Symmetry in Running

CLMC-Locomotion Seminar

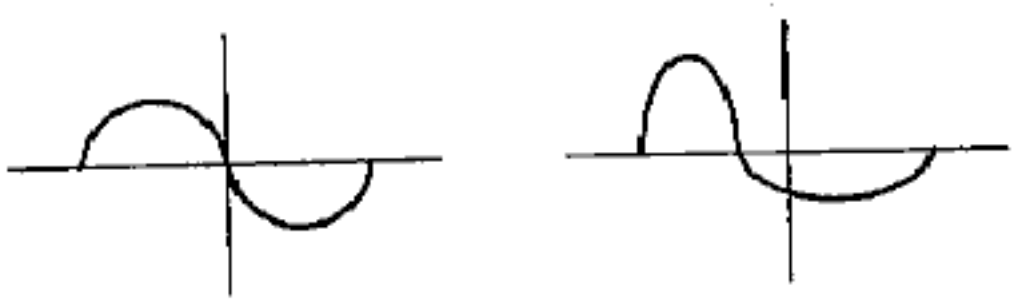
11/5/03

Steady State Running

- For constant forward running speed and stable upright posture during running:
  - Torques and horizontal forces integrate to zero
  - Vertical forces integrate to weight*time

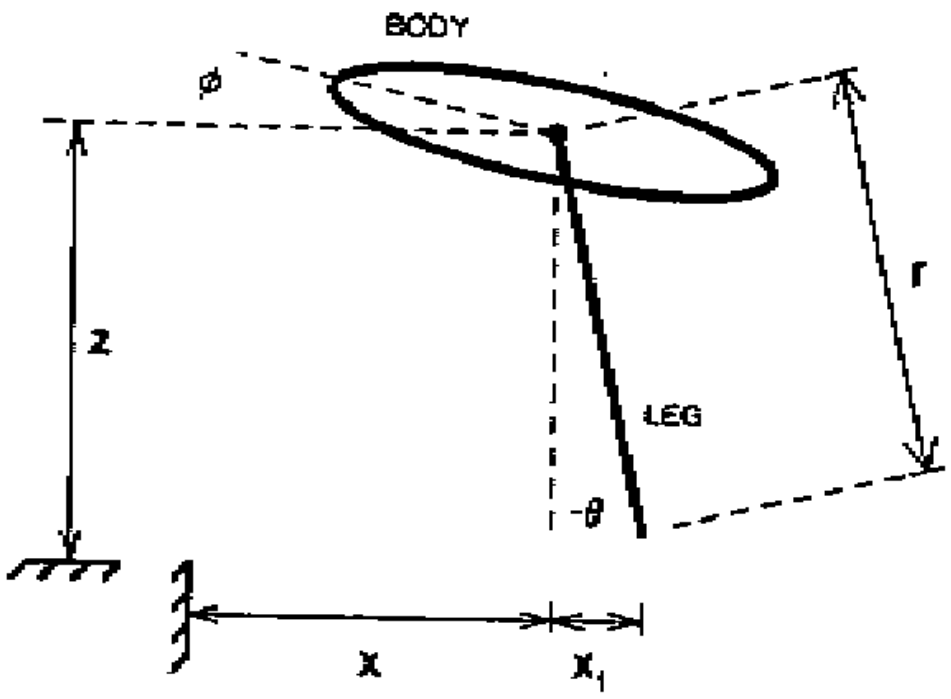
How to achieve steady state?

- Symmetric Functions will integrate to zero
  - So will some asymmetric functions



- Raibert's key point:
  - Symmetric body and leg motion results in steady-state locomotion

Symmetric Motion



Body Symmetry

$$\begin{cases} x(t) = -x(-t) \\ z(t) = z(-t) \\ \phi(t) = -\phi(-t) \end{cases}$$

