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Impact Force Patterns on a Landing Cat

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Abstract

The impact force patterns of a cat landing from various heights were investigated. The cat was dropped onto a force plate from heights ranging between 0.20 and 1.00 m. It was found that the relationship between the cat's maximum force of impact and its drop height was much lower than would be expected for an inanimate object of similar mass and consistency. The cat clearly manipulated the way in which it landed in order to reduce its impact force. It was also shown that the cat landed one foot at a time, with a consistent force and timing pattern.

Introduction

Mimicking the well-adapted structures and materials we come across in nature is one way in which humans are capable of solving complex problems. The term biomimetics is used to describe this approach and has given rise to technological advancements over the past several decades.

At the Massachusetts Institute of Technology, a cheetah robot has been in the works for the past decade. By observing a cheetah's build, scientists imitated its arrangements of bones and tendons by separating elements for compressive loads to form a lightweight structure, capable of supporting larger loads.[1] The MIT scientists have also begun investigating the purpose of a tail and how it helps improve maneuverability. They plan on imitating a tail-like structure to see if there are improvements in balance for their cheetah robot.[2]

Biomimetics allows scientists to observe how biological species function and use the principles to design new technologies. In order to properly perform biomimicry, the characteristics of the biological species must first be understood. In this paper, the characteristics of the landing movements of a cat will be investigated, specifically observing the impact forces on a cat as it lands from various heights. Because cats are known to be capable of landing from great heights with minimum injury, this investigation may come of interest to future robot developers. By mimicking the methods that cats use to land safely, scientists will be able to produce robots with even more capabilities.

In equation 1 it is shown that the force on an object during a collision is related to its mass and its rate of change in velocity.

$$F = m\Delta {}^{v}\!/_{t} \tag{1}$$

Applied to a landing cat, the longer the time it takes for the cat to land, the smaller the force would be. In this investigation, the mass of the cat, m, remains constant, while the impact velocity, v, increases as the drop height increases. With an increased velocity the force, F, needed to stop the moving object during a collision would also be expected to increase. The relationship between the impact force and the drop height of a landing cat will be investigated, as well as the possible methods the cat uses to reduce its impact force when landing. By studying the way in which cats or other animals land, improvements to current technologies and new innovations may arise, whether it be jumping robotic Cheetahs, or even running motorbikes.

Methods

The cat used in this investigation had a shoulder height of approximately 0.32m, a body length of approximately 0.40m, and a mass of 5.37±0.01kg. The experiment was set up with a Vernier Force Plate placed on a solid surface. A piece of plywood board, approximately 0.90m in width, 0.46m in length and 0.01m in thickness, was placed over the force plate throughout the entire experiment to widen the surface area for the cat to land on. The cat was lifted by holding it across its midsection and dropped from 5 different heights, ranging between 0.20±0.05m and 1.00±0.05m, repeated for 3 trials at each height. When holding the cat prior to its drop, the left hand was placed between its front leg joints and chest, while the right hand was placed between the cat's stomach and its hip joints. Both hands were held at the same height so that the bottoms of the cat's paws were held at the drop height, equidistant from the force plate. The cat was then released by both hands simultaneously in a smooth motion, allowing the cat to fall directly onto the force plate. The forces of the cat's landing process were recorded. The maximum force produced by the landing cat was the primary piece of data being analyzed in this experiment. The experiment was then repeated using a 3.32kg medicine ball, the largest mass available. This medicine ball, chosen because it has a consistency similar to a cat's body, was tested in order to compare the maximum landing force of a cat with the maximum landing force of a similar but inanimate object.

Results and Discussion

Figure one clearly shows that a cat does in fact influence the maximum impact force when landing. It is apparent that the cat must have manipulated the way it lands in order to reduce its force of impact. The medicine ball's maximum force when dropped from 1.00m is up to 5 times greater than the cat's maximum force at that height, even though the ball was less massive. The graph also portrays very different relationships between the drop height and the maximum force of impact for the cat and the ball. The maximum impact force on the ball increases linearly with height, while the cat shows a positive curve.

