The Effect of Staircase Slope and Step Height On Energy Consumption

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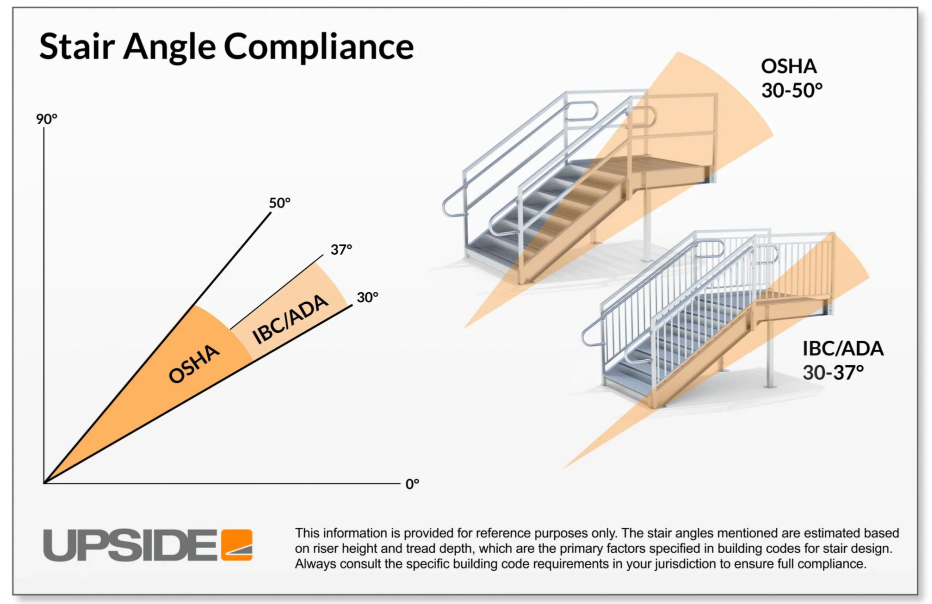
Introduction

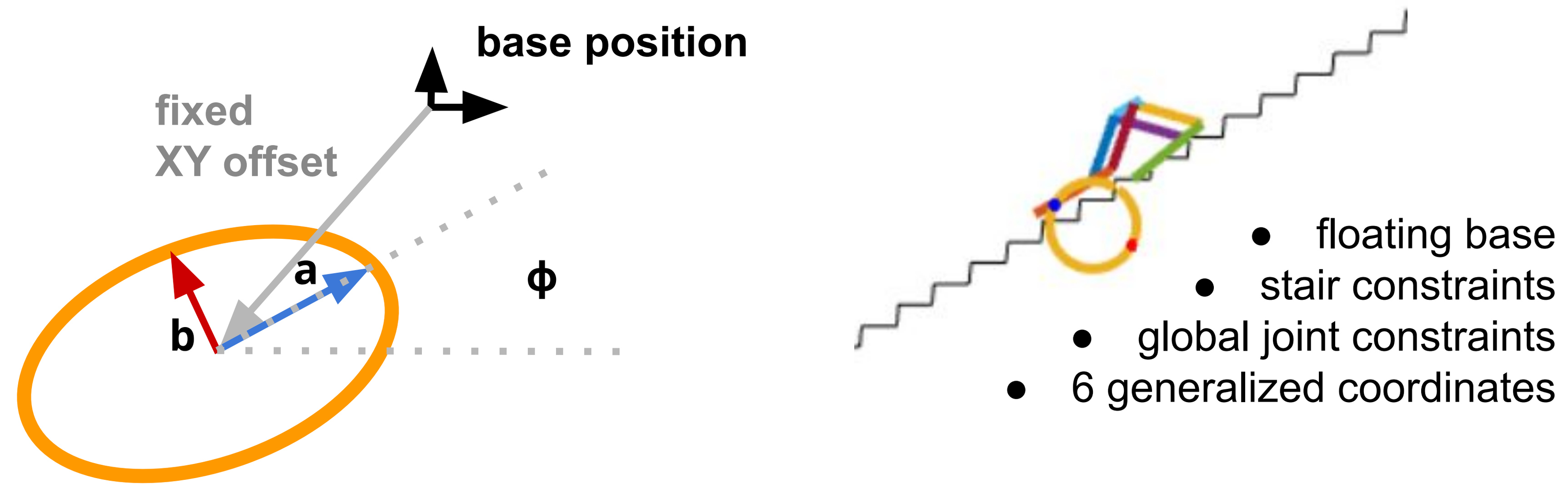
Stairs are ubiquitous in our daily environments. Thoughtfully designed stairs can transport heavy foot traffic up and down efficiently, while poorly designed stairs can lead to pedestrian fatigue. What staircase slope is easiest to climb? Similarly, people usually take the stairs one step at a time, but could taking longer strides (ie, skipping steps) prove to be a more efficient approach?