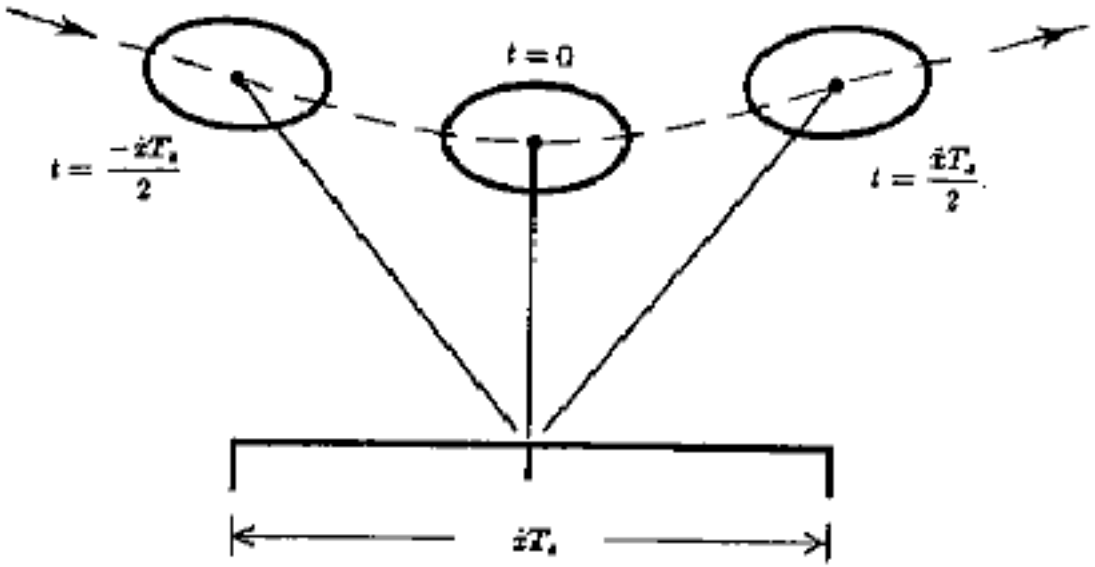
Leg Symmetry

$$\begin{cases} \theta(t) = -\theta(-t) \\ r(t) = r(-t) \end{cases}$$

Actuator Symmetry

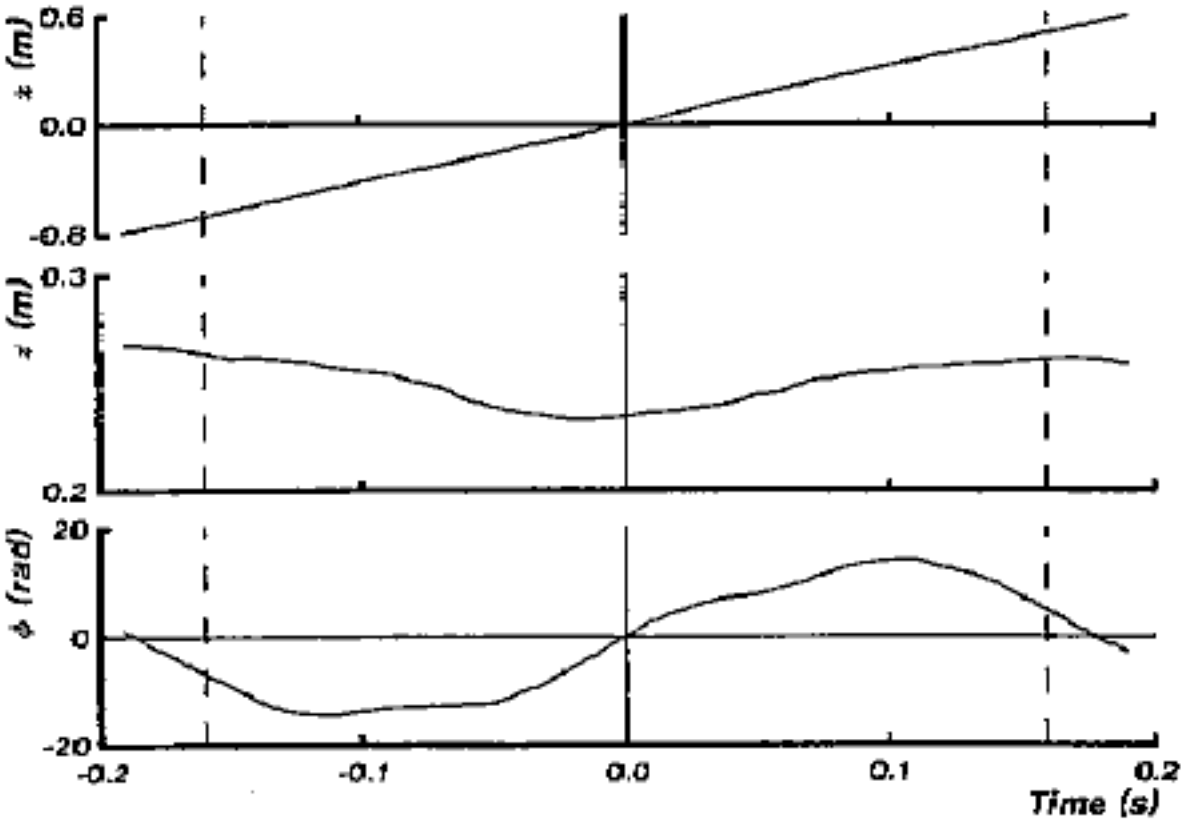
$$\begin{cases} f(t) = f(-t) \\ \tau(t) = -\tau(-t) \end{cases}$$

