Analysis of the Aerodynamic Properties of the Javan Cucumber Plane Form in the Design of Seed Airfoil for the use of Ecological Restoration

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Abstract

This project looks to design a seed vehicle inspired by the Javan cucumber for seed dispersals for ecological restorations. A CFD analysis is used to determine the base coefficient of lift and drags under different flow conditions, angle of attacks. Such results from the initial analysis of the Javan Cucumber airfoil will be used to redesign the plane form, looking at the same aerodynamic properties to develop a more aerodynamics design. The redesign portion looks to optimize the lift-to-drag ratio and lift slopes as well as the maximum lift force and minimum drag force through changing the aspect ratios.

Nomenclature

$\alpha\ (AoA)$	**Angle of Attack**
AR	**Aspect Ratio**
a	**Lift slope**
C_L	**Coefficient of Lift**
C_D	**Coefficient of Drag**
COG	**Center of gravity**
Λ	**Geometrical swept angle**
b	**Wingspan**
S	**Wing area**
LE	**Leading edge**
TE	**Trailing edge**

Introduction

The cause of degradation of ecosystems stems from various modes, mainly due to human activities. Restoration efforts for such ecosystems include the need to mimic the region's biodiversity before its destruction. Such tasks can be challenging in remote areas.
Efforts to repopulate degraded ecosystems take on methods such as the deployment of drones to disperse seeds. While such methods may be less successful than manually planting such plants, costs and labor associated with such methods may be reduced through these methods. However, the deployment of drones. The use of biometry in the seed dispersal process has been explored as options to also increase germination rates. This paper looks to explore the ways seed disperse in a more efficient way by reducing the flight path time of these said drones by increasing the aerodynamic flight times of the seed vehicles.

Plants can reproduce and spread through various methods. For this analysis, only the dispersal of the seeds by air travel will be explored. Within this method, seed dispersal is characterized by how they travel through air, often through the geometric design of the seed external shell. These designs are characterized as a pappus and winged seeds in which further breaks down by the general motion of the seed travel.

The seed that will be analyzed under the mathematical model is the Alsomitra Macrocarpa, Javan Cucumber. By nature, the Javan Cucumber seed highlights the lowest rate of descent with a high wing loading, capable of gliding at a descent rate of 0.3–0.7 m s^{-1}. The Javan Cucumber seed is classified as a winged seed, specifically a gliding flight path seed. Gliding seeds has a spiral path of gliding rather than a straight path or a curved path with a large turning radius.
Several factors must be considered when doing an analysis of the aerodynamics of the seeds. In a parachute seed dispersal, under low wind speed conditions, such seed travels mainly vertically. The physical qualities that must be considered include the aspect ratio (wingspan and area), thickness and mean chord. Aerodynamic factors that must be taken into account are the aerodynamic forces under different flow conditions and AoA and aerodynamic ratios (Aspect ratio and gliding ratios).

Problem statement

Due to the advent of monoculture, deforestation and habitat destruction caused by human activities, the biodiversity of many environments has severely been impacted. The challenge of this project is designing an aerodynamic vehicle for seeds to be dispersed in more remote areas to improve efficiency in its deployment through reducing the flight paths.

Method

To an early protype, a CFD analysis will be used to help analyze existing seeds design. Such analysis will include looking at flight time, drag and lift coefficients at various Reynold's number (of the flows typically experienced typically in the seed's native habitats).
In developing a prototype for the purpose of seed dispersal, results from the theoretical analysis will be used to determine important factors that must be kept like the seed analyzed. Changes to the design will include considering the feasibility of producing a prototype. Such considerations as various design of the airfoil of the design will be considered including various thickness, locations of COG, inclusions of parameters such as flaps. The mathematical model will then be applied to this newly designed seed vehicle to compare it to the existing seed.
It must also be considered that the complexity of such airfoil design must be easily manufactured in large quantities, therefore simplification of such designs found from the seed analysis will be used. It is less demanding to manufacture and ensure shape consistency if gliders are designed from flat sections. The possibility of using simpler shapes of equivalent maximum thickness, such as a flat-like symmetric airfoil was an possible consideration but due to inconsistency in stability in design, such avenue was not pursued further.