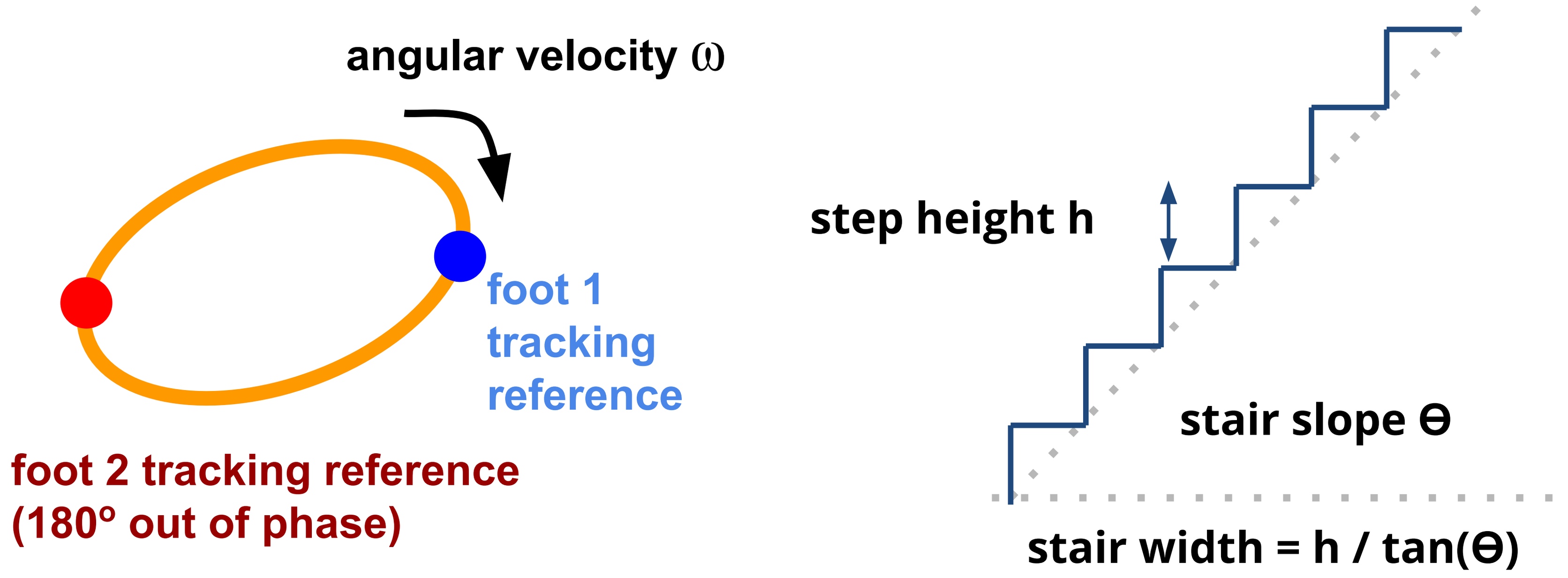
The OSHA recommends stairs to be between 30 and 50 degrees [1]. We hypothesize that there is an angle in this range that minimizes the amount of energy needed to climb a given height. We also hypothesize that there is a step height that maximizes energy efficiency.

