Scansorial Landing and Perching

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http://bdml.stanford.edu


BBC Motion Gallery
5583-3

Advantages of Perching

- Greatly extend mission time
- Stable vantage point while perched
- Possibility of landing and physically interacting with a surface.
- Perching combines the best of climbing and flying:
  - Agile and fast while flying
  - Can cover long distances
  - Low energy consumption while perched
  - Wait for better weather conditions
  - Quiet (no motor noise)

RiSE platform climbing library at SwRI, San Antonio, TX

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Why vertical surfaces?

- Common in urban environments
- Easy to detect
- Often provide a large surface to simplify landing
- After an explosion, earthquake, etc. walls may be comparatively safe, clean and uncluttered

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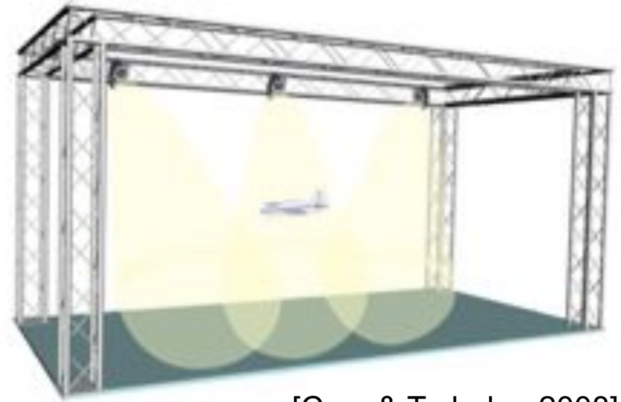
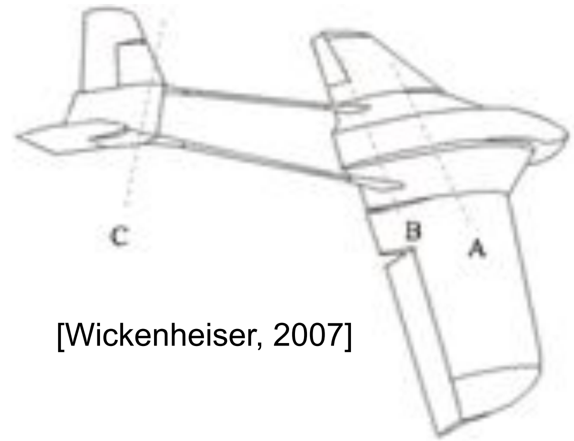
Related Work

- *On agile flight:*
  - *How et al. (MIT) on indoor flying and hovering*
  - *Oh et al. (Drexel) on autonomous hovering*
- *On perching aerodynamics & control:*
  - *Wickenheiser et al. (Cornell) on vehicle morphing for perching*
  - *Tedrake et al. (MIT) on controllability of fixed-wing plane for perching on a wire*
- *Hybrid aerial/terrestrial vehicle (Quinn)*
- **No detailed consideration of the landing system**
- **Slow maneuvers sensitive to disturbances**
- **Use of highly accurate motion capture system/sensors to enable control**



[Cory & Tedrake, 2008]



[Wickenheiser, 2007]

[Green & Oh, 2006]

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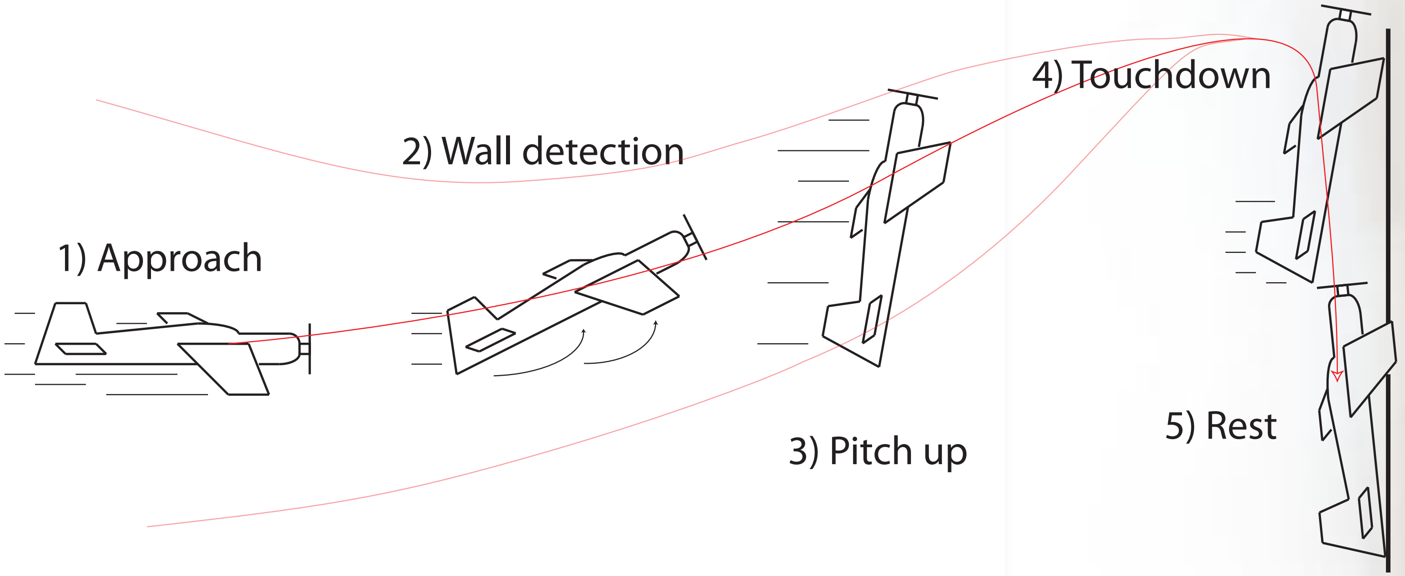
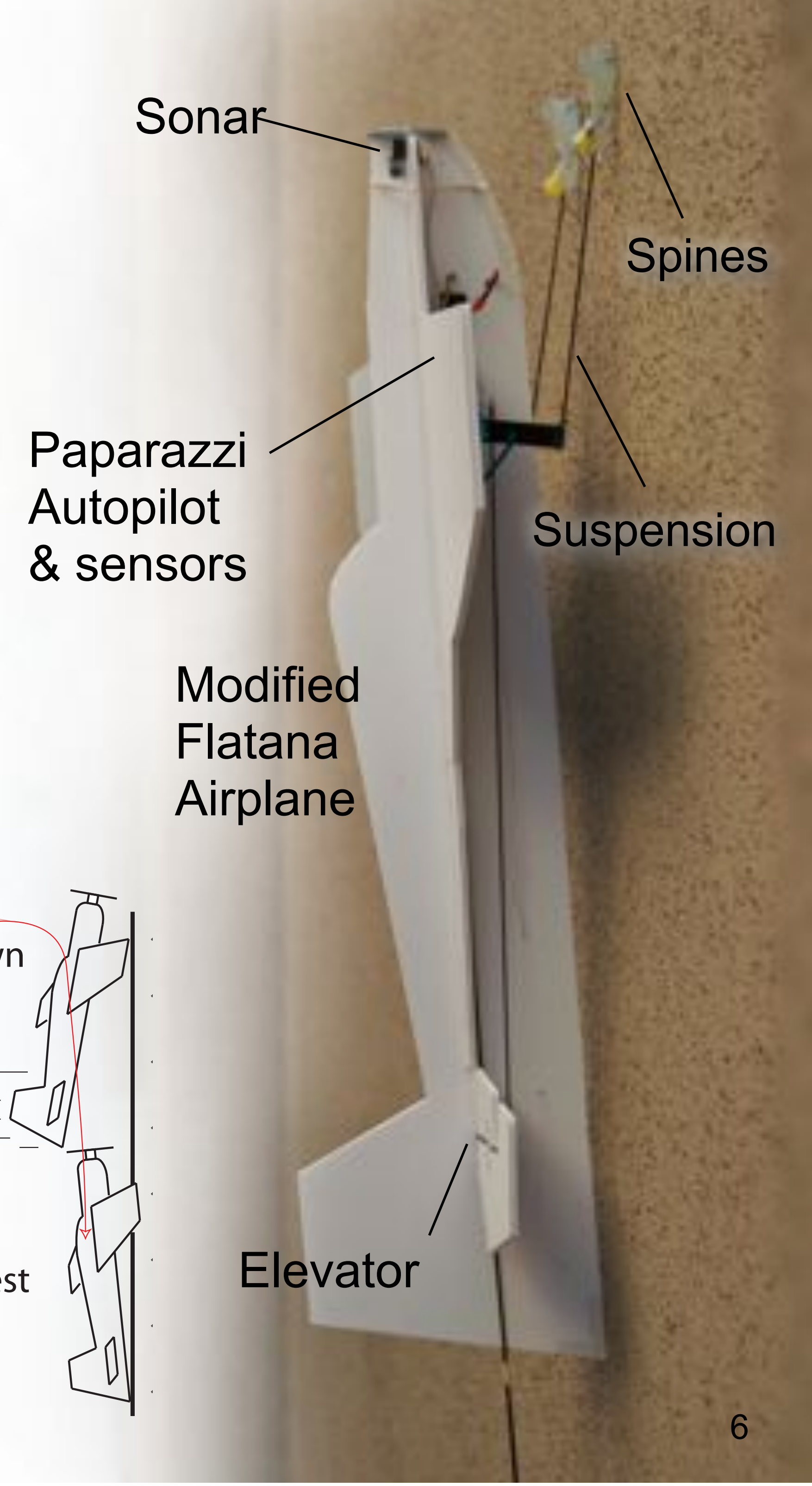
Approach:

- Conventional plane
- *Quick* maneuver to minimize disturbance effects
- Focus on suspension and spines to simplify sensing and control
- Everything onboard





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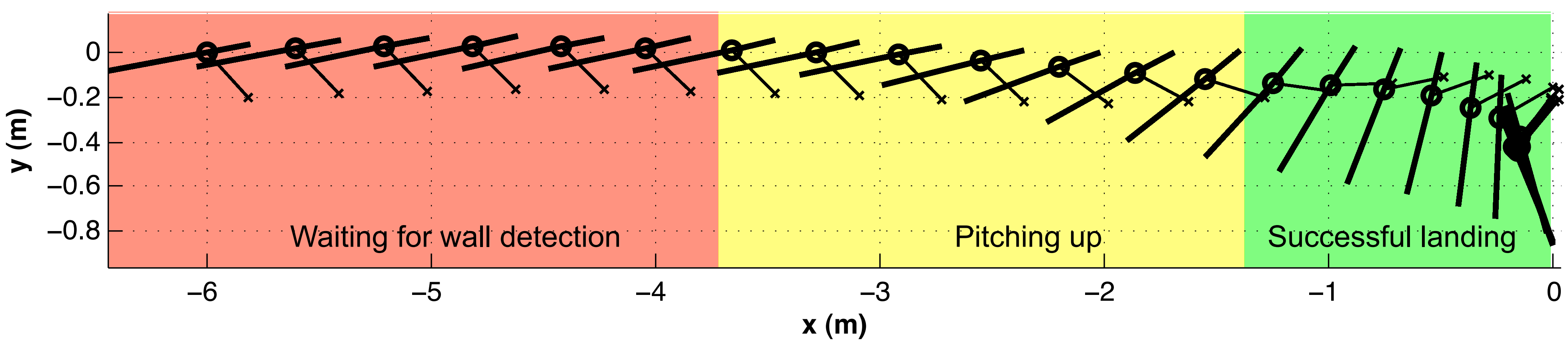
Perching Strategy

1. Fly toward wall ~ 9 m/s
2. Detect wall with ultrasonic sensor
   - 20 Hz, 6 m range
3. Pitch up to slow down (takes about 2-3m)
4. Touchdown possible for about 1.5 m before impact
5. Touchdown at 1-3 m/s. Let suspension absorb impact

Simulated trajectory of the perching maneuver



(inspired by [Cory & Tedrake 2008])

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Perching

Biomimetics and Dextrous Manipulation Laboratory

Stanford University
June 10th, 2009

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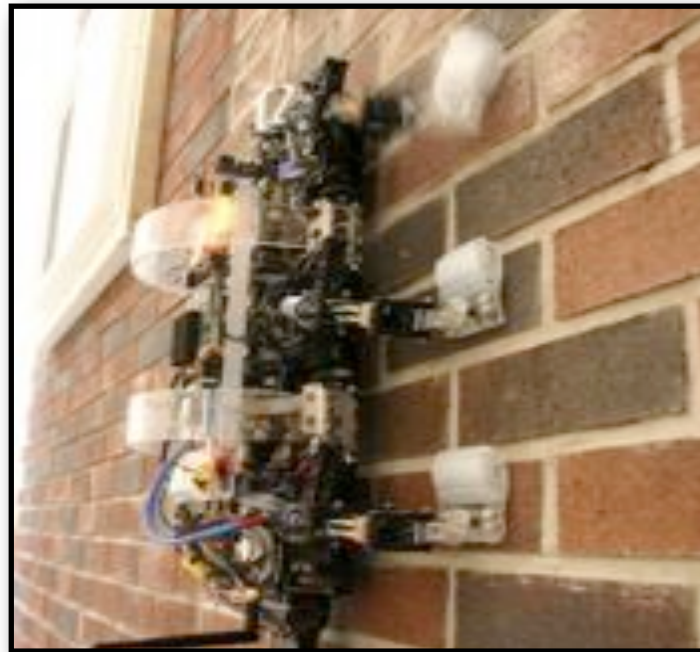
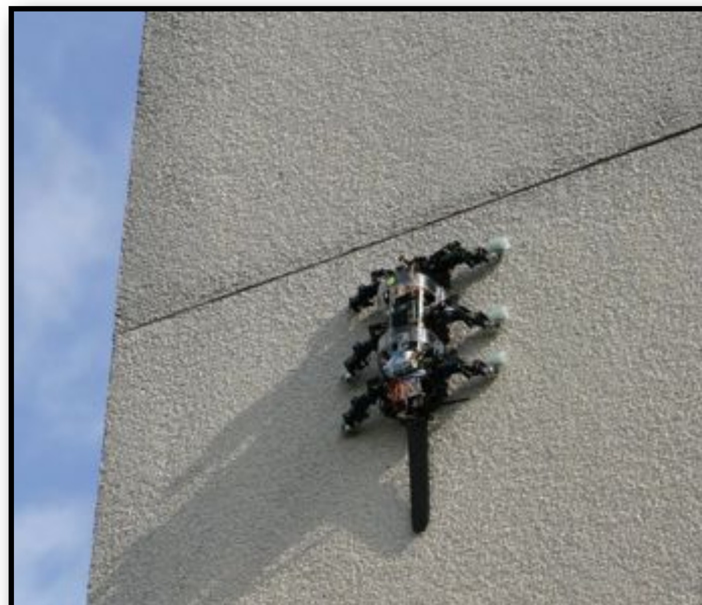
Clinging with spines

Why spines?

- require no power
- work on a range of outdoor surfaces
- relatively unaffected by films of dirt and moisture
- leave no trace of their passage
- provide many loading cycles



- Used on **Spinybot** and **RiSE** to climb brick, stucco, concrete rock...
- Spine mechanisms take advantage of robot's control over foot trajectories and forces.
- With UAVs, the challenge is to provide desired trajectory and forces using momentum of the plane.



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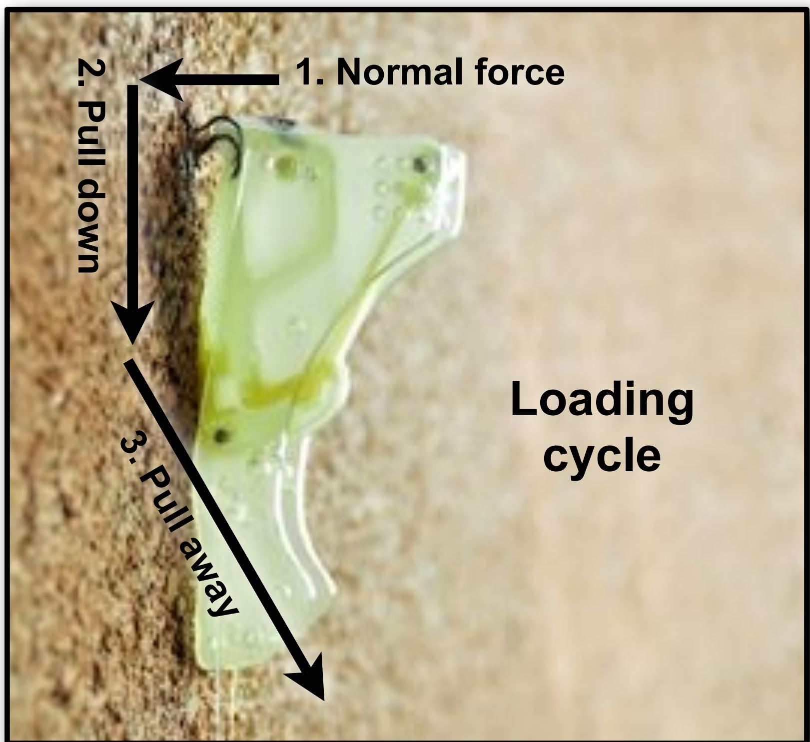
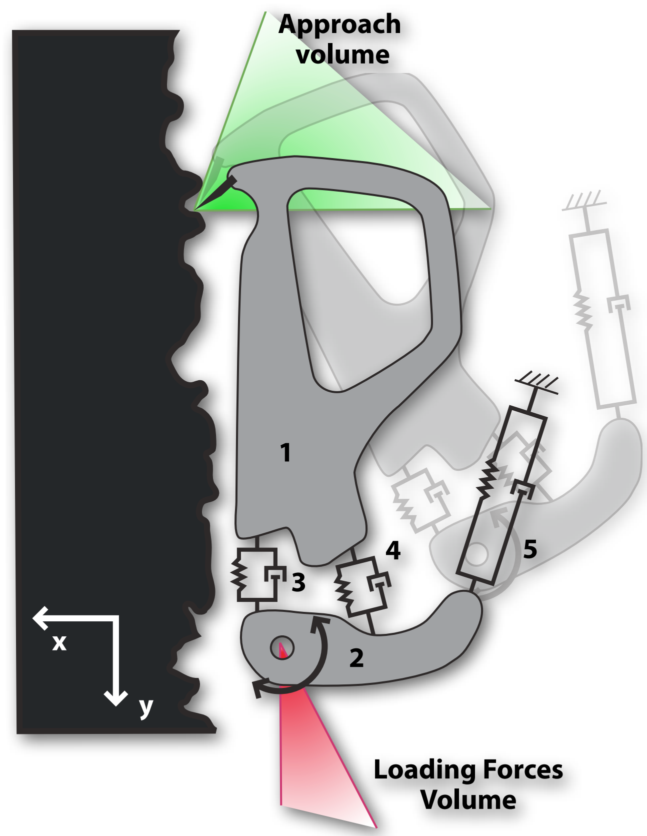
Spine suspensions

