

# Hummingbird-Inspired High-Speed Deceleration and Flea-Inspired Vertical Take-Off

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## Abstract

A design for a bio-inspired robot and simulation are discussed. A flea-inspired jumping mechanism is studied in addition to a hummingbird-inspired wing system for accurate navigation and deceleration. The primary goal of the robot is to deliver a fragile payload, an egg, to the a desired height and location. This paper reviews similar projects and discusses a novel hybrid system. The sytem is split into vertical take-off and controlled gliding.

*Keywords:* Flight, Bio-inspired, Hummingbirds, Fleas

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## 1. Introduction

Of all the various types of robotic locomotion, a dichotomy can be drawn such that there are two main categories, robots that require pre-established infrastructure and robots that do not. A rumba requires flat surfaces to traverse, where as DARPA's dog can navigate the uneven surface of a grassy hill. Robots that do not require specific environmental geometry can be deployed in countries that have limited infrastructure to deliver important supplies, conduct search and rescue, and study hazardous environments. In the case of disaster relief, supply delivery via all-terrain, long-distance autonomous vehicles can be critical to developing nations.

This paper outlines a proposal for a high-velocity aerial robot drawing inspiration from hummingbirds and fleas. The robot will use near-vertical take-off, requiring no runway. The bio-inspiration comes from the manner in which humming-birds rapidly decelerate. When humming-birds are in mating season, the males attract females executing a looping *display dive* reaching speeds of up to approximately 27 meters per second, Bennet-Clark and Lucey (1967). The design will incorporate an initial acceleration mechanism to propel the robot to a high altitude. Once the apex of the trajectory is reached, hummingbird-inspired wings and tail feathers will be deployed to mimic the deceleration.

The near-vertical take-off mechanism is inspired from the jumping mechanism of a flea. Fleas are capable of jumping with an acceleration of 102 g-forces, (Bennet-Clark and Lucey, 1967,

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p. 62). This is a tremendous acceleration that is not easily reverse engineered. This proposal will explore a design for a jumping mechanism based on scaling the acceleration capable of fleas, but with a larger mass. A comparison of energy density relative to size of a payload will be made.

The basic design of the robot will be broken up in to two main sections: **1)** the initial acceleration mechanism and **2)** the deceleration mechanism. A simulation will first be made, and as a stretch-goal, a prototype will be assembled.

## 2. Formulation of the problem

The primary goal is to deliver a payload, such as an egg to some height unharmed using a robot that is bio-inspired. The problem is broken up into two parts. The first part is to find a way to rapidly ascend upward. The second part is to implement a *reasonable* deceleration. These two subproblems use two different mechanisms, one inspired by the flea for take-off and one inspired by the hummingbird for landing.

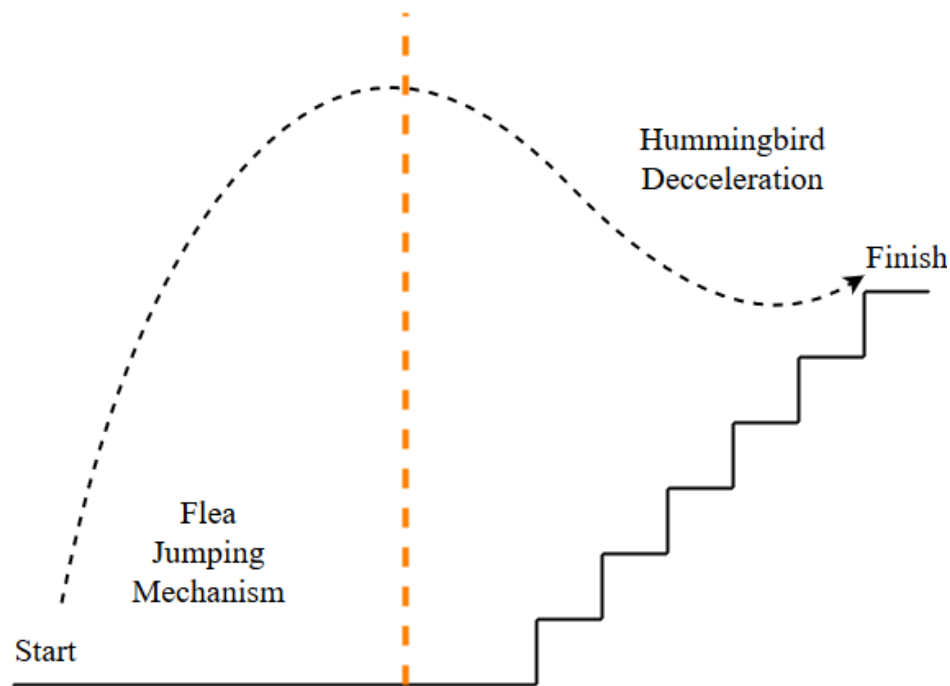


Figure 1: This is a visual representation of the goal of delivering an egg to the top of a staircase. The orange line separates the two different mechanisms into their respective roles for the trajectory of the payload.

