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# Advanced Swing Leg Control

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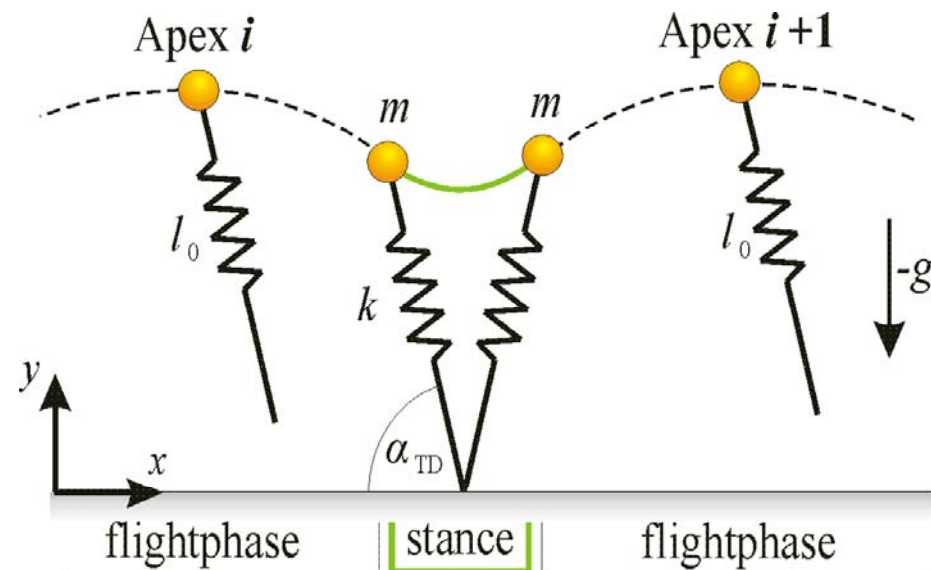
seit 1558

Locomotion Laboratory  
Friedrich-Schiller-Universität Jena

Supported by DFG  
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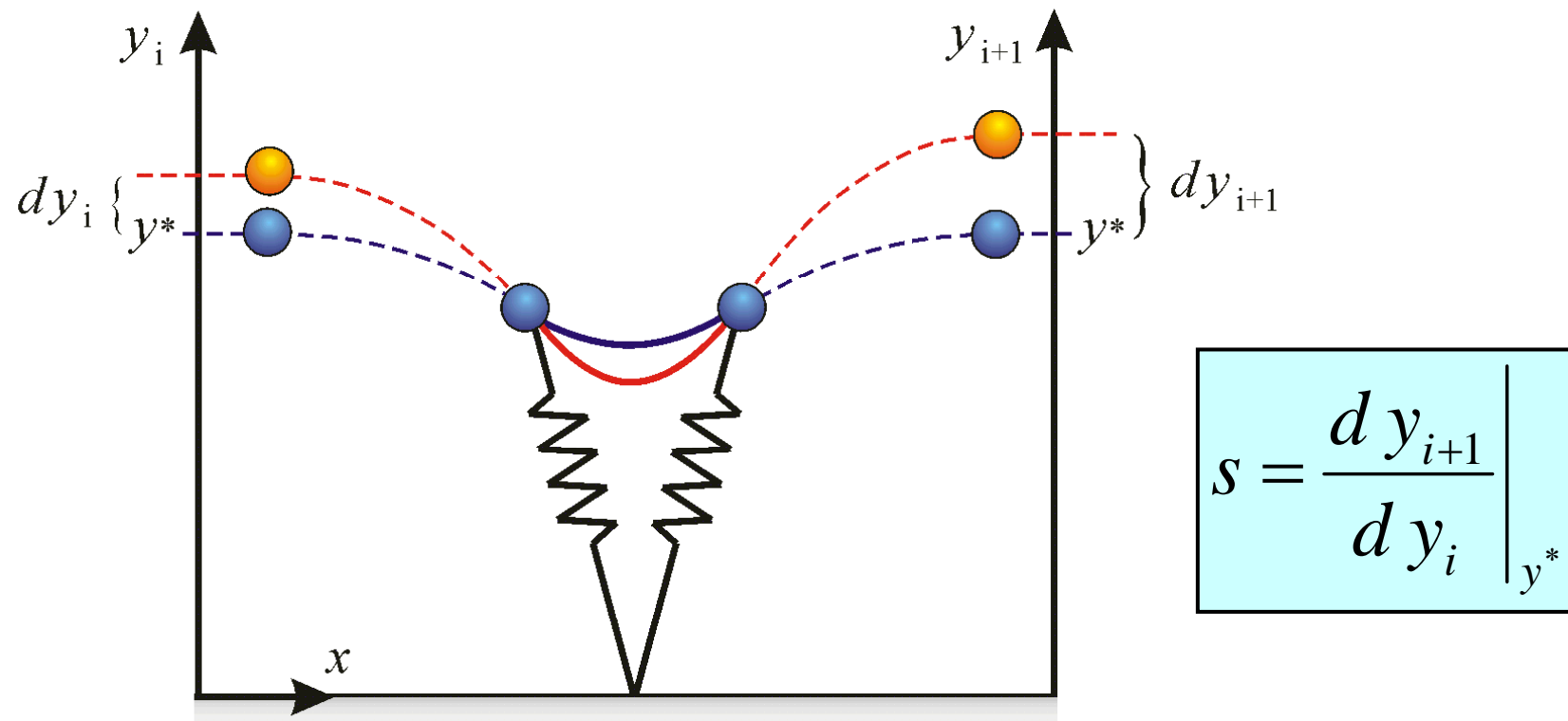