Example of Symmetric Motion

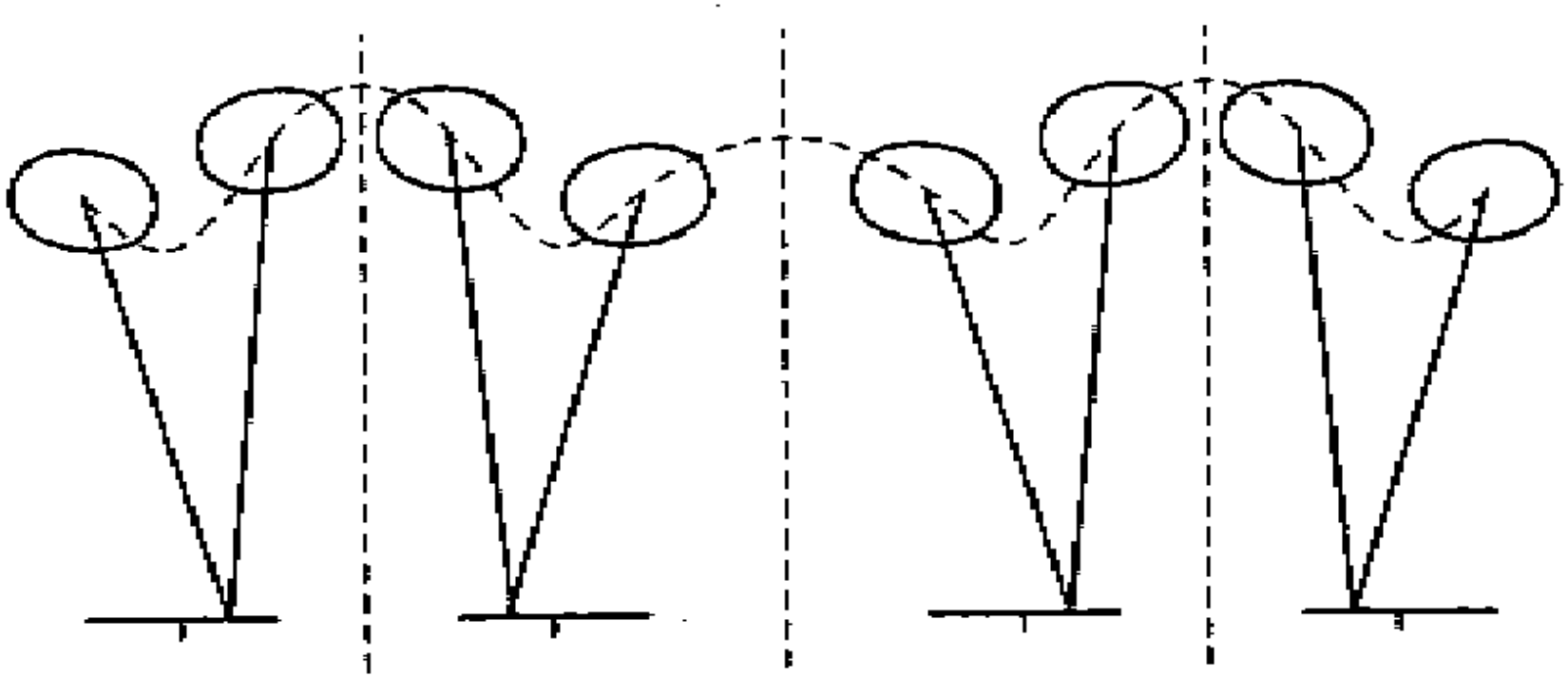


At a point in time: center of support must be under COG,
Pitch angle must be zero, vertical velocity must be zero