- Small spines (10-15 μm tip radius) catch and hang on asperities
- Individual spine suspensions distribute the load
- Loading trajectory required





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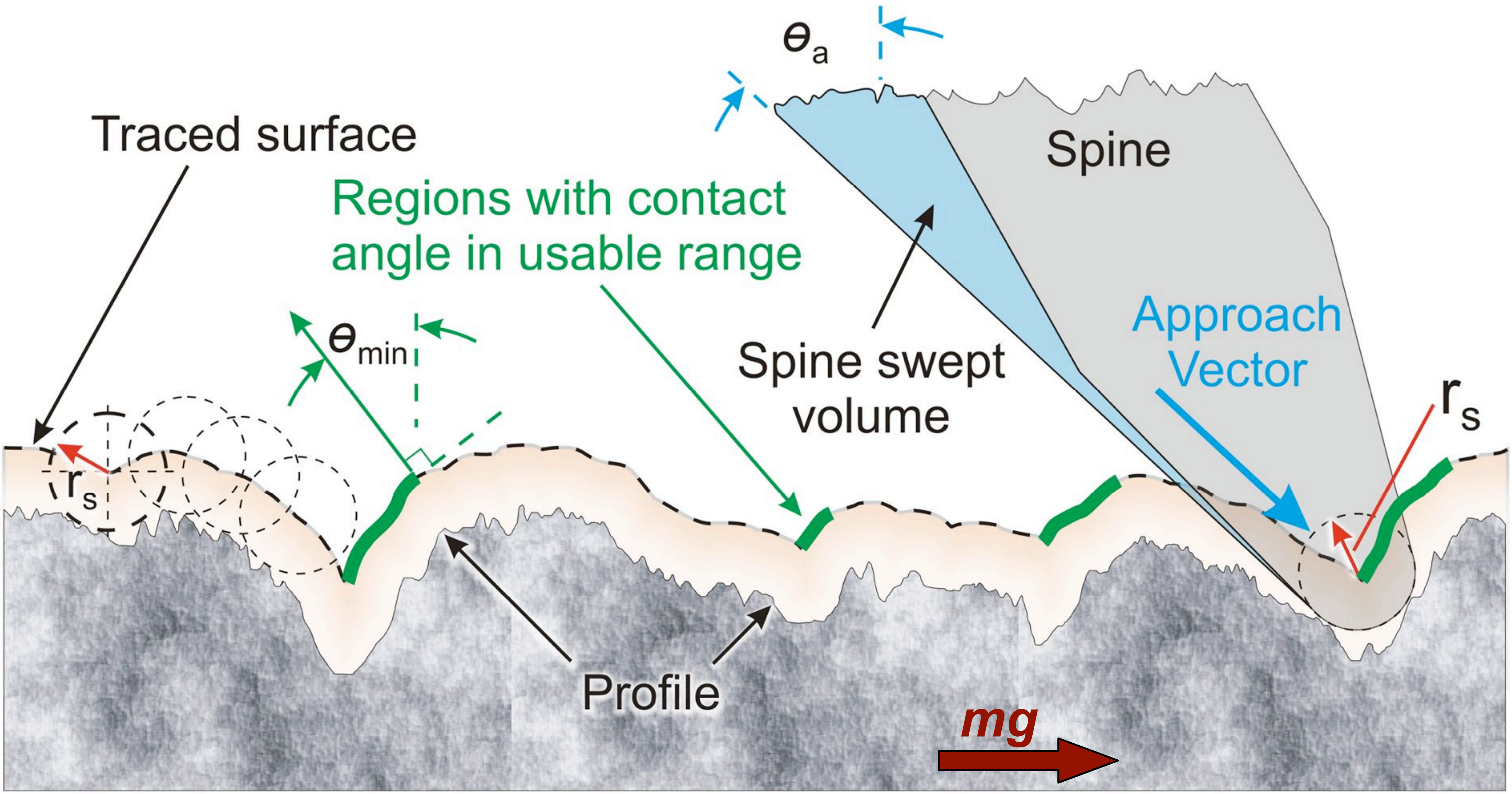
Spine/surface interaction



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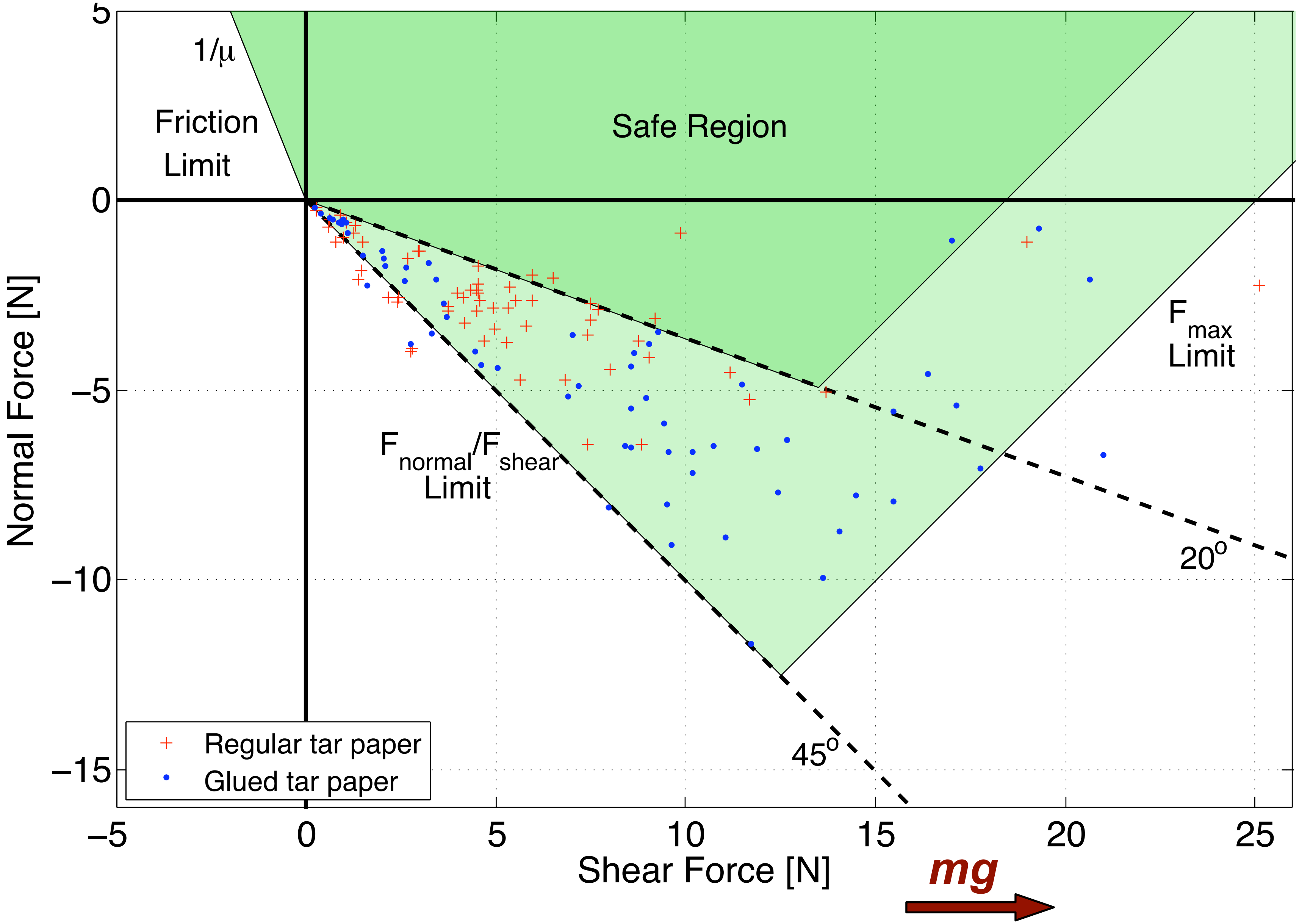
Spine limit curve -- 1 foot, 10 spines

(for roofing paper -- similar to stucco or composite roof shingles)