CFD Setup

The mode of analysis of the Javan Cucumber plane form using CFD analysis of coefficient of lift and drag under different angles of attack. The parameters set for the analysis are based off previous studies done [1] as well as the geometric configuration set by [2] was taken for the modeling. Values such as chord length, aspect ratio, COG and thickness were based on the data average collected from the literature.
The CFD setup used in this analysis utilized the K-omega SST model with an enclosure dimension of 54 mm for the upstream and width, 71.5 mm for the height and 500.5 mm for the downstream. Such values are based on the aspect ratio of the airfoil (143 mm). The mesh setup uses an unstructured tetrahedral mesh, with a growth rate of 1.3, and a element inflation layers with proximity. The number of elements used is 451,601. The y+ value was set to be about one to capture the boundary layers of the airfoil.
The density and viscosity of the air is held at a constant with a density of 1.225 kg/m^3 and a viscosity of 1.7894E-5 kg/(m*s) for the Re of 50,000 and a density of 0.7459 kg/m^3 and dynamic viscosity of 2.577E-5 kg/(m*s). A constant 5 m/s velocity is used for all testing.
The same setup will be utilized for the redesigning portion of the project.

Results

<u>Unmodified Seed airfoil</u>

The measurements obtained for the unmodified seed airfoil measurements are obtained from Azuma, A.. et al. [2]. The mean values are the ones used in this project and can be seen below:

Parameters	b (mm)	S (mm^2)	AR	COG (from LE, mm)	Λ (degree)
	143	5,970	3.5	160	13.7

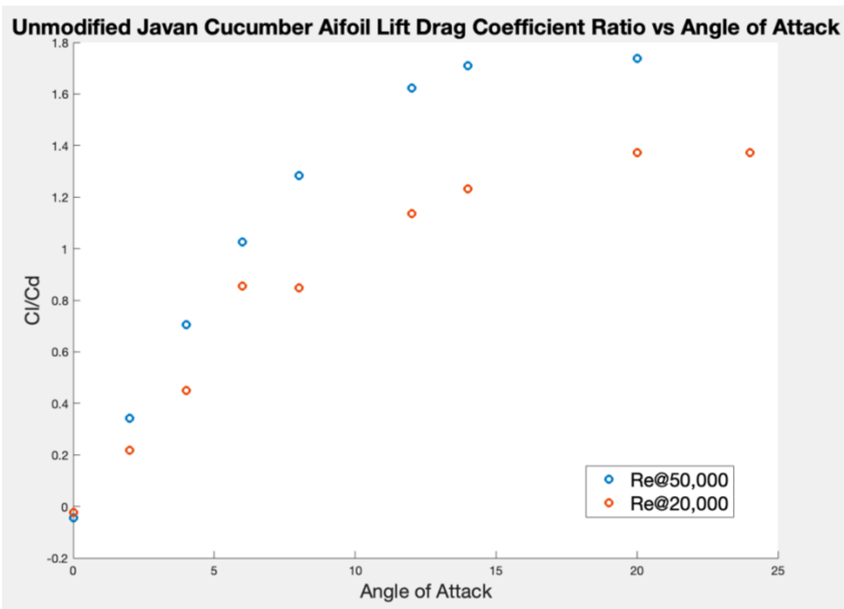

Figure 1: Lift-to-drag coefficient ratio vs AoA graph of the unmodified wing form of Javan Cucumber of two Re numbers

Redesign parameters:

In considering the redesign of the airfoil, some key factors to improve upon from the unmodified form is an increase lift slope as well as a higher maximum coefficient of lift. The airfoil's performance should be consistently better for different Re numbers to consider one more adaptable to more environments.