Another Example: Cat



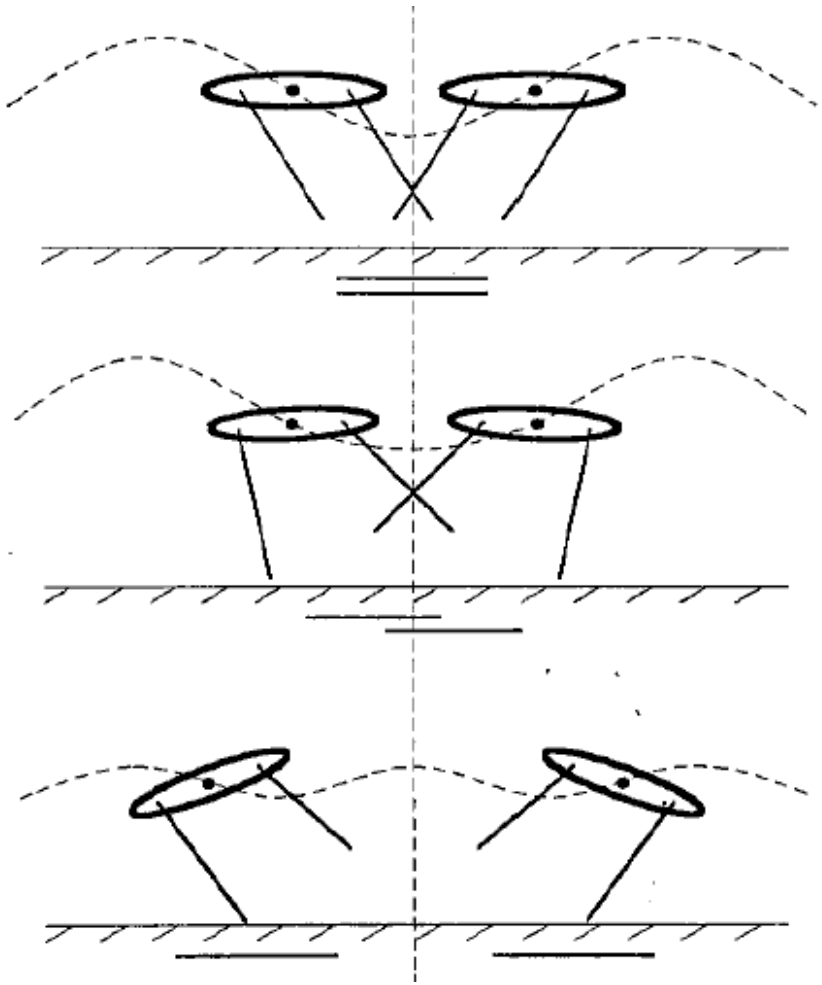
Pairs of Antisymmetric Steps



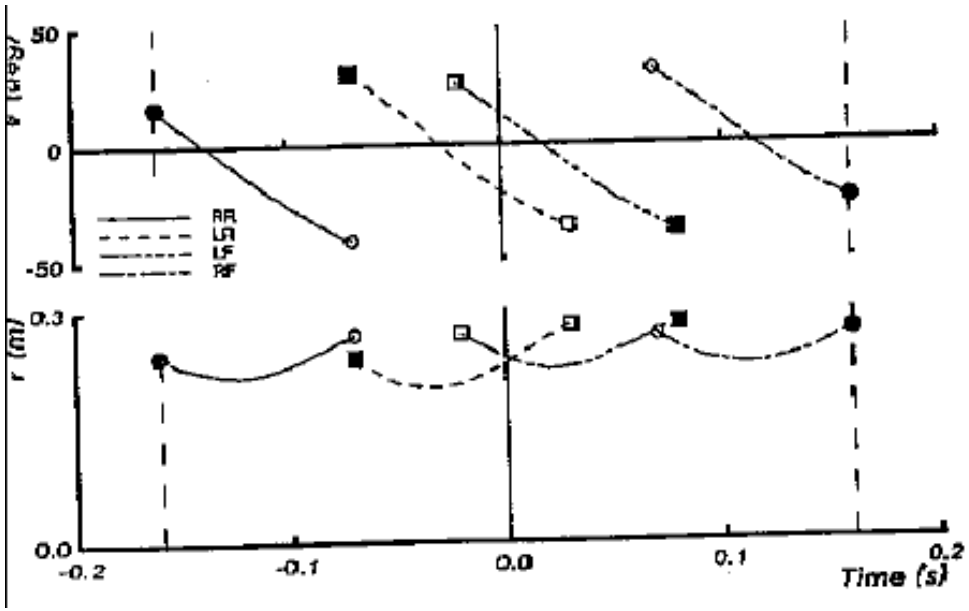
Individual steps need not be symmetric
But pairs of steps should be anti-symmetric

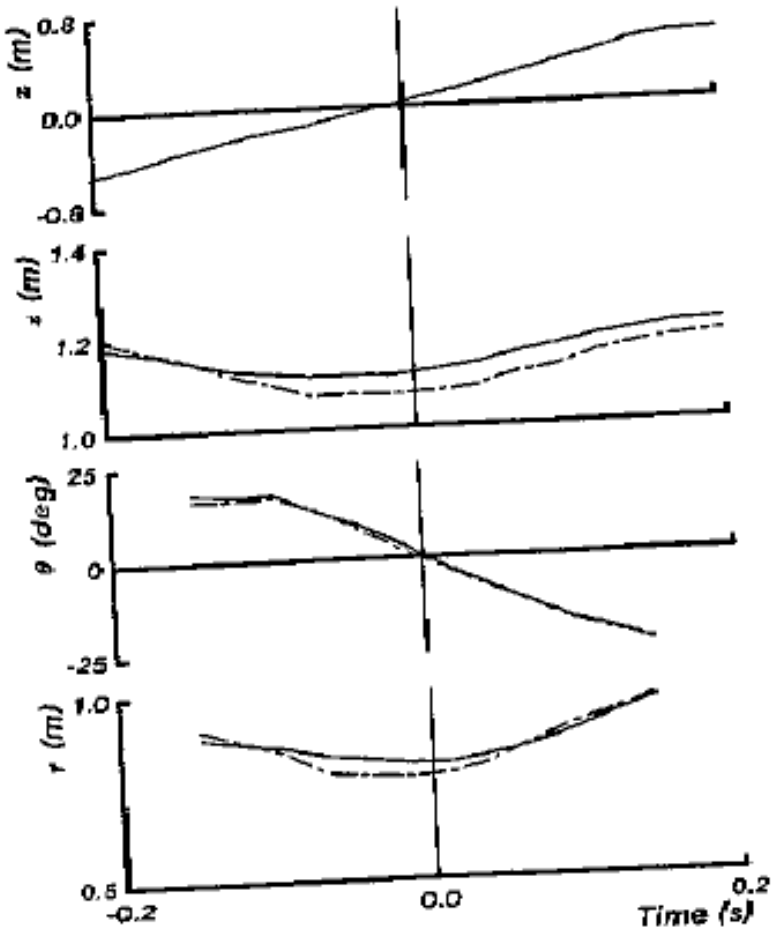
Symmetry with multiple legs

$$\theta_j(t) = -\theta_k(-t),$$
$$r_j(t) = r_k(-t),$$
$$\tau_j(t) = -\tau_k(-t),$$
$$f_j(t) = f_k(-t).$$



Animals do this (sometimes)





How to generate symmetry?

- Very difficult
  - Need to predict where the center of mass will be when the vertical velocity and pitch angle are zero.
  - Raiberts method:
    - Assume forward speed is constant during support and period of support is constant.
    - Also tabular solutions

Asymmetry in Running

- Velocity is not constant
- Legs are not lossless
- Must add energy into the system
- Mechanical system is asymmetric

So what's the point?

- Simplicity
- Easy to analyze
- But other than that??