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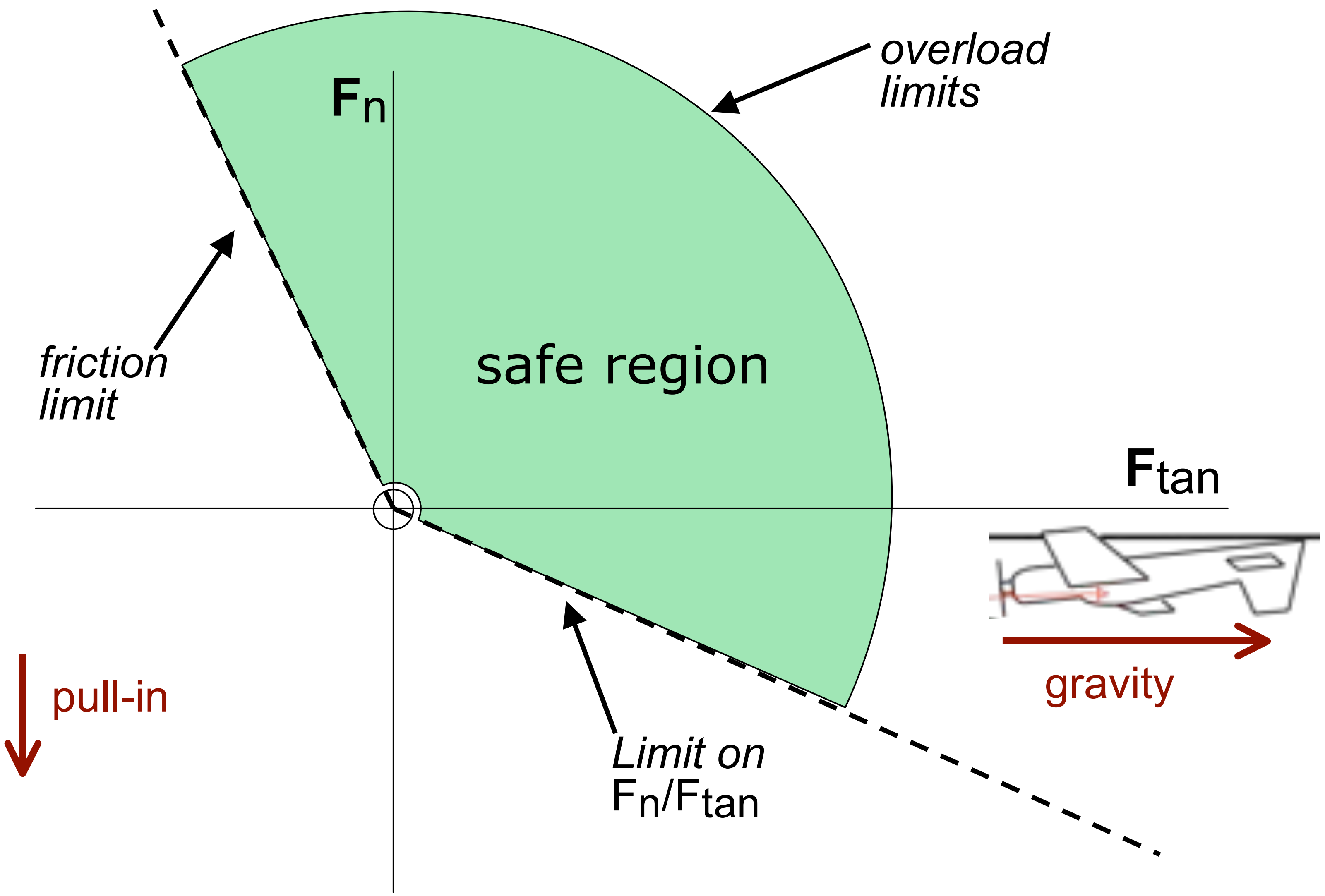
Revisit spine constraints, from standpoint of the plane



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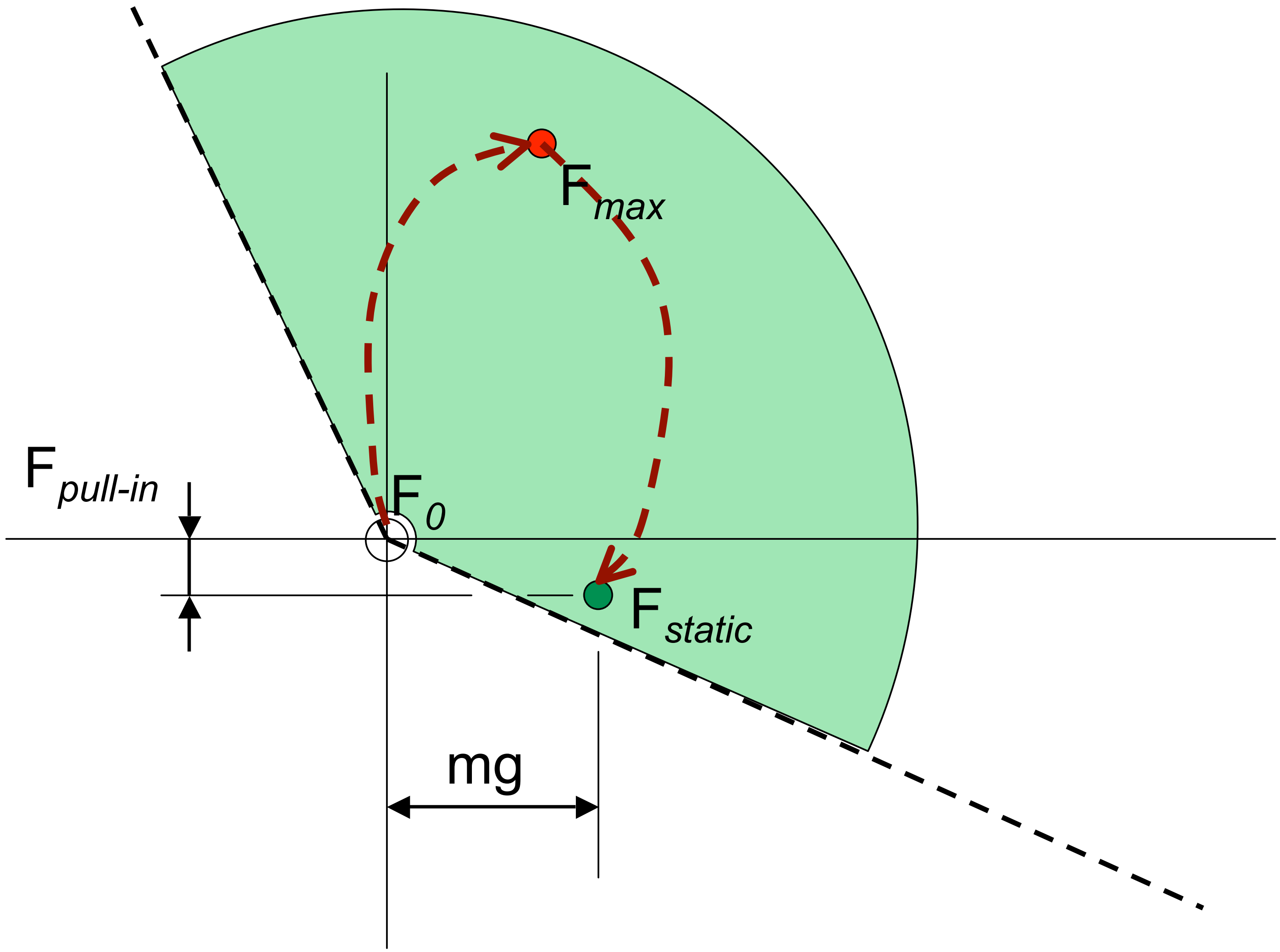
Spine constraints, from the standpoint of the plane



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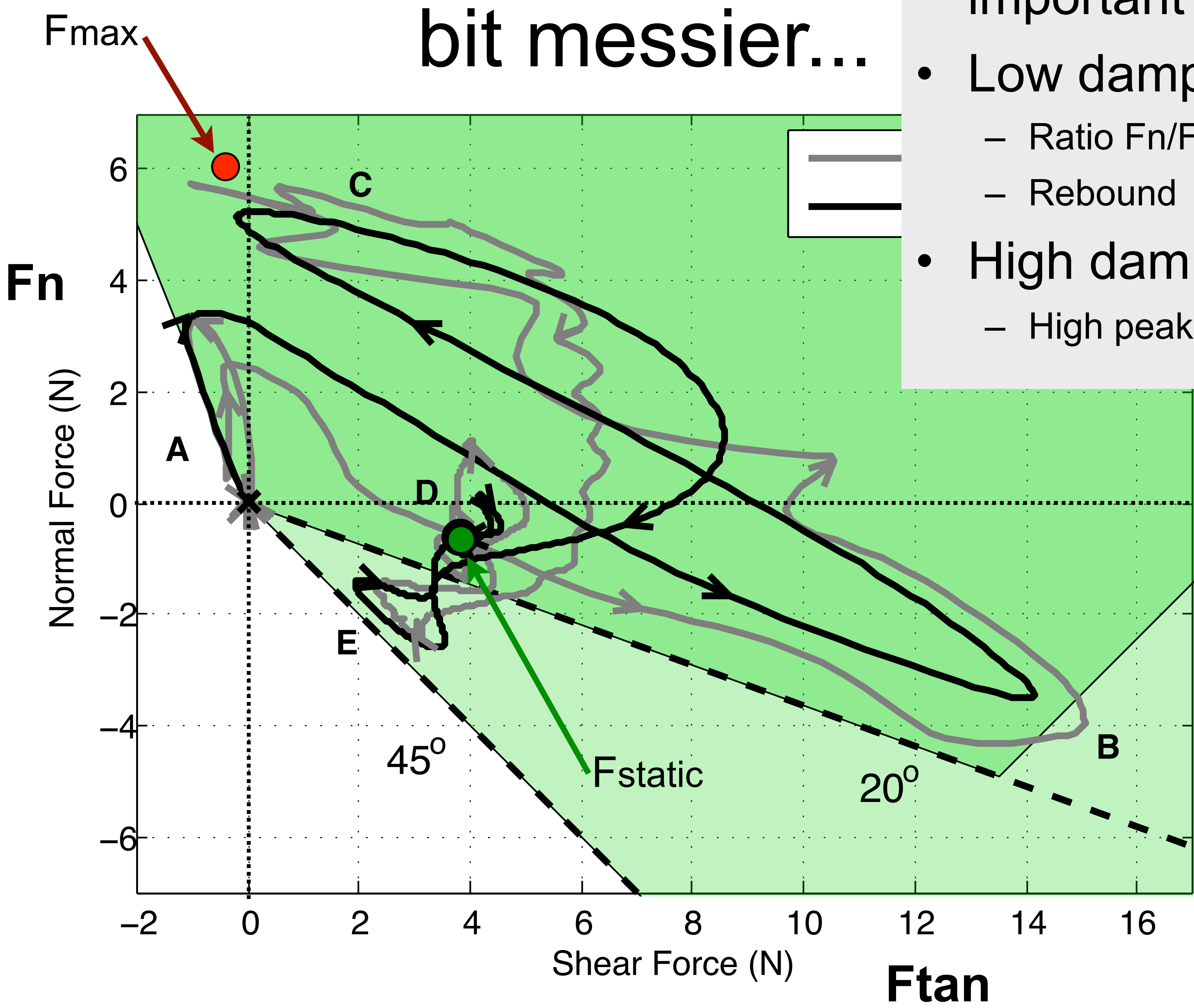
The actual picture is a bit messier...