Simulation Methods

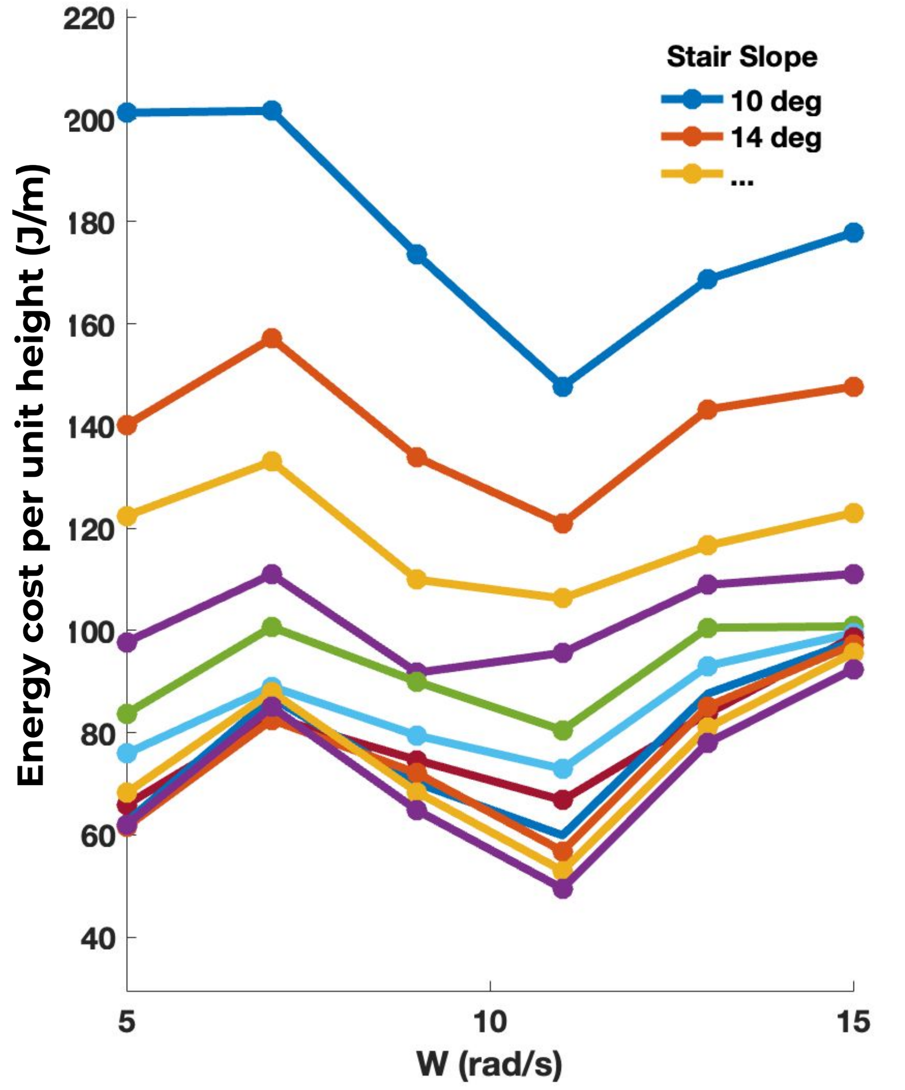
Simulation Setup

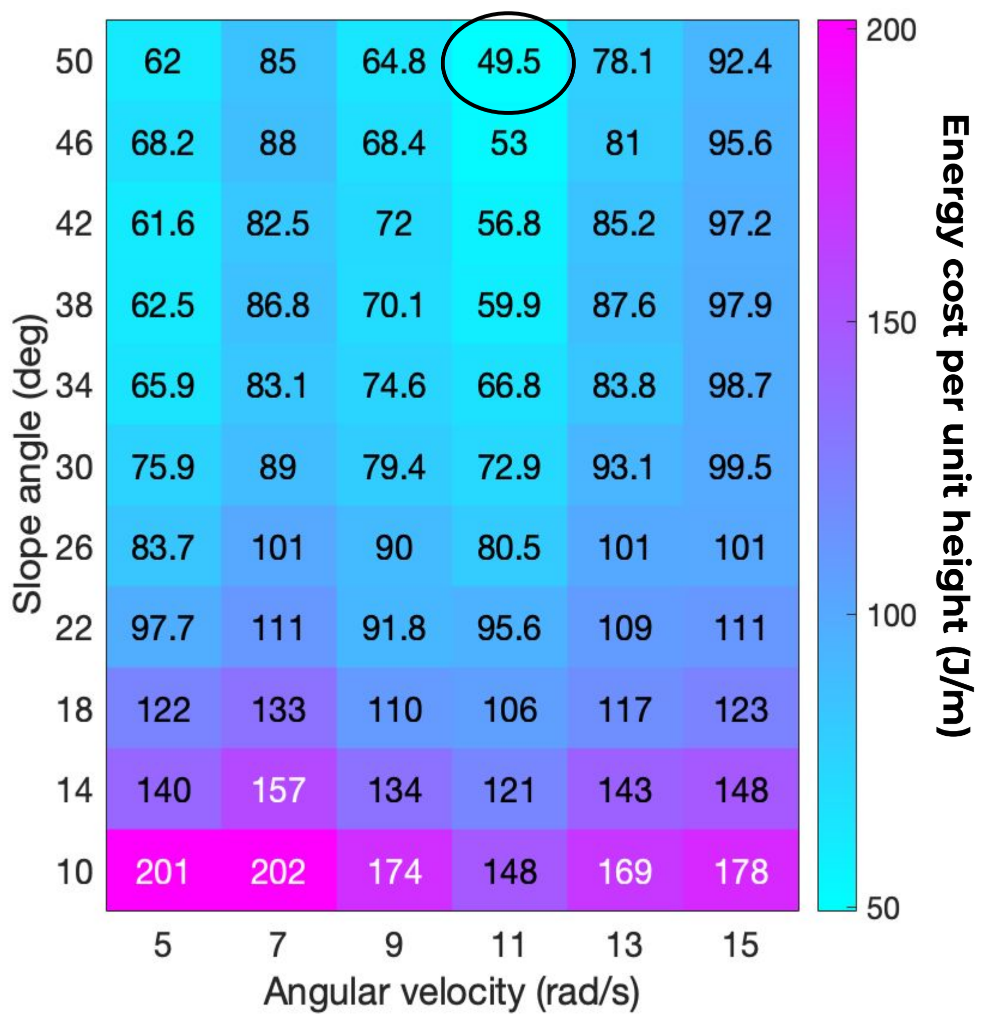


Test Parameters



Simulation Results

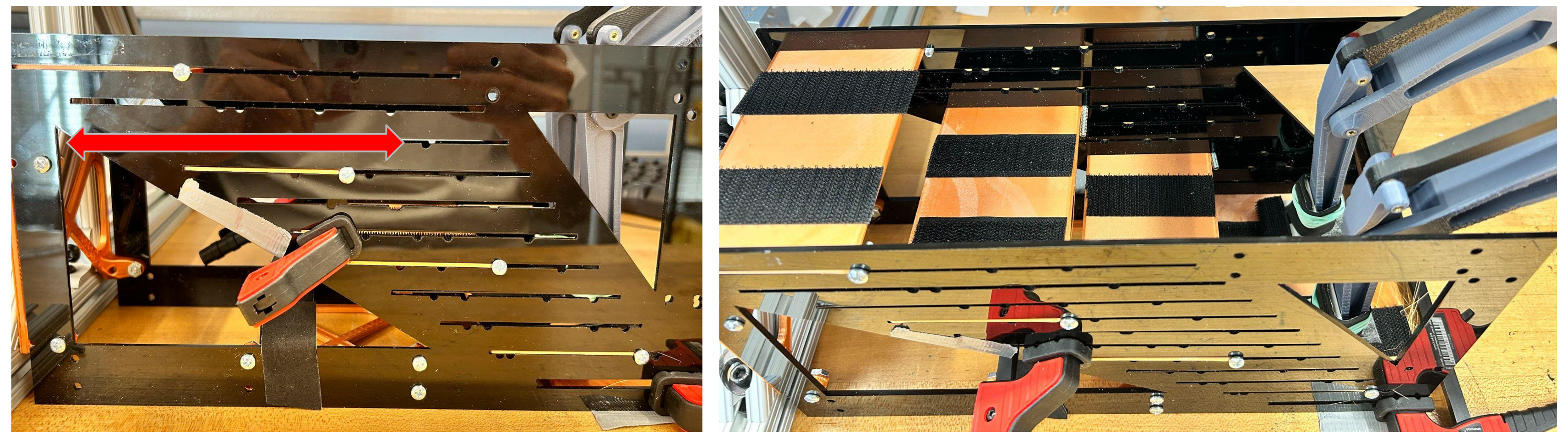




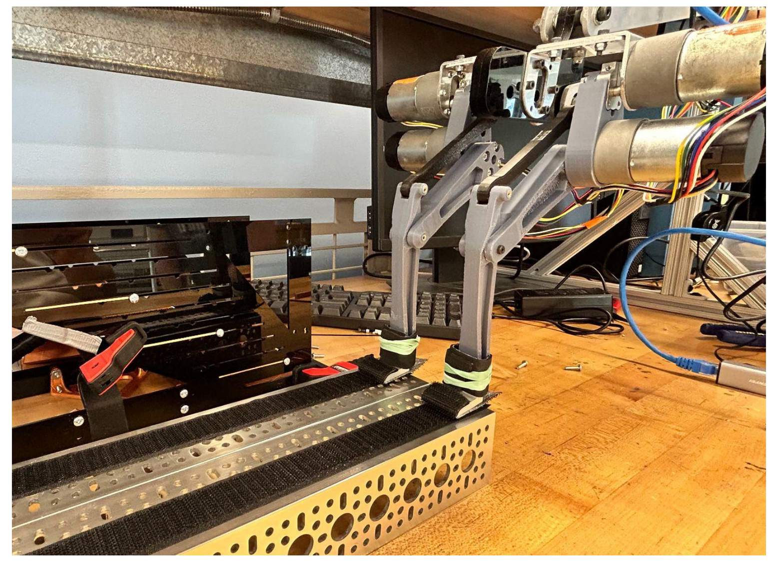
Slope angle (deg) \ Angular velocity (rad/s)	5	7	9	11	13	15
50	62	85	64.8	49.5	78.1	92.4
46	68.2	88	68.4	53	81	95.6
42	61.6	82.5	72	56.8	85.2	97.2
38	62.5	86.8	70.1	59.9	87.6	97.9
34	65.9	83.1	74.6	66.8	83.8	98.7
30	75.9	89	79.4	72.9	93.1	99.5
26	83.7	101	90	80.5	101	101
22	97.7	111	91.8	95.6	109	111
18	122	133	110	106	117	123
14	140	157	134	121	143	148
10	201	202	174	148	169	178

Average energy cost per unit height (J/m) = $\int_0^t P(t)\,dt$ / final height.
Where $P(t) = i(t)^2 / R_{motor}$ and $i(t) = \tau(t) / K_t$.

Experimental Methods



Stairs with adjustable angles and step heights.