## Spring mass running

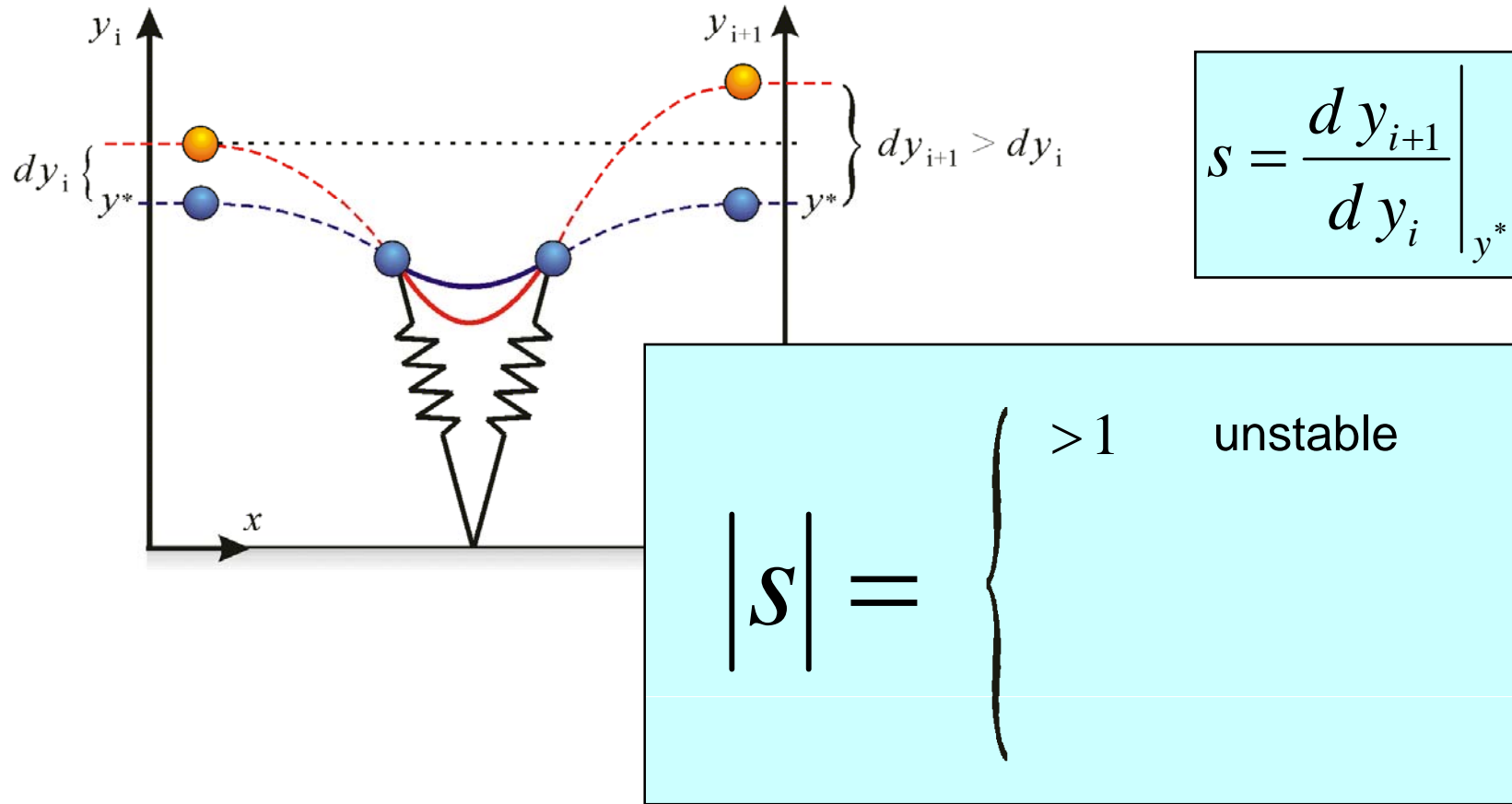


Blickhan, *J. Biomech*, 1989

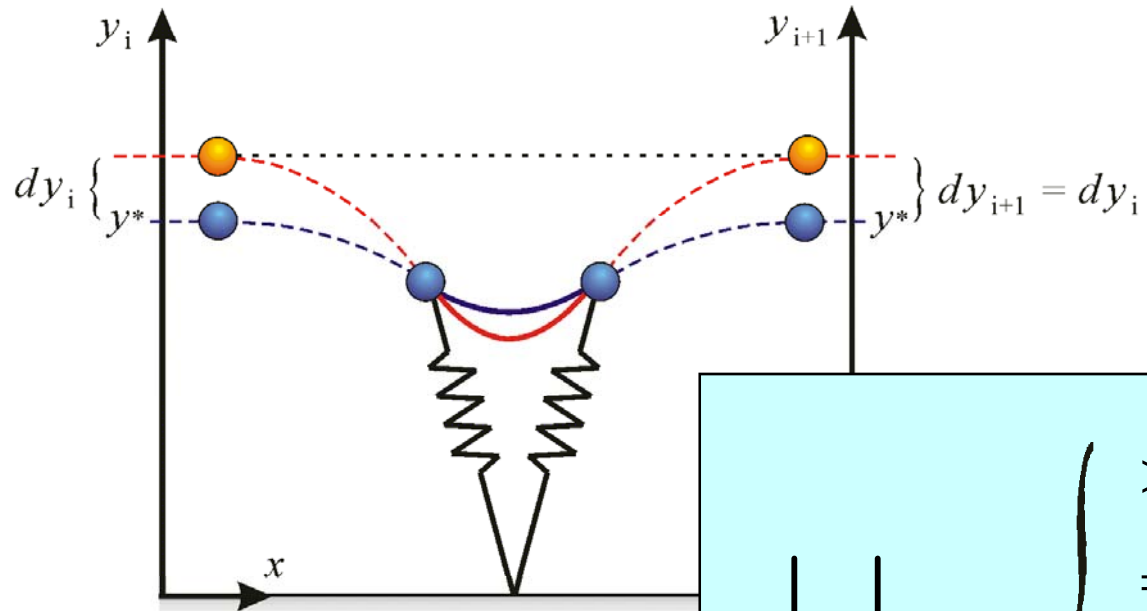
## System Analysis



# Stability



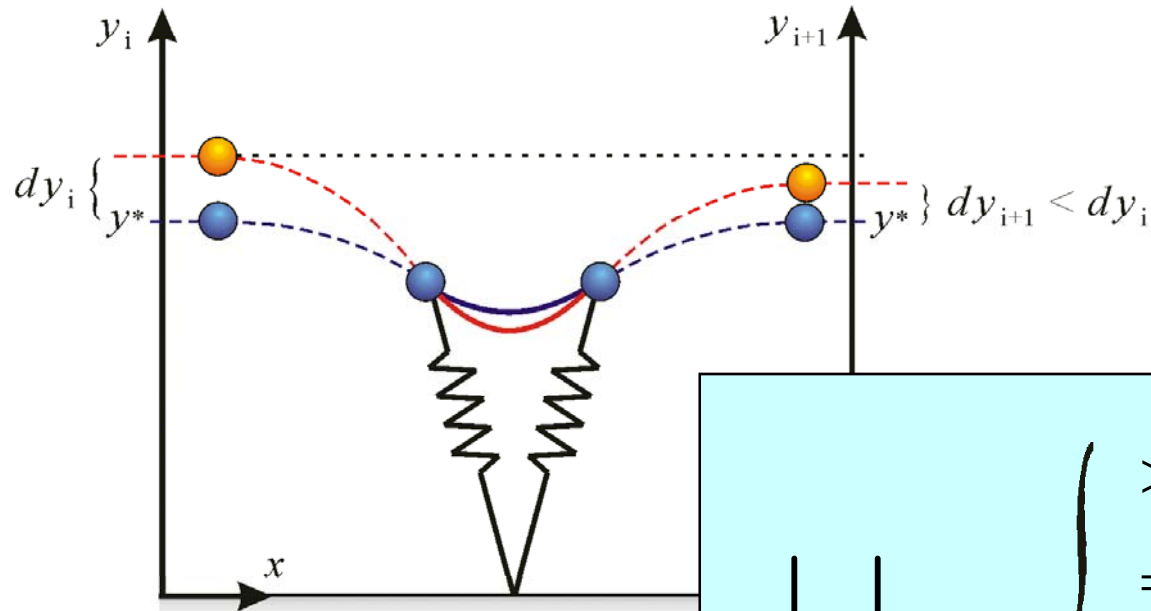
# Stability



$$s = \left. \frac{d y_{i+1}}{d y_i} \right|_{y^*}$$

$$|s| = \begin{cases} > 1 & \text{unstable} \\ = 1 & \text{indifferent} \end{cases}$$