- Loading trajectory is important
- Low damping ratio:
  - Ratio Fn/Ftan too high
  - Rebound
- High damping ratio:
  - High peak force



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Leg suspension requirements

Early tests revealed that **vertical rebound** was the main failure

Solution: design suspension (links, springs, dampers, nonlinear elements) to **absorb** kinetic energy and **direct** forces toward spines with:

- **moderate peak landing force**
- **moderate suspension travel** (no knee contact)
- **no negative tangential forces** (vertical rebound, detachment)
- **small negative normal forces** (no horizontal bounce-off)

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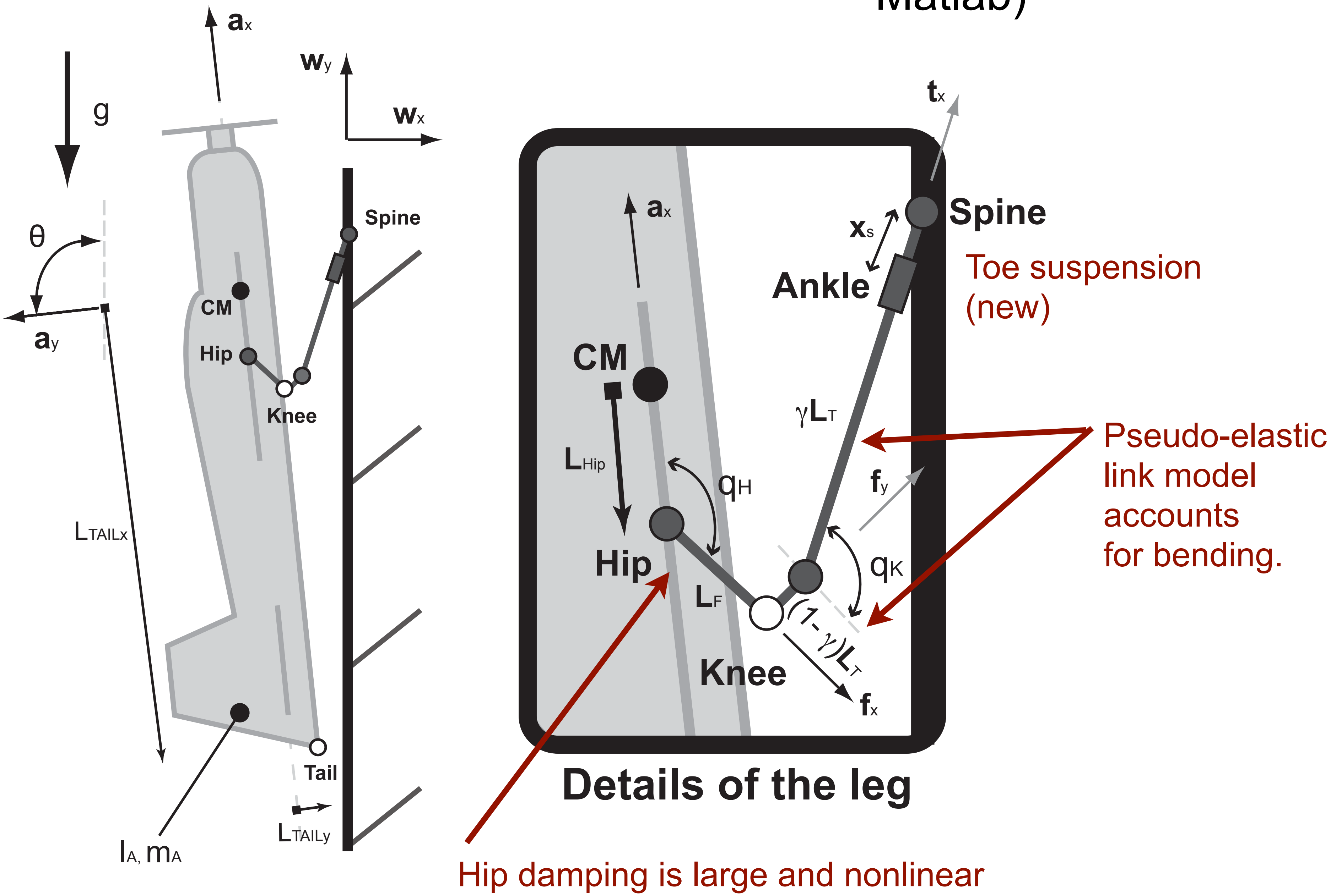
Suspension model

(dynamic equations via Autolev; simulations in Matlab)



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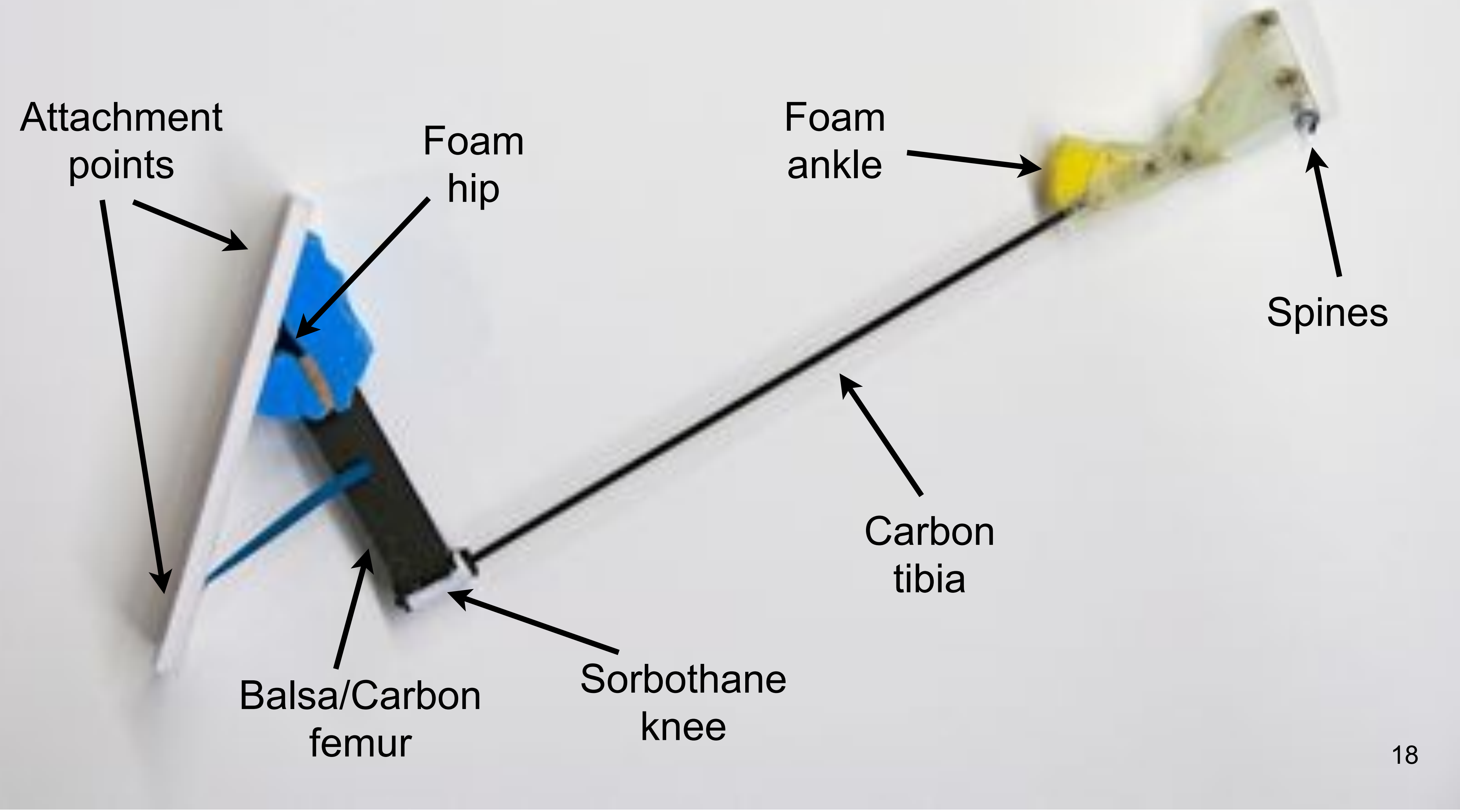
Leg Structure



