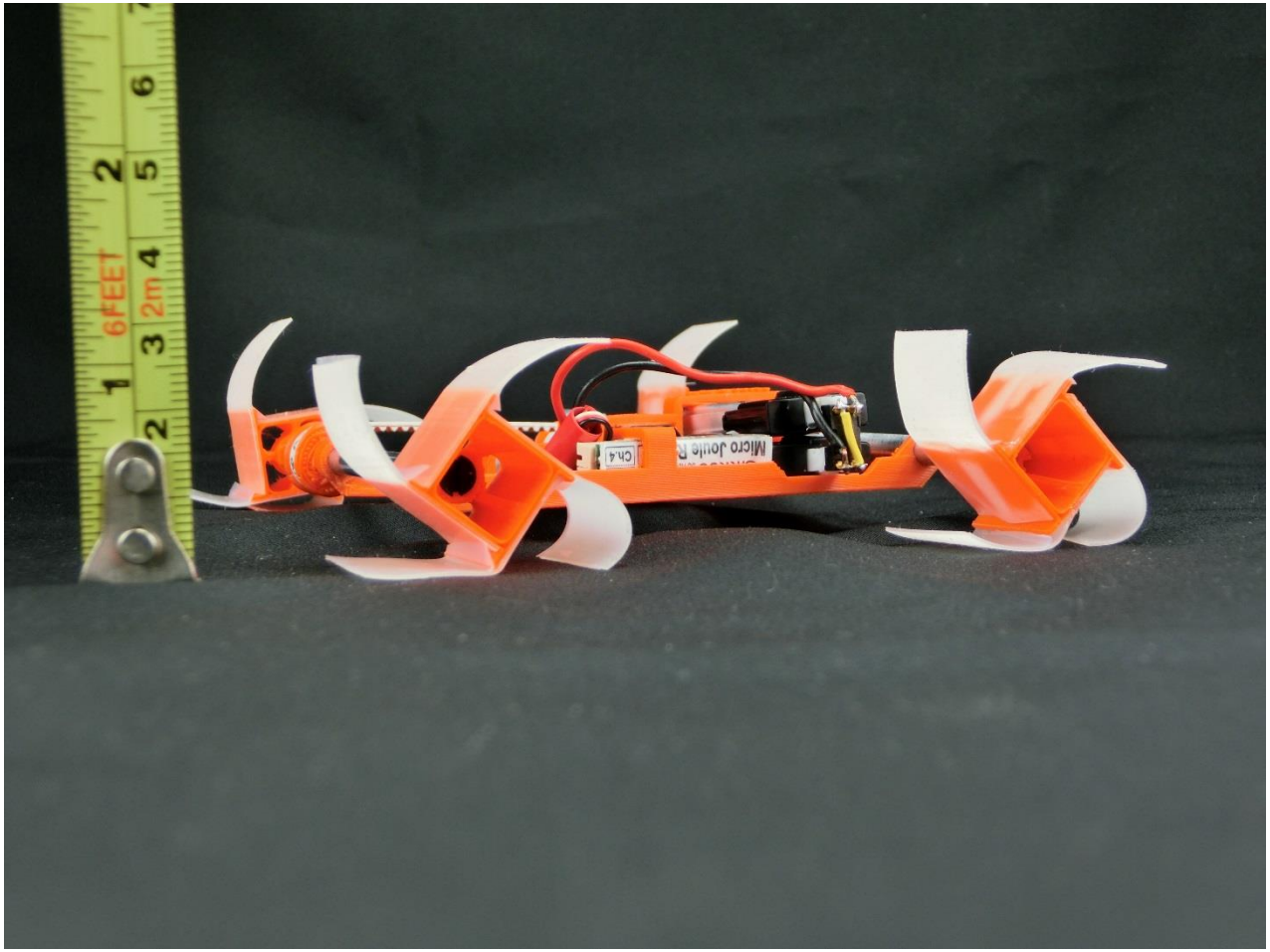
Less than 1” tall

William Breckwoldt