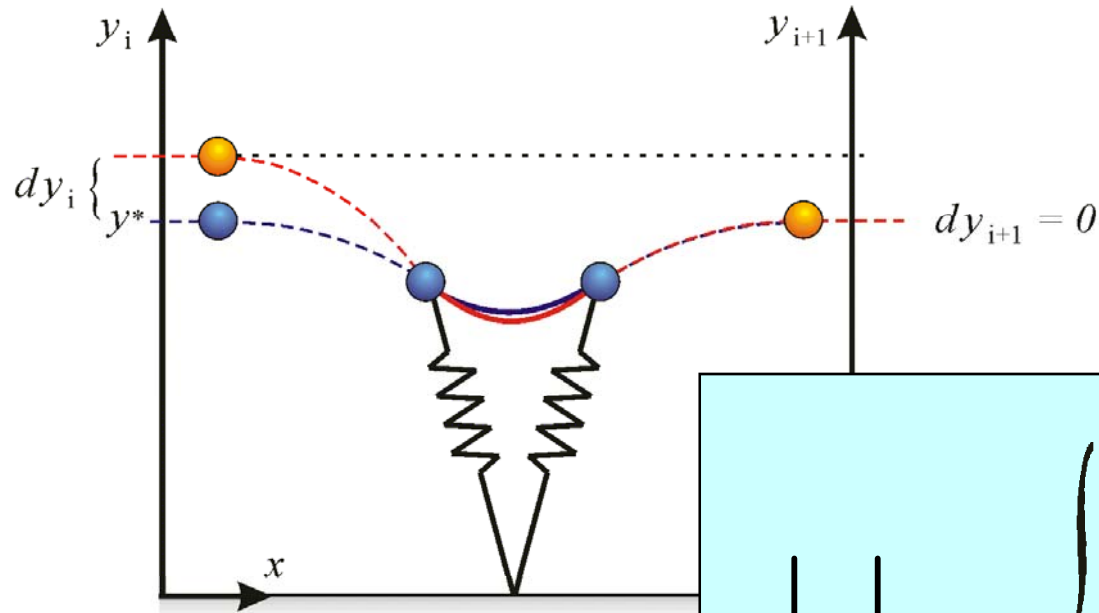
# Stability



$$s = \left. \frac{d y_{i+1}}{d y_i} \right|_{y^*}$$

$$|s| = \begin{cases} > 1 & \text{unstable} \\ = 1 & \text{indifferent} \\ < 1 & \text{stable} \end{cases}$$

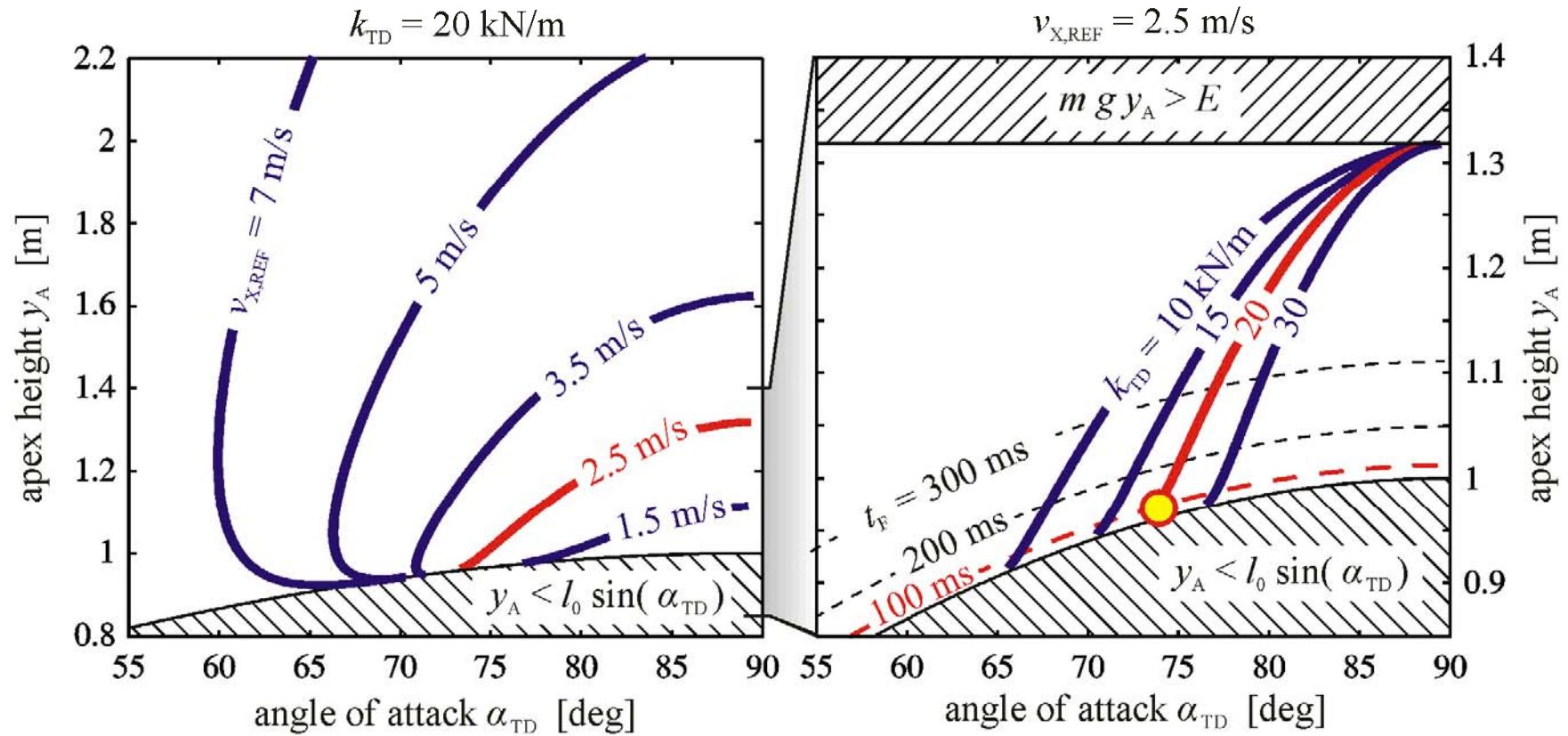
# Stability



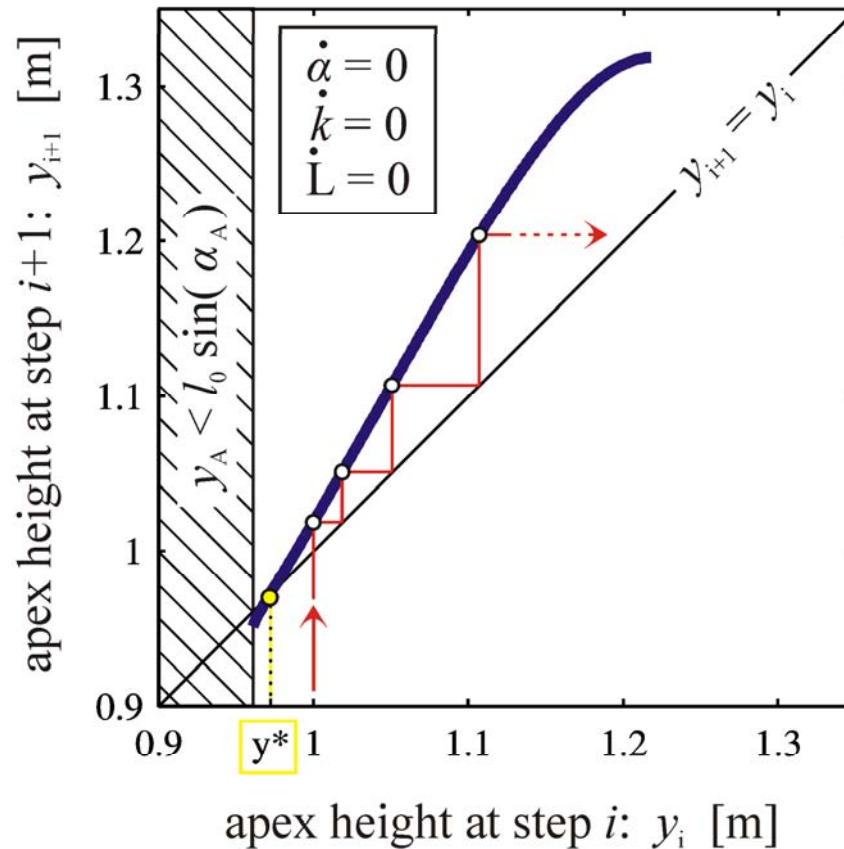
$$s = \left. \frac{d y_{i+1}}{d y_i} \right|_{y^*}$$