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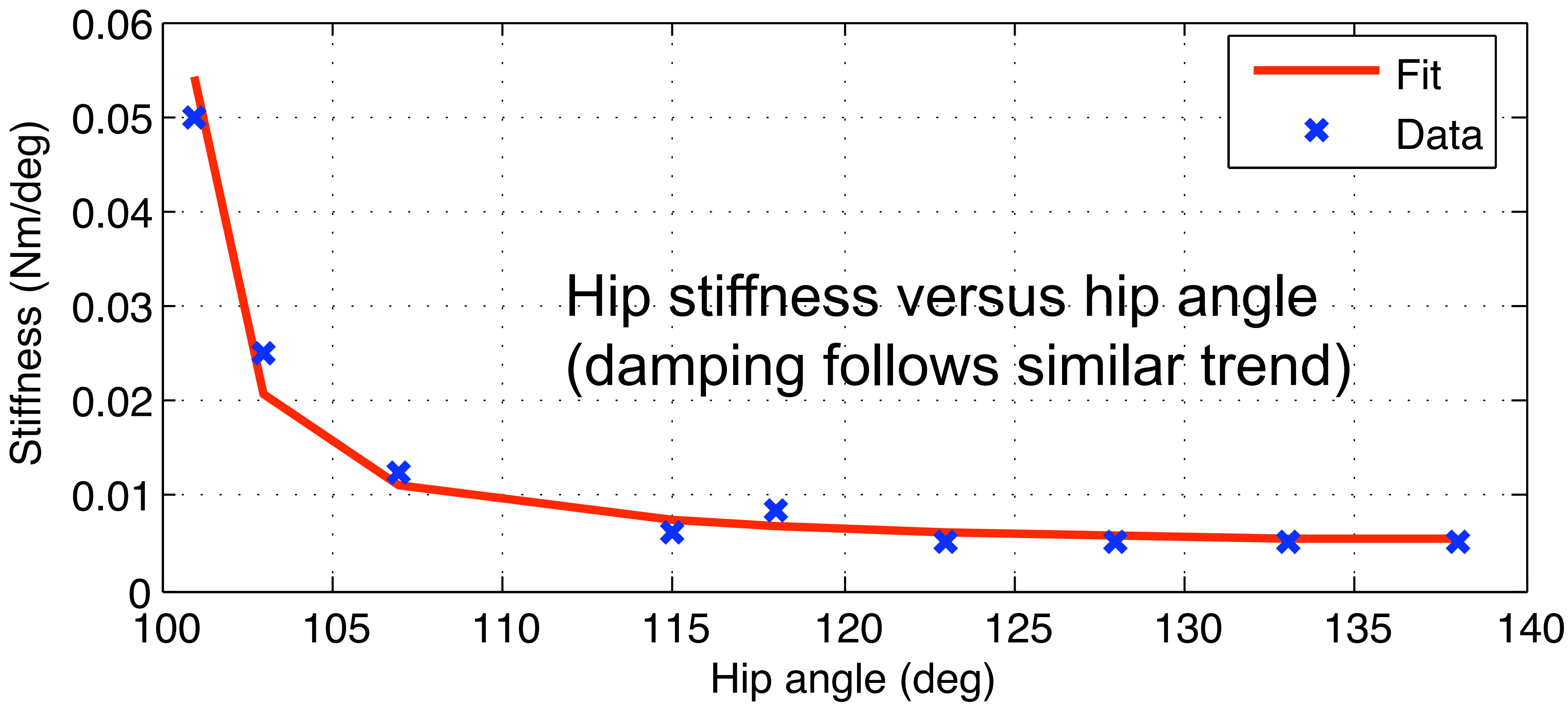
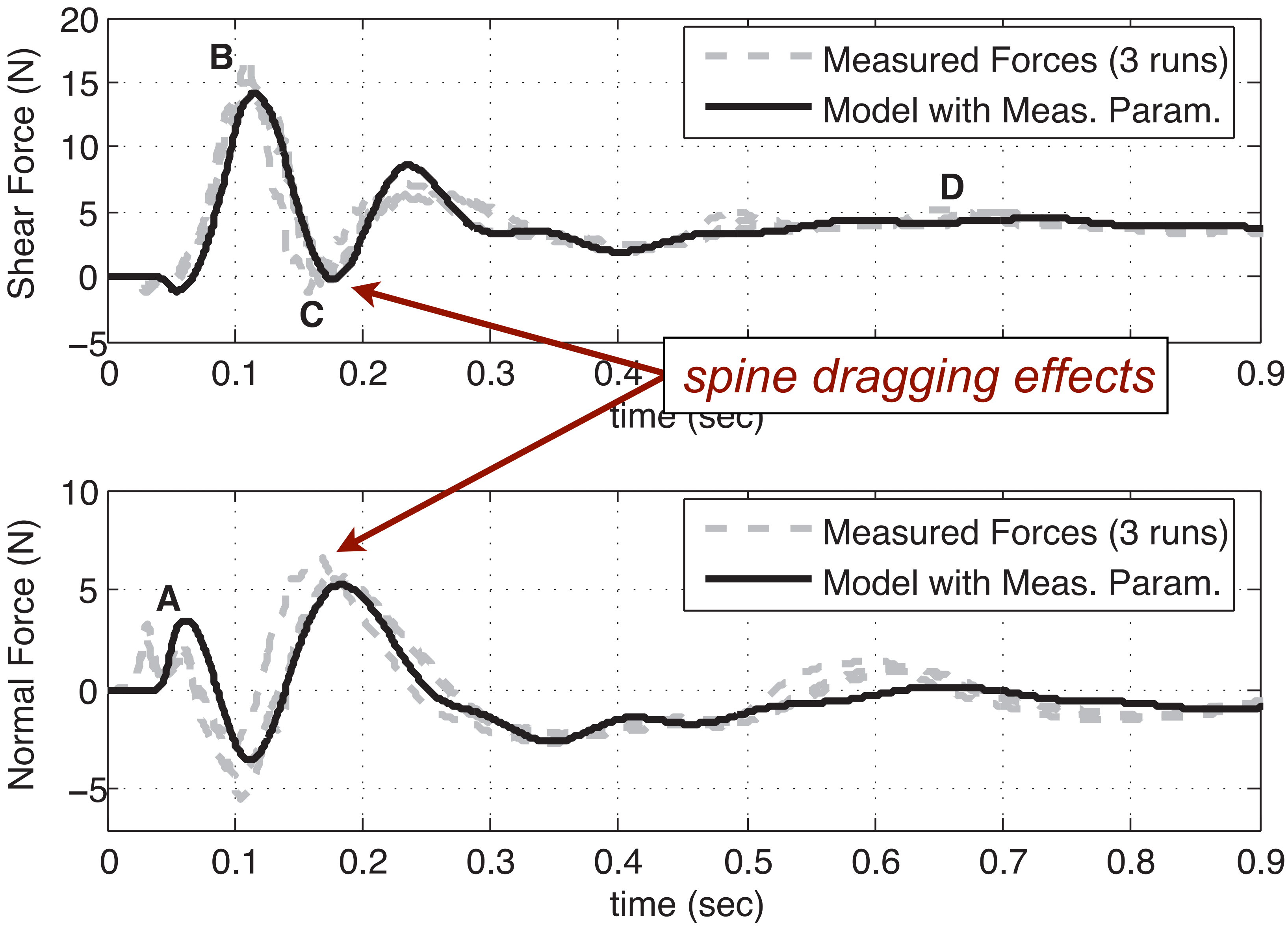
Nonlinear elements



- Material properties +
  kinematics to create roughly constant force
- Damping scaled w.r.t position and velocity
- Urethane foam exhibits reduced damping at high velocity

Comparing model & force plate data



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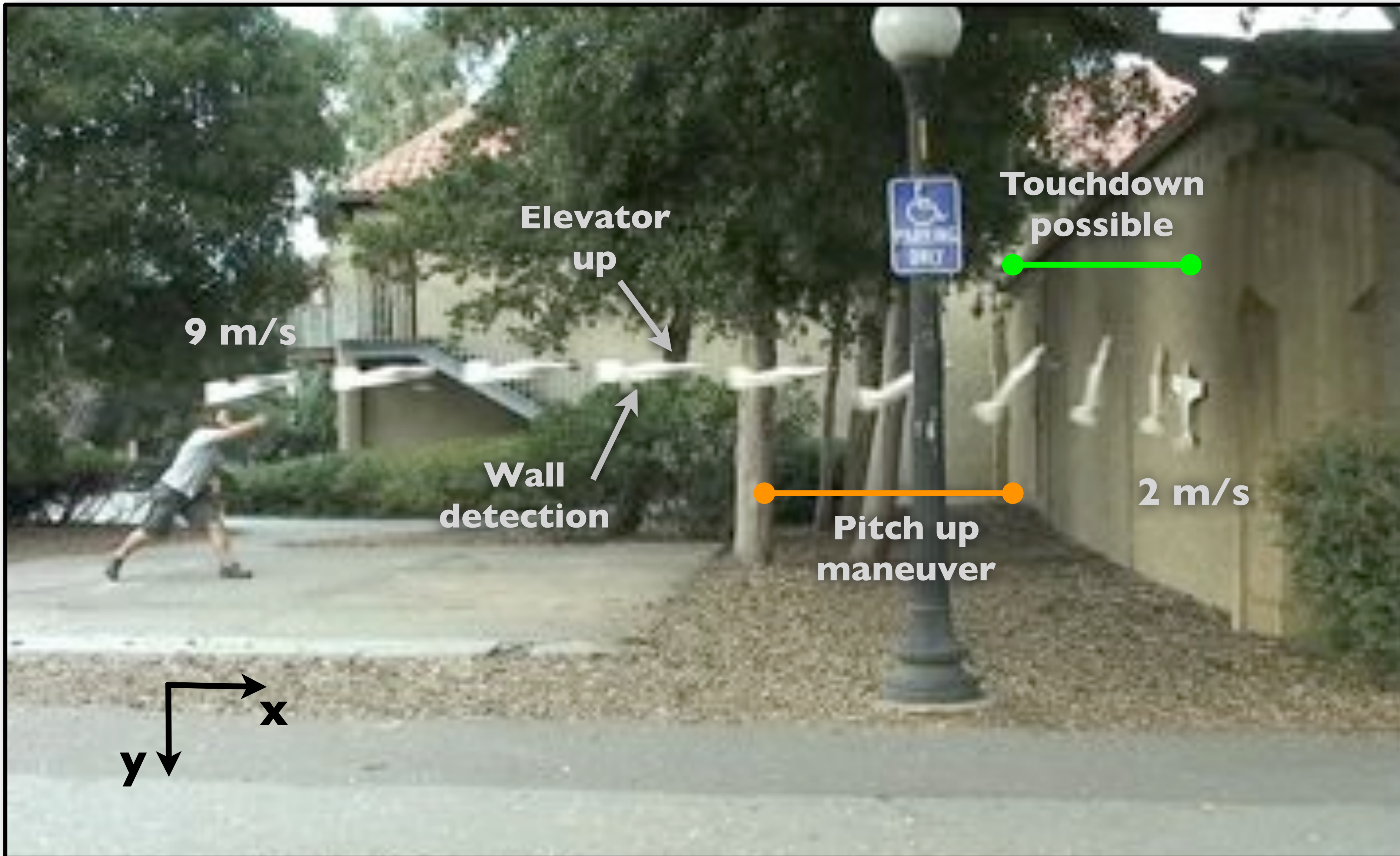