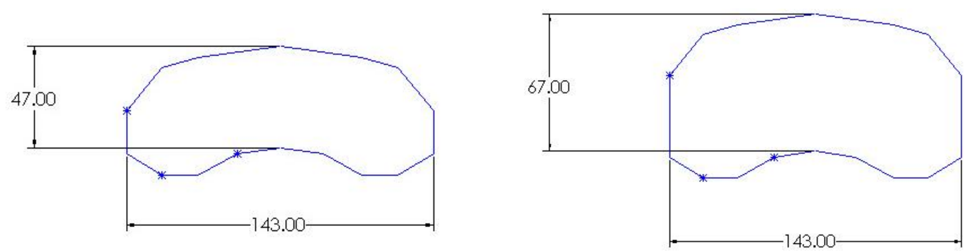

Figure 2: Design of wing planform of the unmodified Javan Cucumber wing (left) and reduced AR Javan Cucumber wing (right)

Design 1 results

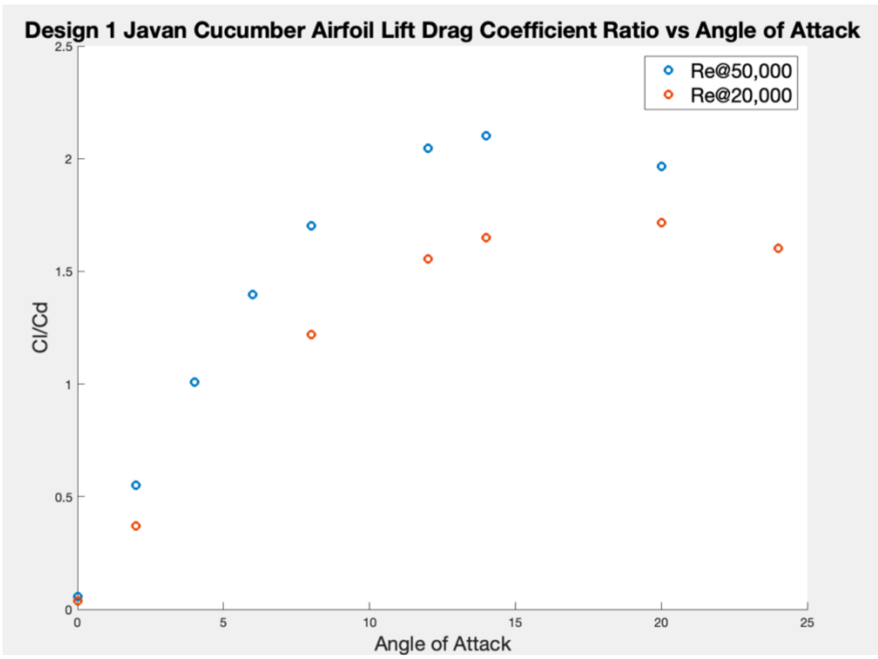

Figure 3: Lift-to-drag coefficient ratio vs AoA graph of reduced AR wing form of Javan Cucumber of two Re numbers

The change in aspect ratio caused an increase in the Lift-to-drag ratio after an increase in AR. The AR in the design one decreased from a value of from changing solely the area. The effects of a lower aspect ratio is explored through this design. Lift slope values are seen to decrease with lower Re numbers as seen in Minami, S., Akuma, A. [4].

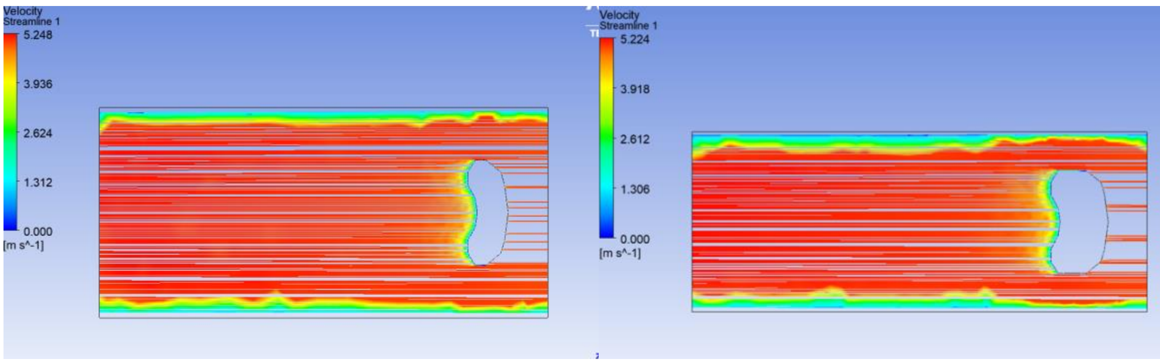

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Figure 3: flow field velocity 2D view of the unmodified Javan Cucumber wing (left) and reduced AR Javan Cucumber wing (right)