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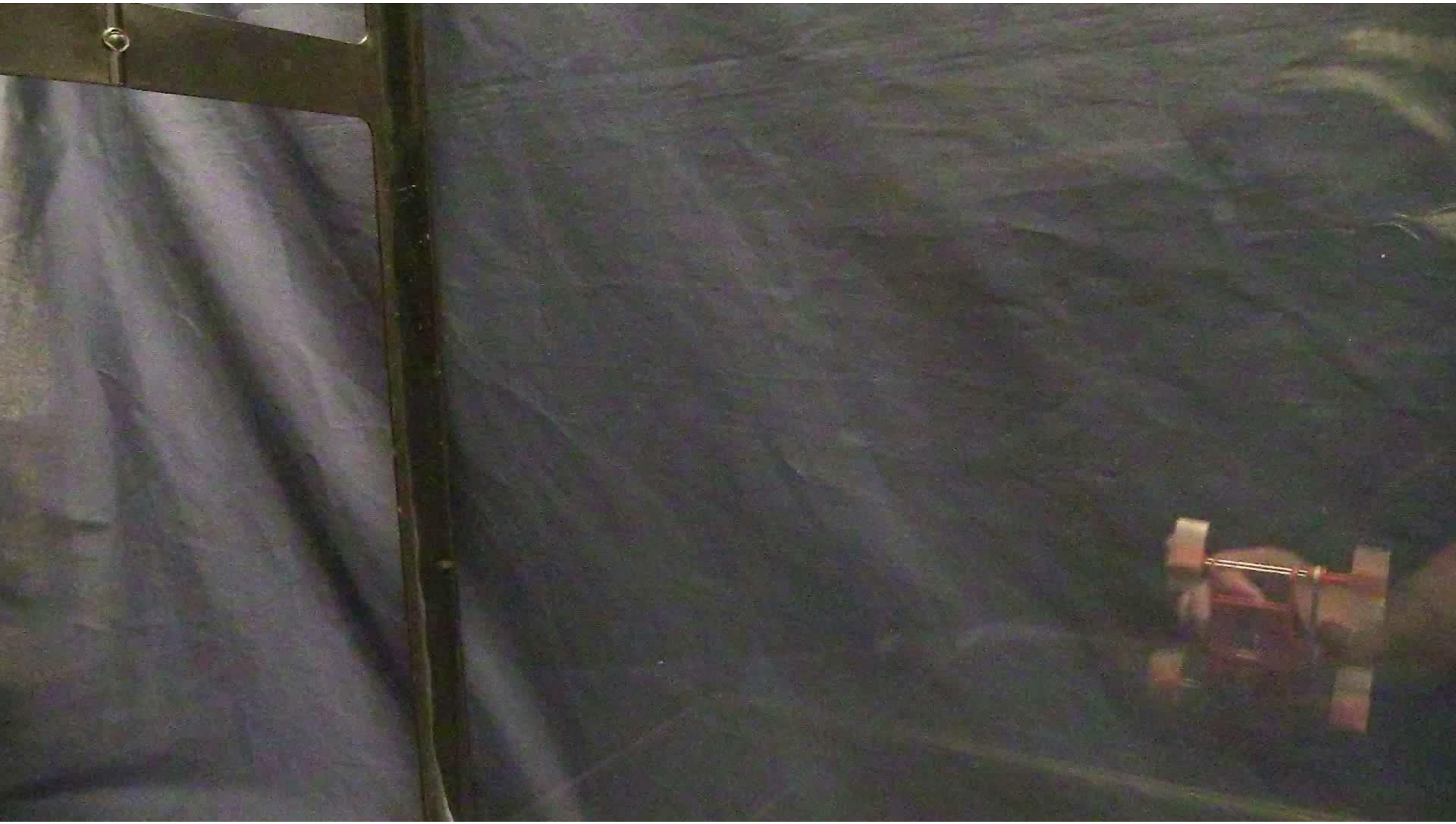
Vertical Ascent