30/40 successful landings (10 autonomous, 20 in manual control)

- Pitch = 65 to 110 deg
- Pitch rate = 0 to 200 deg/s
- v_x = 1 - 2.7 m/s (forward)
- v_y = up to 1 m/s (downward)

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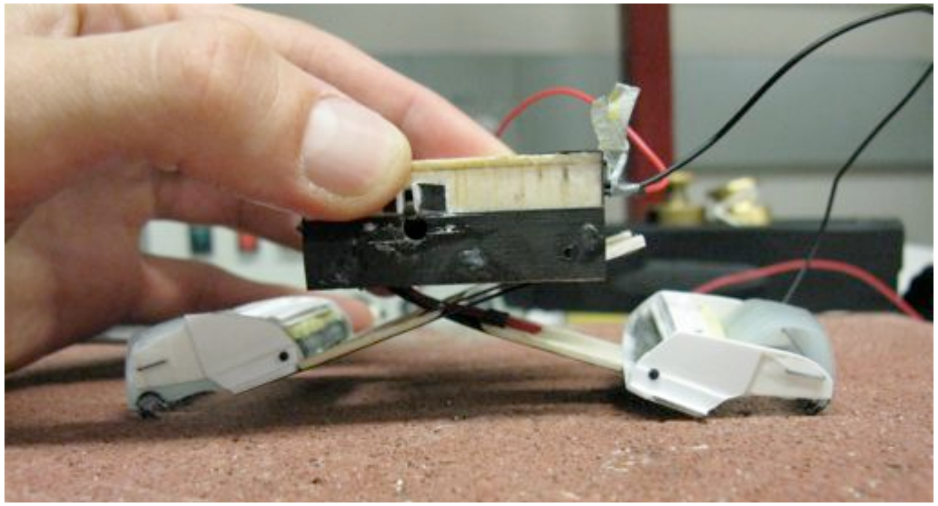
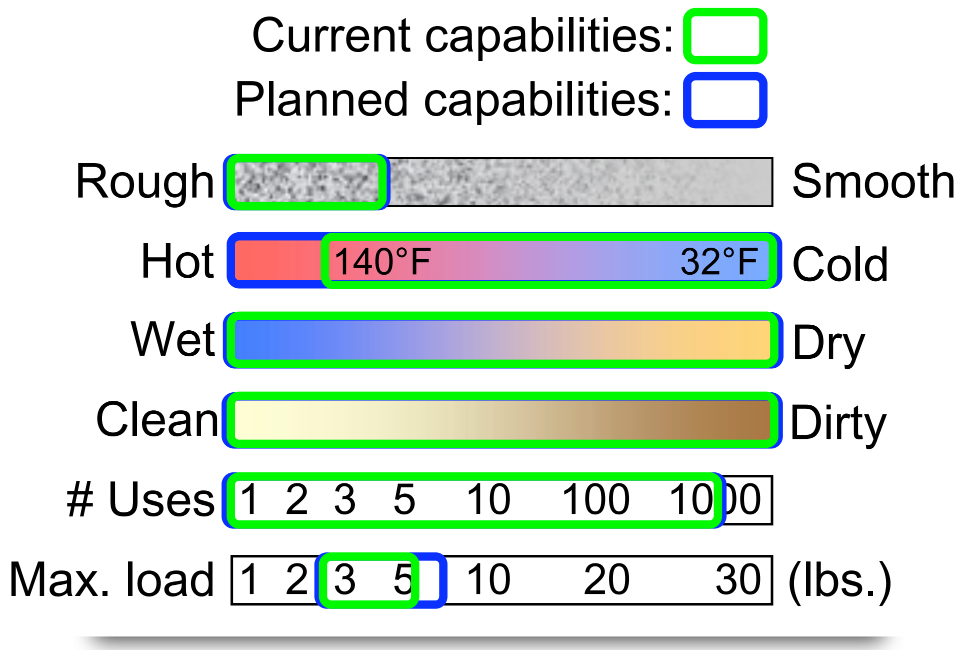
Improvements and future work

- Land on other surfaces (horizontal, inverted)
  - > use opposed spines
- Real conditions (windy, etc.)
- Maneuver on the wall (hybrid scansorial robotics)
- *Take off from the wall!*





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Improvements and future work

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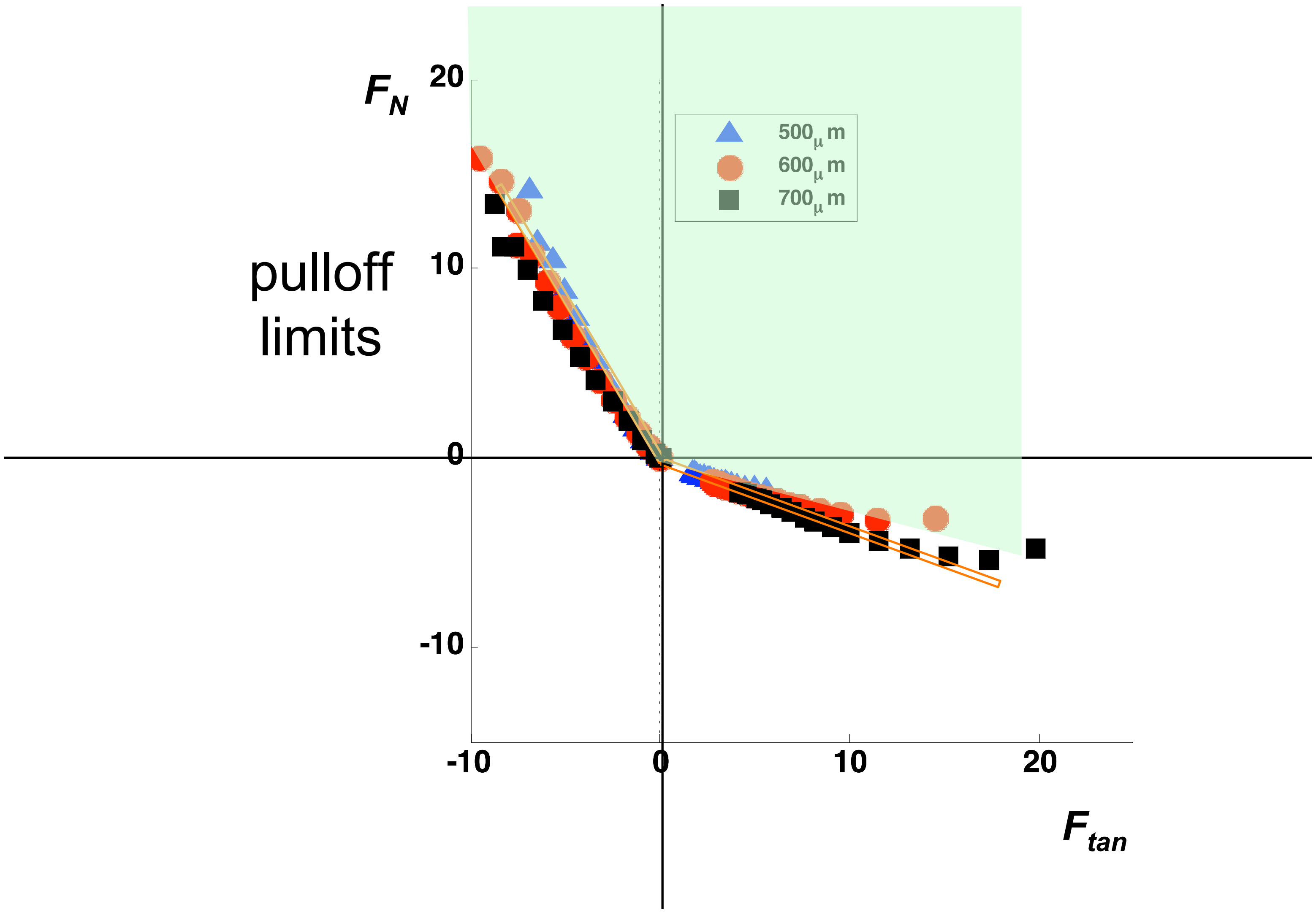
Limits for directional adhesion
(e.g. Stickybot)