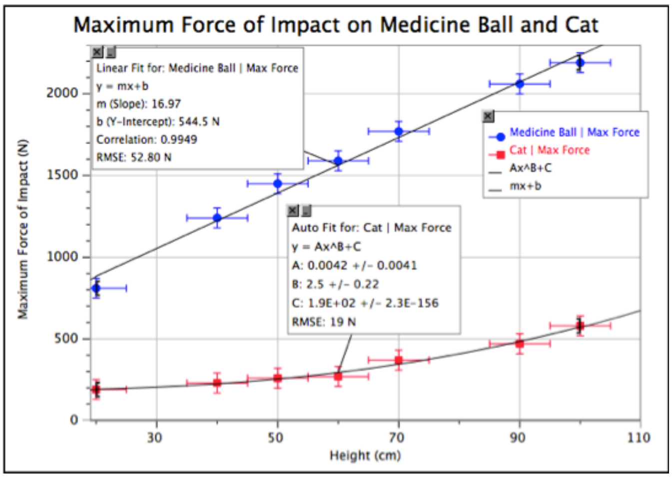

Figure 1 shows the maximum force when both the medicine ball and the cat where dropped from various heights.

Figure 2 represents a closer view of the results. The cat's maximum force of impact while landing forms a positive power relationship at various heights. From the lower heights, between 20cm to 60cm, there is little increase in the maximum force. Thus for the lower height it seems that the cat was able to compensate for the increased impulse needed for it to stop fully by proportionally increasing the time taken for it to stop. As the height increases above 60cm, the cat seems unable to compensate to such an

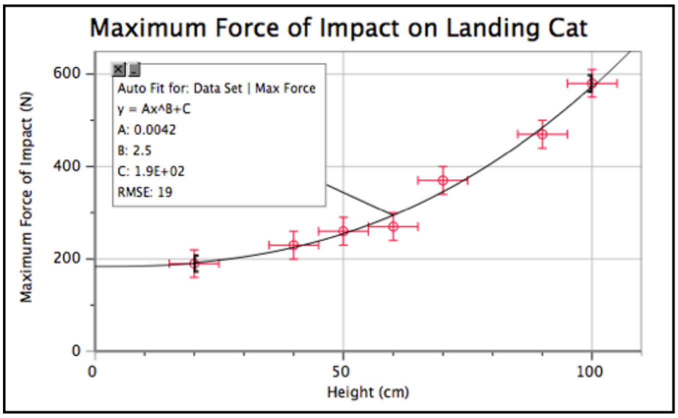

Figure 2 shows in closer detail the maximum of the cat when dropped from various heights.

extent as it had at the lower heights, as the maximum force increases significantly at heights from 70cm to 100cm. However, it should be noted that the maximum force of impact of the cat, even at the greatest heights measured, still increases at a lower rate than the medicine ball.

The relationship between the maximum impact force on the landing cat as a function of height is shown in equation 2. The maximum force was correlated to the height to the power of 2.5 with a y intercept, C, of 190N. Maximum force measurements below drop heights of 20cm were not recorded, thus the application of equation 2 below a drop height of 20cm is unlikely to be reliable.

$$F_{\max} = 0.0042^{2.5} + C \qquad (2)$$

In order to better understand the relationship between the maximum force and the height demonstrated in figures 1 and 2, it would be helpful to investigate the nature of the force over time of impact in detail for both the medicine ball and the cat. By studying this relationship, insight into the technique by which the cat reduces its maximum force it experience may be gained.

As shown in figure 3, the inanimate medicine ball experienced a single smooth force curve as it landed on the force plate. The maximum force of impact of the ball was 2245N and the landing time took a total of 0.019 seconds in this particular trial.

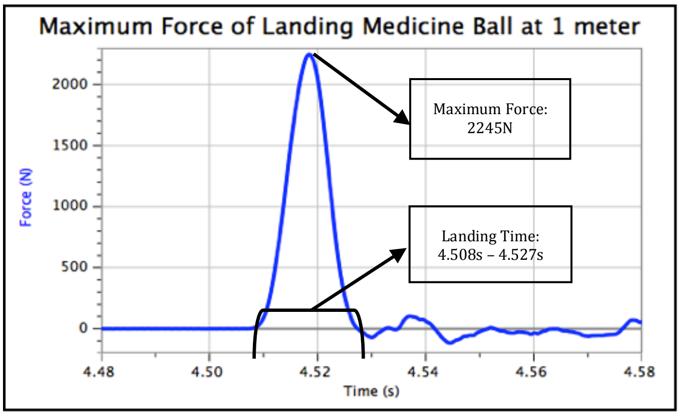

Figure 3 shows the graph between the force and the time when the medicine ball was dropped from 1 meter.