$ s  =$	}	$> 1$	unstable
		$= 1$	indifferent
		$< 1$	stable
		$= 0$	superstable

# Periodic Solutions



## Periodic Solution but Unstable

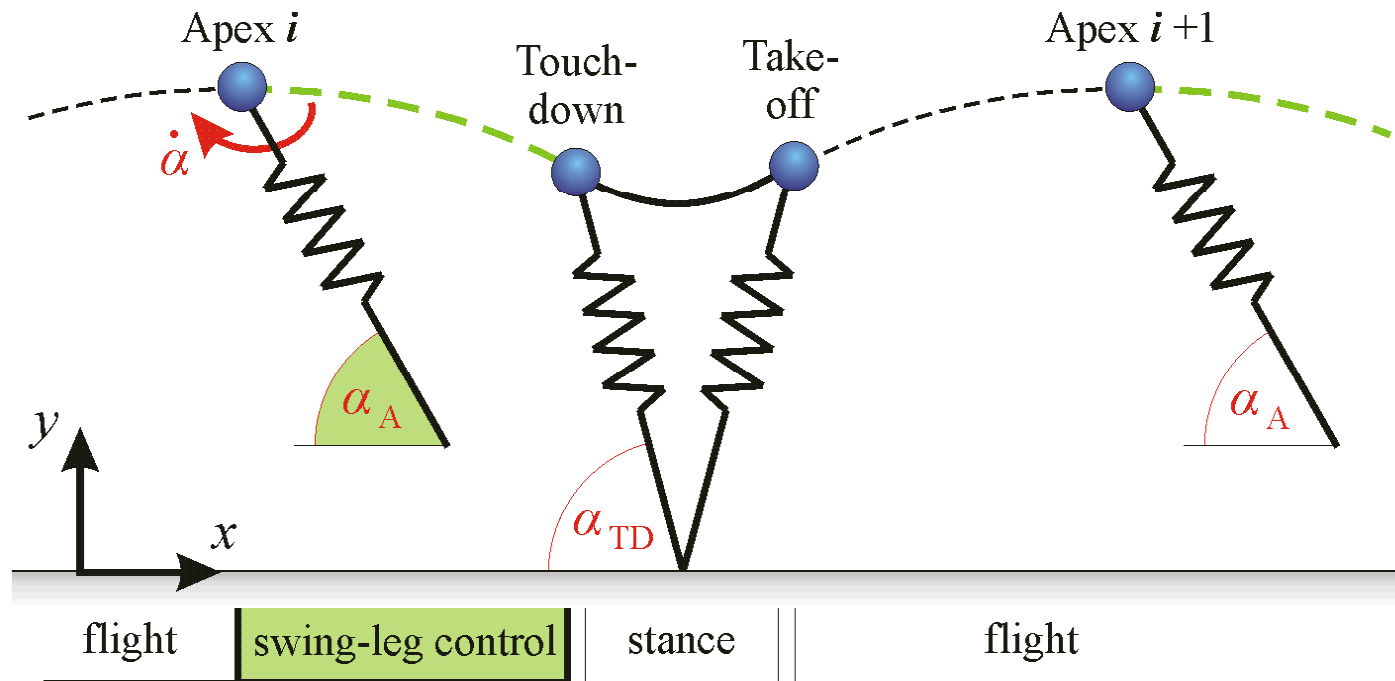


$$\begin{aligned}
 v_{X,REF} &= 2.5 \text{ m/s} \\
 t_F / 2 &= 50 \text{ ms} \\
 y_A &= 0.97 \text{ m} \\
 k_{TD} &= 20 \text{ kN/m} \\
 \alpha_{TD} &= 73.8^\circ
 \end{aligned}$$

**Slope**

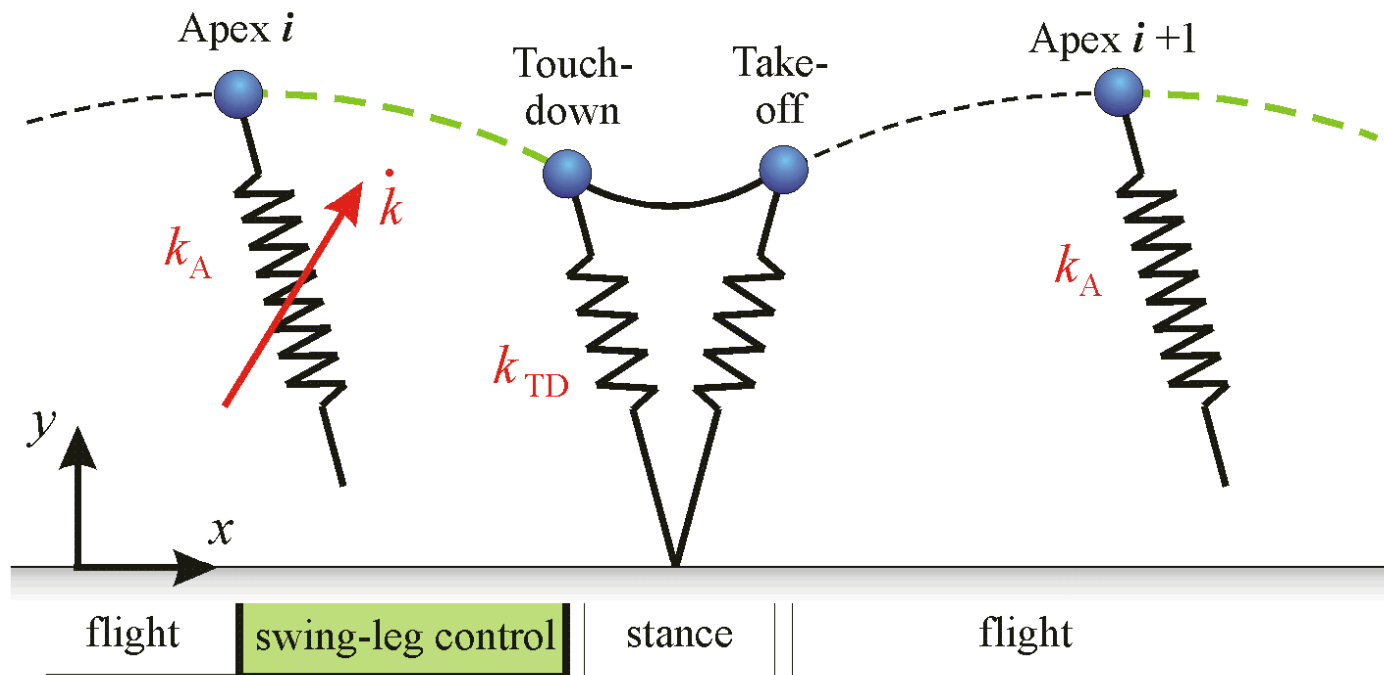
$$s = \left. \frac{d y_{i+1}}{d y_i} \right|_{y^*} > 1$$