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Spine limit curve -- 1 foot, 10 spines

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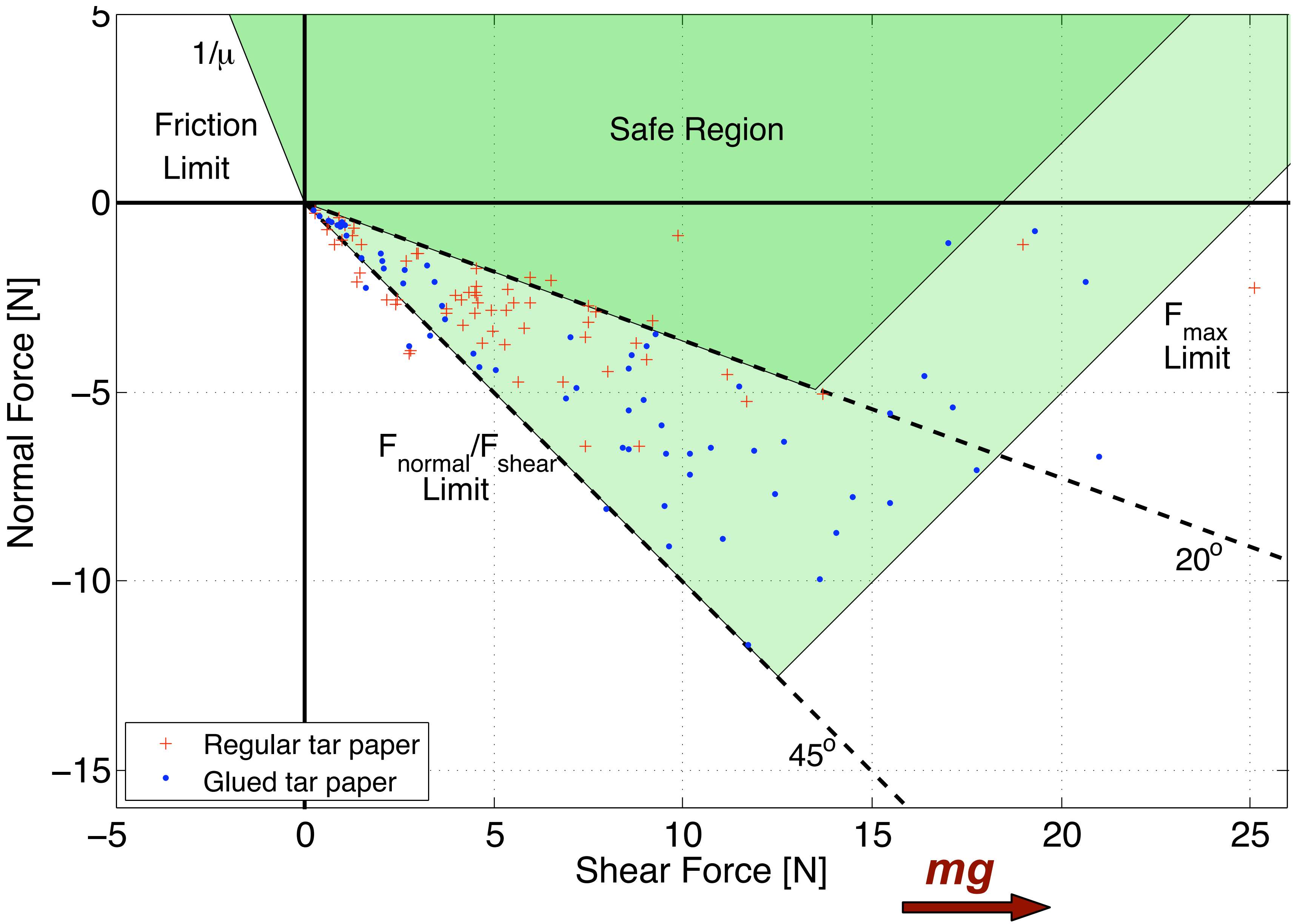

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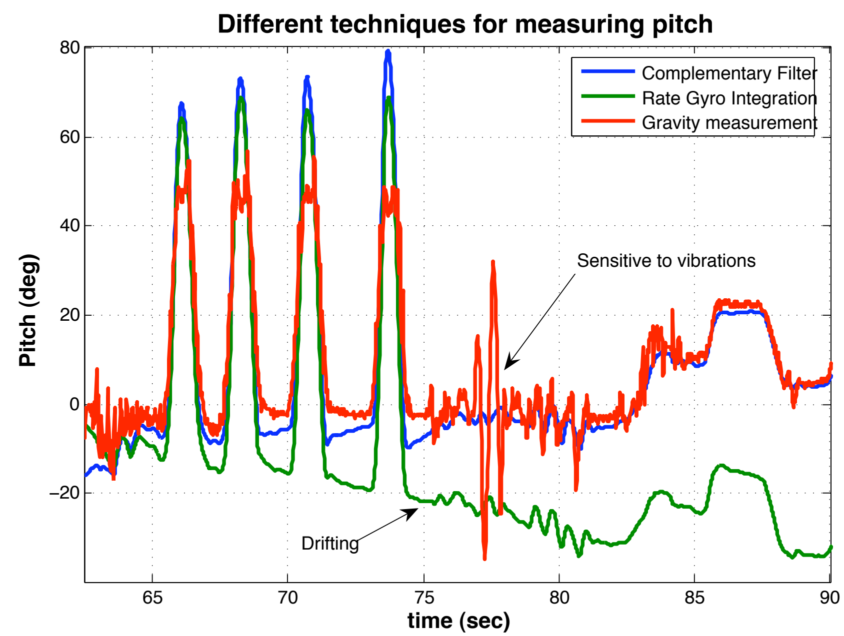
Onboard Sensors

- Simple wall detection using the LV-Maxsonar:
  - Range of 6 m
  - Update rate of 20 Hz
- Onboard accelerometer and gyro are used for data analysis
- Combined using a second order complementary filter:

$$\left(\frac{\tau s+1}{\tau s+1}\right)^2 \theta(s) = \frac{\tau^2 s}{(\tau s+1)^2}\dot{\theta}(s) + \frac{2\tau s+1}{(\tau s+1)^2}\theta(s)$$

- Need something better!!!



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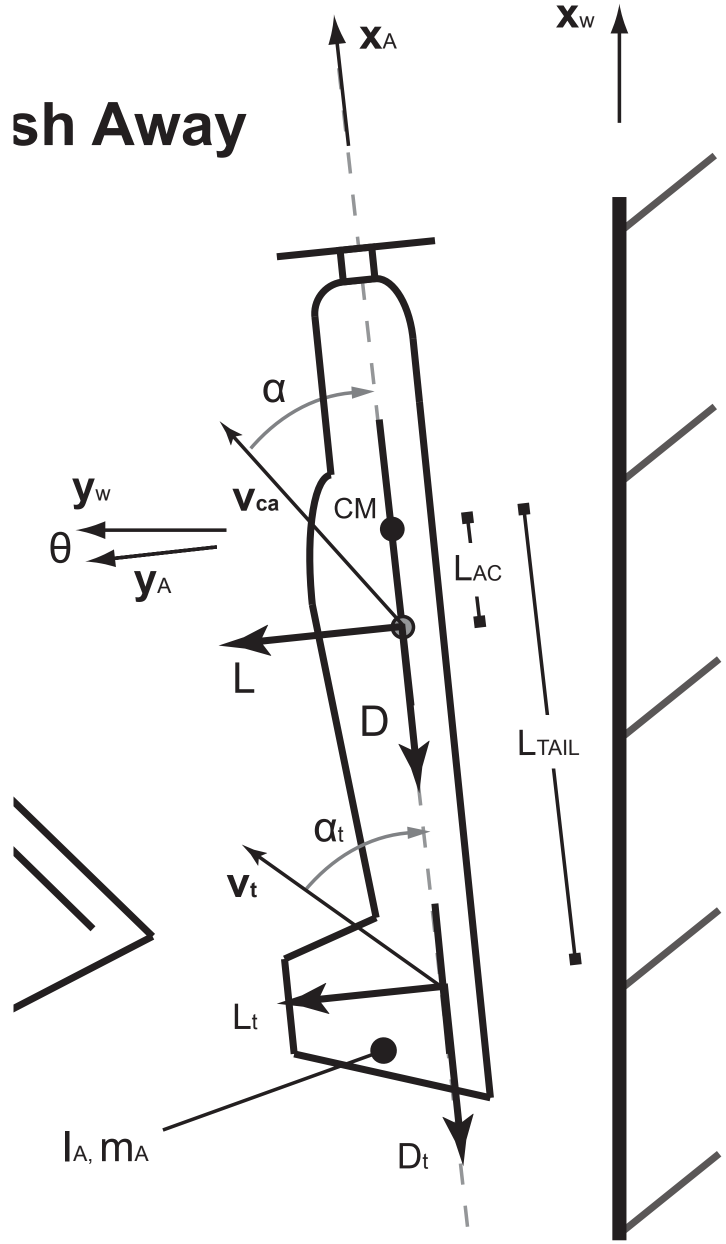
Aero Model

(inspired by [Cory & Tedrake 2008])

$$
\begin{aligned}
C_L &= 2\sin(\alpha)\cos(\alpha) \\
C_D &= 2\sin^2(\alpha)
\end{aligned}
$$

$$
\begin{aligned}
L &= \frac{1}{2}\rho v^2 A C_L \\
D &= \frac{1}{2}\rho v^2 A C_D
\end{aligned}
$$



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