### 2.1. Acceleration Mechanism

As shown in **Figure 1**, the jumping mechanism will be used to achieve substantial height for the payload delivery. In order to draw inspiration from how a flea uses its energy to jump so high,

energy usage will be explored in relation to payload mass as well as maximum height. A flea can jump many times its own height, but it is small in mass, approximately 45mg (Bennet-Clark and Lucey, 1967, p. 63). Fleas have a ratio of mass to jump height and energy density. For a larger robot, a similar ratio could be achieved if energy density is proportionally higher to account for the larger mass. The larger mass is in part introduced by the need to carry an egg, which a flea does not have.

It should be noted here that there is no path planning associated with the jumping mechanism. There may be an initial jump angle relative to the ground, but guiding the egg to the desired location is dealt with in the second part of the robot design. The proposed design for the jumping mechanism is shown in **section 4**.

## *2.2. Deceleration Mechanism*

This second part of the problem is associated with the bio-inspiration of a hummingbird. Hummingbirds are able to rapidly decelerate from specifically a diving trajectory. Assuming a substantial height is reached, this deceleration mechanism will be deployed to guide the egg to its desired location safely. Wings will be used to realize this behavior. The design for this is shown in **section 4**.

## **3. Method of solution**

The flea-inspired leg is the primary focus of the vertical take-off mechanism. It is treated as a two-link planar robot leg. The forward and inverse kinematics are discussed here, followed by the free-body diagram.

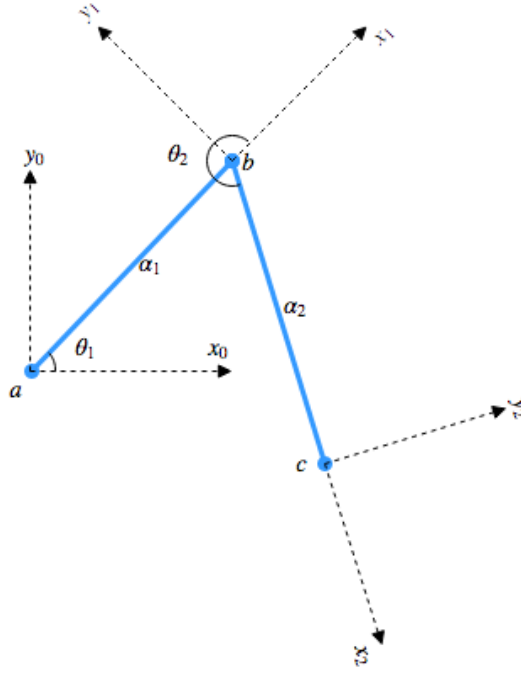


Figure 2: Model for a planar, two-link, robot leg.

### Forward Kinematics:

$$x = x_2 = \alpha_1 \cos \theta_1 + \alpha \cos(\theta_1 + \theta_2) \quad (1)$$

$$y = y_2 = \alpha_1 \sin \theta_1 + \alpha \sin(\theta_1 + \theta_2) \quad (2)$$

The resulting **orientation matrix** is as follows:

$$\begin{bmatrix} x_2 x_0 & y_2 x_0 \\ x_2 y_0 & y_2 y_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta_1 + \theta_2) & -\sin(\theta_1 + \theta_2) \\ \sin(\theta_1 + \theta_2) & \cos(\theta_1 + \theta_2) \end{bmatrix} \quad (3)$$

### Inverse Kinematics:

$$\theta_1 = \tan^{-1} \left( \frac{y_{des}}{x_{des}} \right) - \tan^{-1} \left( \frac{\alpha_1 \sin \theta_2}{\alpha_1 + \alpha_2 \cos \theta_2} \right) \quad (4)$$

$$\theta_2 = \cos^{-1} \left( \frac{x_{des}^2 + y_{des}^2 - \alpha_1^2 - \alpha_2^2}{2\alpha_1 \alpha_2} \right) \quad (5)$$

The inverse kinematics represents the angles,  $\theta_1, \theta_2$  of the two-link leg to be functions of a desired position,  $(x_{des}, y_{des})$ . When controlling the acceleration of the robot's mass upwards, the inverse kinematics will be used to command a position of the end of the robot leg at various time steps. A desired acceleration can be incorporated into a feedback loop, which is discussed further.

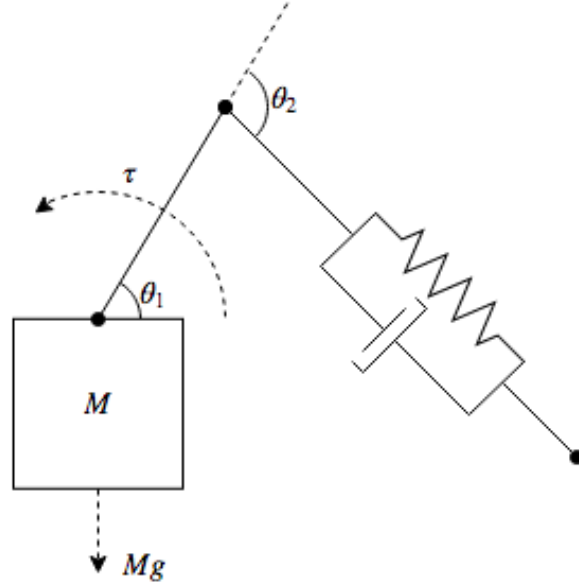


Figure 3: Free-body diagram of the FleaSlug robot

The simulation will look at a number of physical aspects of the robot, but will focus on two main things. The first is energy usage and finding a similar method to store comparable energy density in a small robot. The discharge rate of the energy used to propel the robot upward will be simulated. The second is the flight of the robot. The wing design, air resistance, and lift will be simulated.