In figure 4, the force versus time graph of when the cat was dropped shows a very different pattern in comparison to the ball in figure 3. There appears to be 4 primary spikes in the cat's landing process. The overall maximum force of impact of the cat is much lower than the ball, only reaching 573N, and has a much longer landing time of 0.192 seconds in this particular trial.

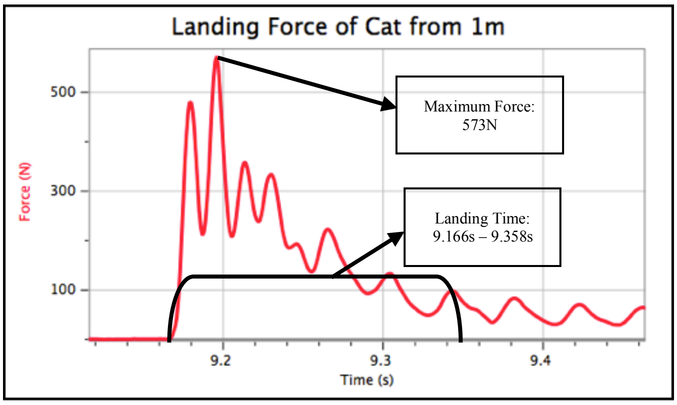

Figure 4 shows the graph between the force and the time where the cat was dropped from 1 meter.

When looking closer at the graph shown in figure 4, it can be seen that there is an apparent pattern with the time of impact between each of the four distinct spikes. Table 1 shows that the times between spikes are all very similar. ranging from 0.017s to 0.020s. It is also apparent that the second spike is the spike with the highest maximum force and the third and fourth spikes have the lowest maximum forces.

	Spike 1	Spike 2	Spike 3	Spike 4
Maximum Force (N)	480.0	572.9	357.7	334.3
Minimum Force (N)	211.1	209.3	238.1	187.4
Time of Impact (s)	9.167	9.187	9.205	9.222
Time Between Impacts (s)		0.020	0.018	0.017

Table 1 shows the significant numerical elements of the graph shown in figure 4.

The minimum force between each of the spikes didn't vary to a great extent and stayed within about 50N of each other. Although the data presented in table 1 is from the specific trial shown in figure 4, similar landing patterns were observed for the majority of typical cases in this investigation. The patterns that appeared in this trial, including the time between each impact, the landing time, and the order of the spikes containing the highest and lowest forces, are similar to the other landing impact patterns recorded.

It appears as though the cat intentionally extends the time that it takes to land as a technique to reduce the force of impact. From figure 4, it seems that the cat lands on one foot at a time. It looks like the cat lands with the first foot pushing hard, then eases off before the second foot begins to land and so on. As there are clearly 4 distinct spikes on the graph, and this was a typical pattern, it seems as though landing with each foot separately and easing off on that foot before the next one lands is a clear strategy to extend its landing time and reduce the overall force on the cat's body. While in figure 3, the end of the landing impact was rather easy to interpret; there is some difficulty when it comes to the cat's landing in figure 4. There appears to be an oscillation at the end of the cat's impact, possibly caused by the cat itself, although further work is needed to confirm this.

Further investigation is needed to ascertain the behaviors that are causing the observed landing patterns. High-speed camera technology, used along with a force plate, would be beneficial in the observing the motions and movements of the cat while it lands. A four-section force plate, with one of the cat's feet landing on each of the four sections, would also be helpful to determine the exact pattern with which the cat lands. It is also presumed that the results may vary with the age, size, and breed of the cat, thus using cats of different characteristics would also increase our understanding of how cats land. It is hoped that a detailed understanding of the way cats land may be used to inform the design of future robots.

Conclusion

It was found that the pattern of the force of impact of a landing cat is very different from those of an inanimate object. The cat appeared to purposefully manipulate the way in which it landed in order to reduce the impact force. When looking closely at the force to time graphs of when the cat landed at specific heights, 4 distinct spikes force appeared on all the typical graphs. This seemed to extend the cat's landing time, thus reducing the its maximum force of impact. However the consistently reoccurring pattern indicates that the cat used a particular strategy to reduce its impact force while landing.

References

[1] Ananthanarayanan, A., M. Azadi, and S. Kim, "Towards a bio-inspired leg design for high-speed running", *Bioinspiration & Biomimetics*, 7(4).

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