## Control Strategy: Swing Leg Retraction



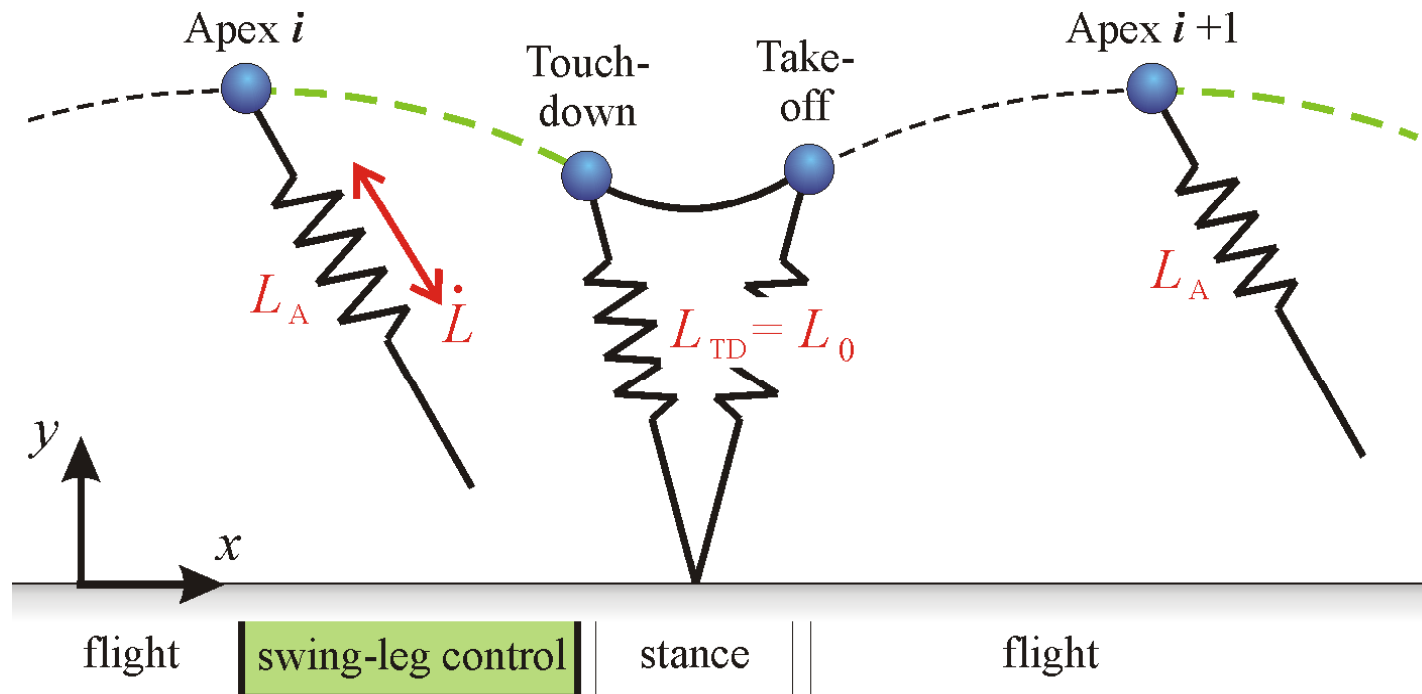
$$\alpha(t) = \alpha_A + \dot{\alpha} \cdot (t - t_A)$$

## Control Strategy: Stiffness Adaptation



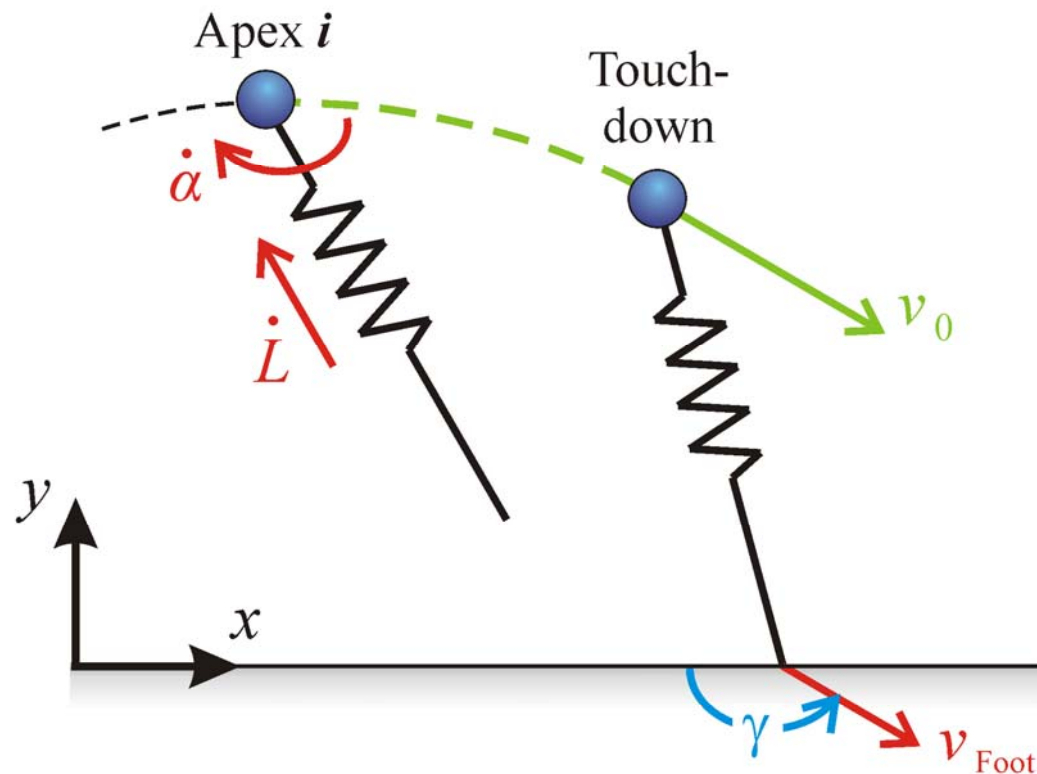
$$k(t) = k_A + \dot{k} \cdot (t - t_A)$$