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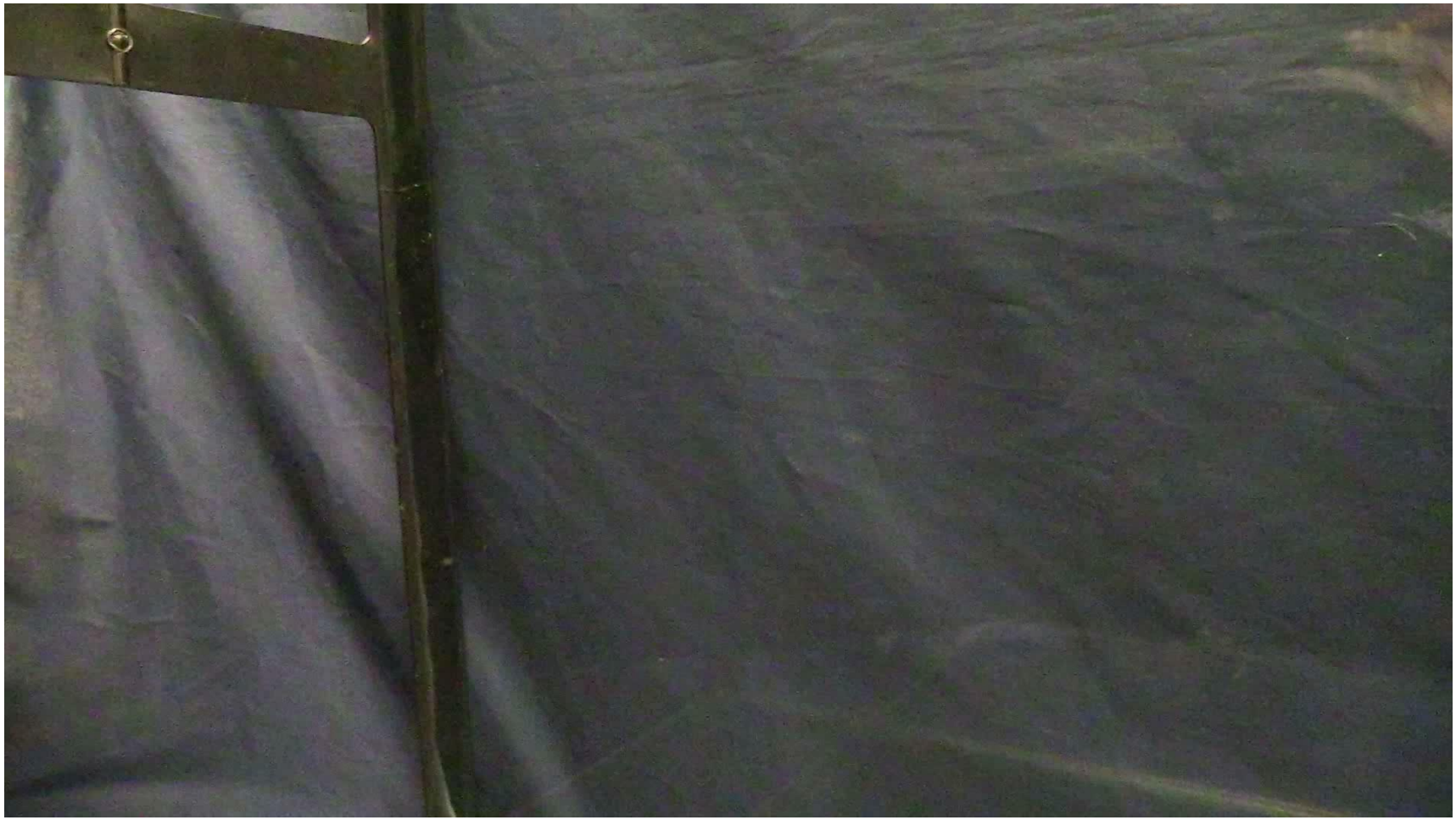
Horizontal Walking on Vertical Glass