Discussion

From the redesign in design one, lowering the aspect ratio is a key factor that can contribute to a higher lift slope. These results indicate that achieving higher lift is more important than mitigating the induced drag. A decrease in overall efficiency in both the unmodified and lower aspect ratio designs suggests that an optimal condition for this design is achieved at higher Reynolds numbers. The primary factor contributing to the stability of the Javan cucumber wing is the proximity of its COG to its aerodynamic center, which is located close to the LE of the wing. This configuration helps maintain stability and control, crucial for the wing's performance.

In the initial stages of methodology development, the use of a thin airfoil approximation was considered. However, stability issues arose with the creation of a flat design, therefore an 3D airfoil was used in its design [7].

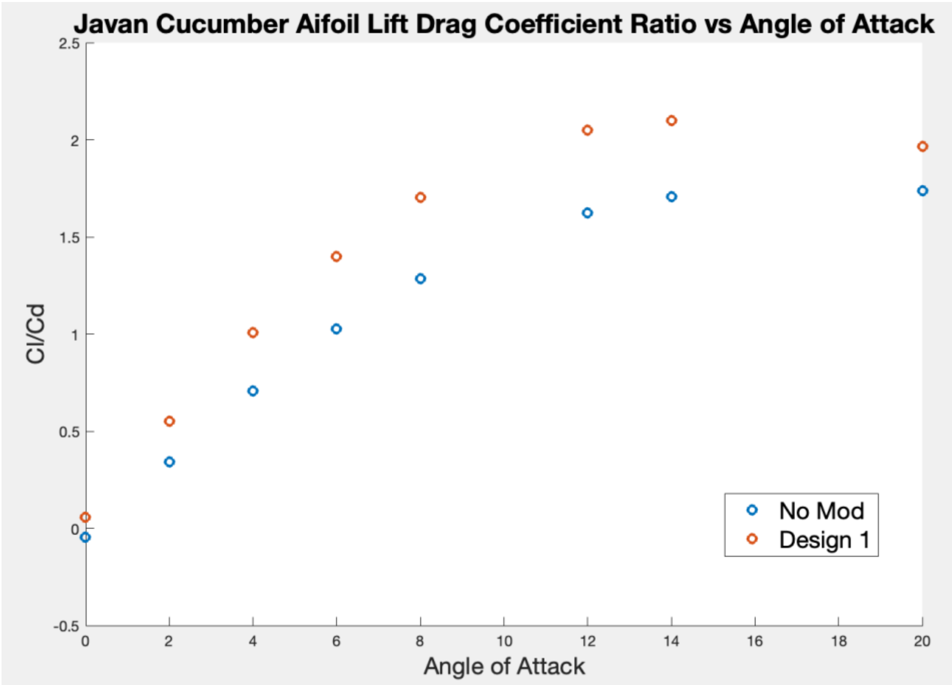

Figure 3: Lift-to-drag coefficient ratio vs AoA graph of reduced AR wing form of Javan Cucumber and reduced AR design under Re@50,000.

Conclusion

This project aimed to design a seed vehicle inspired by the Javan cucumber to enhance seed dispersal for ecological restoration. CFD analysis was employed to study lift and drag coefficients under various conditions. The focus of the analysis was on improving the vehicle's aerodynamic performance by optimizing lift-to-drag ratio, lift slopes, and maximum lift and minimum drag forces. CFD simulations were conducted to assess different design alterations and Reynolds numbers.

Results indicated that achieving higher lift was an more crucial factor over induced drag. Optimal conditions were observed at higher Reynolds numbers, highlighting the importance of stability and control. Throughout the project, considerations were made for simpler designs, such as thin airfoils, but ultimately, three-dimensional designs were chosen for improved stability.

This project provides insights into seed dispersal aerodynamics and highlighted the significance of using bio-inspired design to optimize aerodynamic parameters for an means of ecological restoration. Future works can explore different designs changes such as exploring ways to increase stability for better flight performances and load carrying. Such project explored in this paper can have other applications in the use of low powered flight devices.

References

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