## Control Strategy: Leg Length Adaptation



$$L(t) = L_A + \dot{L} \cdot (t - t_A)$$

## Foot Landing Condition

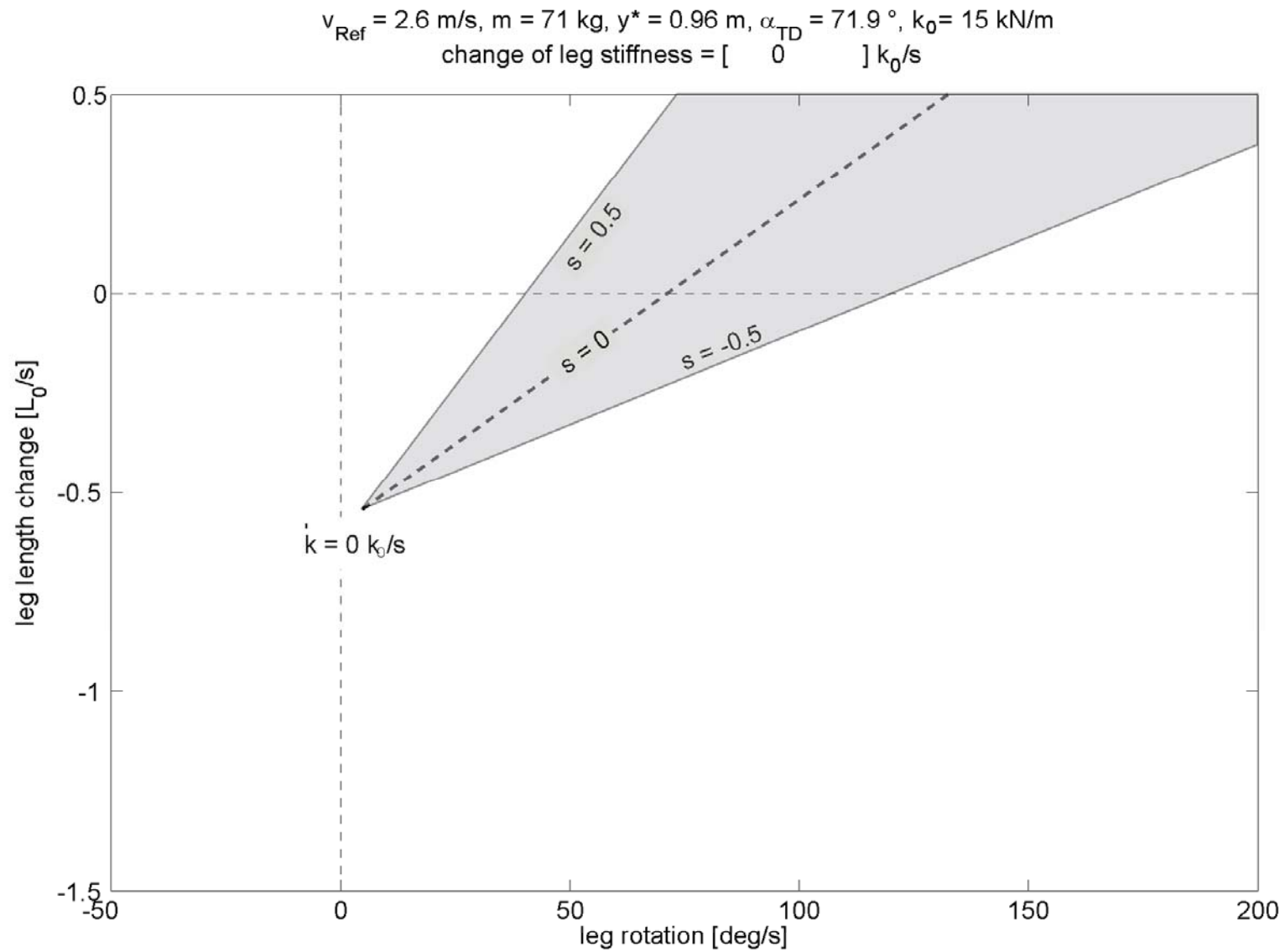


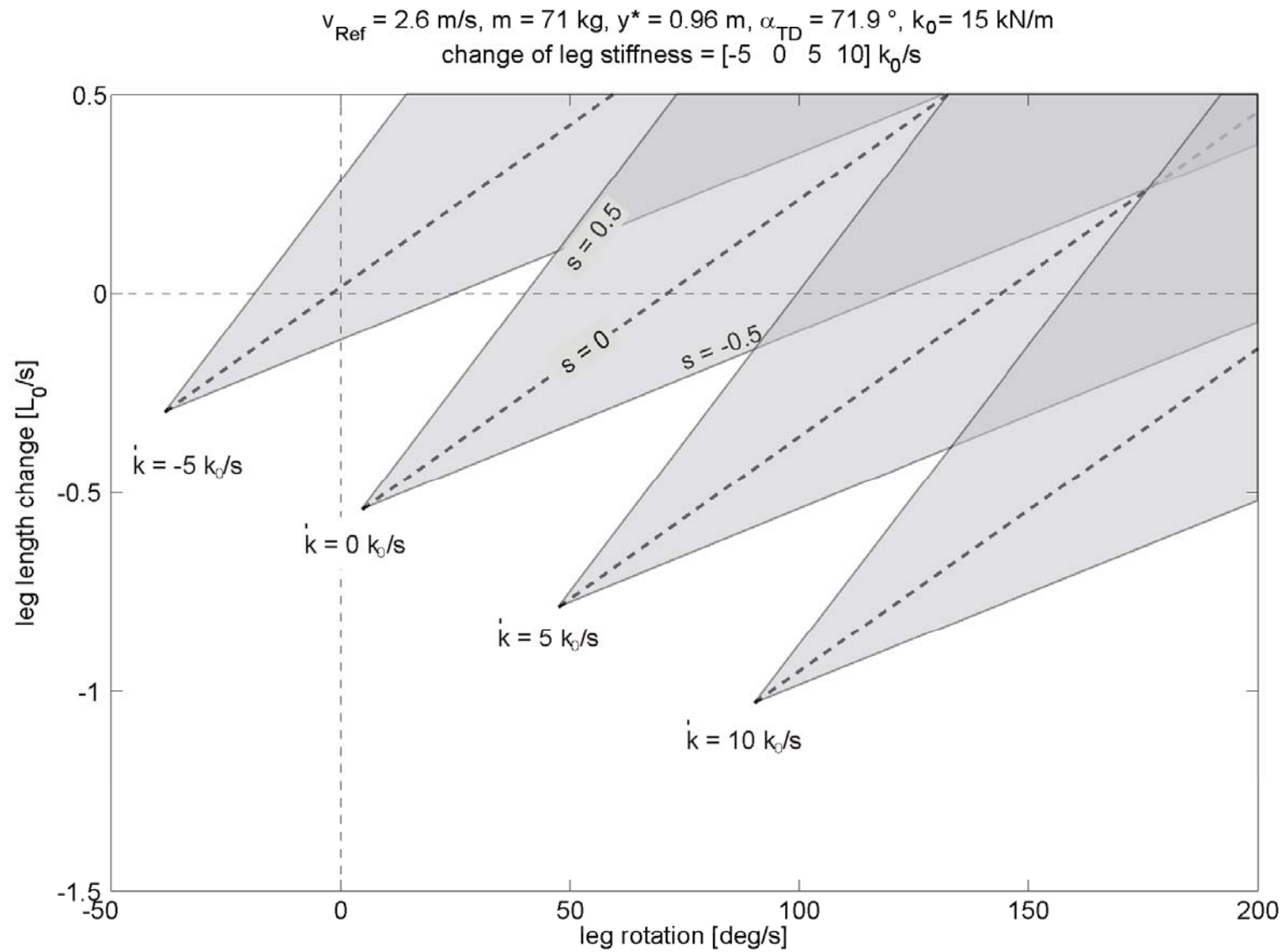
Ground Speed Matching:

$$GSM = \left( 1 - \frac{v_{Foot}}{v_0} \right) \cdot 100\%$$

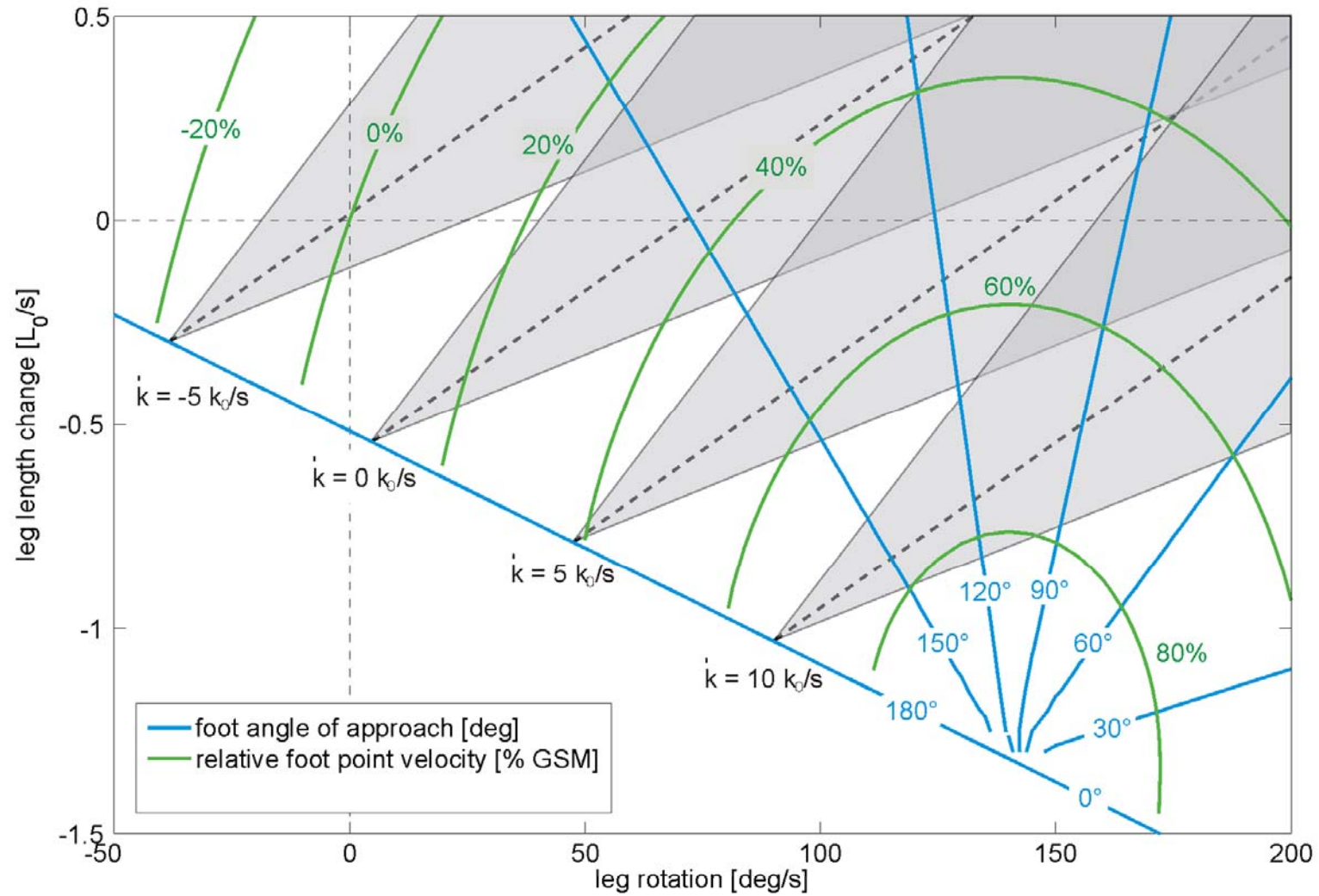
Foot Approach Angle:

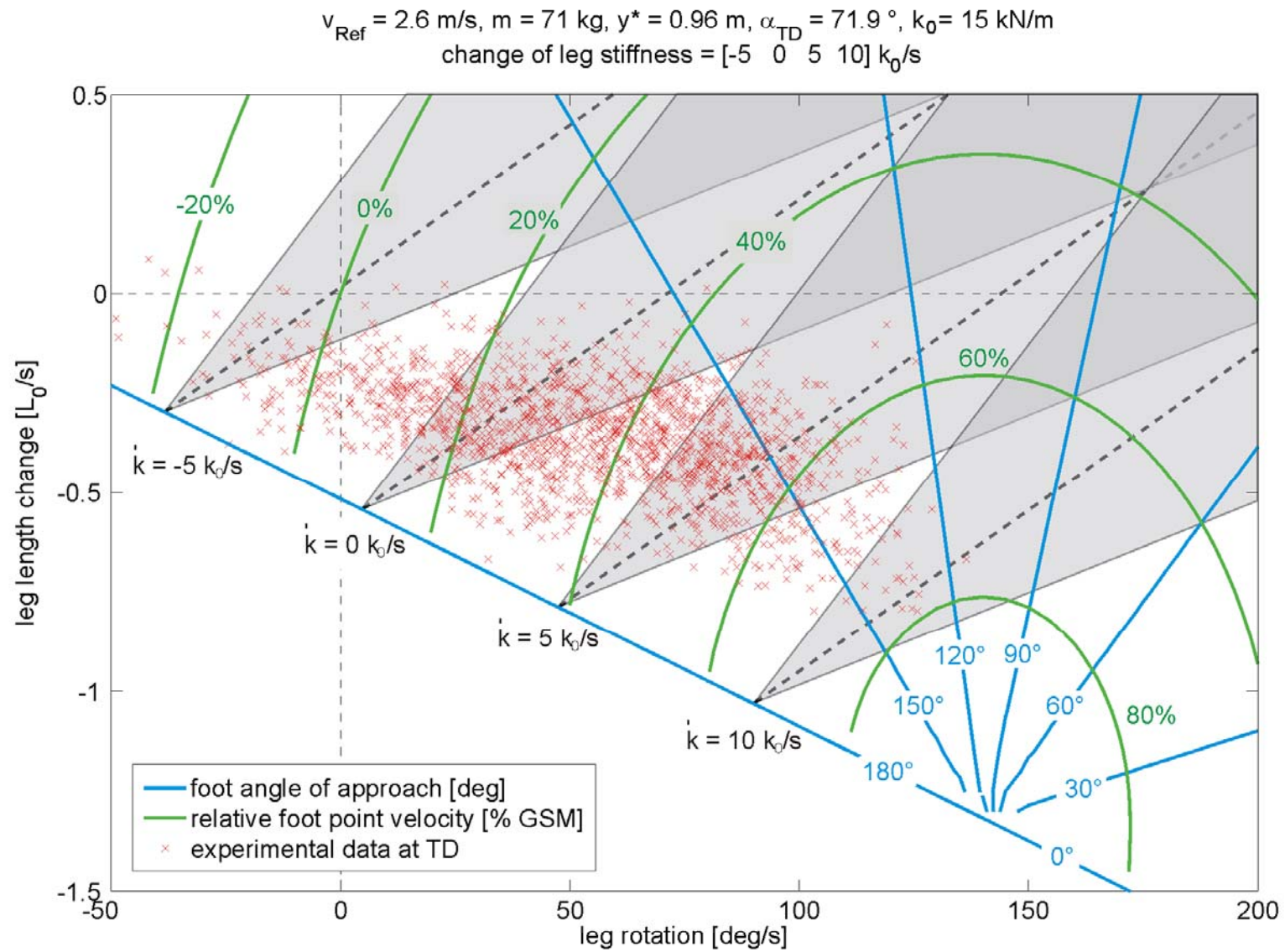
$$\gamma = \tan^{-1} \left( \frac{v_{x, Foot}}{v_{y, Foot}} \right) + 180^\circ$$