Vertical Descent



Wall transition: Horizontal walking on vertical surface

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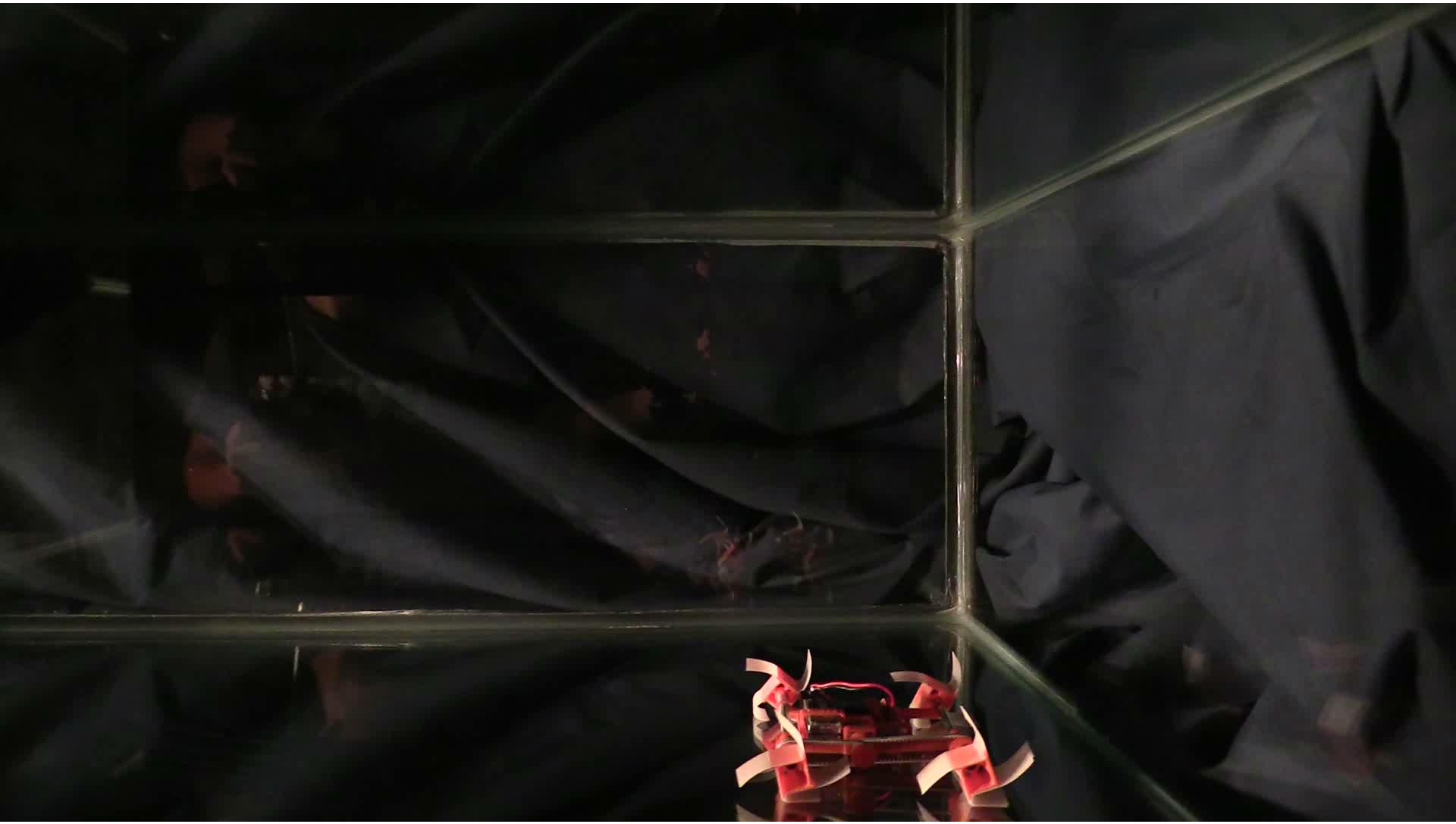
Transition: Floor to vertical wall