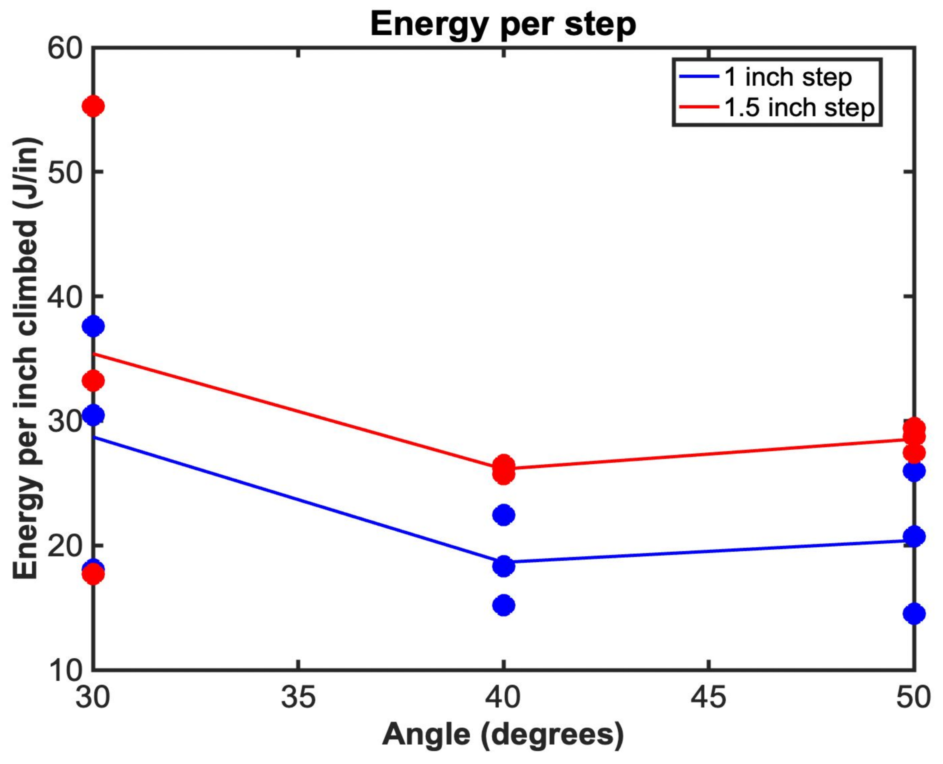


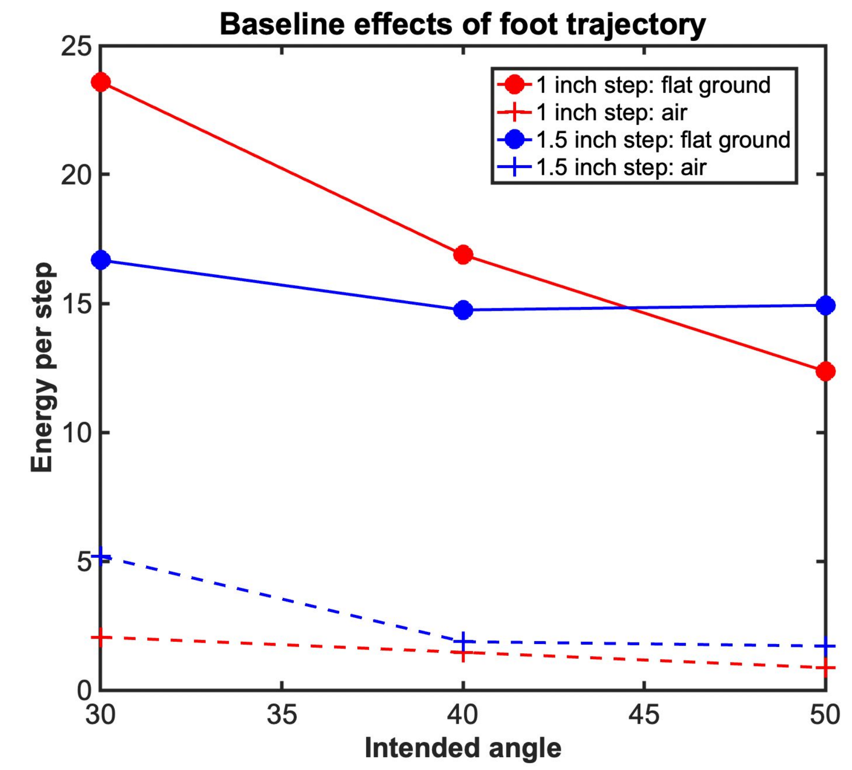
On-ground locomotion test setup.

Test Parameters

Stair slopes: 30°, 40°, 50°
Step heights: 1 inch/step, 1.5 inch/step
Locomotion: Walking on the stairs, on the ground, in the air
Measured power usage three times per run.

Experimental Results





Discussion

Experiments indicate that in the range we tested, higher step height requires more energy per inch climbed. It also appears that a 40 degree incline is optimal.

In future work, we would increase the length of the setup to achieve better steady state. We would also change the step cycle frequency in addition to the trajectory of the different step heights.

For simulation, the heuristic nature of ellipse tracking led to a significant variability in the results, future work should try optimizing trajectory for each set of conditions.

Conclusion

This study reveals that there are tradeoffs between exerting lots of work at once vs in many smaller bursts. Taking bigger steps may be faster but is generally less efficient. Similar principles apply to walking, running, and other modes of locomotion.

References

[1] https://upsideinnovations.com/blog/optimal-stair-angle/