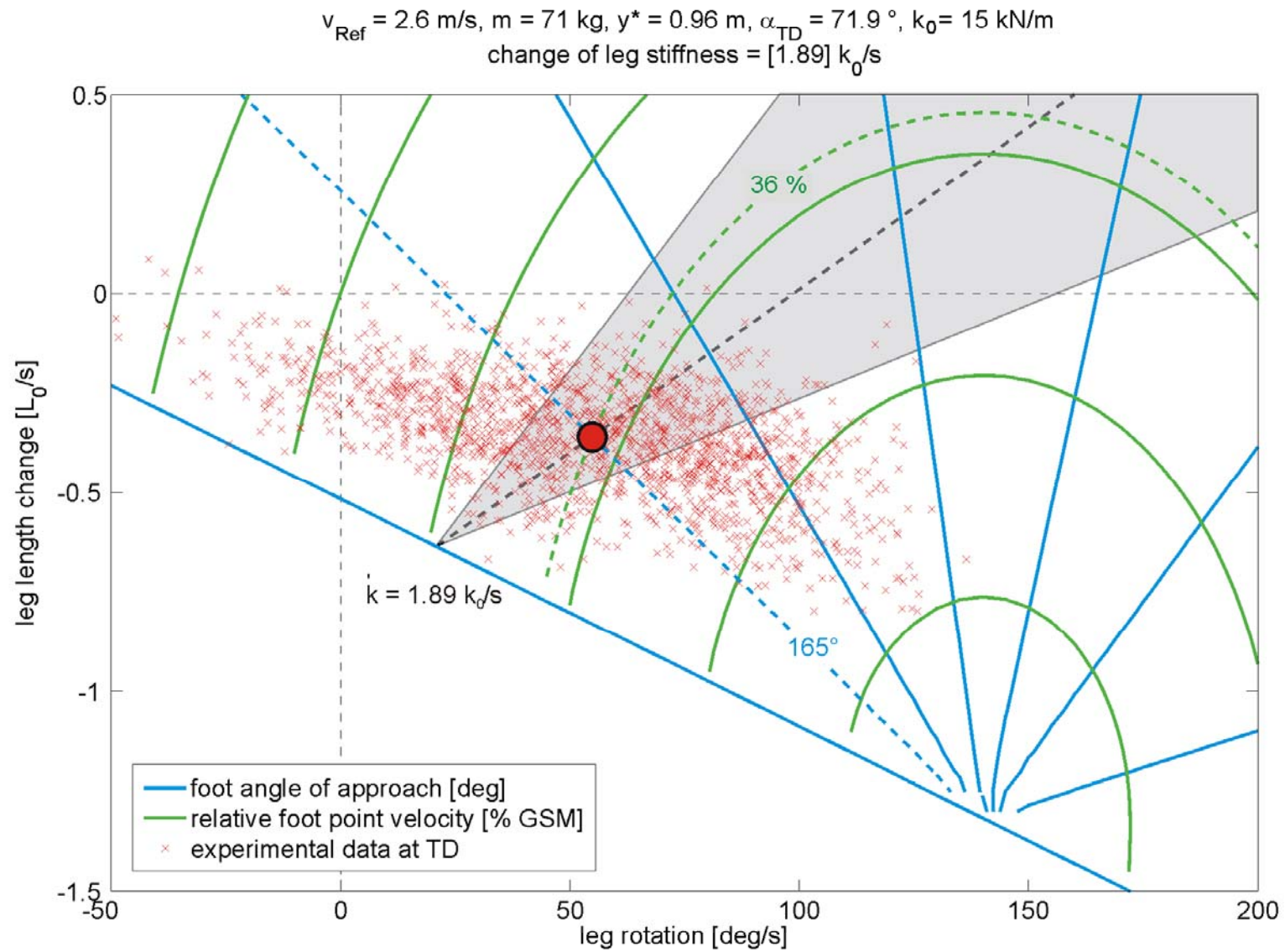




$v_{Ref} = 2.6 \text{ m/s}$ ,  $m = 71 \text{ kg}$ ,  $y^* = 0.96 \text{ m}$ ,  $\alpha_{TD} = 71.9^\circ$ ,  $k_0 = 15 \text{ kN/m}$   
 change of leg stiffness =  $[-5 \ 0 \ 5 \ 10] k_0/s$







## Take-Home Messages

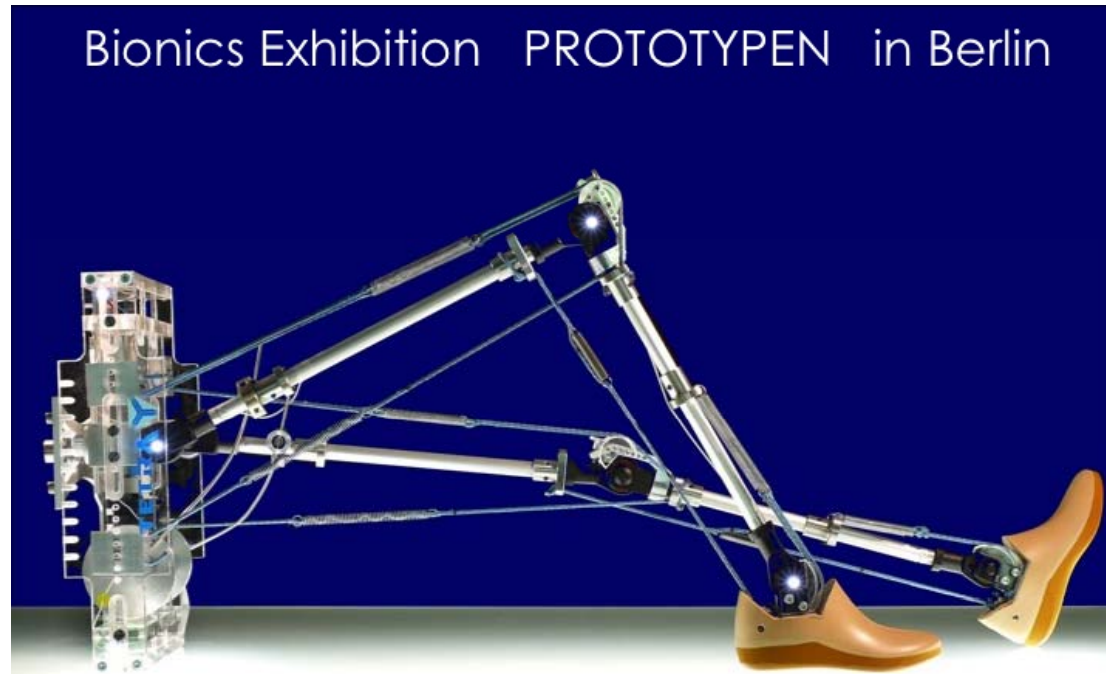
- every periodic solution can be stabilized
- control strategies are redundant
- for low energy ( $E_{REF} \sim v_{REF} = 2.6 \text{ m/s}$ ) control strategies are:

retraction of the leg  $\dot{\alpha} < 0$

stiffening of the leg  $\dot{k} > 0$

shortening of the leg  $\dot{L} < 0$

# Thanks for Your Attention!



Bionics Exhibition PROTOTYPEN in Berlin

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