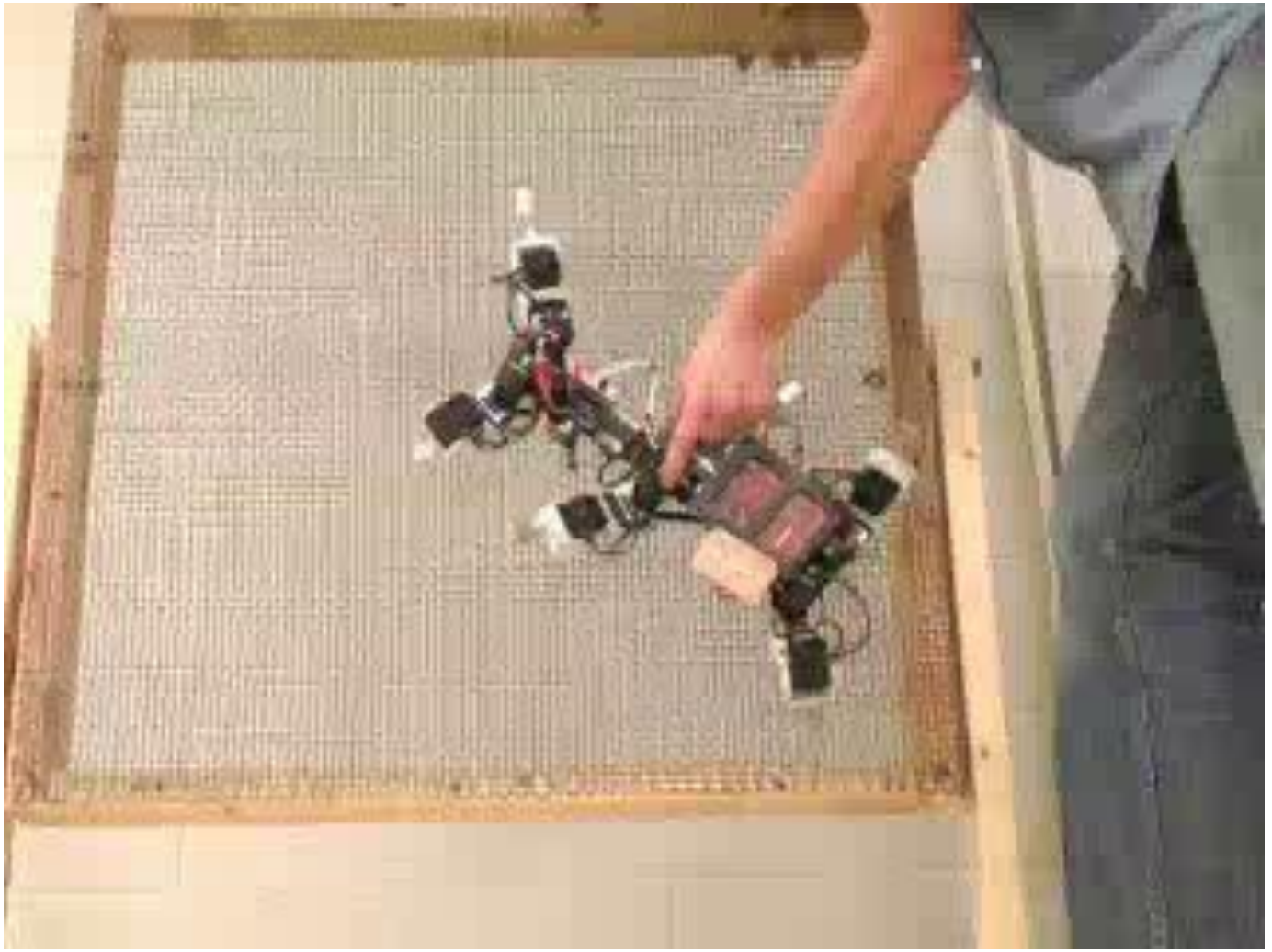
Transition to Ceiling?