Once the simulation is completed, a stretch goal for this project will be fabricate and construct the robot based on the simulation. A simple 8-bit microcontroller will be used to control the robot, its wings, the jumping mechanism, and possible safety features.

#### 4. Implementation

Both the jumping mechanism and wings for deceleration will be outlined here. This section shows possible designs for the robots mechanisms.

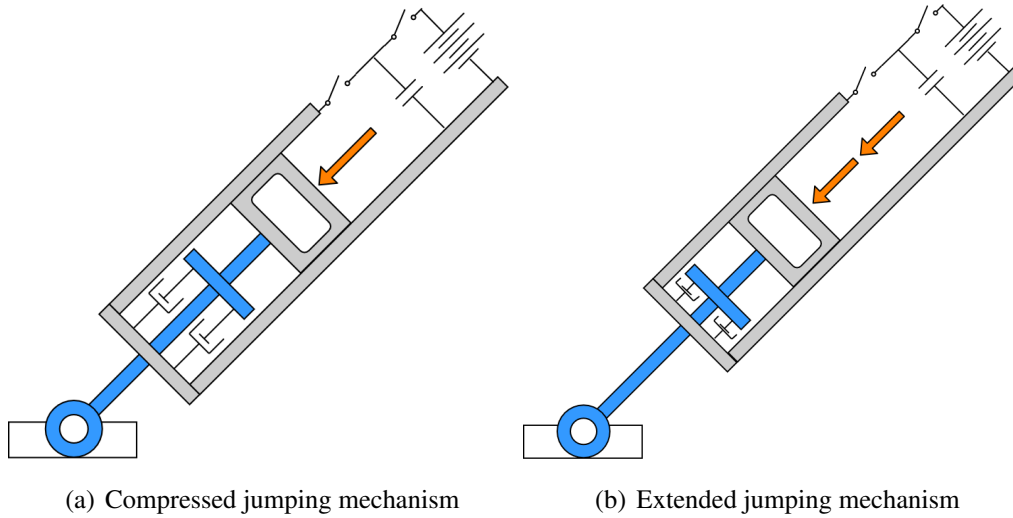


Figure 4: Example of a chart

The mechanical implementation for the flea-inspired jumping mechanism is shown in **Figure 4**. To achieve the necessary energy density, a small battery and a large capacitor will be used. The capacitor allows for large quantities of charge to be discharged rapidly. The current will flow through the armature, pushing the piston-like leg (blue) out. The micro-controller mentioned in **section 3** will control the flow of current and capacitor charging and discharging.

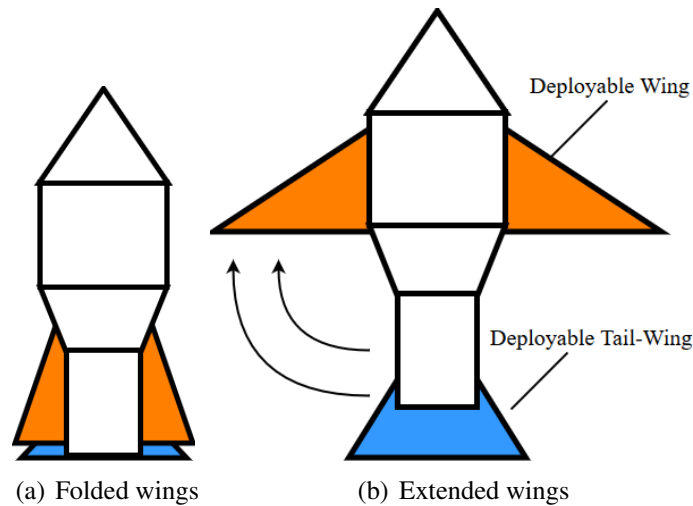


Figure 5: Example of a chart

**Figure 4** shows the deployable wings. The wings must be folded at first to maximize the height. When the wings are folded air resistance is less and the jumping mechanism can propel the

robot higher. The on-board micro-controller will control the timing of the wings and when they are deployed.

## **5. Numerical results and discussions**

When numerical results are prepared, they will be shown here. The acceleration over time, the velocity over time, the position over time, and other information will be graphed and compared to the simulation if the physical robot is constructed.

## **References**

Bennet-Clark, H.C., Lucey, E.C.A.. THE JUMP OF THE FLEA: A STUDY OF THE ENERGETICS AND A MODEL OF THE MECHANISM. *Journal of Experimental Biology* 1967;:18.