How are we doing?

- New adhesive material is greatly improved
- Ascend a smooth, clean vertical surfaces using adhesive feet - YES
- Non-directional (up, down, sideways) - YES
- Steering - POSSIBLE
- Overcome small obstacles - ?
- Walk inverted on horizontal surfaces - ALMOST
- Transition between orthogonal surfaces – YES
- Conclusion: VERY PROMISING

DIGbot Climbs using Distributed Inward Gripping



Luther Palmer

Eric Diller

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Drainage Inspection Robots

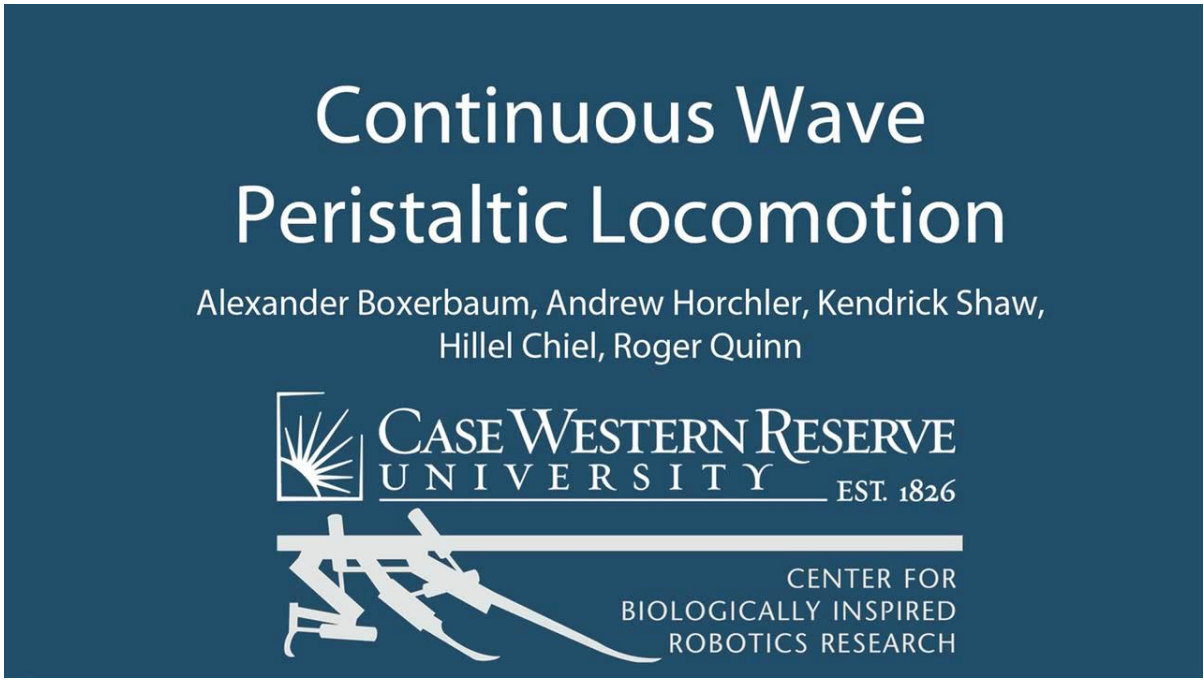
With Barr and Prevost
Cleveland, Ohio

Soft-Worm Robot

Peristaltic Motion
Continuous Waves

Alex Boxerbaum Hillel Chiel

- One motor
- Cam tensions cables
- Hollow
- Move through water, oil, gas lines
- Can be made small
  - Endoscope



Boxerbaum, et al. 2010-12

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Lab Photo - Spring 2013